TRANSPORT PLANNING & TRAFFIC SAFETY

MAKING CITIES, ROADS, & VEHICLES SAFER

EDITED BY

GEETAM TIWARI
DINESH MOHAN

CRC Press
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Contents

Preface

TRIPP, the Transportation Research and Injury Prevention Programme at the Indian Institute of Technology Delhi, had earlier (in 2005) brought out, ***The Way Forward: Transportation Planning and Road Safety*** which may, in a manner of speaking, be considered a prequel to the present volume. Certain important areas of concern do overlap but the problems of safety and mobility are eternal while the context of time and place is constantly shifting and changing, hence the periodic need to review and reassess the subject under consideration. TRIPP has been organizing an annual International Course on Transportation Planning and Traffic Safety since 1991. The structure and content of the course has been modified every year based on the feedback received from the participants and the Course faculty. The content of ***Transport Planning and Traffic Safety: Making Cities, Roads, and Vehicles Safer*** is based on the lectures delivered in the course, supplemented by relevant additional texts. This book is intended to be the source book for road safety training courses as well as an introductory textbook for graduate level courses on road safety taught in engineering institutes.

In recognition of the importance of Road Safety as a major health issue the World Health Organisation has declared 2011–2021 the Decade of Safety Action. Several countries in Europe, North America and Asia have been successful in reducing fatalities and injuries due to road traffic crashes; however, many low income countries continue to experience high rates of traffic fatalities and injuries. This book brings together the international experience and lessons learnt from countries which have been successful in reducing traffic crashes and their applicability in low income countries. The content is interdisciplinary and aimed at professionals – traffic and road engineers, vehicle designers, law enforcers, and transport planners. The objective is to highlight the public health and systems approach of traffic safety with the vulnerable road user in focus.

Geetam Tiwari
Dinesh Mohan

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Abbreviations

- ABS – Anti-lock Braking System
- *AICC – Autonomous Intelligent Cruise Control*
- AIS – Abbreviated Injury Scale
- ATDs – Anthropometric Crash Test Dummies
- BRT – Bus Rapid Transit
- CODEm – Cause of Death Ensemble Modeling
- COPD – Chronic obstructive pulmonary disease
- DALE – Disability-Adjusted Life Expectancy
- DALY – Disability-Adjusted Life Year
- EB – Empirical Bayes
- ESC – Electronic Stability Control
- FHWA – Federal Highway Administration
- GBD – Global Burden of Disease
- GDP – Gross Domestic Product
- GHBMC – Global Human Body Modeling Consortium
- HBA – Hydraulic Brake Assist
- Healy – Health Life Year
- ICTCT – International Committee on Traffic Conflicts Technique
- IFSTTAR – The French Institute of Science and Technology for Transport, Development and Networks
- IIT – Indian Institute of Technology
- IMRSC – Inter-Ministerial Road Safety Committee
- IPT – Intermediate Public Transport
- IPC – Indian Penal Code
- IRC – Indian Roads Congress
- IRTAD – International Traffic Safety Data and Analysis Group
- IRSB – Inter-sectoral Road Safety Board
- ISA – Intelligent Speed Adaptation
- LMC – Low Motorised Countries
- LMICs – Low- and middle-income countries
- MCCD – Medical Certification of Cause of Death
- MHFW – Ministry of Health and Family Welfare, India
- MoRTH – Ministry of Road Transport and Highways, India
- MoUD – Ministry of Urban Development, India
- NCDs – Non-communicable diseases
- NCR – National Capital Region
- NCTD – National Capital Territory of Delhi
- NH – National Highway
- NHAI – National Highway Authority of India
- NHTSA – National Highway Traffic Safety Agency
- OAPEC – Organization of Arab Petroleum Exporting Countries
- OECD – The Organisation for Economic Co-operation and Development
- OR – odds ratio

- PIL – Public Interest Litigation
- PMHS – Post Mortem Human Subjects
- RSST – Road Safety Study Team
- RTC – Road Traffic Crashes
- SIDA – The Swedish International Development Cooperation Agency
- SRS – Sample Registration System
- TERI – The Energy and Resources Institute, New Delhi
- THUMS – Total Human Model for Safety
- TRACE – Traffic Accident Causation in Europe project
- TRL – Transport Research Laboratory
- TRIPP – Transportation Research and Injury Prevention Programme
- TRRL – Transport and Road Research Laboratory (UK)
- UEMOA – West African Economic and Monetary Union
- VKT – Vehicle Kilometers Travelled
- VMT – Vehicle Miles Travelled
- VRUs – Vulnerable Road Users
- WHO – World Health Organisation
- YLD – Years lived with disability
- YLLs – Years of life lost

Authors

Anoop Chawla is a Henry Ford Chair Professor in the Mechanical Engineering Department at the Indian Institute of Technology, Delhi. His research focus includes Artificial Intelligence related areas, Knowledge based systems, Model based reasoning, Knowledge acquisition, Machine learning, object oriented programming, Knowledge Based systems applications in engineering (in design, in engineering diagnostics, in manufacturing etc.), Modeling in CAD/CAM/CAE: Modeling of vehicles for safety in crashes, Modeling using Finite elements and rigid body dynamics, Surface and solid modeling Computational geometry, and Computer aided design.

Christer Hyden obtained his civil engineering degree at Lund University in 1971. Since then he has been employed at the Lund University in the Department of Traffic Engineering (now the Department of Technology and Society). He completed Ph.D. research on Traffic Conflicts: The development of a method for traffic safety evaluation: The Swedish conflict technique. His main areas of research are safety in urban areas, assessment technique like the traffic conflict technique, speed, speed limiters in cars, and ITS. He has been the Chairman of ICTCT-International Cooperation on Theories and Concepts in Traffic Safety. He won the Volvo traffic Safety Award, 1991, and Sigge Thernvalls Stora Byggpris.

Dinesh Mohan is Volvo chair professor emeritus in the Transportation research and Injury Prevention Programme, Indian Institute of Technology Delhi. He obtained his Ph.D. degree in Biomechanics from the University of Michigan, Ann Arbor. He started his research career at the Insurance Institute of High Safety, USA. His research includes the vibrations of anisotropic plates, mechanical properties of human aortic tissue, head, chest and femur injury tolerance, injuries in human free falls, the effectiveness of helmets, and the first evaluation of the airbags in real world crashes. He continues to work on the epidemiology of road traffic crashes and injuries in rural India, pedestrian, bicycle, and motorcycle crash modelling, and aids for the disabled. His current interest includes sustainable transport policies, and people's right to access and safety as a fundamental human right.

Geetam Tiwari is coordinator of the Transportation Research and Injury Prevention Programme (TRIPP) at IIT Delhi, and MoUD Chair Professor for Transport Planning at the Department of Civil Engineering, IIT Delhi. She obtained her B. Arch degree from the University of Roorkee, and a Master of Urban Planning and Policy, and Ph.D. in Transport Planning and Policy, from the University of Illinois, Chicago. She has received the degree of Doctor of Technology *honoris causa* from Chalmers University of Technology, Sweden, in 2012. She has been an Adlerbretska Guest Professor for sustainable urban transport at the Chalmers University of Technology, Sweden, 2007–2010. She has been working in the area of traffic and transport planning focusing on pedestrians, bicycles, and bus systems. She is editor-in-chief of the *International Journal of Injury Control and Safety Promotion.*

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Hermann Knoflacher was trained in civil engineering, mathematics and geodesy. He became a full professor in transport planning and traffic engineering in 1975 at the Vienna University of Technology. Since then he has worked in transport and city planning. He published eight books in the area of transport planning and traffic engineering. His research interests include design of transport elements, transport systems and user behaviour, traffic infrastructure and mobility, sustainable development of cities and mobility, traffic safety, energy consumption, and basic interdisciplinary research.

Kavi Bhalla is an assistant professor, Department of International Health, Johns Hopkins University, Baltimore, USA. He obtained his B. Tech. in mechanical engineering from the Indian Institute of Technology Delhi, and his Ph.D. from Cornell University, Ithaca, USA. His research focuses on assessing the health effects (injuries, air quality, physical activities, others) of transport and urban policies. A substantial amount of the work is on road safety in low- and middle-income countries. He co-led the injury expert group of the 2010 revision of the Global Burden of Disease (GBD-2010) project. He is broadly interested in the design of products, environments, and systems that are safe and have positive health impacts.

Karin Brolin is an associate professor at the Chalmers University of Technology, Gothenburg, Sweden. Dr. Brolin earned her Ph.D. at the Royal Institute of Technology (Stockholm) with a thesis titled: Cervical Spine Injuries – Numerical Analyses and Statistical Survey. From 2006–2009 she worked with finite element consultancy, support and sales at Engineering Research Nordic AB in Linköping. Dr. Brolin joined Chalmers in 2009 and became Docent at Chalmers in 2012. Her research focus is Human Body Modelling (HBM). HBM is a powerful tool for injury analysis in automotive crash and/or impact simulations. Her specialties include Dynamic Finite Element Analyses, Neck Injuries, and Impact Analyses.

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Nicole Muhlrad is a civil engineer and emeritus researcher at IFSTTAR, France. She has worked extensively in low income countries in the area of road safety management and policies. She is an active member of ICTCT, an association developed out of an international working group of safety experts with the aim to identify and analyse dangerous situations in road traffic on the basis of criteria, other than past accidents, analogous to the methods of air and industrial safety.

She continues to work with several European organisations on road safety data collection and management policies.

Pierre Van Elslande is a research director at the French Institute of Science and Technology for Transport, Development and Network (IFSTTAR) in its Accident Mechanisms Research Laboratory, where he coordinates a multidisciplinary team in the domain of safety research. With a background in Ergonomics (Master's degree) Psychology and Education Sciences (Master's degree) and in Cognitive Psychology (PhD), his research domains specifically deal with human processes involved in traffic malfunctions, in the contexts of their production and their environmental determinants. They are directed towards both the general knowledge of human functioning, and the ergonomic application of such knowledge to promote a safer driving system.

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Shrikant Bangdiwala is a research professor of biostatistics at the University of North Carolina, Chapel Hill, USA. He serves as a member of the Board of Scientific Counselors of the National Center for Injury Prevention and Control at the CDC, and as chair of the Multinational Data and Safety Monitoring Board of the NIAID Division of AIDS at NIH. He holds visiting faculty appointments at the University of Valparaiso (Chile), at the University of Chile (Santiago), and at the University of South Africa (Johannesburg). He is currently co-Editor-in-Chief of the *International Journal of Injury Control & Safety Promotion*, and was elected member of the International Statistical Institute. His research area includes Nonparametric methods, Methodology for clinical trials, Reliability and validity of diagnostic tests, and Graphical methods for descriptive analyses.

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Understanding the Road Safety Performance of OECD Countries

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CONTENTS

ABSTRACT

The road safety performance of economically developed OECD countries over the last century shows a remarkable and consistent pattern. In most of these countries, road traffic deaths were rising until the 1960s but have declined steadily since then. Understanding the road safety history of OECD countries can provide useful insights to road safety professionals in low-and middle-income countries (LMICs) to help them better manage safety in their transportation systems. This chapter examines the trends in performance of OECD countries through three perspectives. The first considers the rising and falling trends in road traffic deaths as a natural developmental process ("economic determinism"). In this perspective, road traffic injuries increase initially as a society motorizes but injuries begin to decline after the society reaches a certain developmental threshold, after which it begins to address its health and environmental issues. The second perspective critiques this position by illustrating that the rising and falling trends can partly be explained by the shift in risk that occurs when motorization is primarily through increasing car-use. As the use of cars increases, the risk to pedestrians initially increases. However, eventually most pedestrians become car users and further motorization reduces the number of pedestrians

and hence their exposure to road traffic injuries. In the final perspective, we look at the issue through the lens of a political process. We reassess the statistical data to show that the late 1960s were a special moment in history when the OECD countries that were at substantially different income levels acted together to regulate transport risk by establishing and funding national road safety agencies. Over the following decades, these institutions were able to implement large-scale national road safety programs that have had a remarkable effect on reducing the road death toll. The main implication of this perspective for LMICs is that countries do not need to wait to be richer to address road safety. Instead, they should act now to establish national institutions with the mandate and resources to regulate and manage road safety in their transportation system.

Key Words: Road Safety Performance; OECD countries; Kuznets hypothesis

1.1 OVERVIEW

The history of the road safety performance of economically developed OECD countries is remarkable. As illustrated in Figure 1.1, road traffic death rates in these countries were rising until the late 1960s. However, road traffic death rates in these countries have been declining steadily ever since. Although the use of motor vehicles grew steadily over the 20th century, OECD countries were able to reverse the increasing trend in road traffic fatalities and have successfully maintained steadily improving road safety performance for over five decades. In sharp contrast, road traffic death rates in most low- and middle-income countries (LMICs) are still rising. Most researchers attribute this increase to the rapid and unmanaged growth in motor vehicle fleets of LMICs. Thus, Figure 1.1 is intriguing because it raises questions that are important for road

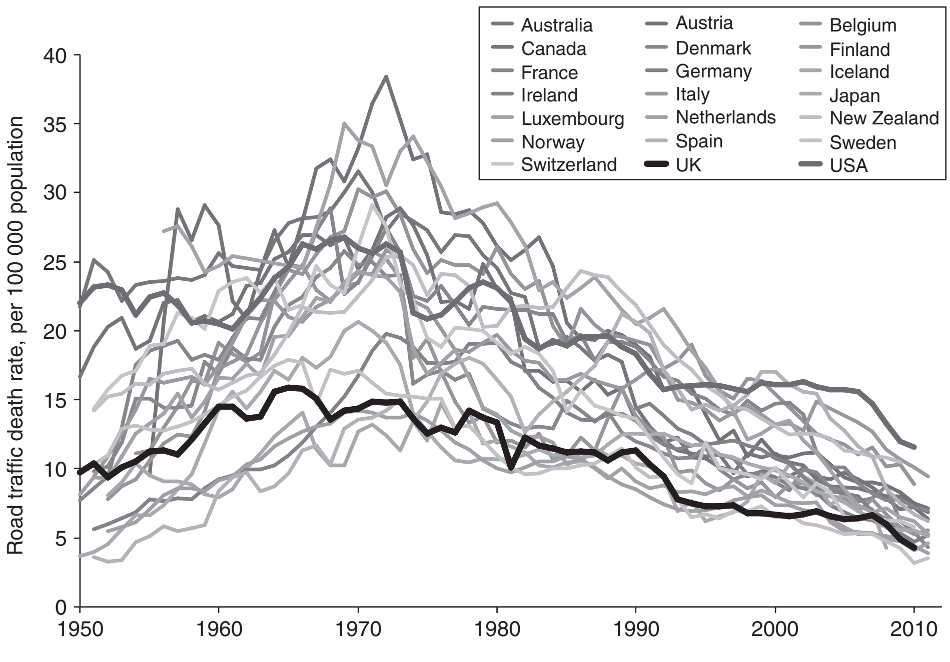

Figure 1.1 Road traffic deaths rates in OECD countries were rising prior to the 1960s but have declined steadily since then.

Source: Author's analysis of national death registration data. Analysis is restricted to 21 OECD countries with high quality death registration data.

Three-year moving average of road traffic deaths rates has been used for countries with fewer than 5 million people.

safety researchers and practitioners in LMICs. *How did OECD countries reverse the rising trend in road traffic deaths despite increasing motorization? How did they manage to sustain improvements in road safety performance over such a long period?*

Let us start by taking a closer look at a few of the features of the time trajectories in Figure 1.1. First, consider the history of the road safety performance of the US. Road traffic deaths rose sharply in the US during the early 1960s. This was a period of dramatic growth of the US Interstate Highway System, which was constructed after passage of the Federal-Aid Highway Act in 1956. The act authorized 42,000 miles of highway construction, of which about half was built by 1965 (WC 2015). At the same time, the vehicle fleet in the US was shifting towards bigger and faster cars, which had the ability to travel at high speeds on the newly developing highway infrastructure. The year 1973 saw the single largest drop in road traffic deaths ever in the history of road safety in the US. This was the year of the oil crisis, when the Organization of Arab Petroleum Exporting Countries (OAPEC) declared an oil embargo that caused the oil prices to quadruple, leading to nationwide fuel shortage. The US Congress responded to the oil crisis by setting a lower national highway speed limit of 55 miles per hour because cars burn fuel less efficiently at higher speeds. Reducing speeds are an effective road safety intervention (Richter et al 2004), and the lowered speed limits likely contributed substantially to the decline in injuries in that year (Friedman et al 2009). Ultimately, however, the lowered speed limits were difficult to sustain and many US states raised their speed limits over the years that followed. The increase in fuel prices also had the direct effect of reducing driving and hence exposure to crashes. More generally, the economy and road traffic injury trends are closely related because the economy directly affects the amount of vehicle use. Thus the rise and fall pattern in the US road safety performance broadly tracks the economic boom- and bust-cycles, with sharp decreases corresponding to the 1980 and 2008 recessions.

In addition to the influence of large economic, social, and political forces, there were important actions specific to road safety that affected national road safety performance. In 1966, the US congress passed the Motor Vehicle Act, which led to the establishment of the National Highway Safety Board (later the National Highway Traffic Safety Agency, NHTSA) at around the time when death rates in the US peaked. Over the decades that followed, NHTSA worked with other government institutions, such as the Federal Highway Administration, to regulate the design of vehicles, highways, and the safe use of roads. We will return to a discussion of the role of national safety agencies later in this chapter.

Next, let us compare the road safety performance of the UK and the US over the last century. The overarching shape of the US and UK curves in Figure 1.1 is similar, with both countries showing a broadly synchronous rise through the 1960s followed by a long-run decline in death rates. However, it is notable that the US curve runs higher than the UK curve over the entire duration. Thus the US has always had a road traffic death rate that exceeds the UK by an approximately fixed amount. This suggests that there may be structural differences between the two nations that have remained broadly fixed for a long time. Perhaps the most notable difference is the way in which transport is configured in the two countries. Travel in the US is more likely to involve longer trips, the use of a high-speed road infrastructure and private motor vehicles, as opposed to the UK, where trips are shorter and the use of inter-city rail or urban mass transit systems is common. Thus, the average annual distance driven per capita in the US is almost twice that in the UK (Luoma and Sivak 2013). This is partly due to the larger landmass of the US but also due to policy choices that have prioritized highway travel and sprawling cities over the last century.

The preceding discussion barely touches on specific road safety interventions, such as speed control, airbags, helmets, and seatbelts, which make up the day-to-day work of most road safety professionals. These interventions are obviously important to road safety. However, when thinking on the broad scale of the safety of large populations over decades, it is also important to think about the political, institutional, and structural relationships that allow road safety interventions to be deployed on a wide scale and sustained for a long time. These relationships are the focus of this chapter.

We now extend this discussion to beyond the US and UK, and consider what the history of road safety in OECD countries can teach us about what lies ahead for LMICs. The rest of this chapter explores the trends of road traffic death rates in OECD countries through three perspectives:

1. Economic determinism: This perspective describes the rise and fall of road traffic death rates in OECD countries as a process determined by economic development. In this view countries invest in road safety once they have reached a certain developmental threshold.
2. Risk substitution: This perspective illustrates that a rise and fall of road traffic death rates should be expected in a society that is motorizing primarily through car ownership. In this view, road deaths begin to decline when most pedestrians become car users, lowering the aggregate societal exposure to road traffic injuries.
3. Political shift in the road safety paradigm: The history of road safety in OECD countries shows that the late 1960s were a special moment in history when OECD countries that were at substantially different income levels acted together to regulate transport risk by establishing and funding national road safety agencies.

1.2 ECONOMIC DETERMINISM: ROAD SAFETY PERFORMANCE AS A DEVELOPMENTAL OUTCOME

Many researchers have studied statistical data of the type shown in Figure 1.1 and attempted to explain the rise and fall trend in road traffic injury rates (Jacobs and Cuttings 1986; Soderlund and Zwi 1995; Van Beeck et al 2000; Garg and Hyder 2005; Kopits and Cropper 2005; Bishai et al 2005; Paulozzi et al 2007; McManus 2007; Law et al 2009; Grimm and Treibich 2012; Nishitateno and Burke 2014). Some of these studies are cross-sectional studies (i.e. single year data from multiple regions) (Jacobs and Cuttings 1986; Soderlund and Zwi 1995; Van Beeck et al 2000; Garg and Hyder 2005; Paulozzi et al 2007), while others use panel data (i.e. data for multiple years from multiple regions) (Kopits and Cropper 2005; Bishai et al 2005; McManus 2007; Law et al 2009; Grimm and Treibich 2012; Nishitateno and Burke 2014). Some are cross-national studies (Jacobs and Cuttings 1986; Soderlund and Zwi 1995; Van Beeck et al 2000; Kopits and Cropper 2005; Bishai et al 2005; Paulozzi et al 2007; McManus 2007; Law et al 2009; Burke 2014), while others focus on sub-national regions of a single country (Garg and Hyder 2005; Grimm and Treibich 2012). Overwhelmingly these studies have tended to analyze road traffic death rates as a function of income growth. Typically, this involves reassessing the data in Figure 1.1 using per capita income as the independent variable (e.g. see Figure 1.2), demonstrating that injuries initially rise with income and then fall, and measuring the parameters of statistical (regression) models that fit this data. This rise-and-fall represents an inverted U-shaped curve, which is the broad pattern of Figure 1.2, and is referred to as the “Kuznets curve”. Thus, all of these studies find that there is a general relationship between income growth and road traffic injury such that when countries are poor they experience rising injuries with increasing income; and when countries are rich they experience declines with increasing income. The underlying logic of this hypothesis is that when countries are poor, growth in income is closely tied to increase in motorization, which leads to higher exposure to road traffic injuries. At this stage it is assumed that countries are too poor to invest in harm reduction. However, after a certain level of economic development has been achieved, countries begin to invest in road safety programs and reduce their road traffic injury rates.

There is a problem with this argument that has not received substantial attention in road safety literature. When the data is presented as shown in Figure 1.2 with income as the independent variable (x-axis), it encourages thinking about national road safety performance as a process that is an outcome of economic development. This logic of “economic determinism”

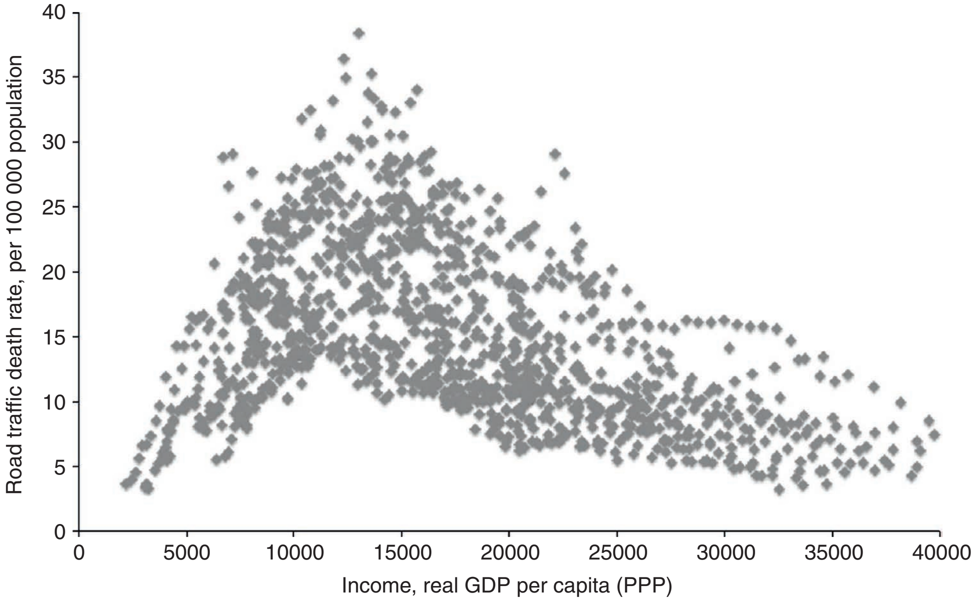

Figure 1.2 The inverted U-shaped relationship between road traffic death rates and economic development in OECD countries, commonly referred to as the "Kuznets curve".
Source: Author's analysis of national death registration data. Analysis is restricted to the same 21 OECD countries shown in Figure 1.1.
Three-year moving average of road traffic deaths rates has been used for countries with fewer than 5 million people.

creates the impression that low-income countries may be too poor to invest in safety now and that it is appropriate for them to wait until they become richer to address road safety. In fact, it implies that income growth is the strategy for road safety rather than direct investment in interventions. As the public health historian Borowy has observed about a paper (Kopits and Cropper 2005) from the World Bank Development Research Group that is arguably one of the most influential publications in global road safety (Borowy 2013):

> "Analysing vehicles per person (V/P) and fatalities per vehicle (FN) data from eighty-eight countries for the period 1963–99, they found a confirmation of the Kuznets curve with a turning point at a per capita GNP of $8600 in 1985 international dollars. On the basis of these data and of prognoses of population and income growths, they projected that it would take many years for developing countries to achieve the low RTI fatality rate of existing high-income countries. RTIs in India, for instance, which had a per capita income of only $2900 in 2000, would only begin to decline in 2042 after a peak of at least twenty-four fatalities per 100 000 persons, or thirty-four when adjusted for estimated underreporting. Brazil would 'already' peak in 2032 and would experience an RTI mortality rate of twenty-six deaths per 100 000 persons as late as 2050, compared to a rate of around eleven enjoyed by high-income countries in 2000. *Only on the last page did the text mention, almost in passing, that these projections were based on a continuity of ongoing policies, while measures such as mandatory helmet wearing or effective traffic separation might lower those numbers."* [emphasis added]

Although criticism of this economically determined interpretation of road safety is relatively subdued in road safety literature, it is instructive to understand the history of the concept in the broader economics literature. The "Kuznets Curve" is named after the Nobel Prize laureate Simon Kuznets, who studied long-term economic processes in the US. In 1955, he published an influential study that described an inverted U-shaped relationship between income inequality and economic growth (Kuznets 1955) that suggested that over the long run as countries develop economically, income inequality first increases but later declines. He speculated that income inequality grew initially due to the transition from agrarian society to industrialization, but declined later as mass education created new opportunities for everybody. Kuznets cautioned against reading too much into the data saying that "*If the above summary of trends in the secular income structure of developed countries comes perilously close to pure guesswork, an attempt to explain these dimly discernable trends may surely seem foolhardy*", and "*I am acutely conscious of the meagerness of reliable information presented. The paper is perhaps 5 per cent empirical information and 95 per cent speculation, some of it possibly tainted by wishful thinking.*" Unfortunately, other researchers who have applied the Kuznets curve to other arenas have often not been similarly cautious and thoughtful.

The Kuznets curve has been fairly important to the field of environmental economics. In the early 1990s, Grossman and Krueger analyzed data on air pollution from a number of cities around the world and described an inverted-U shaped curve, which is now known as the "Environmental Kuznets Curve" (Grossman and Krueger 1993). The concept received a large boost in popularity in this field when it was included in the World Bank's influential 1992 World Development Report (World Bank 1992). The logic of the environmental Kuznets curve was that in the early stages of industrialization, pollution grows rapidly because people are more interested in jobs and income than in clean air and water. Poor societies cannot afford to pay for reducing harm but the balance shifts as incomes rise. People begin to value the environment more and intervene to establish environmental regulations. There have been numerous investigations of the Kuznets curve in the literature on environmental economics and numerous critiques of the method, including those on theoretical and technical grounds. Stern (2004) traces the history of this concept in a paper aptly titled "The Rise and Fall of the Environmental Kuznets Curve" Stern 2004).

As with road safety, the economic determinism of the Kuznets hypothesis has been used to argue against LMICs investing in environmentally sustainable practices. As Stern (2004) discusses the World Bank's 1992 World Development Report, presented income growth as partly the solution to environmental damage in LMICs. The report stated "*As incomes rise, the demand for improvements in environmental quality will increase, as will the resources available for investment* (World Bank 1992)." Others have made the same point but much more forcefully. Beckerman (1992) claimed that "*there is clear evidence that, although economic growth usually leads to environmental degradation in the early stages of the process, in the end the best – and probably the only – way to attain a decent environment in most countries is to become rich.*" Thus, unfortunately, the Kuznets hypothesis has been used by those politically opposed to investing in protecting the environment to argue that countries should "Grow first, then clean up" (Dasgupta et al 2002).

To be fair, the large and growing literature on the Kuznets curve in road safety has not yet taken a position as explicitly hostile to safety regulations. Nevertheless, it is important to understand that in the best-case scenario, such econometric analysis can only help us understand the level of income at which rich countries began to regulate road safety. Such analysis provides no guidance to LMICs on what they should do now.

A broader issue with the Kuznets hypothesis in road safety is that it may not apply to LMICs today. The data in Figure 1.2, which shows the inverted-U Kuznets curve, are for OECD countries and do not include any LMICs. Several previous studies (Soderlund and Zwi 1995; Garg and Hyder 2005; Kopits and Cropper 2005; McManus 2007; Grimm and Treibich 2012), including the influential World Bank study discussed above, have analyzed road traffic deaths data from LMICs and demonstrated the existence of a Kuznets curve. However, all of these studies rely on data from traffic police even though it is well known that traffic police substantially underreport road traffic deaths. Estimates of underreporting in the poorest regions of the world typically

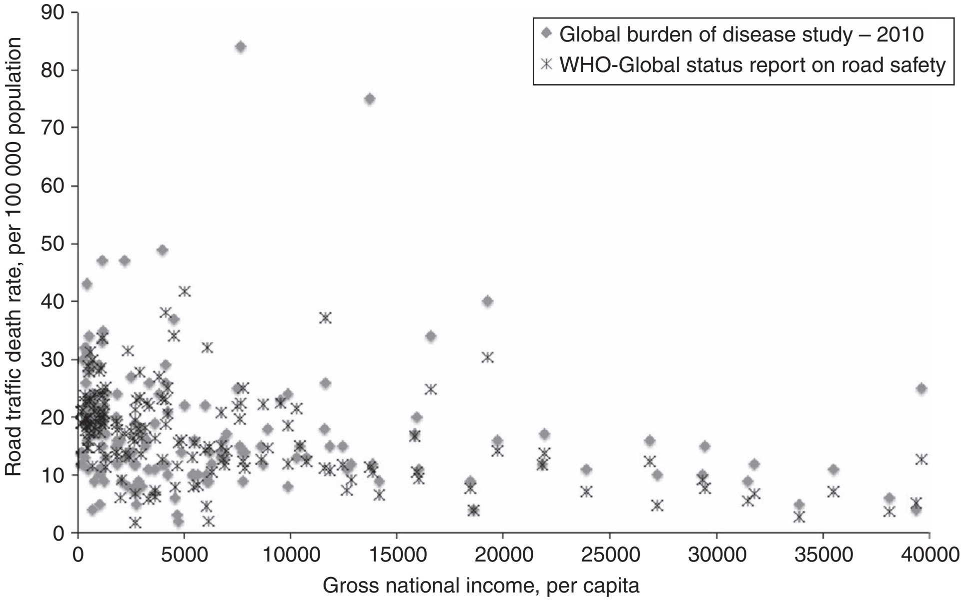

Figure 1.3 Relationship between road traffic death rates and income in all countries in the year 2010.

exceed 500% (Bhalla et al 2014), which makes the use of police data a poor choice for studying the relationship between national income and road safety performance.

Recently, two major studies have assessed the road traffic death rates in all countries using statistical analysis that rely on national health data and methods that adjust for biases and underreporting. These studies are the 2010 Global Burden of Disease Study (Bhalla et al 2014), and the 2013 WHO Global Status Report on Road Safety (WHO 2013). Figure 1.3, which illustrates the relationship between income and road traffic death rates in the year 2010 using data from these studies, does not show a U-shaped Kuznets curve. For the most part, there is no relationship evident between income and road safety performance. In fact, the graph shows very large variation in road safety performances of countries at the same income level. This is particularly true of poor countries where road traffic death rates vary more than fivefold. The reasons for such variations are poorly understood but are likely due to a wide range of structural factors that affect road safety outcomes. These factors include questions as to whether transport in a country is primarily by road or rail, the types of highways used in road transport, and the types of vehicles commonly used, in addition to road safety prevention programs. Clearly, Figure 1.3 demonstrates that it is more useful to understand why countries at the same income level perform very differently than to understand the relationship of road safety performance with income.

1.3 RISK SUBSTITUTION: CAR OCCUPANTS ARE AT MUCH LOWER RISK THAN PEDESTRIANS

In an earlier study, we developed a structural model to explore the evolution of road traffic injury risk as a society motorizes (Bhalla et al 2007). Our analysis showed that if a society motorizes through the process of people buying cars, there is a shift in individual risk that manifests itself at the societal level in an inverted-U shaped profile of aggregate injury rates. In summary, when pedestrians become car users, their individual risk declines. As the use of cars increases, the risk

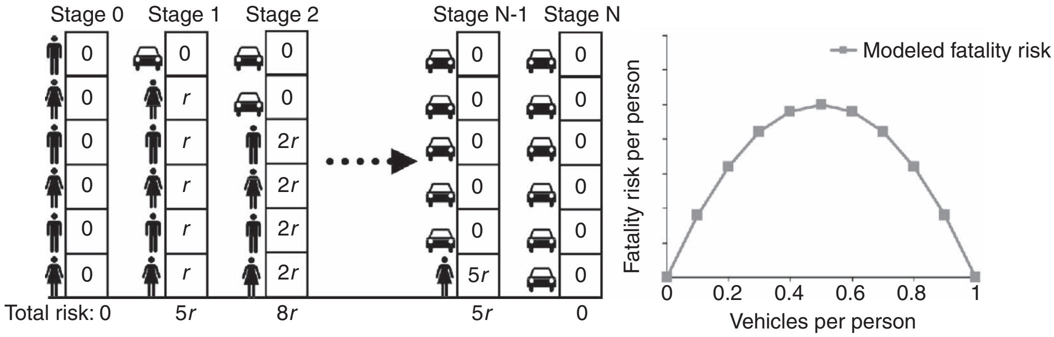

Figure 1.4 The evolution of risk in a world with only cars and pedestrians. The figure on the left illustrates the motorization process in N stages. r is the threat to each pedestrian per car, while the risk car occupants is assumed to be negligible in comparison. The figure on the right shows the resulting net societal risk.

to other pedestrians initially increases because of the large number of pedestrians in the society during the early stages of motorization. However, eventually most pedestrians become car users and further motorization reduces the number of pedestrians and hence their exposure to road traffic injuries.

Let us think about this example in a bit more detail: Consider a crude model of a society that consists of only pedestrians and cars, and where motorization occurs by pedestrians buying cars. Figure 1.4 illustrates this simple process. At the beginning (Stage 0) everybody is a pedestrian. Subsequently (Stage 1) one pedestrian motorizes by buying a car. Stages 2 to N involve an increasing number of pedestrians buying cars until everybody is in a car and there are no more pedestrians.

Now consider a simple model for the evolution of risk in this society. We assume that each car imposes a risk $\boldsymbol{r}$ of death on each pedestrian. We further assume that the risk to the car occupant is negligible in comparison and assumed to be zero. Now, if the society has $\boldsymbol{N}$ members, of which $\boldsymbol{C}$ own cars, then the number of pedestrians is $\boldsymbol{N - C}$. If each car imposes a risk $\boldsymbol{r}$ on each pedestrian, then they create a total societal risk of $\boldsymbol{r \cdot C \cdot (N - C)}$, which is a downward facing parabolic function of the number of cars, i.e. the relationship between society and the number of cars is an inverted U shaped function of the number of cars. As the society motorizes from all-pedestrians to all-occupants, the aggregate fatality risk initially rises as additional cars pose an increasing threat to the largely pedestrian population. But, when more than half the commuting population consists of car users ($\boldsymbol{C = N/2}$, peak of parabola), increasing motorization leads to a fall in the aggregate fatality risk.

Since vehicle ownership is closely related with income in most societies, the graph in Figure 1.4 illustrates that when societies motorize through car ownership the overall risk profile resembles the inverted-U shape of the Kuznets curve of Figure 1.2. This is the consequence of a "substitution effect," as high-risk but low-threat pedestrians are replaced by low-risk and high-threat vehicles. Thus, the people who shift from being vulnerable road users (VRUs) to vehicle occupants diminish their own risks but raise the threat to the remaining VRUs. At low levels of motorization, there are a large number of VRUs on the streets and the increased threat to the population outweighs the decreased risk to the individual. However, at high motorization levels there are relatively few VRUs, and the decreased personal risk leads to a falling trend in fatalities per capita even in the absence of traffic safety interventions.

Clearly, this is an extremely simplistic model and the real world is substantially more complicated. For instance, the risk to car users is not zero as assumed. Instead, car users have risks from being exposed to other cars as well as the risk of single vehicle crashes. These risks are substantially smaller than the risk of injuries faced by a pedestrian in a crash but they are non-zero. Including this effect in our thought experiment is relatively easy. We should expect that these additional effects would cause the societal risk curve shown in Figure 1.4 to shift such that the peak occurs a bit later (i.e. at a higher level of motorization), and the curve doesn't return to zero at full motorization.

What is the role of interventions in this model? Road safety interventions will cause the curve to rise slower during the early motorization phase, and decline faster in the late motorization phase. Note that we have not made an explicit comparison between our stylized model and the actual empirical data shown in Figures 1.1 & 1.2. This is because the reality of the history of motorization and the evolution of risk in OECD countries is substantially more complicated than such stylized models can allow. Instead, our purpose was to conduct a simple thought-experiment that would allow us to understand better the structural determinants of the long run trends in road safety.

In fact, the future of motorization in LMICs is likely to be substantially more complex than even the history of motorization in OECD countries. Consider that road transport in most LMICs is substantially more heterogeneous with a wider mix of vehicle-types than has ever been witnessed in OECD countries. Furthermore, different LMICs are already on fairly different motorization trajectories. For instance, motorization in many Southeast Asian countries is occurring through a much higher proportion of motorized two-wheelers than in in many Latin American countries, where cars dominate.

Accounting for such features in a stylized model is substantially more difficult than the model presented above. In our previous work (Bhalla et al 2007), we attempted to develop a road safety model for heterogeneous traffic and used it to project safety in societies that chose a range of different pathways to motorization. The road safety model allowed four types of road users (pedestrians, motorized two wheelers, cars, and buses) and accounted for a full matrix of risks for interactions between these road users. We used this model to predict risk as societies motorized in a range of different scenarios that included heavy reliance on buses, cars, and motorized two wheelers. A few key findings from this model are as follows:

- The post peak decline in societal risk seen in Figure 1.4 occurs primarily due to a decline in the pedestrian population in society. However, LMICs are unlikely to have the large increases in car use and the accompanying declines in pedestrian population that occurred in OECD countries because of physical limitations of road space. Thus, in most potential scenarios of motorization in LMICs, mass transit will play a key role. Since the use of mass-transit requires pedestrian travel (to and from the bus/metro station), pedestrians will always comprise a substantial proportion of the road users in LMICs. This implies that societal risk in LMICs does not diminish with motorization (i.e. risk curves continue to rise). Therefore, planning for the safety of pedestrians will always need to be a priority for LMICs.
- Scenarios that are dominated by use of buses are safer than those dominated by private motor vehicle use. This is because bus passengers are at much lower risk than occupants of other private motor vehicles.
- Motorization scenarios that are dominated by use of motorized two wheelers may have aggregate societal risk that is comparable to scenarios involving high car use. This is an unusual finding that is explained as follows. The societal risk associated with a particular type of vehicle has two components: (1) risk to self, and, (2) risk imposed on others. Although motorcyclists are at very high risk of injury (risk to self), they impose much lower risk on others. In contrast, car occupants are at relatively low risk of injury but impose a relatively higher risk on other road users. The aggregate effect is that in our models the total societal risk in high motorcycle use was similar to that from high car use. Note that this is true despite the fact that for individuals motorcycles are the most dangerous mode of transport. However, at the societal level, we also need to account for risk to other road users.

For more details of this analysis, the reader should look at the original paper (Bhalla et al 2007).

1.4 POLITICAL ACTION: THE ROLE OF INSTITUTIONS AND INTERVENTIONS

Finally, we return to the data on the road safety performance of OECD countries, but this time from a perspective that asks: *How did OECD countries reverse the rise in road traffic deaths in the 1970s?* This is the original question with which we started this paper.

In order to motivate the answer to this question, consider Figure 1.5, which compares the road safety performance as a function of income (Figure 1.5a) with time histories (Figure 1.5b), and highlights data for the US and UK. It is remarkable that the road traffic death rates in these countries behave almost synchronously in time, with the reversal from rising to falling mortality rates occurring in the early 1970s (Figure 1.4b), even though the two countries had considerably different income levels at this time (Figure 1.4a). Remember that the Kuznets hypothesis suggests that the reversal in trends occurs when countries reach a certain income level. Yet the data shows that time was a much stronger determinant of the reversal point than income. Figure 1.5b suggests that something special happened in the 1970s that transitioned all of these OECD countries into a new historic period in road safety even though they were at different levels of economic development.

In fact, a vast literature from OECD countries has already described the early 1970s as a special moment in road safety history when OECD countries underwent a paradigmatic shift from blaming the driver ("the nut behind the wheel") to reducing risk in all aspects of the transportation system, including roads, vehicles and road users. Carol MacLennan (1988) has traced this history in the US (MacLennan 1988). During the 1920s–1960s, industry groups controlled road safety programs in the US and had a dominating influence in defining the problem and the remedies. The first organized attempt to address road safety occurred in the 1920s, when concerned auto industry and other private business groups organized two major conferences. As fatalities continued to rise through the 1930s, these industry groups established the Automotive Safety Foundation to fund and organize road safety programs across the US. By the 1940s, these groups were successful in bringing the attention of President Truman to road safety and two conferences were organized under the President's banner. The 1949 conference established the President's Committee for Traffic Safety, a quasi-government agency established for coordinating and reporting on local traffic safety programs. The Committee was staffed by civil servants and managed by industry representatives with substantial funding from industry.

As MacLennan discusses, what is notable about the period is that industry groups dominated traffic safety and had a strong influence on how the road safety problem was perceived. Discussions of traffic safety during this period were permeated by the belief that drivers are responsible for accidents. The view was that while responsible professionals were using the best available technology to design cars and the road environment, crashes occurred because drivers were irresponsible and careless. Road traffic statistics during this period routinely presented driver behavior as responsible for between 75% and 95% of all traffic crashes.

Because the problem was defined as careless drivers, remedies focused on punishing the bad driver and instilling good driving habits in the public. Research in traffic safety during the 1920s–1960s was dominated by psychologists trying to understand the "accident prone" individual, and on understanding the attitudes of drivers and repeat violators (Burnham 2009). Since the driver was the problem, most remedies also focus on the driver – driver education, traffic control, and enforcement of laws. Notably there was very little attention paid to the design and regulation of cars and highways during this period.

In the 1950s and 1960s, resistance to the view that drivers were the sole cause of accidents grew among medical doctors and engineers (MacLennan 1988). Over time a political movement developed that led to a shift towards the view that cars and highways were important causes of

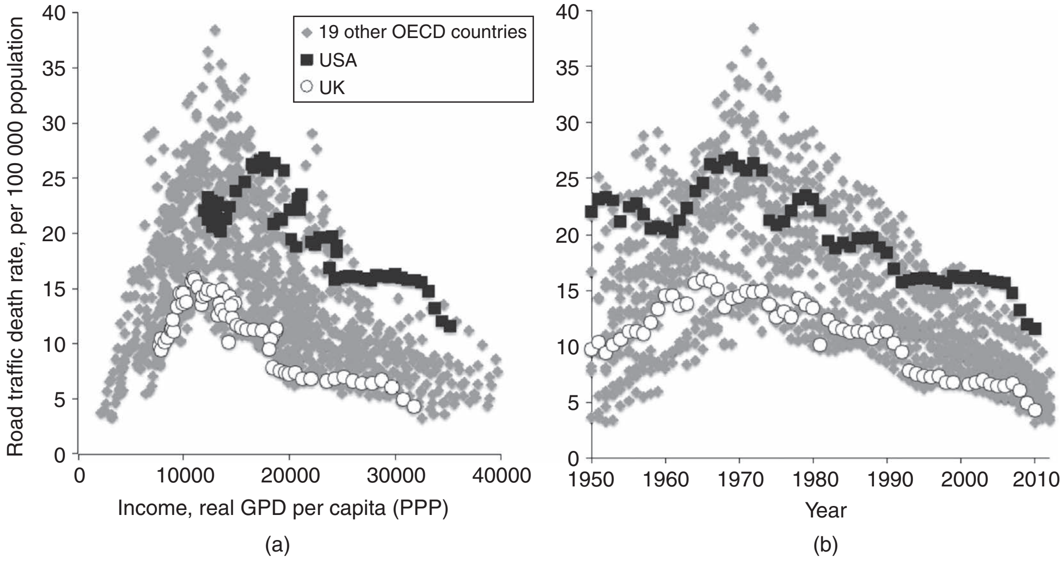

Figure 1.5 Comparison of road traffic death rates as a function of income, (a), and time, (b)
Source: Author's analysis of national death registration data.
Three-year moving average of road traffic deaths rates has been used for countries with fewer than 5 million people.

injuries and should be subject to strong government regulation. During the 1950s, pioneers like Hugh DeHaven (pilot and engineer) and Colonel John P. Stapp (US Air Force officer and medical doctor) conducted research on crash dynamics and the tolerance of the human body to impact forces. By 1956, DeHaven had built a safety car prototype at the Cornell Aeronautical Laboratory that could withstand a 50 mph impact without serious occupant injuries. Simultaneously medical doctors like Claire Strait had been trying to persuade car manufacturers to include seatbelts, padded dashboards, and exclude sharp protruding objects from the interior of vehicles. In 1953, the American Medical Association passed a resolution recommending that auto manufacturers include seat belts in all vehicles.

The ultimate congressional challenge to the automotive industry came in the mid-1960s when a book by Haddon et al (1964) titled *Accident Research* influenced Senator Ribicoff to hold hearings on the safety of vehicles sold to the US government. Subsequently the government's purchasing agency set standards for such vehicles and the industry adopted some of them for all vehicles. At around the same time, Ralph Nader, a young lawyer, published a book *Unsafe at Any Speed*, which presented the car as an unsafe product produced by an unregulated industry. A scandal developed when it became known that General Motors was using private detectives to do surveillance on Nader. The widespread public outrage from this incident created an opportunity for political action. In 1966, the US Congress passed the Motor Vehicle Safety Act, which established the country's national road safety agency (later called the National Highway Traffic Safety Administration, NHTSA) with a mandate to regulate the safety of vehicles. The first administrator of NHTSA was William Haddon, a physician who developed a comprehensive view for managing transport risk. The "Haddon Matrix" has proven to be influential in injury prevention far beyond road safety (Haddon 1972, 1980).

Thus, the political movement of the 1960s was successful in transitioning road safety in the US to a new era of government regulation of the safety of cars, roadways and road users. Figure 1.1 suggests that this transition initiated a process that reversed the rising trend in road traffic injuries and resulted in steadily improving road safety in the decades that followed.

TABLE 1.1 Road safety regulation history of Sweden, United Kingdom and the Netherlands.

Sweden	**United Kingdom**	**Netherlands**
1968: Sweden established a new national road safety agency 1975: Front seat belt use become mandatory 1975: Motorcycle helmet use required 1976: Driving test for motorcycle 1977: Daytime running lights 1978: Moped helmets required 1979: Night light on bicycles required 1982: Slow moving vehicles required to have warning sign 1986: Reflectors required on bicycles 1987: Speed fines increased 1988: Child seat belts required 1990: BAC limit lowered from 0.05 to 0.02%; Start trials with automatic speed enforcement 1994: Number of random breath tests doubled 1995: Median steel wire barriers introduced 1996: airbags required in new cars 1997: "Vision Zero" is taken by Parliament 1999: Seat belt use law expanded (taxi drivers, lorry occupants); winter tyres mandatory in winter conditions	1970: Heavy vehicle driving tests & limits driving hours 1971/72: 16 years olds are limited to riding mopeds only 1973/74: Compulsory helmets; 50 mph speed limit; vehicle lighting regulations 1975: Roundabouts introduced 1977: New helmet standards 1978: Mandatory rear fog lamps on new vehicles 1980: Stricter helmet standards 1982: Two part motorcycle test introduced; Tougher braking standards for heavy vehicles 1983: Front seatbelt use mandatory 1987: Amber flashing light mandatory on slow moving vehicles 1988: New mirror requirements for heavy vehicles. Buses to have 70 mph limiters. 1991: Safety audits mandatory on trunk roads and motorways 1992: 60 mph limiters required for heavy vehicles; speed cameras introduced 1994: Speed limiters lowered for buses and trucks. 1996: Driving test strengthened 2000: Government issues new road safety strategy and targets	1971: Mandatory presence of seat belts in new cars 1972: Mandatory helmets for motorcycles 1974: Speed limits reset; Alcohol limit set to 0.05% 1975: Mandatory helmets for mopeds 1976: Rules for children in cars (e.g. forbidden on laps in front) 1977: Heavy vehicles, trailers must have reflective markings 1979: Pedal reflectors required for mopeds and bicycle 1983: Reduced 30 km/h zones introduced 1985: Periodic vehicle inspection required 1987: Side reflectors required on mopeds and bicycle. 1990: Rear seat seatbelts required to be fitted in new cars 1992: Mandatory use of seat belts in lorries and vans; and in car rear seats. 1995/1996: Speed limiters for lorries and buses 2001: Mopeds no longer allowed on cycle paths 2002: Prohibition of handheld phones while driving

Source: Based on the SUNflower reports (Koornstra et al 2002; Wegman and Lynam 2002).

Statistical analysis showed that about 37,000 fewer deaths occurred between 1975 and 1978 than would have been expected without federal automobile safety standards. Robertson (1981) also suggests that a similar process occurred across OECD countries. Above, we have described what road safety programs looked like in the pre-regulation era (i.e. the focus was on taming careless drivers). Let us now turn our attention more generally to OECD countries to understand what road safety programs look like in an era of regulations.

Sweden, UK and the Netherlands ("SUN" countries) are widely acknowledged to be among the countries that perform the best in road safety. The SUNflower reports (Koornstra 2002; Wegman 2002) track the development of road safety in these countries. Table 1.1 provides a selected summary of the policy regulations in these countries, excerpted from the SUNflower reports. What is remarkable about Table 1.1 is that it illustrates a history of sustained activity and increasingly stringent regulations that target a wide range of risk factors including vehicles (seatbelts, air bags, speed limiters), roads (cable barriers, safety audits), and drivers (helmets, fatigue, speeding, drink driving). Most interventions are introduced on a small scale and then their scope is expanded over the years that follow. Underlying these efforts are road safety plans that include quantitative safety targets developed around a road safety vision of reducing or eliminating severe injuries. This general approach is now referred to as the "Safe System" approach, which has a strong focus on building the institutional capacity to develop and deliver road safety programs in a long-term results-focused strategy (Bliss 2004).

1.5 CONCLUSION: WHAT DOES THIS ALL MEAN FOR DEVELOPING COUNTRIES?

The key insight that OECD countries were at different stages of economic development in the 1970s when they enacted road safety policies has important implications for LMICs. It shows that countries do not have to wait to be economically developed to implement strong safety regulations. As we have discussed, the traditional analysis based on the Kuznets hypothesis assumes that road safety is an outcome of economic development that plays out slowly as countries become richer and then invest in road safety. In this view, most LMICs would be considered too poor now to undertake strong road safety action.

However, this view is incorrect for two reasons. First, it ignores the large variation in road safety performance of countries at the same income level. Countries could learn a lot about what works and doesn't work in road safety by understanding the reasons for this variation. Second, the Kuznets hypothesis does not consider that OECD countries were at very different income levels when they undertook strong government action. Instead, when we trace the history of road safety in OECD countries, we see a political process that culminated in strong government regulation of roads, vehicles, and road users in the 1970s. Most developing countries still subscribe to a pre-1970s paradigm of road safety, where the problem of road safety is attributed to careless road users. Most interventions, including many high-profile international efforts, focus on education to instill good behaviors and punishment of bad behaviors. The history of OECD countries shows that such programs do not work but that success in addressing road safety began with strong regulations. In order to reduce the road traffic death toll of developing countries, they should act now to establish national institutions with the mandate and resources to regulate and manage road safety in their transportation system as was done successfully in the 1970s by OECD countries.

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CHAPTER 2

Road Traffic Injury as a Public Health Problem

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CONTENTS

ABSTRACT

In this chapter we have outlined the conceptual basis of injury control and emphasized the fact that the issue of road traffic injuries has to be treated as a public health problem and must be dealt with as we would tackle any serious disease. It is important to understand that we must move away from finding fault with victims, and seeking retribution, to a more reasoned approach with dealing with systemic improvements and finding solutions which by and large do not put an extra burden on road users. Road traffic injuries result from a complex interaction of sociological, psychological, physical and technological phenomena. Since injuries result from an exchange of energy between the environment and the human body, it is possible to develop

safety policies and strategies in a scientific and comprehensive manner. Haddon's ten strategies and the Haddon Matrix have been discussed in this chapter that help us organise our thoughts and for resource allocation analysis, strategy identification, and planning.

Key Words: Road traffic injury; public health; injury control; Haddon's matrix

2.1 INTRODUCTION

In this chapter, we demonstrate that control of traffic deaths and injuries must follow the same principles as control of any other public health problem. In the past, most of the products people used, the homes they lived in, and the infrastructure around them was built and created by them or with the help of people they knew. If they suffered any harm or injury from such arrangements, they blamed themselves and the community around them. If there was a solution to the problem, the responsibility for implementing it lay with the community. Modern systems, however, do not allow us to live in isolation or independent of larger systems. Normal activities all too often preclude individual choices. For example, most of us cannot choose the time at which we travel to work or the roads we use. Almost all of us have to be a part of traffic as motorised or non-motorised road users every day and this is not always by choice. The vehicles we use, the highways we travel, and the infrastructure around us is mostly designed, built and maintained by people we do not know and are unlikely to meet.

The potential hazards that may be built into these systems can also be unknown to us. Since almost all of us have to participate in the transportation system every day, all of us are also constantly exposed to the probability of being hurt, disabled, or killed. This is no different from being exposed to bacteria or viruses in the air, water and food, that we breathe, drink and eat every day. If a number of people suffer from diseases due to something in the environment we refer to it as a public health problem. Therefore, a large number of people suffering injuries while traveling can also be defined as a public health problem.

In 1961 Gibson, an experimental psychologist, introduced the concept that we could think of accidents in relation to the 'ecology of dangers' (Gibson 1961). He gave us the idea that dangers are 'environmental facts' and theoretically it should be possible to 'locate and specify all sources of danger in the geographical, the artificial, the animate, and the social environments'. He goes on to state that 'I exclude from consideration disease, or at least infection, as a source of danger because it is a special type of danger with its own peculiarities ... Injuries to a living organism can be produced only by some energy interchange'. This understanding of injuries logically leads us to the fact that bodily injury is just one kind danger along with infectious and contagious diseases. Therefore, in Gibson's words:

> 'The term "accident" it seems to me, refers to a makeshift concept with a hodgepodge of legal, medical, and statistical overtones. Two of its meanings are incompatible. Defined as a harmful encounter with the environment, a danger not averted, an accident is a psychological phenomenon, subject to prediction and control. But defined as an unpredictable event, it is by definition uncontrollable. The two meanings are hopelessly entangled in the common usage. There is no hope of defining it for research purposes. Hence I suggest that the word be discarded in scientific discussion'.

Gibson's approach to thinking of all injuries as being produced by some energy interchange and in principal etiologically similar to any other disease, was shared by many other researchers of the time. Dr. William Haddon was on of the first public health professionals to formalise this approach and promote the idea that road traffic injuries be considered a serious public health problem (Haddon 1968).

Road traffic injuries result from a complex interaction of sociological, psychological, physical and technological phenomena. This understanding of injuries has helped us design safer products, environments, and roads and traffic management systems. Once we accept that injury control is a public health problem, it becomes our ethical responsibility to arrange for the safety of individuals. This, in turn, makes it possible to initiate a scientific policy for injury control and safety promotion.

2.2 TRANSPORTATION SYSTEMS AND HUMAN ERROR

Injury control, the safety of individuals, and societal arrangements are all interlinked. William Haddon wrote seminal pieces on the folly of focussing on "human error" as the main cause in the occurrence of traffic injuries and fatalities (Haddon and Baker 1981; Haddon 1968, 1970a, 1972, 1973, 1980). He also did not like the use of the word "accident" as he thought that this leads a feeling of inevitability to the occurrence of these incidents. Further, he was also convinced that the term "accident prevention" was too limiting and prevented the evolution of other safety countermeasures useful in limiting the severity of injury and in injury management after the event. Instead, he promoted the use of the phrase "injury control" as being more neutral and scientific. But, he did not address the issues of ideology and the power of the elites that influence societies and the policies the latter promote.

Perrow on the other hand, agrees with Haddon that individuals cannot always be held responsible for "human error" under the system they operate in, but he provides a more sophisticated model of systemic imperatives (Perrow 1994, 1999): "I wish to point away from the basic and pervasive sin identified by those who casually examine organizational failures, that of operator error; this is given as the cause of about 80% of the accidents in risky systems. I would put it at under 40%. I will suggest that what is attributed to operator error stems primarily from the structure they operate in, and thus, stems from the actions of elites. Elite errors and elite interests stem from their class and historical power positions in society, and changes in these positions are glacial."

Policy makers and traffic safety professionals in every country find it very difficult to institute changes that actually result in a dramatic decrease in traffic fatalities and injuries in a short time. Experience has also shown that not all individuals follow all the instructions given to them to promote road safety. Attempts to "educate" people regarding safety are also not always very effective and wide variations are found between people's knowledge and their actual behaviour (Williams 2007; Robertson 1983). This is partly because we cannot select who is going to use the road and who is not. While some control can be exercised in licensing drivers of motor vehicles, almost no control is possible in selection of pedestrians and bicyclists. Almost everyone in a population can be a road user and this has implications on how we deal with the issue of traffic injuries as a public health problem.

Systems that ensure a life safe from injury cannot be put in place without a societal and political understanding of the ethical responsibilities of the state and civil society to ensure all individuals a right to life, according to currently available knowledge and technology. This right is implicit in the public health approach followed in controlling communicable and non-communicable diseases. As in the case of all diseases, we should be able to assume that most human beings would try to prevent the occurrence of an episode of ill health if they are able to. This involves an understanding of the phenomenon to a certain extent and at the same time the provision of means to individuals and societies to be able to do something about it. Research has revealed severe limits to ensuring individuals' safety by "educating" them, and that there is a wide variation between people's knowledge and their actual behaviour (Robertson 1983).

Traffic systems must be designed safely for all those who might make mistakes or judge the environmental cues inaccurately. Such designs, rules, and regulations would reduce the probability of people hurting each other or themselves, even when someone makes a mistake. Perrow states this issue forcefully: 'Above all, I will argue, sensible living with risky systems means keeping the controversies alive, listening to the public, and the essentially political nature of risk assessment. Ultimately, the issue is not risk, but power; the power to impose risks on the many for the benefit of the few' (Perrow 1999).

2.3 ROAD TRAFFIC INJURY AS A DISEASE

Certain principles of public health need to be understood so that the same can be applied to the control of traffic related injuries:

2.3.1 There is no basic difference between traffic injuries and the occurrence of any other disease

When we go to a doctor with a complaint of ill health the doctor does not spend a great deal of time trying to fix blame on individuals on why the problem may have occurred in the first place. The police are also usually not involved in trying to solve the problem. Law makers, police departments and others usually get involved if the treatment given is wrong, if some public health authorities have not been doing their jobs properly, or if the problem is so serious and wide spread that societal intervention is necessary. We have understood for a long time that we should not blame the victims for contracting a disease if we want to solve the problem. This approach has helped us in improving our health status through the centuries. The same approach has to be adopted for road traffic injuries as a new disease of the twentieth and twenty-first centuries.

2.3.2 Road traffic injury can be defined as a disease that results from an acute exposure of the human body to a transfer of energy from the environment around it

There are no basic scientific distinctions between injury and disease (Baker and Haddon 1974). When some fluid collects in the brain due to a disease one may die or be disabled permanently if the problem is not controlled. The cause of death due to a head impact with the road in a motorcycle crash could be the same – cerebro-vascular oedema. While the immediate cause of death or disability would be the same in both cases, most of us would have different approaches in trying to solve the problem. Any infectious disease may cause fever, pain, disability, or death. Injuries do the same. Therefore, the concept of injury is coextensive with the concept of disease. Table 2.1 illustrates this relationship.

Once all of us start looking at traffic injuries as diseases, the community may stop viewing them as events resulting primarily from carelessness of the victims as individuals. Long ago we learned that it does little good to blame the victim of a disease for being sick. For example, when a patient goes to a doctor with malaria, the doctor does not blame the victim for not killing the mosquito before it bit her. The most effective disease control measures often consist of modifying the environment and helping people to be in better control of their lives under most situations. Measures that attempt at trying to make individuals behave in an "ideal" manner have little chance of succeeding. Up to now, our efforts at traffic injury control in many countries

TABLE 2.1 Comparative Epidemiology of Malaria and Skull Fracture (as sustained by an unhelmeted motorcyclist crashing into a tree).

Pathological Condition	Host	Agent	Vector/ Vehicle	Interaction
Malaria	Man	Plasmodium sp.	Mosquito	Mosquito bite
Skull Fracture	Man	Mechanical energy	Motorcycle	Crash with tree

TABLE 2.2 Some Strategies For Control.

General Principle	Malaria	Skull Fracture
1. Prevent creation of hazard.	Keep mosquitoes from breeding.	Ban manufacture of motorcycles.
2. Eradicate existing hazard.	Kill mosquitoes by fumigation, etc.	Ban use of motorcycles. Remove trees near roadsides.
3. Interpose barrier.	Use mosquito nets.	Place a barrier between roadway and hazards like trees.
4. Minimize result of host-agent interaction.	Take appropriate anti-malarial medication when in malaria infested area.	Use helmets when riding motorcycles.

have often been retarded by a preoccupation with fixation of blame. This has led to repeated attempts to prevent injuries by changing the behaviour of their potential victims. Such attempts are usually costly, not often successful, and have added to the public's sense that injuries are an unavoidable evil. However, as Table 2.2 demonstrates, the same general principles used in disease control may successfully be applied to injuries.

2.3.3 "Accidents" and injuries are not "Acts of God"

It is a vital first step to realize that the occurrence and outcome of events which may cause injury, are predictable and subject in many cases to human control. We are able to predict the situations under which the probability of road crashes are likely to increase, and the designs of vehicles and the road environment which would result in less severe injuries during a crash. Often an injury can be prevented even where an "accident" cannot. We may not be able to prevent all motorcycle crashes but in a motorcycle crash, the occurrence and severity of head injury depend on whether or not a helmet was used and on the quality of the helmet. Even the so-called natural disasters are not really "natural." If they were, then the effects of floods and earthquakes would be the same in the rich and poor countries.

How a physical event influences human beings is very largely influenced by human beings themselves. Even the occurrence of the physical event itself is very often a result of man's activity. For example, floods may be caused by deforestation, faulty design of dams, blocking up of drainage in cities, etc. Therefore, human beings and how they organise their societies have a great deal to do with whether or not harmful events and disasters take place and how these events affect us. We can design our environment and products such that the incidence and effects of road traffic crashes and disasters are minimized.

2.3.4 Not all injuries can be prevented

Most efforts to reduce traffic injuries are termed "accident prevention" campaigns. We should be clear that *accident prevention* is just one aspect – and not always the most rewarding one – of a much larger range of countermeasures used in effective road traffic injury control programmes. It is important that all programmes also include measures of reducing injury severity if a crash does occur, and well-designed systems for emergency care, treatment and rehabilitation after the crash. This is because making mistakes is very "normal" and not "abnormal" in activities that involve a vast majority of persons from a given population. It is normal for professional drivers to be distracted during some periods of their long driving hours; it is normal for executives driving to work to be day-dreaming at some point in the journey; it is normal for a teenager to take more risks than an elderly person while driving a motorcycle; and it is normal for children to do the unexpected and hurt themselves as pedestrians or bicycle riders. In short, we will never eliminate carelessness, absentmindedness, and even neglect in day-to-day activity. However, by designing our products and environment to be more tolerant of these normal variations in human performance, we can minimize the number of resulting accidents and injuries.

Crashes are the result of a temporary imbalance between an individual's performance and the demands of the system in which (s)he is functioning. They can be prevented by alterations in either, but most effectively by focusing on the system as a whole, and not on its user alone. A crash can occur when the victim was in fact performing quite well in absolute terms but the demands of the system exceeded the current performance level of the user. In many areas of public health we understand this very well. We know that drinking water should be purified at its source; it is unreasonable to expect everyone to boil his water before drinking it. Those societies, which depend upon individuals to purify their own drinking water suffer from much higher rates of communicable diseases than those which purify water at the source. Ironically, it is quite common to create a product or environment that is likely to cause injury, warn the user to be careful, and then blame the user if a mishap occurs. We would never tolerate a person who introduced cholera germs in a city water supply and then asked every citizen to boil the water before drinking it, using the argument that those who knowingly don't do so would be responsible for getting sick. Nevertheless, this is the kind of argument we all too often use when dealing with matters concerning road safety. We put in place hazardous roads, vehicles and driving rules and then expect road users to be safe by behaving in some ideal manner.

2.3.5 Injury control measures can be developed systematically

When we evaluate traffic injuries as a health problem, we find it very difficult to think of all the possible countermeasures because the problem appears to be too large and unwieldy. It is generally easier to work in a systematic manner. One useful approach is to consider each traffic injury problem as resulting from an interaction between several discrete factors, occurring over distinct phases in time and space. Each phase – pre crash, crash and post crash can then be analysed systematically for human, vehicle, road and environmental factors. Another way to analyse a traffic safety issue is to concentrate on managing the excess energy that may contribute to the occurrence of a crash that causes injuries during the crash. Once the multiple factors associated with the crash are identified and analysed, their countermeasures can be discussed and prioritised for implementation over short and long term periods. These approaches are discussed in the next section.

2.4 DEVELOPING INJURY CONTROL MEASURES

2.4.1 Safe infrastructure and systems

Road safety management is a systematic process in which we consider the road infrastructure, the road users, and the vehicles as integral components of a complex interactive system as shown in Figure 2.1. Each part of the system interacts and is influenced by the others and can produce unexpected results. The road transport system has to be developed in a way that does not jeopardise the environment or public health and welfare of its participants. In this approach, it is essential that a road environment be created that minimises the risk of road users making mistakes and that prevents serious human injury when designing, operating and maintaining the road network. The entire traffic and transport system must be designed to account for the limitations and capabilities of road users.

In the road transport system the design of vehicles, infrastructure and policing methods have to be aimed primarily at the prevention of traffic crashes irrespective of the characteristics and

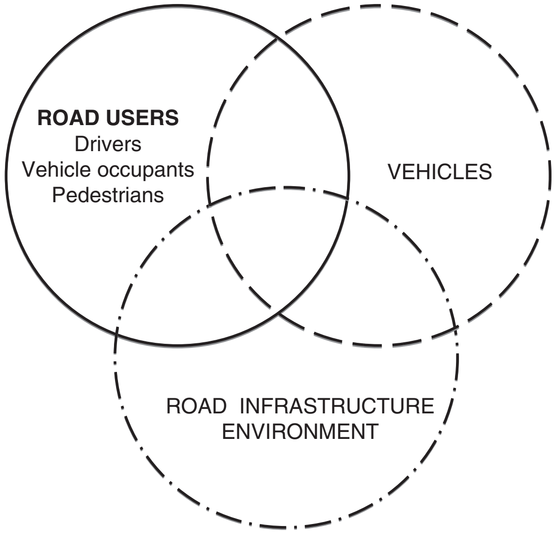

Figure 2.1 Road safety management as a complex system in which we consider the road infrastructure, the road users, and the vehicles as integral components of an interactive system.

skills of the road users. In the event of a crash the system has to be designed such that the consequences are kept to the absolute minimum. The requirements of such an infrastructure are (adapted from reference (SWOV 2003)):

1. *Functionality*: Traffic should be distributed over the road network as was intended.
2. *Homogeneity*: For road users using the same space there should be small speed and mass differences between transport modes that can collide.
3. *Recognition*: Traffic situations should, to a great extent be predictable. The road infrastructure should provide clear indications on what behaviour is expected from you and from other road users.

It is far more effective to provide *automatic protection* than to hope that people will behave in a "safe" way. Automatic approaches protect individuals without their having to perform some action or behave in a specific manner. For example, a person who chooses not to use her manual seat belt (or who forgets to buckle it) has no protection in the event of her car crashing. If there is an air cushion system in her car, however, it will inflate to protect her regardless of her state of mind, level of inebriation, or intelligence.

2.4.2 The energy control approach and Haddon's ten strategies

The idea that injuries result as a consequence of energy exchange between the environment and the human body had gained currency in the 1960s (Gibson 1961), but it was Haddon who formalised the concept and used it to suggest a systematic way of conceptualising a host of safety countermeasures for a specific problem (Haddon 1970b). The principles as outlined below focus on eliminating the source of energy, reducing the amount of energy released and reducing its harmful effects.

Ten basic, generalized, strategies for reducing damage by control of energy transfer (Adapted from Reference Haddon 1973 and Robertson 1983).

1. To prevent the creation of the hazard in the first place. *Examples*: prevent production of plutonium, thalidomide, LSD, banning use of dangerous vehicles.

2. To reduce the amount of hazard brought into being. *Examples*: reduce speeds of vehicles, lead content of paint, mining of asbestos.
3. To prevent the release of the hazard that already exists. *Examples*: pasturizing milk, bolting or timbering mine roofs, impounding nuclear wastes, design of petrol tanks so that they do not explode.
4. To modify the rate or spatial distribution of release of the hazard from its source. *Examples*: brakes, shutoff valves, reactor control rods.
5. To separate, in time or space, the hazard and that which is to be protected. *Examples*: isolation of persons with communicable diseases, walkways over or around hazards, evacuation, banning of trucks moving through cities in the daytime.
6. To separate the hazard and that which is to be protected by interposition of a material barrier. *Examples*: surgeon's gloves, containment structures, childproof poison container closures, sleeve around the exhaust pipe of a motorcycle.
7. To modify relevant basic qualities of the hazard. *Examples*: altering pharmacological agents to reduce side effects, using breakaway roadside poles, making crib slat spacings too narrow to strangle a child, designing cars with crumple zones, etc.
8. To make what is to be protected more resistant to damage from the hazard. *Examples*: immunization, making structures more fire- and earthquake-resistant, giving salt to workers under thermal stress.
9. To begin to counter the damage already done by the environmental hazard. *Examples*: rescuing the shipwrecked, reattaching severed limbs, extricating trapped vehicle occupants.
10. To stabilize, repair, and rehabilitate the object of the damage. *Examples*: posttraumatic cosmetic surgery, physical rehabilitation, rebuilding after fires and earthquakes.

2.4.3 Resource allocation analysis, strategy identification, and planning – Haddon's matrix

Over fifty years ago, Edward McGavran, Dean of the University of North Carolina School of Public Health, articulated the concept of treating the community as if it were a patient (McGavran 1958), and a few years later Patricia Z. Barry further wrote that "Traditional health program efforts toward the prevention of injury have been based on assumptions of individual responsibility for safety. The degree of impact which such programs have on injury incidence rates has not been determined. Health personnel are urged to adopt an orientation to the community, rather than to individuals, in approaching problems in injury control. The theoretical implications of individual versus community orientation are discussed using illustrative material from injury problems in childhood" (Barry 1975). A consensus was emerging that if traffic injuries had to be controlled, greater success would be possible if there were a substantial shift from blaming individuals to examining the problems a community faces with respect to its environment and the products in use.

Haddon was responsible for putting these ideas together and coming up with an aid to resource allocation analysis, strategy identification, and planning, the so-called Haddon matrix (Haddon 1980) as shown in Figure 2.2.

The use of the matrix is illustrated by an example below.

Incident: A car approaches a road junction and goes through, passing the light which has just turned red. The car hits a motorcycle which has entered the junction from the left or right. The motorcyclist gets thrown sideways and hits a pedestrian walking on the side of the road. The car driver gets facial injuries, the motorcyclist sustains head injuries, and the pedestrian suffers a leg fracture

Use of the matrix: Each cell of the matrix is used to make a list of countermeasures that could be put in place to control damage from such incidents. The numbers in the cells of

PHASES	FACTORS: Human (Road users)	Vehicle(s)	Environment (Roads, infrastructure, laws, enforcement, etc.)
Pre-event (Preventing the crash)	1	2	3
Event (Control of injury during the crash)	4	5	6
Post event (Control and treatment of injury after the event)	7	8	9

Figure 2.2 Hadon's matrix adapted for resource allocation analysis, strategy identification, and planning measures for traffic safety (adapted from Haddon 1980).

the matrix show to which phase and to which factor each of the countermeasures in the list below would be assigned.

1. Training of drivers, pedestrians to walk facing traffic, motorcyclists to wear bright clothing and luminous helmets.
2. Car equipped with anti-skid brakes, compulsory use of headlights in daytime by motorcycle riders, speed control devices in vehicles.
3. Vigilant policing, red light cameras at junctions, brighter illumination at junctions, safe sidewalks of adequate width, no left turn on red light, strict roadside checks for drinking and driving, use of roundabouts instead of light-controlled junctions, law mandating use of daytime running lights by motorcyclists.
4. Use of protective clothing and helmets by motorcyclists and seat belt by car occupants.
5. Car manufactured according to best practices in crashworthiness, car equipped with seat belts and airbags, pedestrian and two-wheeler friendly design of vehicle fronts.
6. No sharp edged street furniture, mandatory laws for helmet and seat belt use.
7. Adequate arrangements for pre-hospital care, treatment in hospital, and rehabilitation if necessary.
8. Automatic switch off arrangements in vehicles in event of a crash, burst resistant fuel tanks, automatic crash notification systems in vehicles after a crash.
9. Police equipped with victim rescue tools, guidelines for managing crash scenes, emergency care system, laws regarding care of victims, universal no-fault insurance policies.

The number of counter measures listed above are not exhaustive for each cell. A multidisciplinary team of experts and policy makers would probably come up with a much longer list. The main point to be noted here is that the use of such tools helps us to come up with a host of possibilities that include all the actors in the traffic safety system and also helps us address all issues in time and space. After such lists are made, policies and strategies can be formulated and priorities set based on following considerations:

(a) Countermeasures to be put in place in the immediate, near and distant future.
(b) Knowledge and technologies available.
(c) Resources and finances.
(d) Political considerations.

2.5 SUMMARY

In this chapter we have outlined the conceptual basis of injury control and emphasized the fact that the issue of road traffic injuries has to be treated as a public health problem and must be dealt with as we would tackle any serious disease. Whenever a very large proportion of the population faces ill health and death due to a specific activity, and that activity, like travel, is almost compulsory in nature, it becomes a public health problem. It is important to understand that we must move away from finding fault with victims, and seeking retribution to a more reasoned approach to dealing with systemic improvements and finding solutions which by and large do not put an extra burden on road users.

Road traffic injuries result from a complex interaction of sociological, psychological, physical and technological phenomena. This understanding of injuries has helped us design safer products, environments, roads and traffic management systems. Once we accept that injury control is a public health problem, it becomes our ethical responsibility to arrange for the safety of individuals. This, in turn, makes it possible to initiate a scientific policy for injury control and safety promotion.

Since injuries result from an exchange of energy between the environment and the human body, it is possible to develop safety policies and strategies in a scientific and comprehensive manner. Haddon's ten strategies and the Haddon Matrix have been discussed in this chapter to help us organise our thoughts, and for resource allocation analysis, strategy identification, and planning.

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CHAPTER 3

Public Health Burden of Road Traffic Injuries

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CONTENTS

ABSTRACT

Road transportation systems affect human health through complex pathways. Governments invest in road infrastructure because it encourages economic growth, which has direct and indirect benefits to health. However, an excessive reliance on motor vehicles harms population health and social wellbeing due to road traffic injuries, air pollution and reduced physical activity, among other effects. In this chapter, we start by reviewing the mechanisms through which road transport impacts population health. Next, we review the magnitude of the health loss due to injuries and vehicular pollution relative to other diseases in regions at different levels of economic development. We show that the health impacts of motorized road transport rank among the leading causes of health loss in all regions of the world. Finally, we describe how researchers construct estimates of the burden of road traffic injuries in information-poor settings.

Key Words: Injury Metrics; Burden of Disease; Public Health

3.1 HEALTH IMPACTS OF ROAD TRANSPORTATION SYSTEMS

The development of road transportation systems affects the health and well-being of society through multiple pathways. While some of these impacts are positive and are the intended

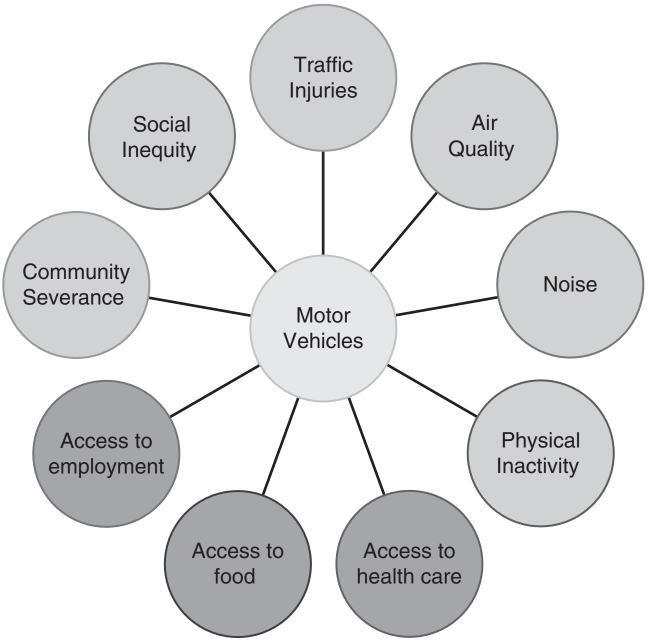

Figure 3.1 Public health impacts of transport policy. Orange bubbles show negative impact; Green bubbles show positive impacts.

consequences of economic development processes, others harm human health through a variety of direct and indirect mechanisms (Figure 3.1).

3.1.1 Why do countries build roads?

National development agencies invest substantial resources in building and maintaining road infrastructure. Improving the mobility of people and goods is seen as a key strategy for driving economic growth and improving the health and well-being of people (World Bank 2008). The development of road networks stimulates economic development by connecting centers of industries and markets, spurring the growth of trade, and reducing costs by improving access to goods and services (Kessides et al 2010). For instance, the Golden Quadrilateral in India is a large-scale highway construction project that began in 2001. It is the fifth-longest highway in the world, that aims to improve the connection of four major cities (Delhi, Mumbai, Chennai, and Kolkata) in the country. Studies of the developmental impacts of this project suggest that it has improved the efficiency of the organized manufacturing sector, and has made medium-sized cities more attractive for manufacturing activities (Ghani and Goswami 2013).

By encouraging economic development, roads indirectly improve the health and wellbeing of populations. Economic development leads to higher employment and raises wages, giving individuals the opportunity to improve their nutrition and their ability to pay for health services. Rural roads have been shown to increase the enrollment of girls in school (World Bank 2008). The education of girls is an end in itself but it is also important to population health because it reduces fertility rates and improves maternal and child health, in addition to other population health benefits (Gakidou et al 2010). In addition to these indirect benefits, improving roads can also directly improve health by improving access to health facilities, and food markets (World Bank 2008).

It is partly for these reasons that motorized road transport has grown briskly in recent decades, especially in regions with the most rapidly growing economies. Since the mid-1990s, China has built a highway system that is expected to surpass that of the United States in the near future (Yan 2011). The aforementioned Golden Quadrilateral project in India is part of a broader effort to improve highway infrastructure and encourage industrial growth (Ghani and Goswami 2013). Most people in sub-Saharan Africa do not have access to all-weather roads. However, international development agencies see the development of highway infrastructure as a key solution to reducing poverty in the region (World Bank 2008; Union 2005).

The belief that growth in road transportation is an essential driver for social development is firmly entrenched in developmental economics. However, several philosophers and social thinkers have questioned the basis of many of the assumptions that underlie the faith in motorization. Notably, Ivan Illich has argued that the modern transportation industry has severely restricted our freedoms by altering mobility to a system of industrially defined routes, driving wedges between neighbors, and pushing people away from their families and friends (Illich 1974). Appleyard studied what happens to social ties in communities when traffic volumes increase on residential streets (Appleyard et al 1982). He showed that when traffic is light, people have many social connections and an active street life. Heavy traffic frays these bonds; residents withdraw to their houses, and children have fewer friends. Knoflacher has assessed the trips and travel times of societies at vastly different levels of economic development and has shown that motorization does not bring additional mobility (i.e. trips per person per day) and no freedom in choice of transport modes (Knoflacher 2007). These arguments, if taken seriously, could have large implications on how we design transportation systems.

3.1.2 How does road transport harm health?

Although the aforementioned critique of motorization-centered economic growth has been largely ignored in current development practice, researchers and policy makers recognize the burden of many "externalities" produced by transportation systems. In economics, an "externality" is the unintended consequence of an action to a third party. In the case of road transport, these include road traffic crashes, air pollution, noise pollution, light pollution, community severance, and congestion (Figure 3.1). Many of these externalities have direct health impacts, causing diseases and injuries. Others have indirect health effects through their impact on quality of life and well-being.

As motor vehicles have proliferated over the last century, road traffic crashes have grown to be amongst the leading causes of death in most countries globally (Lozano et al 2012). Managing road safety has proven difficult in the high-speed and high-energy road networks that characterize modern industrialized societies. In the 1970s, OECD countries began to recognize the need to improve safety, and invested substantially in improving safety in their transportation system. These efforts included establishing national safety agencies, strengthening legislation, enforcing traffic laws, redesigning highway infrastructure and vehicles to be safer, and educating drivers (WHO 2004). These efforts have led to a reduction in road traffic death rates in OECD countries since their peak a few decades ago. However, road traffic death rates remain a leading cause of death for children and young adults even in the countries that have made the most progress in road safety. In the Sweden, UK, and the Netherlands, which are widely acknowledged as the best performing countries (Koornstra et al 2002), road traffic injuries rank in the top five causes of death for people aged between 1 and 45 years (Lozano et al 2012).

Motor vehicles are a leading contributor to air pollution, carrying significant risks to human health (HEI 2013). Car and truck emissions include particulate matter, hydrocarbons, nitrogen oxides, carbon monoxide, sulfur dioxide, and other toxins. Fine particulate matter can penetrate deep into human lungs and poses the most serious health risk. Hydrocarbons combine with nitrogen oxides to form ground level ozone, irritating the human respiratory system and reducing lung capacity. Sulfur dioxide, which is a key product from the burning of sulfur containing diesel, forms fine particles harming the health of young children and those with asthma. In addition to emissions produced during operation, motor vehicles are significant sources of pollution during their manufacture, disposal, and in building and maintaining the supporting infrastructure (roads and refueling systems).

As societies have motorized, people have begun to walk less. This reduction in physical activity is an important contributor to increasing obesity and a wide range of non-communicable diseases that are associated with sedentary life styles. For instance, in the US, obesity has increased steadily since the 1980s in all states and among all age, sex, and socio-economic groups (Mokdad 1999). Researchers have shown that about one-third of all deaths in the US due to coronary heart disease, colon cancer, and diabetes are due to sedentary lifestyles (Powell and Blair 1994). People lead less active lives today because our choice of transport modes (walking, bicycling, or using motor vehicles) is determined by our built environment and the type of transport network (Ewing and Cervero 2010).

These issues — traffic injuries, vehicular emissions, and physical activity — are interlinked. Transportation policies and interventions designed to address one of these often affect the others. The science of understanding these inter-relationships is in its infancy at present. As an example of the findings of such work, early research suggests that the health benefits of cycling (increased physical activity, lower ambient air pollution) outweigh the injury risks (De Hartog et al 2010; Rojas-Rueda et al 2011; Woodcock et al 2009). As a result, it has been argued that it is important to promote cycling even if it results in an increase in injuries from bicycle crashes (Roberts 2013). Simultaneously, research shows that people tend not to walk and bike if they perceive these activities to be unsafe (Delinger and Stanton 2002). This suggests that safety is a pre-requisite for encouraging active transport in communities.

Urban planners, public health practitioners, transport planners and civil engineers are increasingly coming together to address these issues in a common framework of sustainable transport that aims to promote active transport (including walking and biking) while simultaneously reducing private motor vehicles. Supporting policies are being promoted by a large number of international developmental agencies, including the United Nations (UN 2011), the Intergovernmental Panel on Climate Change (Kahn Ribeiro et al 2007), and the multi-lateral development banks (RIO 2013). Reversing the growth of private motor vehicles and encouraging active travel is critical to ensuring that we leave the next generation with a livable planet.

3.2 MAGNITUDE OF THE PUBLIC HEALTH BURDEN OF ROAD TRAFFIC

The previous section described the multiple ways in which transportation policies impact human health. This raises several questions: *How much do these negative health impacts matter? Do we need to worry about them? How do these harms compare with other threats to our health and well-being*? Answering these questions is essential for deciding where to focus policy attention, providing balanced investments in solutions, monitoring progress of health and safety programs, and informing public debates about social priorities. However, addressing these questions requires a non-trivial analysis that requires addressing several theoretical and practical issues.

The most important theoretical issue in comparing the public health burden of multiple diseases is that it requires assessing the mortality and non-fatal health outcomes for population in varying age groups. It is common for researchers to describe the magnitude of a health problem by reporting the number of deaths. This has two problems. The first issue is that eventually everybody dies, making a simple comparison of death counts not meaningful. Consider that lung cancer and road traffic crashes annually kill about the same number of people globally (1.5 vs. 1.3 million people) (Lozano et al 2012). However, while most lung cancer deaths occur late in life, road traffic deaths impact young people, robbing them of many years of life. Thus, a more meaningful comparison is to aggregate the number of years of life lost (YLLs) due to premature mortality, compared to a full life. YLLs are calculated by subtracting the age at death from the longest possible life expectancy for a person at that age. Road traffic crashes result in almost twice as many life years lost as lung cancer (62 vs. 32 million YLLs) (Lozano et al 2012).

The more challenging issue is that many health conditions lead to varying levels and duration of disability, making it impossible to compare their health burden based solely on mortality. Consider, that a condition like low back pain is not usually considered a cause of death but is the source of substantial disability. How do we compare the public health burden of low back pain with conditions that kill? This requires the use of a *summary measure of population health* that measures the health of a population by combining data on mortality and non-fatal health outcomes into a single metric. Population health researchers have proposed several such metrics, including the Disability-Adjusted Life Year (DALY), Quality-Adjusted Life Years, Disability-Adjusted Life Expectancy (DALE), and the Health Life Year (Healy) (Gold et al 2002). Among these, the DALY is the most widely used measure in burden of disease studies. DALYs measure the health gap between the current health status of a population and an ideal where everybody lives a full life in perfect health. DALYs aggregate two components: years of life lost (i.e. YLLs as described above), and years lived with disability (YLD), which is the product of the number of disability cases, the average duration of the disability, and a weight factor reflecting the severity of the condition on a scale of 0 (perfect health) to 1 (death). These disability weights reflect social preferences for different health states and are empirically determined through large population surveys (Salomon et al 2012).

3.2.1 About the Global Burden of Disease (GBD) Project

The Global Burden of Disease Project (GBD) is a study that tracks the public health burden of all diseases in all countries. GBD was originally commissioned in 1991 by the World Bank to develop a comprehensive and comparable assessment of the burden of 107 diseases and injuries and 10 selected risk factors for the world and eight major regions. The findings represented a major improvement in global knowledge of population health metrics and proved to be influential in shaping the global health priorities of international health and development agencies. The study also stimulated numerous national burden of disease analyses that have informed debates on health policy over the last two decades.

The 2010 revision of the project (GBD-2010) is the most recent iteration of the study, and is a comprehensive update of the original study and presents estimates for 291 diseases and injuries, 67 risk factors, and 1,160 sequelae (non-fatal health consequences) disaggregated by sex and 20 age groups, for 21 regions covering the entire globe. The study is a collaboration of hundreds of researchers around the world, led by the Institute for Health Metrics and Evaluation at the University of Washington and a consortium of several other institutions including: Harvard University, Imperial College London, Johns Hopkins University, University of Queensland, University of Tokyo, and the World Health Organization.

As part of GBD-2010, a concerted effort was undertaken to improve the estimates of the public health burden of road injuries. A substantial project-wide effort was made to incorporate data from vital registration and sample registration systems, as well as demographic surveillance systems, among many others. This broad search was coupled with a targeted effort to improve data on road injuries from the most information-poor settings. As a result, a wealth of data from regions such as sub-Saharan Africa was used for the first time in epidemiological research. Key data sources for injuries included:

- Vital registration statistics: These are tabulations from national vital registration systems, which usually record the causes of death listed on death certificates.
- Verbal autopsies: These are causes of death determined by a trained interviewer using a structured questionnaire that collects information about symptoms preceding death. Such surveillance is commonly done in regions that do not have reliable vital registration systems.

- Mortuary/burial registers: Medico-legal records from mortuaries and burial permit offices were another important source of data for information-poor regions.
- Household surveys: These were a critical source for estimating the incidence of non-fatal injuries.
- Hospital databases: Large hospital registries were used as a valuable source of information about the sequelae resulting from injuries.
- Prospective studies of disability outcomes: The results from follow-up studies of patients after an injury were used to estimate the duration of disability and the probability of its performance.

These data sources are discussed in more detail in the next section. Prior to their analysis in GBD-2010, these data were subjected to a systematic harmonization and data cleaning. This includes adjusting for completeness of mortality data sources, mapping across different coding schemes, and reattribution of poorly specified causes. Mortality from road crashes was estimated in 40 age-sex groups for all countries from 1980 to 2010 using Cause of Death Ensemble Modeling (CODEm), which involves developing a large range of plausible statistical models between the cause and known covariates, testing all possible permutations of covariates, and generating ensembles of the component models (Foreman et al 2012). The performance of all component models and ensembles is evaluated based on their out-of-sample predictive validity and the best-performing model or ensemble is chosen. The burden of non-fatal outcomes of injuries was estimated by first constructing estimates of the incidence of the external causes of injuries using household survey data, hospital data, and the injury mortality estimates. Hospital databases were used to estimate the incidence of health outcomes (e.g., fractures, dislocations, etc.) that result from road injuries. Long-term disabilities were estimated from these health outcomes using data collected from studies that have followed patients after they sustained a road injury. Finally, YLDs were computed by applying disability weights. These methods rely on many assumptions and will likely undergo substantial refinements in the years to come. However, they are the only known attempt at large-scale coupling of empirical data to construct global estimates of the burden of non-fatal road injuries.

3.2.2 Estimates of the Global Burden of Disease

Results from GBD-2010 show a world undergoing a rapid transition in population health, away from mostly infectious disease in children to non-communicable disease (NCDs) and injuries that affect adults. Over the last two decades, life expectancies have increased across most of the world, the burden of HIV and malaria has fallen, and fewer children younger than 5 years are dying. However, the results also reveal huge health gaps in different regions of the world.

Figures 3.2 and 3.3 illustrate the cause-of-death profiles of different regions of the world highlighting the dramatically different health needs of regions. In sub-Saharan Africa, which is the least developed of the regions shown, the mortality profile is dominated by infectious and neonatal diseases comprising about two-thirds (66.5%) of all deaths; and accounting for nine of the top-10 causes of death. NCDs comprise about one-fourth (24.9%), and injuries account for the remainder (8.6%). By comparison, in India infectious and childhood disease comprise a smaller proportion (35.0%) of all deaths, NCDs comprise a larger proportion (53.5%), and injuries comprise the remainder (11.5%).

China has a mortality profile that is remarkably similar to that of high-income countries despite having a much lower income. This is primarily because of China's success in managing infectious and childhood diseases. These account for only 5.9% of deaths in both China and high-income countries (Figure 3.1). In sharp contrast with Africa, NCDs and injuries account for nine of the top-10 causes of death in China.

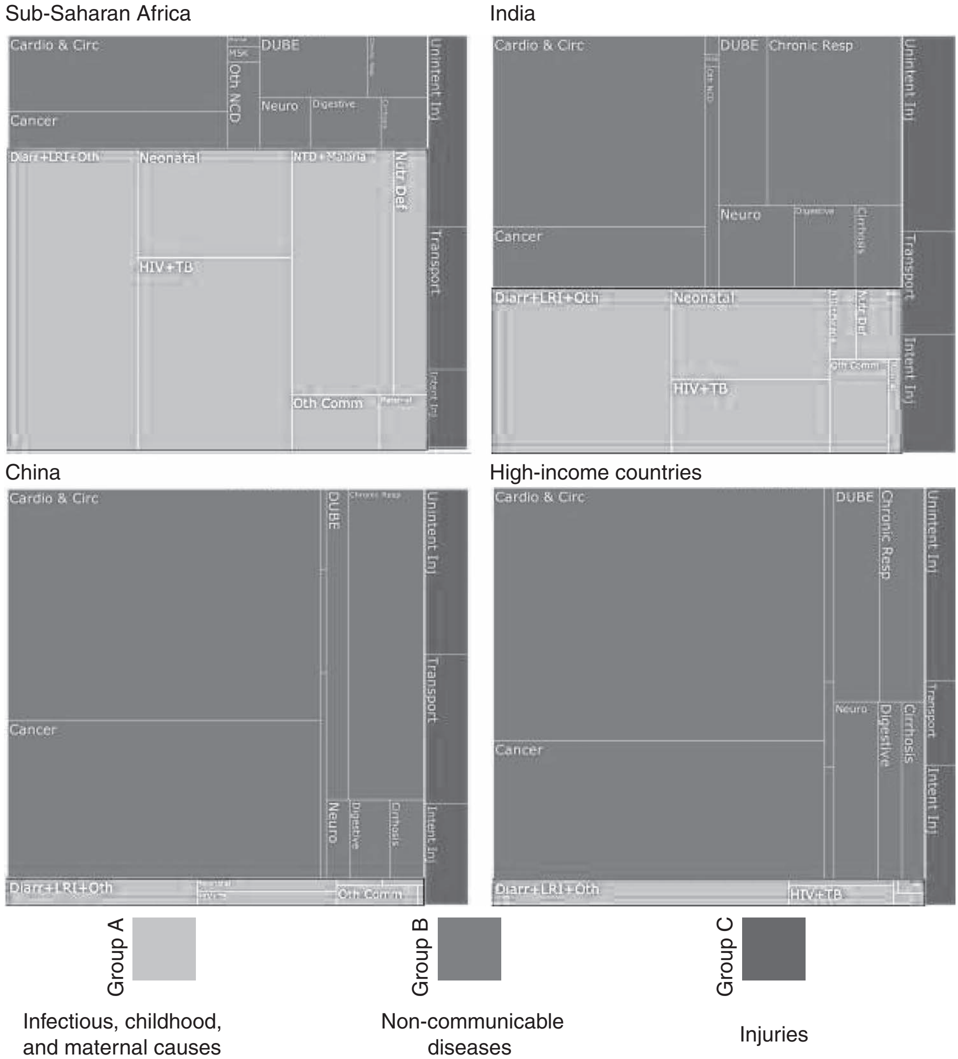

Figure 3.2 Distribution of causes of death in 2010 in regions of the world at varying levels of economic development. These are square pie charts. Area of each square is proportional to the size of health loss.
Source: GBD-2010 (Lozano et al 2012).

Road injuries are a leading cause of death in all four regions (Figure 3.3) but the importance of road traffic deaths varies relative to other causes in regions at different stages of development. Although the per-capita ownership of motor vehicles steadily increases in regions with economic development, the proportion of deaths that are due to road crashes has a more complex relationship. Road injuries comprise the same proportion of all deaths (2.8%) in Sub-Saharan Africa and India, and have a similar cause-of-death rank (10 and 9, respectively). The proportion of road deaths is substantially higher in China (3.4%), and they are the fourth leading cause of death. However, the proportion of road deaths is substantially lower (1.2%) in high-income countries (8th leading cause of death). This is a result of the trend in road traffic crashes and the trend in other diseases in these countries. These results suggest that as the economies of low- and middle-income countries have grown, they have made substantial progress in reducing infectious

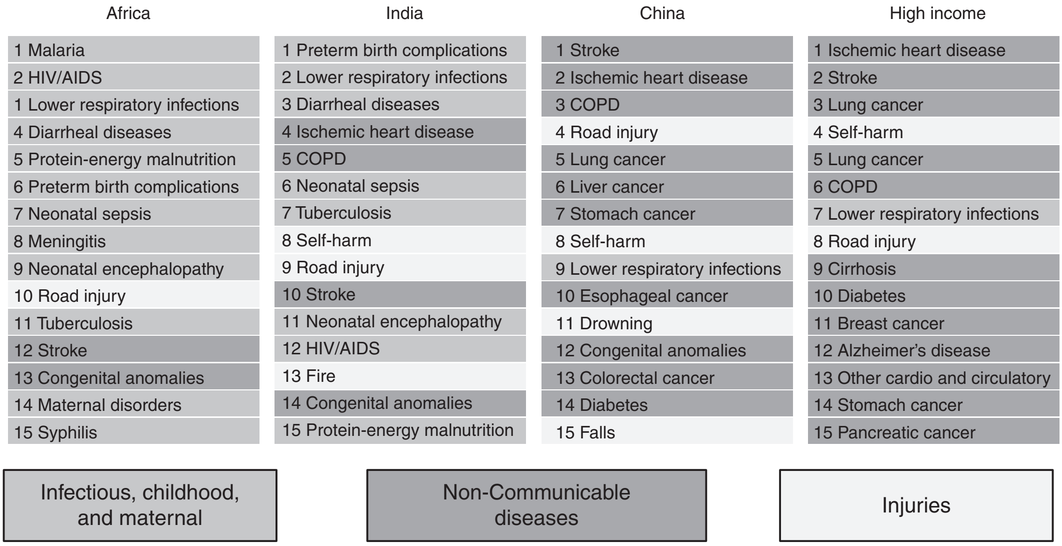

Figure 3.3 Leading causes of premature deaths in 2010.
Source: (Lozano et al 2012).

TABLE 3.1 Leading cause of death worldwide, associated DALYs, and burden attributable to motorized road transport in 2010.

	Global burden of disease		Burden attributable to motorized road transport	
Rank & Cause	**Deaths**	**DALYs**	**Deaths**	**DALYs**
1 Ischemic heart disease	7,029,270	129,795,464	90,639	1,909,563
2 Stroke	5,874,181	102,238,999	58,827	1,148,699
3 COPD	2,899,941	76,778,819	17,266	346,376
4 Lower respiratory infections	2,814,379	115,227,062	5,670	489,540
5 Lung cancer	1,527,102	32,405,411	11,395	232,646
6 HIV/AIDS	1,465,369	81,549,177		
7 Diarrheal diseases	1,445,798	89,523,909		
8 Road injury	1,328,536	75,487,102	1,328,536	75,487,104
9 Diabetes mellitus	1,281,345	46,857,136		
10 Tuberculosis	1,195,990	49,399,351		
All other causes	24,207,527	1,682,995,639		
Total	**52,769,676**	**2,482,258,070**	**1,512,333**	**79,613,9**

Note: In the "burden attributable to motorized road transport" column, emissions from road transport contribute to deaths and DALYs from ischemic heart disease, stroke, COPD, lower respiratory infections, and lung cancer. Road transport crashes contribute to deaths and DALYs from road injury.
Source: Transport for Health Report (Bhalla et al 2014).

diseases. However, progress in managing road safety has been much more difficult except in high-income countries which have expended substantial efforts to address safety issues (Koornstra et al 2002).

Table 3.1 illustrates the leading causes of death worldwide, associated DALYs, and the amount of these deaths and DALYs that can be attributed to vehicular air pollution and motor vehicle crashes. Injuries and air pollution generated by motorized road transport were associated with six of the top 10 causes of death and five of the top 10 causes of DALYs in 2010. In fact, the top three causes of death, premature mortality (YLLs), and overall health loss (DALYs) are diseases that are linked to air pollution, which is closely associated with motorized road transport. Overall, injuries and air pollution from road transport caused 1.5 million deaths globally, representing 2.9% of deaths from all causes. Together, they were the sixth-leading cause of death in 2010, with a death toll exceeding that from HIV/AIDS, tuberculosis, malaria, and diabetes. They were responsible for 79.6 million healthy life years lost, or DALYs, which is 3.2% of the total global burden of disease and injuries.

Injuries resulting from road crashes account for 95% of the combined burden of ill health (pollution and injuries) from motorized road transport. Road injuries killed 1.33 million people globally in 2010 and were the eighth-leading cause of death, accounting for 2.5% of all global deaths. The road injury death toll exceeded that from diseases such as tuberculosis and malaria which receive substantial attention in the global health research and development community. They were the 10th-leading cause of healthy life years lost (DALYs), contributing 3.0% of the total global health burden. They were also the eighth-leading cause of premature mortality. Exposure to pollution from vehicles, in terms of particulate matter pollution derived from vehicular emissions, resulted in 184,000 deaths globally. This includes 91,000 deaths from ischemic heart disease, 59,000 deaths from stroke, and an additional 34,000 deaths due to lower respiratory infections, chronic obstructive pulmonary disease (COPD), and lung cancer combined.

3.3 MEASURING THE LOCAL BURDEN OF INJURIES

The final section of this chapter discusses how researchers can estimate the burden of road traffic injuries in a specific population of interest, such as a country, province, or city. We will focus on the most important measurement issues in injury metrics and provide pointers to other resources that have more detailed information.

3.3.1 General approach

The main goal of a burden of road traffic injury analysis is to generate a set of numbers that convey the magnitude of the harm to health caused by crashes. Estimates from such an analysis are almost always viewed in a comparative context. For instance, researchers may be interested in knowing the burden of road traffic injuries relative to other health issues in the country in order to assess whether the issue is being appropriately addressed in local health priorities. Alternatively, they may be interested in comparing the road safety performance of one region with that of other regions in order to learn from other experiences. Thus comparability (across diseases or across regions) is critically important to burden of disease analysis. This has important implications on the data sources and methods used in estimation.

Consider the issue of underreporting in police statistics. Around the world, the data from traffic police are the most commonly available statistics on the incidence of road traffic crashes. However, most injury researchers are aware that these official government statistics underreport road traffic injuries (Aeron-Thomas 2000; Elvik and Mysen 1999; Bhalla et al 2014). The amount of underreporting varies by injury severity, with comparatively less underreporting of deaths compared with non-fatal injuries. Similarly, we expect underreporting to vary by region based on the surveillance capacity of the local police agency and legal requirements that affect reporting. In most countries, there are relatively few studies that have characterized the quality of police data by cross checking with other data sources. In the absence of such evidence, police data do not provide incidence data that can be compared across countries or across diseases.

Rather than relying solely on police data, an alternate approach is recommended for estimating the burden of road traffic injuries (Bhalla et al 2009). This approach involves analyzing sources other than police reports, including death registers, hospital records, funeral records, injury surveillance studies, and health surveys, to triangulate to a local snapshot of the incidence of fatal and non-fatal road traffic injuries. The analytical process includes filling information gaps, adjusting for completeness and coverage, and the redistribution and reclassification of cases coded to ill-defined causes. These triangulated estimates should then be compared with police-based figures to test the validity of official government statistics. Once reliable estimates of the incidence of road traffic injuries have been developed, standard burden of disease methods can be applied to convert incident cases into summary measures of population health (YLLs, YLDs, and DALYs). A detailed step-by-step guide to estimating DALYs from incidence data is available in the WHO publication *National Burden of Disease Studies: A Practical Guide* (WHO 2001).

Let us start by defining the key concepts of interest, followed by a discussion about data sources and analytical methods. The information presented below draws substantially from a previous publication (Bhalla et al 2009).

3.3.2 Definitions of key concepts

Table 3.2 summarizes a set of definitions related to road traffic injury measurements. These are derived from the Tenth Revision of the International Statistical Classification of Disease and Related Health Problems (ICD-10) (WHO 2004) because it provides a more inclusive definition for what constitutes a "road" particularly as it relates to low- and middle-income countries.

TABLE 3.2 Definitions for describing the national burden of road traffic crashes.

Concept	**Concept Definition**
What is a "Road Traffic Crash??"	A road traffic crash is an event that produces injury and/or property damage, involves a vehicle in transport, and occurs on a road or while the vehicle is still in motion after running off the road. Note the use of the term "crash" instead of "accident."
What is a "Road??"	A road is the entire width between property lines (or other boundary lines) of land open to the public as a matter of right or custom for purposes of moving persons or property from one place to another.
Types of road user transport mode	Pedestrian, bicycle, motorized two wheeler, motorized three wheeler, car, van (including pickup trucks), truck, bus, others.
What is a road traffic "fatality??"	Any death for which a road traffic crash is the underlying cause. The "underlying cause" of a death is the disease or injury which initiated the train of events leading directly to death regardless of how long ago the event occurred. Note that there is no time limit between the crash and the death. There is also no restriction on where the death happens (at crash scene, hospital, home, etc.).
What is a road traffic "injury??"	A road traffic injury is an injury caused in a road traffic crash. "Injury" is the reduction in functional health status due to energy exchanges that have relatively sudden discernable effects.
Levels of injury severity	Injury severity is defined in terms of the levels of impairment – i.e. reduction in functional health status – e.g. minor/moderate/severe impairments.
Types of institutional medical care	A hospital admission is a hospital stay exceeding 24 hours. Visits less than 24 hours are referred to as outpatient visits.

Source: Based on Bhalla et al. 2009.

The definition does not restrict a "road" to a path prepared for vehicle use but includes any public path (including, e.g., a path in a rural field) that is customarily used for transport in the community. Similarly, the term "road traffic crashes" encompasses all crashes that occur on the road, regardless of whether they involved motorized or non-motorized vehicles.

The definition of what constitutes a road traffic death based on how soon after the crash the death occurs has been discussed extensively in the literature (WHO 2009). Such time restrictions (death within 1 day, 1 week, 1 month and 1 year) are operational definitions that take into account the practicality of reporting for the agency collecting the data. Conceptually, however, there should not be any time restriction on an underlying cause of death. Furthermore, burden of disease methods rely extensively on estimating mortality based on death registration data, which are usually coded using ICD rules that do not include a time-based restriction on the underlying cause of death. Thus, not adopting a time-based restriction is also operationally easier in such work. Finally, it should be noted that translating between estimates that rely on the various time-restricted definitions is relatively straightforward. The adjustment ratios (WHO 2009) show that only a very small fraction ($\sim$3%) of road injury deaths occur after 30 days from a crash.

In comparison to deaths, non-fatal injury outcomes are more difficult to define and classify. Langley et al propose an energy-based definition for injury – "the damage produced by energy exchanges that have relatively sudden and discernable effects (Langley and Brenner 2004). Defining thresholds for levels of injury severity is conceptually difficult and, as a result, has received substantial attention by injury researchers. The crudest injury classifications are dictated by the operational simplicity of classifying injury severity by hospital admissions and outpatient care. However, especially in comparative work across countries, such a definition is problematic because access to medical care can vary substantially. Instead, a conceptual definition should be based on medical pathology. The Abbreviated Injury Scale (AIS) and its derivative scales are the most commonly used injury severity classifications. However, these existing measures have threat to life as their central focus and do not effectively describe the loss of functional health status that can result from non-fatal injuries. Thus, for instance, an injury requiring an amputation that results in life-long disability, and hence a substantial health burden, can have the same AIS level as an injury with no discernable disability a few days after the event. This is a severe shortcoming of AIS-based injury scales for characterizing the public health burden of non-fatal injuries. There is a growing body of work that focuses on measuring the long-term health impairments due to non-fatal injuries. A recent review paper by Plunder et al. provides an overview of existing knowledge about measurement issues related to measuring the population health burden of non-fatal injuries (Polinder et al 2010).

3.3.3 Triangulating from local data sources

Although injury researchers typically turn to traffic police data for information on the incidence of fatal and non-fatal injuries, as discussed above, police data often underreport injuries. Therefore, injury researchers should start by doing an environmental scan of data sources that can inform epidemiological estimates of injuries in the population of interest. The types of data sources identified vary substantially by region. Table 3.3 illustrates the types of data sources (other than police data) available in four low- and middle-income countries, Iran, India, Mexico, and Ghana. These countries are at varying levels of economic development and have substantially different health surveillance infrastructure and capacity.

Let us first consider methods for estimating the incidence of road traffic deaths. High quality vital registration data are considered the gold standard for population-level cause-of-death analysis. Such data are usually collected by national vital registration systems, which are intended to be comprehensive in terms of population coverage. Such data systems exist in many developing countries although the coverage and completeness of reporting and the quality of cause of death

TABLE 3.3 Selected data sources for estimating the incidence of deaths and injuries from road traffic crashes in four countries.

Country	Deaths	Non-fatal injuries
Iran (Bhalla 2009)	**National death registration system:** covers 29 provinces (i.e. all except Tehran); ICD-10 derivative causes of death. **National forensic medicine system:** estimates available for all provinces.	**Hospital data sample:** Data collected from all hospitals in 12 provinces (outpatient for 4 days, and hospital admissions for 4 weeks), followed back to household post-discharge. **Demographic and Health Survey (DHS):** Approx. 110,000 households, included questions about road traffic injury involvement and care
India	**National Sample Registration System** (Hsiao 2013): Nationally representative sample of deaths in India, causes evaluated by verbal autopsy. **National Medical Certification of Cause of Death (MCCD) System:** Cause of death for reporting hospital in urban areas; covers approx. 500,000 deaths from all causes annually.	**World Health Survey (WHS):** representative sample with questions about road traffic injuries and care; conducted in six states **Survey-New Delhi:** 5,412 households, all injury causes (Verma and Tiwari 2004) **Survey-Bangalore:** 20,000 households, stratified by urban/rural and socio-economic status (Aeron-Thomas et al 2004) **Survey-near New Delhi:** morbidity patterns in 9 villages, 25,000 households, monitored for 1 year (Kumar et al 2008)
Mexico	**National death registration system:** ICD-10 coded cause of death, estimated to be near complete.	**SAEH-Ministry of Health national hospital discharge database**: covers all Ministry of Health hospitals, approx. 115,000 unintentional injury hospital admissions. **Instituto Mexicano del Seguro Social (IMSS) national hospital discharge database**: approx. 175,000 injury hospital admissions; external causes not recorded. **World Health Survey:** representative sample with questions about road traffic injuries and care. **Encuesta nacional de Salud y Nutricion (ENSANUT) national health survey:** Sample size 54,068 individuals, included questions on RTI involvement and care.
Ghana	**Mortuary data – Kumasi:** Data collected from 1996–1999; 2005–2006 (Adofo et al 2010; London et al 2002). **Demographic Surveillance System (DSS) Sites at Navrongo:** verbal autopsy based cause of deaths.	**World Health Survey:** representative sample with questions about road traffic injuries and care. **Survey – Kumasi (urban) + Brong Ahafo region (rural):** sample of approx. 21,000 individuals (Mock et al 1999).

Source: Based on Bhalla et al 2009.

attribution can vary substantially (Mahapatra et al 2007; Lopez et al 2007). Iran and Mexico have national vital registration systems that have high population coverage and are relatively complete. In the absence of national death registration systems, some countries rely on sample registrations systems, which rely on a representative sample of deaths. In India, for instance, the Sample Registration System (SRS) uses verbal autopsy performed by trained paramedics to track causes of deaths in representative set of urban and rural communities and reports the causes of death (including one category for road traffic injuries) (Hsiao et al 2013). In addition, in urban areas in India, cause of death information is also available from hospitals that report to the national Medical Certification of Cause of Death (MCCD) system. Although the sample of deaths included is not representative, it reports approximately 500,000 deaths annually (an estimated 30% of all urban deaths). Finally, some regions of the world, notably Africa (represented by Ghana in Table 3.3) do not have functional national death registration systems that can provide cause of death statistics. In such cases, community health surveillance projects (such as the INDEPTH network of disease surveillance system sites) may be able to provide useful insight into the patterns of causes of death from which road traffic injury death rates can be estimated (Bhalla et al 2013).

Converting these data sources to incidence estimates requires several analytical adjustments. In analyzing vital registration data, estimates of the true completeness and coverage should be derived by comparing the total number of deaths reported by the registration system with total national deaths, estimates for which are often available from other more reliable sources. Death registration systems often include a large number of deaths coded to poorly specified causes (e.g. unspecified accident, undetermined intent, and unknown cause of death). As a general rule, deaths coded to partially specified causes of death should be reapportioned to fully specified causes using all available information. For detailed examples of how to assess road traffic mortality using death registration data, see our analysis for Iran (Bhalla et al 2008), Mexico (Bartels et al 2010), and Sri Lanka (Bhalla et al 2010).

In many countries (e.g. Ghana in Table 3.3), available mortality data can only provide reliable statistics for sub-national regions, and a process of aggregation and triangulation is necessary to develop a national road traffic injury mortality estimate. For instance, there are no nationally representative sources of information about causes of death in most African countries (Bhalla et al 2013). However, in many countries, urban mortuaries can allow generating estimates of urban injury deaths, and rural Demographic Surveillance Sites can allow estimating road traffic mortality in selected rural settings. Thus, aggregating estimates of urban and rural deaths using data from mortuaries and DSS sites can be used to generate plausible estimates of national road traffic deaths.

Next, let's consider the sources of information for estimating non-fatal injuries. The two primary sources of data for estimating non-fatal injuries are hospital datasets and health surveys, both of which can be either national or sub-national. As illustrated in Table 3.2, often countries have some combination of both types of datasets. Hospital data and household surveys have complimentary strengths. Household surveys are usually the only population representative source of estimate of incidence of injuries in a region. Surveys can be specific to injuries or be broader national health surveys; Table 3.2 illustrates examples of both. Injury specific surveys typically measure more details about road traffic crashes, but often tend to be at a community level. For our purposes, national surveys, even if they only include fewer questions about injuries, have the advantage of providing direct estimates of the national incidence of non-fatal injuries.

Unlike surveys, hospital datasets are usually poor sources of information for measuring population incidence of injuries for several reasons. It is often difficult to define the catchment-population for individual hospitals. Even when a hospital registry aggregates data from all hospitals in a region, such data only provide information about hospitalizations in the population. However, in low-income settings many severely injured victims may not have access to a hospital. The strength of hospital data is that they provide medical descriptions of injuries making it possible to characterize the disability outcomes and, thus, the public health burden of injuries.

Therefore and efficient way to couple health surveys and hospital data is to use the surveys to estimates the population incidence of road injuries, and hospital data to estimate the disability consequences of severe injuries.

In summary, the guiding principle of the burden of disease approach is that estimates of population health metrics (such as incidence and prevalence) should be generated after careful analysis and correction for bias of all available data sources. It is important to ensure comparability of estimates with other diseases and/or across regions. Researchers interested in developing estimates should start with the many resources available that provide guidelines and examples of analysis.

ADDITIONAL RESOURCES

– *GBD Project website* (http://www.healthdata.org/gbd): The website provides description of data sources, methods, and tools for visualizing results of the GBD study.
– *National Burden of Disease Studies: A Practical Guide*: (WHO 2001) The manual provides detailed guidance on how to estimate burden of disease using local data sources.
– *Global Burden of Injuries Project* website (http://www.globalburdenofinjuries.org): Includes data, methods, and estimates for estimates of the incidence of road traffic injuries in 18 countries (Bhalla et al 2011), burden of injuries in sub-Saharan Africa (Bhalla et al 2013), and detailed case studies for several low- and middle-income countries.

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CHAPTER 4

Land Use-Transportation Planning, Mobility and Safety

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CONTENTS

ABSTRACT

This chapter presents the relationship between land use-transport policies and its impact on traffic crashes. Land use policies and design of infrastructure both have a major impact on road traffic crashes (RTC) in cities. City planning and land use policies which include the location of different activities, location of residential areas, built area densities and planning of transport networks, influence the choice of destinations, and transport modes as well as the distances that various people have to travel. Thus exposure to road traffic risk and the distances traveled by people for different purposes is influenced by the planning policies at city level. We present a case study of Delhi, India to show the impact of urban planning policies on the safety of road users. The case study presents the impact of relocating poor households from the self-selected locations in Delhi to the outskirts for the construction of Metro and other city developments plans between 1997–2001. It is possible to evolve methodologies and plans which account for benefits and dis-benefits to the society as a whole, and which help resolve conflicts between mobility and safety at various levels. These methodologies are urgently needed in societies which have hierarchical structures and where the level of complexity is high due to the presence of heterogeneity in every walk of life.

Key Words: Transport Planning; Land use plan; Traffic crashes

4.1 INTRODUCTION

Modern city plans originated in UK in late the 19th century and continue to influence the development of cities in different parts of the world to date. Traditionally they involve preparation of land use plans suggesting how city land should be used for different activities to meet the demand of future city residents. Land use master plans recommend built area densities and the type of activity that should be permitted in specific areas. City land is divided into smaller parcels and marked for residential, commercial, industrial, institutional, green areas, recreational areas, etc. Land use plans are basic to the conventional transport plans, which include forecasting the number of trips originating and going to different parts of the city, the different travel modes, and the routes that people will choose to reach their destinations. This basic four-step model is shown in Figure 4.1. The basic premise underlying the individual choice of destination, travel mode, and route is "higher probability of selecting the destination, travel mode and route which maximizes personal utility".

Both land use master plans and four step sequential transport models have been criticized for their 'simplistic approach' (Hall 2003). Very top down approach of land use master plans, and the failure to accommodate and respond to the rapidly changing needs of city residents has often led to cities growing in violation of the master plans (Adhvaryu 2010; Halleux et al 2012; SPA Delhi 2012; Zekovic et al 2015). However, to a large extent, land use and transport plans influence choice of destination, travel modes, travel distances and routes. The risk of getting involved in traffic crashes differs by travel modes and travel routes. Travelling longer distances by a high risk mode on a high risk route will increase the risk of traffic crashes. This chapter explains the close relationship between land use transport policies and the risk of getting involved in traffic crashes.

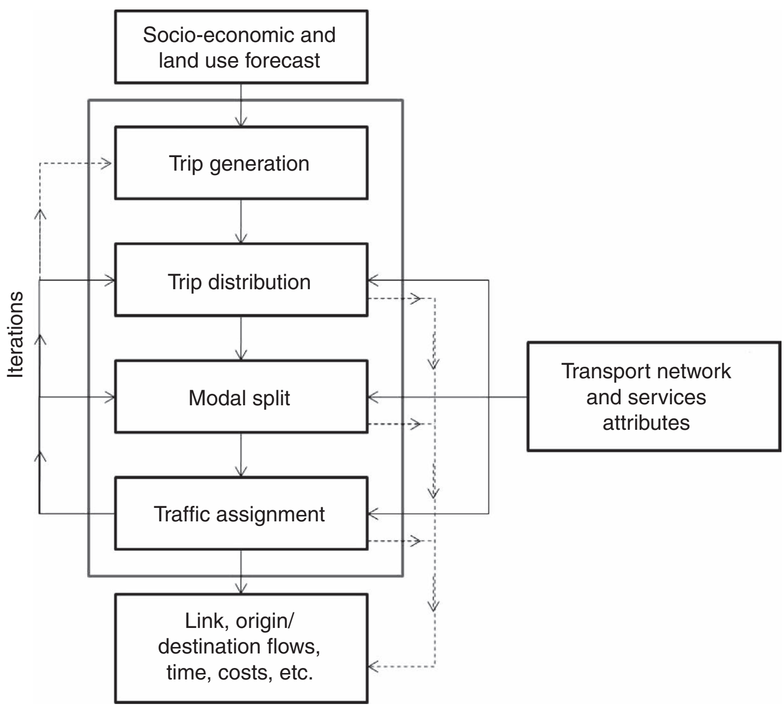

Figure 4.1 Four step travel demand model.

4.2 ROAD TRAFFIC CRASHES AND LAND USE PLANNING

Land use policies and the design of infrastructure both have a major impact on road traffic crashes (RTC) in cities. City planning and land use policies which include the location of different activities, location of residential areas, built area densities and planning of transport networks influence the choice of destinations and transport modes as well as the distances that various people have to travel. Thus exposure to road traffic risk and the distances traveled by people for different purposes is influenced by the planning policies at city level.

Kenworthy and Laube (1999) explored data from 46 cities. The data revealed that the degree of dependence on the automobile, and land use policies significantly influence road safety levels. Traffic fatality data from 1990 showed that the rich Asian cities and European cities with relatively low dependence on the automobile had lower fatality rates −6.6/100000 population and 8.8/100000 population than North America 14.6/100000 population. North American cities have a highly developed extensive road system, but two times higher fatality rate. Newman and Kenworthy (1999) reported that cities such as Amsterdam and Copenhagen, with the highest rates of bicycling, experienced 5.8/100000 population traffic fatalities and 7.5/100000 traffic fatalities, respectively; less than half that of US cities.

In recent years, a number of studies have shown a close relationship between sprawl and traffic crashes (Ewing and Cervero 2010; Ewing and Dumbaugh 2009). Sprawl is defined as low density residential developments with a strict separation of homes, shops and workplaces, limited access and large block sizes. Early planners assumed that by providing straight roads and wider roads, drivers' ability to see any oncoming hazard and have time to decelerate would be enhanced. These ideas were adopted by Clarence Perry and Clarence Stein (1930) for planning new towns. The separation of traffic function was reinforced by land use type. Schools and churches were included in neighborhoods and retail and commercial uses were moved along arterial roads to reduce heavy through traffic. This conventional development pattern was based on three safety principles: I-Safety could be improved by building wide straight roads to improve sight distances. II-Heavy traffic could be prevented from entering neighborhood areas and reduce conflicts with oncoming traffic by reconfiguring the street network. III-Four way intersections could be replaced with cul de sacs and three way junctions to reduce conflicts. These principles have been followed in the development of urban areas in Europe, North America and Australia since the last century. In the last fifty years these principles have influenced urban planning all over the world.

In the last two decades, a number of researchers have studied safety in urban areas and questioned the wisdom of single use low density land use patterns.

Table 4.1 presents a summary of some of the recent studies showing the relationship between urban sprawl and traffic crashes.

Most studies seem to agree that:

1. Dense urban areas are safer than lower density suburban environments. This is because per capita lower vehicle miles are travelled in denser areas at lower speed as compared to low density suburban environments.
2. Development with lower vehicle miles travelled is likely to have lower a crash rate. This is related to density, diversity, design, and destination.
3. Density in urban areas and design treatments like narrower streets, street trees, and traffic calming measures appear to enhance a roadway's safety.

Dumbaugh et al (2009) found specific results:

1. Areas with increased vehicle miles travelled (VMT) experience more crashes with crash incidence increasing by roughly 0.75% with every million miles of travel.
2. Arterial thoroughfares were associated with a 15% increase in total crashes with each additional mile of travel.

TABLE 4.1 Summary of studies showing the relationship between urban sprawl and traffic crashes.

Authors	Main Findings
(Lovegrove and Sayed 2007)	Related number of crashes to amount of travel within geographic unit.
(Galster et al 2001)	Accounted for multifaceted nature of design and density and their relationship to sprawl.
(Ewing et al 2003)	Created a sprawl index and examined the relationship between this index and traffic crashes. The main findings include sprawling areas that are associated with more traffic and pedestrian fatalities.
(Trowbridge et al 2009; Trowbridge and McDonald 2008)	Constructed sprawl indices to show that sprawl is associated with more teen driving and longer ambulance arrival times. In both papers the authors conclude that sprawl can lead to more traffic fatalities.
(Lambert and Meyer 2006; Lucy 2003)	Used another index of sprawl and found that sprawl is associated with more crashes.
(Mohamed et al 2014)	Created a sprawl index from five underlying land use characteristics using data from Southeast Michigan. Their results showed that number of injuries and fatalities in a jurisdiction increases with the magnitude of sprawl in neighbouring jurisdictions. This is because more drivers per capita in sprawl jurisdictions traverse similarly sprawled neighbouring jurisdictions for daily activities.
(Dumbaugh and Rae 2009)	Analysed GIS data on crash incidence and urban form for the city of San Antonio in Texas. They found urban arterials and arterial oriented commercial developments to be associated with increased incidence of traffic related deaths. They also found that higher density communities with more traditional pedestrian scaled retail configurations to be associated with fewer crashes.

3. Each additional arterial oriented retail or commercial parcel increased total crashes by 1.3% and each additional big box store increased crashes by 6.6%.
4. Each additional person per net residential acre decreased accident incidence by .05%.
5. A 2.2% reduction in crashes was associated with pedestrian scaled commercial development.

Urban planners now recommend increased density, diversity, destinations and design in urban environments. It is expected that this promotes narrower, shorter, more enclosed and interconnected streets, leading to safer travels.

Density is measured by the number of people, households or jobs per unit area (acre or km^2), diversity refers to mixing of commercial, residential and industrial areas. Design involves street typology of a community which can vary from straight interconnected streets to loops of curvilinear streets. Design also involves sidewalks, pedestrian crossings, and roadside trees.

4.2.1 Transportation planning system and safety

The basic need for transportation planning arises from (1) the temporal and spatial spread of various activities that people wish to participate in and (2) rapid change that takes place in the environment we live in, affecting the strong interactions between transportation and the rest of the society (Manheim 1980).

Transport planners are expected to prepare comprehensive mobility plans for safe and efficient movement of people and goods in urban areas. This requires that all modes of transport must be considered as a single multi modal system within the social, economic and political system of the region.

As discussed by Manheim (1980) consideration of the total transportation system includes the following:

1. All modes of transportation must be considered.
2. All elements of the transportation system must be considered – the persons and things being transported; the vehicles in which they are conveyed, the network of facilities through which the vehicles, passengers and cargoes move including terminals and transfer points as well as line-level facilities.
3. All movements through the system must be considered.
4. For each specific flow, the total trip from point of origin to final destination, overall modes and facilities must be considered.

Such a comprehensive definition of the transportation system enables the analyst to consider explicitly the assumptions introduced by eliminating individual elements of a highly complex and interrelated system.

The transportation system of a region is tightly interrelated with the socio-economic system. Travel demand is a function of the level of economic activities, the income level and the physical components of present transport systems amongst other things. Direction of travel is determined by the spatial and temporal location of activities i.e. land use patterns. Often the transportation system influences growth and changes in the socio-economic system. Changes in the socio-economic system will cause changes in the transportation system. This is a fundamental intervention and must be considered explicitly. The socio-economic system, i.e. activity system, consists of many subsystems overlapping and interrelated—social structures, political institutions, housing markets etc.

Manheim (1980) has proposed the interrelationship between the transportation system and pattern of socio-economic systems drawing an analogy from microeconomics. The system of interest in the context of transportation planning can be defined by three basic variables: T the transportation system is the 'supply of goods'; A the activity system (pattern of social and economic activities) creates the 'demand for goods provided by the transport system; and F the pattern of flows in the transportation system, that is, the origin, destination, routes and volumes of goods and people moving through the system as a result of interaction between the transport system and activity system (Figure 4.2).

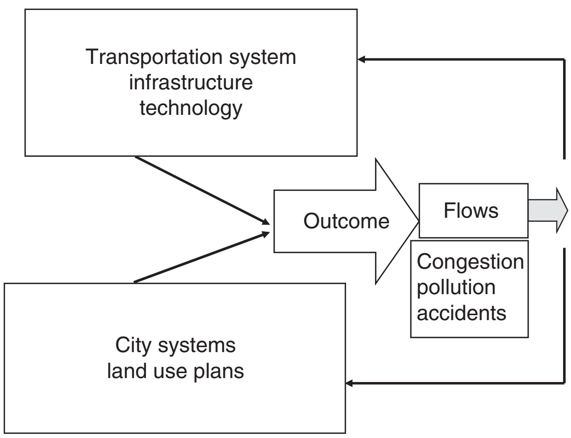

Figure 4.2 Interaction between transport and land use system.

Three kinds of relationship can be identified among these variables.

1. The flow pattern in the transportation system – number of people, vehicle type, choice of travel mode between specific origins and destinations – is determined by both the transportation system and the activity system.
2. The current flow pattern will cause changes over time in the activity system: through the pattern of transportation services and quality of access provided, and through the resources consumed in providing those services.
3. The current flow pattern will also cause changes over time in the transportation system: in response to actual and anticipated flows, new transportation services are developed or existing services are modified.

4.3 CONFLICTS AND TRADE OFFS IN TRANSPORTATION PLANNING

Cities tend to have a heterogeneous mix of people having different demands, requirements, and preferences. In order to understand the tradeoffs between mobility and safety involved at various levels of transportation planning we need to add a few more dimensions to this model of transportation planning.

Disaggregating the transportation system under consideration, e.g. considering modes of transport as private motorized vehicles, public motorized vehicles and non-motorized vehicles. Similarly, an activity system could also be disaggregated by income groups. Socio-economic and physical characteristics of land use patterns tend to be homogeneous for people of similar income levels. The activity system may be modelled as an overlapping or interconnected subsystem for each income level in society. Now the equilibrium flow involves several levels, as indicated in Figure 3. Each level has different requirements for efficient and safe movement. An ideal solution would be to provide a separate infrastructure for each flow. On the other hand, if we are willing to trade off some of the benefits – i.e. reduced speeds, or reduced safety, one could provide infrastructure which is used by different modes at the same time. This is the first level trade-off involving cost or use of scarce resources with transportation benefit.

The various types of flows not only have different but many times conflicting requirements. Buses need frequent stops to pick up and drop off passengers, however private cars need uninterrupted movement. If the public transport system and private cars have to use the same infrastructure one has to decide whether the design is for the bus transport or it is to fulfill the demand of car owners. The second level involves tradeoffs between demands of different types of flows.

Figure 4.2 shows a feedback loop from flow subsystem to transportation system as well as the activity system. This indicates that the type of flows should determine the characteristics of transportation system – modes and infrastructure required in the future as well as land use patterns – and the spatial and temporal spread of activities. Following this, the future transportation system should be such that it can fulfill the varied demands of various flows.

Similarly, land use planning should reflect the demands of low income people – shorter travel distance, higher density development mixed land use, as well as the demand of higher income persons which includes low density, larger residential plots, infrastructure for private vehicles etc.

However, as shown in Figure 4.3 the feedback loop has a filter. The policy makers/decision makers and “technical experts” weigh various options and the trade-offs involved and permit only a few flow patterns to be fed into the transportation and activity system. Thus we end up designing our future transportation system and activity system which takes into consideration requirements of higher income groups owning private motorized transport. Other types of flows, bicycles, public transport etc. continue to exist in a hostile environment.

Our process of transportation planning creates a safe environment for some at the cost of others. The conflicts between different income groups and different modes is apparent in low income countries. This is discussed in the following section.

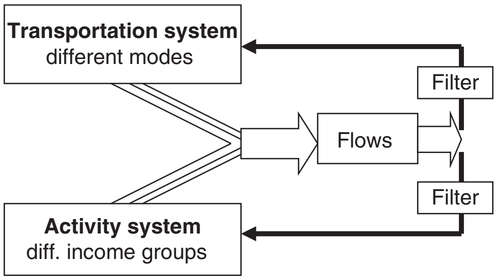

Figure 4.3 Conflicts in Transport and Land use interactions.

4.4 TRANSPORT-LAND USE PATTERNS IN LOW INCOME COUNTRIES

Low income cities in Asia, Africa and Latin America have had a mix of formal plans and informal development. Usually city master plans fail to accommodate the needs of the poor, resulting in the formation of squatter settlements. Squatter settlements all over the world are called informal settlements because they are not part of the official plan. Neuwirth (2005) describes the squatter as a new migrant to the city who builds a shelter with his own hands on land that does not belong to him. Nearly one billion people who live in squatter settlements are people who came to the city in search of jobs, needed a place to live that they could afford, and not being able to find it on the private market, built it for themselves on land that wasn't their own. The conventional definition of informal – unofficial, illegal or unplanned – denies people jobs in their home areas and denies them homes in the areas where they have gone to get jobs.

As upper and middle-income earners have acquired private vehicles, real estate developers increasingly locate new developments to be easily accessible by private vehicle, even if this leaves them inaccessible by public transport and non-motorized transport. To the extent that high-speed, high-capacity roads have been built, they have tended to encourage the haphazard development of long corridors, resulting in longer trip distances for residents of such areas. Although Asian cities have spread out to some extent as they have motorized, this is a slow process and most still retain high urban densities, especially in their inner areas. High-density cities are unsuited to high rates of private car use and inevitably have low levels of road capacity. Congestion has therefore become serious even at low levels of motorization. The rise of private vehicular traffic has decreased bus speeds and service levels drastically and made non-motorized transport dangerous and difficult. Travel for the poor has thus become slower and more difficult even as other economic and planning forces have caused many of them to be displaced from central informal settlements to more peripheral locations (Immers and Bijil 1993).

Many economic development programs completely miss the link between housing location, livelihoods of the poor, and transport. Access to affordable transport is one of the most important factors in determining livelihoods for the urban poor. A survey by SPARC in central Bombay of pavement dwellers showed that 80% walked to work. Their choice came down to: "they were willing to live in congested dwellings without safety or security just so they could walk to work" (Gopalan 1998). Other studies have found similarly very limited mobility by the urban poor. Some of the urban poor have to make a different trade-off by accepting long travel distances from a peripheral location in order to obtain affordable but secure housing. For some this trade-off is forced on them, since in many cases relocation sites (after evictions) are often in remote locations that take little or no account of access issues (Fernandes 1998).

Mixed land use patterns reduce the length of trips and thus exposure to road traffic injuries. Often poor households are relocated at the outskirts of the city limits where land is cheap. This results in long pedestrian and bicycle trips increasing exposure to road traffic crashes. Thus road traffic risk to different road users is influenced by the city planning policies.

Figure 4.4 Relocation of low income households in Delhi (Source: Arora 2007).

We present a case study of Delhi, India to show the impact of urban planning policies on the safety of road users. The case study presents the impact of relocating poor households from the self-selected locations in Delhi to the outskirts for the construction of Metro and other city developments plans between 1997–2001.

4.4.1 Urban planning policies and relocation of poor households

Delhi has witnessed large-scale evictions and resettlements in Delhi between 1997–2001 when polluting industries were relocated from the city center following the Delhi high court orders, and then again in 2007–2009 while preparing for the commonwealth games in 2010. What lies behind the low-income household relocations are development projects like commercial complexes, flyovers, recreational parks, and wide roads to improve the landscape of the city.

Figure 4.4 illustrates the trends of eviction of low-income settlements from the central areas of the city and relocation to the peripheral areas. Peripheral development and relocation of urban squatters has meant an increase of the spatial segregation of social groups, fostering uneven distribution of urban amenities and restricting access to income-generating activities, resulting in a disrupted perception of the urban environment and increasing the overall insecurity of the population regarding the most contentious urban problems. The high cost of serviced urban land, coupled with the decrease in the ability of government to provide satisfactory income options for the relocated, has resulted in the adoption of a style of urban development that does not involve social integrating measures, contributing to raise the poverty levels even further.

Arora (2007) estimated the indicators of mobility from the household surveys of low income settlements in the vicinity of the Metro line and households that were relocated to new locations as per the land use polices to provide land for metro construction. The study showed the distance to schools increased for 52% of the households, the distance to health services increased for 63% of the households, and the distance to urban services increased for 52% of the households. The

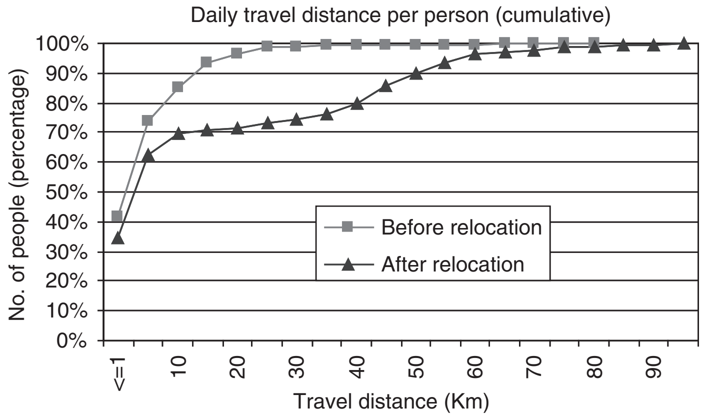

Figure 4.5 Change in travel distance before relocation and after relocation.

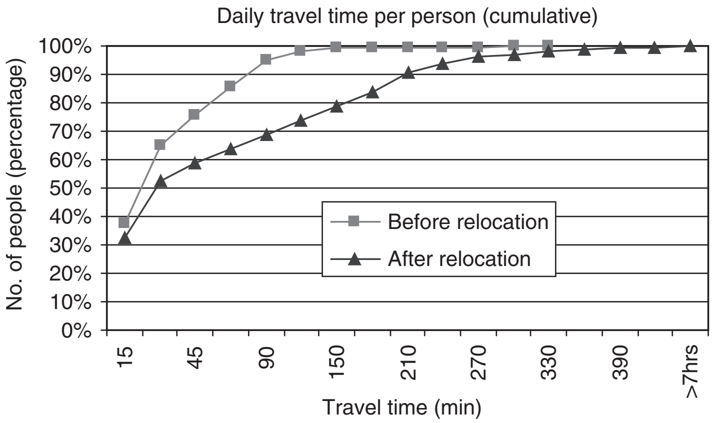

Figure 4.6 Change in travel time before and after relocation.

highest impact was seen in the indicators measuring access to the bus system – the distance to the bus stop increased for 72% of the households and the time gap between successive buses increased by more than 100% for 98% of the households.

Figures 4.5 and 4.6 show change in distance and travel time before and after relocation.

The mobility indicators for travel to work – distance, time and cost – increased for 83%, 82% and 61% of the households respectively. The distance, time and cost for education increased for 34%, 35% and 4% of households respectively.

The results of the study showed that for poor households relocated to new areas, there had been a significant impact on the indicators of accessibility and mobility. The land use accessibility deteriorated as distance to education, health services and other urban services increased for 52%, 63% and 52% of the households respectively. The transport accessibility deteriorated even more as distance to the bus stop increased for 72% of the households and the bus frequency decreased, on an average, from 5 min to 63 min (almost 13 times). The mobility of the households increased significantly. Average trip rate for work increased for 49% of the households and decreased for 30%, implying a change in the number of trips made for work by the households. The mobility indicators for travel to work – distance, time and cost – increased for 83%, 82% and 61% of the households respectively.

4.5 IMPACT OF TRIP LENGTH AND MODE OF TRAVEL ON FATALITY RISK

Bhalla et al (2007) have suggested a methodology for estimating fatalities based on the interactions of road users. They argue that "the probability of a fatal crash between two road users can be modelled as the product of the probability that a crash occurs between the road users and the probability that the crash is fatal". Thus, if $c_{\text{victim}}^{\text{threat}}$ is the probability that a road user (victim) is struck by a vehicle (threat), and $r_{\text{victim}}^{\text{threat}}$ is the case fatality ratio (CFR) for the victim of the crash, then the probability that the victim is killed is given by

$$fatal_{\text{victim}}^{\text{threat}} = c_{\text{victim}}^{\text{threat}} \times r_{\text{victim}}^{\text{threat}} \tag{4.1}$$

$r_{\text{scooter}}^{\text{car}}$ is the probability that a scooter-rider is killed in the event of a car-scooter crash, while $r_{\text{car}}^{\text{scooter}}$ is the probability that the car occupant is killed. Single-vehicle crashes are incorporated by including the physical environment as a threat. Thus, for instance, $r_{\text{scooter}}^{\text{environment}}$ is the probability that a single vehicle scooter crash is fatal. In this formulation, we assume that a crash can involve at most two vehicle types.

For each pair of transportation modes, the probability of a crash between the threat and the victim depends on a number of factors that include:

1. The population of road users that belong to the victim's travel mode, U_{victim}, and the number of "at-risk" kilometers travelled (i.e., distance over which the victim is exposed to the threat) by each of these road users, d_{victim}
2. The total number of threat vehicles, M_{threat}, and the number of km travelled by each of these vehicles, d_{threat}
3. Vehicle attributes (e.g., antilock brakes, visibility, stability)
4. Driver attributes (e.g., socio-demographic characteristics, license status, alcohol use, driver training)
5. Roadway infrastructure (pedestrian walkways, lane separating medians); and
6. Broader systemic attributes (legal and insurance systems).

That is, $c_{\text{victim}}^{\text{threat}} = f$ (U_{victim}, d_{victim}, M_{threat}, d_{threat}, vehicle attributes, driver attributes, roadway attributes, systemic attributes).

They proposed the following form for this relationship

$$c_{\text{victim}}^{\text{threat}} = K_{\text{victim}}^{\text{threat}} \times U_{\text{victim}} \times d_{\text{victim}} \times M_{\text{threat}} \times d_{\text{threat}} \tag{4.2}$$

So,

$$fatal_{\text{victim}}^{\text{threat}} = K_{\text{victim}}^{\text{threat}} \times U_{\text{victim}} \times d_{\text{victim}} \times M_{\text{threat}} \times d_{\text{threat}} \times r_{\text{victim}}^{\text{threat}}$$

The probability of a specific threat-victim crash is proportional to the product of the total "at-risk" miles/kms travelled by road users in the victim's travel mode ($U_{\text{victim}} \times d_{\text{victim}}$) and the total distance travelled by the vehicles that pose the threat ($M_{\text{threat}} \times d_{\text{threat}}$). The proportionality constant, $K_{\text{victim}}^{\text{threat}}$, accounts for all the other variables listed in items 3–6 above and captures the relationship between road use and the probability of a crash. Thus, for car-pedestrian crashes, $U_{\text{pedestrian}} \times d_{\text{pedestrian}}$ is the number of at-risk miles (Km) walked by all pedestrians, $M_{\text{car}} \times d_{\text{car}}$ is the total number of miles (km) travelled by all cars, and $K_{\text{pedestrain}}^{\text{car}}$ is a proportionality constant that relates the rate at which shared roadway use results in pedestrian-vehicle crashes. Since the variables M_{threat} and d_{threat} do not have a physical interpretation for single-vehicle crashes, Bhalla et al assumed that

$$c_{\text{victim}}^{\text{environment}} = K_{\text{victim}}^{\text{environment}} \times U_{\text{victim}} \times d_{\text{victim}}$$

so that the proportionality constant $K_{\text{victim}}^{\text{environment}}$ relates vehicle use to the probability of a single-vehicle crash.

The CFR, the probability of fatality in the event of a crash, depends on precast variables that describe the characteristics of vehicles and victims, the crash variables, and the post-crash victim care. These include:

- Vehicle characteristics (e.g., size, mass, and shape) and safety design technology (e.g. availability and use of seat belts and airbags);
- Victim attributes including age, sex, height, and weight;
- Crash conditions including vehicle speed, direction of vehicle travel, crash avoidance maneuvers, weather conditions, and roadway infrastructure; and
- Post-crash medical care including response time of emergency medical services, and quality of on-site and trauma care;

That is,

$r_{\text{victim}}^{\text{threat}} = f$ (vehicle attributes, victim attributes, crash conditions, post-crash medical care).

Combining Equations (4.1) and (4.2),

Vehicle occupancy relates the number of vehicles to the number of occupants. Thus, $\boldsymbol{U}_{\textbf{victim}} = \boldsymbol{o}_{\textbf{victim}} \times \boldsymbol{M}_{\textbf{victim}}$, where o_{victim} is the vehicle occupancy of the victim's transport mode. If $\boldsymbol{D}_{\textbf{victim}} = \boldsymbol{U}_{\text{victim}} \times \boldsymbol{d}_{\text{victim}}$ is the total at-risk vehicle distance traveled by road users of the victim's transport mode, and $\boldsymbol{D}_{\textbf{threat}} = \boldsymbol{M}_{\textbf{threat}} \times \boldsymbol{d}_{\textbf{threat}}$ is the total distance travelled by threat vehicles, we get:

$$fatal_{\text{victim}}^{\text{threat}} = K_{\text{victim}}^{\text{threat}} \times o_{\text{victim}} \times D_{\text{victim}} \times D_{\text{threat}} \times r_{\text{victim}}^{\text{threat}} \tag{4.3}$$

Total fatalities among road users in a particular mode of transportation can be computed by adding the fatality contributions from all threats. Thus, for instance, $\Sigma_{\text{threat}} fatal_{\text{car}}^{\text{threat}}$ computes all car-occupant fatalities. Similarly, $\Sigma_{\text{victim}} fatal_{\text{victim}}^{\text{car}}$ is the total fatalities caused by cars among other road users. The aggregate traffic fatalities (all victims from all threats) are then $\Sigma_{\text{threat}} \Sigma_{\text{victim}} fatal_{\text{victim}}^{\text{threat}}$.

The methodology shows that the impact of increase in trip length increases the risk of a fatal crash. Risk may differ for different modes.

Since the current planning policies have increased the distances of travel for households relocated to new areas, their risk of a fatal crash has increased. The mobility indicators for travel to work – distance, time and cost – have increased for 83%, 82% and 61% of the households respectively. The members of the relocated households are travelling longer distances than before on arterial or national highways coming to the city. These roads do not have dedicated facilities for pedestrians, bicycles or buses, resulting in increased risk to these road users.

4.6 MOBILITY AND SAFETY CONFLICT

Transportation planning has been mainly concerned with producing long-range plans for multimodal transportation systems for intra and inter urban travel. Transportation plans have included operational improvements in existing facilities and services, and location and design decisions for new facilities and services. At present, many different variations in methodologies are being used in a wide variety of operational, planning, design, and policy applications, in both private and public sectors involving short range as well as long range perspectives. The main concern of all these methodologies has been the estimation of travel demand and planning and the design of facilities to meet the forecasted travel demand more efficiently i.e. improving flow and speed of the goods and people being transported.

The negative externalities associated with transport systems include harmful emissions and noise, and traffic crashes resulting in loss of property and deaths. There has been a growing concern to include these negative externalities in the transportation planning process such that the transportation plans address the question of increasing mobility and reducing the negative externalities of the transport system at the same time.

The conflict resolution between mobility and safety requires the following.

Perception of benefits and risks can be influenced by adopting the right methodology. For example, indices to measure mobility can include the number of persons moved per unit time instead of the in-vehicle travel time.

Better understanding of the function of streets, space utilization etc. will give us different design criteria. For example, in residential areas streets are used as play areas by children, and for walking and as a place for social interaction; therefore they should be designed for maximum speeds of 5–10 km/h for cars. Similarly, in mixed urban land uses in city centers, infrastructure design should be able to meet the demands of pedestrians and bicyclists because the land use demands low speeds for walking and browsing in shopping areas. Pedestrians and bicyclists have much better capacity for utilization compared to cars.

Another important dimension in the perception of mobility benefits and risk perception is the perception that the time saved by driving faster exceeds the reality (Campbell 1992). The increased mobility is distributed among many road users, usually realized in very small units of a few seconds. The safety benefit is sustained by a relatively small number of people who save many years of time (from premature death). An important issue involving transportation strategies aimed at increasing the speeds of motorized vehicles is that the increased accident risk is sustained by pedestrians and other non-motorized vehicles who do not realize the increased mobility (at least not while acting as a pedestrian). Thus the benefits accrue to one sub-group, while disadvantages are imposed on another. Estimating benefits and dis-benefits to the society as a whole it has been shown that the time gained through mobility and time lost through crash deaths and injuries sums to be about the same. That is, the cumulative minutes saved through faster travel approximately balance the cumulative extra minutes spent being dead (Miller 1989).

Transportation system planning involves complex interactions between the existing transportation system and the activity system, which includes socioeconomic, political and physical land use patterns. Each subsystem viewed at a disaggregated level reveals varied demands of mobility and safety which may have conflicting requirements. The choice of transportation planning methodologies and which plans get implemented involves decisions in resolving conflicts and tradeoffs of benefits and dis-benefits which are often experienced by different groups of people. Therefore, transportation planning methodologies, plans, and policies reflect the value system of the most powerful group.

It is possible to evolve methodologies and plans which account benefits and dis-benefits to the society as a whole and which help resolve conflicts between mobility and safety at various levels. These methodologies are urgently needed in societies which have hierarchical structures and where the level of complexity is high due to the presence of heterogeneity in every walk of life.

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CHAPTER 5

Safety Promotion: Education and Legislation

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CONTENTS

ABSTRACT

Road safety efforts around the world focus a great deal of attention on public education and information campaigns. However, scientific studies done over the past few decades show that very often these programmes are not very successful in altering human behaviour. At times some educational programmes also have an effect that is opposite to what was intended. There is no evidence that public education and information campaigns when used alone have a significant effect in reducing road traffic injuries. This is especially true for programmes aimed at young children. In this chapter we discuss the reasons why public education programmes have not been very successful and a summary of the studies done over the pat fifty years that give us convincing evidence regarding this. The chapter includes guidelines for effective information and education programmes.

Key Words: Road safety; education; campaigns; safety information

5.1 INTRODUCTION

Whenever a community is faced with a rising incidence of injury in any activity it launches an 'educational' programme to control the problem. Such programmes can be very expensive and time consuming. However, scientific studies done over the past few decades show that very often these programmes are not very successful in altering human behaviour (Robertson 1980b, a; Roberts et al 1994; O'Neill 2001; Duperrex, Roberts, and Bunn 2003; Lund and Aaro 2004; Robertson et al 1974; Robertson 1983; Williams 2007; Sandels 1975). At times some educational programmes also have an effect that is opposite to what was intended. However, the promoters of all educational campaigns erroneously believe that:

- Useful information regarding safety in the environment can be transferred easily to the brain of all human beings.
- Knowledge regarding safety will always result in safer behaviour and greater use of safety devices.
- Skills to operate something safely can be taught to all; improving people's skills results in safer outcomes.

Experience with educational and propaganda campaigns shows that these assumptions are not necessarily true (Robertson 2007; O'Neill 2001; Sandels 1975; Duperrex, Roberts, and Bunn 2003; Roberts, Kwan, and Cochrane Injuries Group Driver Education 2003). In many cases people either do not receive the information at all, receive only part of it, or even, receive the opposite of what is intended. Studies show that it is not necessary that people act according to what they know is correct (Smith et al 1997; Kraus, Riggins, and Franti 1975). Some groups, like teenagers, even end up doing the opposite of what they are told is correct (Kraus, Riggins, and Franti 1975). Many 'skilled' persons, like experts in car driving or skiing, are known to sustain more injuries than 'ordinary' persons (Williams and O'Neill 1974)!

In this chapter some of these findings have been summarised and guidelines outlined for conducting effective educational programmes. The following sections illustrate how some of the above assumptions are not always valid and how to impart effective education for injury control.

5.2 INFLUENCE OF SYSTEMS AND THE ENVIRONMENT ON 'HUMAN ERROR'

Policy makers and traffic safety professionals in every country find it very difficult to institute changes that actually result in a dramatic decrease in traffic fatalities and injuries in a short time. Public education campaigns are based on the assumption that most crashes are the result of 'human error' and road users can be 'educated' to avoid making such mistakes. William Haddon wrote seminal pieces on the folly of focussing on 'human error' as the main cause in the occurrence of accidents (Haddon and Baker 1981; Haddon 1968, 1980a, b; Baker and Haddon 1974). He did not like the use of the word 'accident' as he thought that this leads a feeling of inevitability in the occurrence of these incidents. Experience has also shown that not all individuals follow all the instructions given to them to promote road safety. Perrow also provides a similar reason that individuals cannot always be held responsible for 'human error' under the system they operate in, because the environment and the system itself influence their behaviour, "I wish to point away from the basic and pervasive sin identified by those who casually examine organizational failures, that of operator error; this is given as the cause of about 80% of the accidents in risky systems. I would put it at under 40%. I will suggest that what is attributed to operator error stems primarily from the structure they operate in, and thus, stems from the actions of elites. Elite errors and elite interests stem from their class and historical power positions in society, and changes in these positions are glacial" (Perrow 1994, 1999).

This is why attempts to ‘educate’ people regarding safety are also not always very effective and wide variations are found between people’s knowledge and their actual behaviour. This is partly because we cannot select who is going to use the road and who is not. While some control can be exercised in licensing drivers of motor vehicles, almost no control is possible in the selection of pedestrians and bicyclists. Almost everyone in a population can be a road user and this has implications on how we deal with the issue of traffic injuries as a public health problem.

Systems that ensure a life safe from injury cannot be put in place without a societal and political understanding of the ethical responsibilities of the state and civil society to ensure all individuals a right to life, according to currently available knowledge and technology. This right is implicit in the public health approach followed in controlling communicable and non-communicable diseases. As in the case of all diseases, we should be able to assume that most human beings would try to prevent the occurrence of an episode of ill health if they were able to. This involves an understanding of the phenomenon to a certain extent, and at the same time the provision of means to individuals and societies to be able to do something about it.

5.3 LIMITATIONS OF ROAD USERS

5.3.1 Perception of risk

Over hundreds of centuries human beings relied on intuition, instinct, and gut feeling to live a safer life. Many of these life saving attributes became embedded in our genes to save us from dangers such as the fear of heights (Dawkins 2008). However, as new risks appear in our environment, we have to learn to assess the actual risk and how to detect it. This is not easy. For example, it is impossible for us to guess that minute traces of pesticides in our food or diesel fumes in the air might lead to cancer. Slovic and Peters (2006) also suggest ‘people judge a risk not only by what they think about it but also by how they feel about it. If their feelings toward an activity are favorable, they tend to judge the risks as low and the benefits as high; if their feelings toward the activity are unfavorable, they tend to make the opposite judgment—high risk and low benefit’. As most road users perceive the benefits of mobility as desirable they are likely to judge the risks on the road as low.

Human beings act to protect themselves when they perceive the risk of harm to be high. Every time you put your hand in a flame you get burned, a risk of almost one hundred per cent. We learn very early not to put our fingers in a flame. But the most educated individuals all over the world still get burned sometimes. Similarly, the risk of falling from heights. Every time you fall from more than two meters you expect to get hurt. Consequently, people don’t go around jumping from the second floor as a matter of habit. We do not need any campaigns to teach people the danger of falls from heights.

On the other hand, the risk of sustaining a serous injury or fatality in road traffic crashes per trip is very low. For city of Copenhagen the risk per million trips was calculated to be 8 per 100 million trips for car occupants and 21 per 100 for bicyclists (Jorgensen 1996). Even if in some locations the risk is ten times higher, it still remains less than 1 per million trips. These risks per trip are far too low for most human beings to take a safety precaution *every time* they take a trip. If human beings started being very careful at such low risk levels, most human activity would stop. This is why people don’t always act according to instructions when on the road, because they do not perceive the risk level to be very high.

5.3.2 Involvement of the whole population

It is very difficult to get everyone to behave in a safe way when we cannot specifically select the people who will be involved in certain activities, such as domestic work, use of the road, and in most of our work environments. In addition, on any day, the population on the road includes individuals preoccupied for any of the following reasons:

- Those who cannot concentrate on the job at hand because they have suffered a recent personal loss or disappointment—such as death of a loved one, loss of a job, failure in an important examination, monetary loss, and the like.
- Those who are preoccupied with problems in personal relationships with a spouse, parent, sibling, or close friend.
- Those who are taking medications or drugs that alter behaviour and perceptual abilities, or those who are under the influence of alcohol.
- Children whose cognitive and motor skills make it difficult for them to understand or follow instructions given to them.
- Elderly people whose motor and cognitive functions are impaired.
- Psychologically disturbed persons who may not be able to function as desired but who cannot be excluded from participating in road traffic.

If we estimated the percentage of individuals who might fall into one of the above categories on any given day, the estimate would amount to a significant proportion—possibly as much as 20 to 30 per cent. These individuals cannot always be identified or prevented from participating in these activities. These are the individuals who are not likely to observe instructions and thus are likely to be involved in crashes. Each one of us has been preoccupied at times and behaved differently on that day compared to all other days.

Traffic systems must be designed safely, not only for "normal" people but also for those who might belong to any of the groups listed above. Such designs, rules, and regulations would reduce the probability of people hurting each other or themselves, even when someone makes a mistake. Perrow states this issue forcefully (7): 'Above all, I will argue, sensible living with risky systems means keeping the controversies alive, listening to the public, and the essentially political nature of risk assessment. Ultimately, the issue is not risk, but power; the power to impose risks on the many for the benefit of the few'.

5.3.3 Evidence on limits of education

Robertson (2007) and Williams (2013) have done seminal work on the limitations of education in general and driver education in particular over the past five decades. Williams concludes that 'However, the aim of most educational and training programs is to change individual behavior. When used alone, they largely fail to do so'. This section is largely based on Robertson and Williams' and many examples taken from their writings.

5.3.3.1 Example 1. Promotion of seat belt use

Television advertisements were prepared by a panel of consumers and advertising experts to promote the use of seat belts. The advertisements were shown on a special cable network received by only certain families (intervention group). Comparison families did not see the special messages on their televisions. Observations of seat belt use were made at random locations in the community before and after the television campaign. The results: There was a slight decline in seat belt use by drivers from both intervention and comparison families, showing that those provided the education did not do better than those who did not (Robertson et al 1974).

A huge amount of energy and money was spent in efforts to find ways to increase seat belt use by educating of car users in North America and Western Europe after the installation of belts was made mandatory in cars in the mid 1960s. However, belt use did not exceed 30 per cent almost anywhere and was less than 20% in most locations until belt use was made compulsory and enforced. Attempts to convince people to use belts through education, exhortation, or persuasion have had little success (Mackay 1985; Williams and Wells 2004). Many surveys have shown that people believe that belt use prevents injuries in a crash but still do not use them.

5.3.3.2 Example 2. Promotion of helmet use

The evidence that helmet use can reduce motorcycle rider fatalities by 30–50 per cent without accentuating the incidence or severity of neck injuries or harming the riders' sight or hearing is convincing and overwhelming (Bowman et al 1981; Mishra, Banerji, and Mohan 1984; Mohan et al 1984; Wagle, Perkins, and Vallera 1993; Tsai and Hemenway 1999; Brandt et al 2002; Hurt 1979; Peden et al 2004; Elvik and Vaa 2004). In spite of this knowledge and efforts of governments and civil society groups to promote helmet use all over the world, the majority of riders in a large number of countries do not wear helmets while riding a motorcycle (W.H.O. 2013). Just as in the case with seat belts, the proportion of motorcyclists wearing helmets rarely exceeds 30 per cent in the absence of a law that is enforced (Auman et al 2002; Radin Umar 2006; Keng 2005; Pervin et al 2009; Gururaj 2005; Mohan et al 2009; Houston 2007; Preusser, Hedlund, and Ulmer 2000; Bachani et al 2011; Haglund and Tibaleka 2012). These studies also show that when a compulsory law is enacted and enforced, helmet use rises dramatically and there is a significant decline in serious head injuries and fatalities. When a law is repealed, helmet use decreases and injury rates increase (Gururaj 2001; Preusser, Hedlund, and Ulmer 2000; Muller 2004; Mayrose 2008; Bledsoe et al 2002). In India, the compulsory helmet law applies all over the country, but states do not enforce it. Where the law is enforced use rates can be over 90 per cent, and where it is not the use rate can be less than 10 per cent (Mohan et al 2009). A study from East Africa reports that 97 per cent of motorcyclists on the streets of Kigali (Rawanda) use helmets compared to only nine per cent in the neighbouring Kampala (Uganda). The main difference is that the helmet law is enforced in Kigali but not in Kampala (Haglund and Tibaleka 2012). The experience of over half a century from all over the world shows that we cannot depend on education alone to ensure helmet use by more than 20–30 per cent of the motorcycle riders. It is only when there is a mandatory use law and it is enforced that the helmet wearing rates are more than 90 per cent.

5.3.3.3 Example 3. Children and traffic safety

Duperrex, Roberts, and Bunn (2003) reviewed 674 published and unpublished studies dealing with pedestrian education and found that 'Pedestrian safety education can result in improvement in children's knowledge and can change observed road crossing behaviour, but whether this reduces the risk of pedestrian motor vehicle collision and injury occurrence is unknown', and advise that '. . . environmental modification and the enforcement of appropriate speed limits may be more effective strategies to protect children from road traffic'. The uncertainty arises from the fact that most studies just test children's knowledge and not whether there was a reduction in traffic injuries. The issue of the effectiveness of education of young children in dealing with traffic was raised by Stina Sandels more than forty years ago and she warned that 'It is impossible to adapt fully small children to the traffic environment. They are biologically incapable of managing many of its demands' (Sandels 1975), and she concluded that 'It is concluded that it is impossible to radically lower the number of children's accidents by teaching safety measures' (Sandels 1974).

A study from Sweden examined the effects of the Swedish Traffic Club and found positive results in behaviour, such as more education by parents and more frequent use of safety devices, but the crash rate of the traffic club group increased (Gregersen and Nolén 1994). It is possible that the children became overconfident because of the course and thought they were more skilled than they actually were.

Child safety seats were available on the market in many western countries in the early 1970s and there a host of educational programmes were initiated to encourage parents to transport their children in the seats and not in their laps. Before the use of child seats was made compulsory an observational study of children in cars in 1976 in USA reported that 'Ninety three per cent of passengers less than 10 years old were not restrained. Eighty nine per cent of passengers 10 or older and 78 per cent of the drivers were not restrained. Sixteen per cent of child motor vehicle restraint devices observed were not used, and 73% of those in use were not used correctly' (Williams 1976). However, the state of Michigan (USA) implemented a law in April 1982 mandating the use of child restraint devices for children under age four travelling in automobiles, and a study done in 1985 reported that 'the proportion of young children travelling restrained increased from 12 per cent before to 51 per cent after the law was implemented. More importantly, a 25 per cent decrease in the number of children under age four injured in crashes was associated with the law' (Wagenaar and Weblster 1985). Reisinger et al (1981) studied the effect of paediatricians' counselling to parents on infant restraint use among 269 women who gave birth to infants in Pittsburgh hospitals. They report that paediatricians were effective in increasing the protection of infants in cars at ages 2 to 3 months but diminished by age four months to an improvement of only 9 per cent.

5.3.3.4 Example 4. Driver education

Driver education and training for beginning drivers and refresher courses for experienced drivers are thought to be very important measures to control traffic crashes. Almost all committees on traffic safety propose establishment of regulated driving schools as an important component of safety policies. However, reviews of driver education conclude that the research evidence suggests that most driver education/training contributes little to reductions in accident involvement or crash risk among drivers of all ages and experience (Williams 2013; Mayhew and Simpson 1996; Vernick et al 1999). In fact some of these programmes can make things worse. Many secondary schools in the United States used to offer classes on driving motor vehicles. Financial cutbacks led to the cancellation of driving classes at several schools. A comparison of locations providing school based driving education and those that did not found that motor vehicle death rate for teenagers fell in those communities discontinuing the classes, compared with communities whose schools continued to offer them (Robertson 1980a). This result has been confirmed by a systematic study of the literature on school-based driver education which concludes that 'There is no evidence that driver education reduces teenage involvement in road traffic crashes. Because driver education encourages earlier licensing it may lead to a modest but potentially important increase in the number of teenagers involved in road traffic crashes' (Roberts, Kwan, and Cochrane Injuries Group Driver Education 2003).

Most evaluations of driver training evaluate knowledge and skill but not the actual records of road traffic crashes after the training. It is assumed that better skills will always reduce the incidence of crashes, but this may not be so. One of the earliest studies to demonstrate this was a study of race car drivers who had been trained in crash avoidance techniques; they had more crashes per driver and per mile than ordinary drivers (Williams and O'Neill 1974). The limitations of driving skill were confirmed by a study in the United States in which the group that scored higher on the road performance test than did those in a control group or a minimum training group had more crashes subsequent to the training (Stock et al 1983).

As drivers' errors are thought to be an important factor contributing to traffic crashes in-service drivers are sent by many organisations for refresher or advanced training courses, but the experience with these types of interventions is also not very positive. A systematic review of post-licence driver education provides no evidence that is effective in preventing road traffic injuries or crashes (Ker et al 2005). The authors conclude that 'Although the results are compatible with a small reduction in the occurrence of traffic offences, this may be due to selection biases or bias in the included trials. Because of the large number of participants included in the meta-analysis (close to 300,000 for some outcomes) we can exclude, with reasonable precision, the possibility of even modest benefits'.

Since motorcycles are more unstable and more hazardous than cars for their occupants, rider training is promoted as a requirement by many authorities. However, we still do not have any evidence on what kind of training would result in a reduction in crash rates. In a systematic review of 23 research studies the different types of rider training were evaluated (Kardamanidis et al 2010). The findings suggest 'On the basis of the existing evidence, it is not clear if (or what type of) training reduces the risk of crashes, injuries, deaths or offences in motorcyclists and the selection of the best rider training practice can therefore not be recommended. That educational efforts may actually increase injuries is also possible'.

The above summary of the effectiveness of driver training programmes paints a gloomy picture. However, this does not mean that driver training and licensing is not necessary. Recent experiments with graduated licensing schemes have shown positive results because the initial driving period of novice drivers is extended and their freedom to drive limited (Williams 2005; Williams 2011; Mayhew and Simpson 1996; Kingham et al 2008; Hedlund and Compton 2004). Driver training is also necessary to make drivers familiar with rules and regulations and to impart important messages regarding driving etiquette. However, it is quite clear that we cannot expect driver education programmes to make significant reductions in crash rates.

5.4 EFFECTIVE COMMUNICATION

Messages that warn car drivers to 'Wear Your Seat Belt' or messages like 'Safety First' or 'Drive Safely' are much too vague, do not give any new information and consequently are ineffective. Even specific messages, however, do not guarantee a reduction in injuries – human behaviour is complex and often unpredictable. Education involves the communication of ideas, knowledge, attitudes, and feelings. Sibley and Harre (2009) advise us that 'Exposure to driving advertisements (either positively or negatively framed) did not significantly alter implicit, automatic self-enhancement biases (measured using a computerized reaction-time task). These findings emphasize that positively framed messages are more effective than negatively framed messages at influencing important psychological processes underlying driving behaviour, although such effects are limited, at least in their immediacy, to deliberative fast-learning(or propositional) processes'. Passive messages on TV, billboards and other media are not very successful in reducing traffic injury rates.

Many road safety agencies believe that frightening people about the outcome of crashes by showing bloody images of disabled and dead victims should encourage road users to adopt safer behaviours. There is no scientific agreement regarding this. Most findings inform us that positively framed messages are more effective than negatively framed messages at influencing driving behaviour, although such effects are limited (Lewis, Watson and White 2008; Lewis, Watson and Tay 2007; Sibley and Harre 2009).

However, we do have methods of effective communication that help us promote policies and regulations in the control of road traffic injuries. The findings can be summarised as follows:

5.4.1 Effective education programmes

1. Joint effort by community leaders and groups, media, schools and professionals based on evidence based countermeasures over long periods of time.
2. Education of professionals and policy makers.
3. Information about new safety products, infrastructure designs and why they are safer.
4. Information on safer but similar (in price and ease of use) vehicles and safety products like helmets, child seats, etc.
5. Programmes in support of new laws and infrastructure designs. The introduction of new laws and infrastructure designs should be preceded by education of road users on the

benefits of the new policies. This should accompanied by descriptions of how and why the proposed designs and polices will be beneficial.

5.4.2 Unsuccessful education programmes

1. Frightening and unpleasant messages are not very effective.
2. Documentaries on TV exhorting people to do things that they already know.
3. Programmes aimed at the powerless people who cannot change their behaviour because of the way traffic is managed and the design of roads. For example, if there are no safe and convenient sidewalks on a road, it is useless telling pedestrians how to behave on the road.
4. Home truths and vague slogans through signs, pamphlets, brochures, and billboards.
5. Painting competitions, rallies and once a year safety programmes for children.

5.5 CONCLUSIONS

There is no evidence that public education and information campaigns when used alone have a significant effect in reducing road traffic injuries. This is especially true for programmes aimed at young children. Some education programmes may change behaviour but not injury rates. Many documentaries and safety advertisements win awards for their artistic quality and retention in people's minds, but they may not result in safety benefits on the road.

Many governments, road safety agencies and road safety activists conduct expensive public education programmes on the assumption that just telling people what to do will change their behaviour for the good. These efforts bring good will to these actors but we have almost a century of experience that these efforts are not very successful. The best efforts to get people to use seat belts and wear helmets have rarely managed to get use rates above 20 per cent. Such efforts also divert attention, resources and energy from policies that will make our roads and vehicles safer and enforcement efforts more successful. On the other hand, education efforts directed at educating policy makers and professionals, giving new scientific information about safer vehicles and safety products, and in support of safety legislation and laws will help us move forward to a much safer world.

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CHAPTER 6

Recording of Traffic Crashes

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CONTENTS

ABSTRACT

This chapter illustrates the strengths and weaknesses of the primary level data base of road traffic crashes (RTC). The chapter reports the results of a study commissioned by the Transport Research Laboratory (TRL) U.K. to evaluate the experience of Bangalore police in adapting the Microcomputer Accident Analysis Package (MAAP) developed by the Overseas Unit of TRL. It also includes the findings of a survey of accident recording procedures in six other Indian cities. The survey was conducted as part of a research project sponsored by the Ministry of Surface Transport, Government of India, in an attempt to standardize the primary level data. The chapter also includes a review of the Road Accident Data Base Management System (RADMS) of Tamil Nadu government which has been in operation since 2009. A standard traffic crash recording form is presented for the preliminary analysis of traffic crash patterns based on information available in police first information reports (FIR).

Key Words: Accident recording; police data; FIR; traffic crash data

6.1 INTRODUCTION

It is a widely accepted fact that a traffic crash is a multi-factorial phenomenon. It is a close interaction between road users, vehicles, and the physical and legislative environment where road users and vehicles mix. Traffic strategies involve experts designing roads, planning cities, designing vehicles, and law enforcement agencies, and health sector experts who have to deal with the aftereffects of traffic crashes. Therefore, traffic crash data are required by different stakeholders to understand different aspects of crashes, to design multi-sectoral countermeasures. Whereas, traffic police are concerned with prosecuting the “guilty” party, the person responsible for causing the crash, long term and effective countermeasures have to be based on the principles of the “Safe Systems Approach” which recognizes the importance of making systemic changes to road designs, vehicles, and legislation which encourages safe user behavior.

A comprehensive approach to accident analysis in road safety covers a range of procedures and different levels of investigation. The necessity of different levels of investigation, with varying degrees of detail for each traffic crash, arises because it is impossible to collect all information pertaining to the road user, the road environment and the vehicle for all RTCs at all times.

6.2 TRAFFIC CRASH DATA

As discussed by Sabey (1990), at the primary level, the numbers of RTC covered are large, but the detail of each is necessarily limited: as the diagnostic content of analysis increases, the greater depth of detail demanded for each in any study is offset by the decrease in numbers. The information recorded by the police at the time of crash forms the primary level data. This covers all crash cases because police reports are required for all fatal and injury cases. There is some underreporting of traffic crashes; in India studies have reported about 5–10% underreporting of fatal crashes and a much higher proportion of underreporting of injury cases (Gururaj 2000; Dandona 2008). The secondary level includes data from traffic surveys and hospital records. Traffic related data such as type of volume of traffic, vehicle mix, and speed of vehicles are not required for every case, nor is it possible to measure them for each crash. Therefore this data is obtained from other surveys conducted on a sample of different road segments having different road geometry and traffic mix. Carefully chosen samples can give very useful data used to understand the effect of traffic mix and speed on crashes. Similarly, carefully chosen samples from hospitals can provide a very good understanding of the types of injuries and injury severity in different crashes. Tertiary level data includes the study of different parts of the vehicle and the road to understand the biomechanics of a traffic crash. This is collected by a very specialized team including road engineers, vehicle designers, and trauma surgeons and traffic psychologists. The detailed data are required for crash reconstruction models and for designing vehicle specifications. Detailed data collection of selected cases can give useful information. This is a resource intensive process, both in time and financial resources. For a comprehensive understanding of the traffic crash situation, all three levels of data have to be combined.

The analyses of primary level data is expected to accomplish the following important functions:

1. To give perspective view of the RTC situation in terms of who is involved (the type of road user), where (urban or rural area, road layout), when (day or night) and under what circumstances.
2. To enable trends to be examined, and provide a basis for comparison against which road safety workers may match their performance, either within or between state or national administrations.
3. To provide a basis for establishing priorities for action.

The starting point for the primary level data should be factual description of the circumstances of the RTC – the road users and vehicles involved, the traffic movements and environmental conditions. Since the main source of primary level data is the traffic police reports, which are prepared with the objective of determining the 'guilty', it becomes imperative to establish a system that does not reflect the police bias.

Deciding what information to collect and ensuring its reliability are fundamental to establishing a useful data base. For the primary level data to be meaningful the other important issues that must be addressed are:

1. How to improve the reliability and consistency of reporting the data elements, and
2. Integrating it with reliable exposure data for distance travelled in different modes of transport to examine trends.

Establishment of a quality data base at the primary level requires improving the quality of police recording system. It is a complex task because (1) the data base maintained by the police – the primary level data – is expected to accomplish multiple objectives, ranging from providing epidemiologic information to documenting the baseline information upon which the evaluation of countermeasures can be judged, and (2) in countries like India, the police or the traffic police, if it exists as a separate entity, does not have the resources or the level of training required to carry out a systematic collection of data as it is done in many high income countries.

6.2.1 Primary level data in India

A standard form for recording road crash related information has been recommended at various national and international forums. The earliest form for recording RTC related information was suggested at the fourth meeting of the Transport Advisory Council held in Delhi in July 1939. The Indian Roads Congress (1982) has summarized the revisions that were done to ensure the recording of relevant information by traffic police. The form was revised again in 2010 by IRC. Despite these efforts towards standardizing the accident recording and reporting system in India, police do not use the recommended IRC forms. The information recorded in each case file is used to determine who the guilty party is, and the case file is required in the court. Any information which is not admissible as valid evidence in the court is not mentioned in the records.

In 1990, the Ministry of Surface Transport made another attempt to improve the base level data. Consequently, a standard form along with a computer package has been developed. The design of this system is described in Mohan (1993). It is based on

1. Review of accident recording procedures in urban and rural areas in India.
2. Review of traffic crash reports from other countries (U.S.A., Europe, Southeast Asia, Australia).
3. Review of recommendations by experts.

The package is designed primarily for use at the regional or local level, by staff with little or no previous computing experience. The package includes a standard form which preferably should be filled at the site of the RTC. The form was designed to guide the policeman at the scene through the full sequence of data entries. It does not require a high degree of skill and assessment which are often not available with the reporting policeman. Data from the police accident report forms could be typed into computer files containing accident records. Consequently, retrieval of data was expedited and simplified compared to the paper record. Identification of locations with high number of RTC could be done very quickly. The analysis of the RTC at a particular site, especially searching for patterns was made much simpler. Ideally, such standardized systems should facilitate the establishment of a scientific primary level data base for RTC. The impact of systems recommended for standardizing the primary level data was assessed in two separate studies (Mohan and Tiwari 1993) covering eight Indian cities of varying geographical and population size.

6.2.2 Error analysis of data recording forms

The recommended forms have been field tested in several police stations in India in order to:

1. Identify shortcomings in the form from the point of view of the police requirements,
2. Evaluate the level of accuracy and reliability of recorded information,
3. Assess the procedure that was followed to implement the recommended system.

Despite the benefits of recording the information directly on the recommended form, the police officials have been reluctant to fill in the form at the site of the accident. It is perceived as a time consuming task. At the time of an accident the first priority is to send the victims for medical treatment, clear the site, and restore the normal flow of traffic as soon as possible. This has resulted in a three staged implementation process. It comprises of:

1. Transferring data from police records to a standard form,
2. Entering data from the standard form to computer files, and
3. Data analyses for remedial measures.

During field visits, the personnel involved at various stages of implementation were interviewed to assess their understanding of the various definitions used in the form, and the difficulties they faced in adopting the recommended system. The evaluation of forms filled out by police in seven other police stations and responses of the policemen interviewed are summarized in Table 6.1. A summary of error analysis of 1200 forms filled out by Delhi police is given in Table 6.2.

6.2.3 Reliability and accuracy of recorded data — case study Bangalore

Bangalore Police had implemented the Micro-computer Accident Analysis Package (MAAP) in 1994–95. The system was evaluated (Tiwari, 1997) and the major issues and insights gained in an evaluation study are summarized below

1. Forms must be in a language which is well understood by an ordinary constable. Table 6.1 shows that the police personnel have difficulty in understanding the following terms: (a)

TABLE 6.1 Results of the field test of the preliminary form in selected police stations.

Variable	**Remarks**
General Information: With the exception, of "Holiday" and "Hit and Run" all other variables filled in all forms	In more than 50% of the forms these variables were not understood.
Description	Difficulty in writing description in English.
Sketch	Sketch was attempted in 60% of the forms, however it was generally unclear and the minimum required information was also missing
Type of accident	Properly marked in 95% of the forms
Accident spot	-do-
Type of road	Properly marked in 75% of the forms. Term "with median" and "without median" not well understood.
Junction Control	Properly filled in 60% of the forms only. Sometimes filled for straight roads also
Type of Vehicle	Properly filled in 95% of the forms.
Vehicle Manoeuver	Properly filled in 20% of the forms. Difficulty in distinguishing and filling type and manoeuver of vehicle 1 and vehicle 2.
Name, address, sex, age of victims	Properly filled in 95% of the forms
Severity of injury	Only 10% of the forms had indicated.
Position in vehicle	Not understood at all.

TABLE 6.2 Error analysis of forms filled in by Delhi police.

About 1,200 forms maintained by the accident cell of Delhi Police were obtained for analysis of accidents in Delhi. These forms are based on the IRC Form A1 and a sample is enclosed in Appendix-I. A random sample of these forms indicates that the following variables were not filled in more than 50% of the cases:

General data

Vehicle damage, Type of road, Type of location, Traffic arrangement, Traffic volume, Light condition, Road condition.

Victim data

Insurance, Accident caused by vehicle, Damage to vehicle, Driver's License No., License type, Driver's education, Victim's education, Victim's responsibility, Victim's injury.

An analysis of the forms show that those filling out the forms have difficulty in filling in the following variables:

Variable	**Difficulty**
1. Location	Difficult to decide what "near" means in descriptors like "near college", "near office complex" etc.
2. Type of road	Difficult to decide what "bend", "narrow bridge", "gradient" mean.
3. Traffic condition	This has variables like "light controlled", "blinker", "police controlled", "traffic light not operating". Difficult to decide what to fill in when these exist but not operating.
4. Traffic volume	Difficult to distinguish "heavy" "moderate", "light" etc. In addition, they don't know what to include, whether that stretch of road has heavy traffic during accident or at most times.
5. Type of collision	Difficult to distinguish terms like "side swipe" and "sliding".
6. Light condition	Descriptors like "twilight", "dark with good st. light" and "dark with st. light" not understood.

Traffic and road geometry terminology with which they are not familiar, e.g. vertical and horizontal grade of the road, median, etc. (b) The complexities involved in the operation of the heterogeneous traffic makes the interpretation of certain terms/definitions difficult, e.g. merging and diverging are not easily identifiable because of the nature of the traffic where lane driving is at a limited scale only. (c) The police department's main objective is to assign blame or fault to a single "cause". Therefore, various definitions and terms are interpreted in that context. For example, yellow marking on the road was interpreted as a median because crossing yellow marking is illegal. Vehicle 1 was coded as the vehicle at fault or the accused vehicle, and vehicle 2 gets biased when it is recorded on the recommended forms.

2. Instead of directly filling the recommended form at the site of the crash, the preferred method was to continue the practice of maintaining a case file for each crash which contains (a) a site plan drawn by the investigation officer; (b) a mechanical inspection report of the vehicle; (c) an autopsy report or injury report of the victim; and (d) the first information report.
3. Generally, a simplified version of the recommended form is used to transfer information from the case file to the form. This is a single sheet format prepared by deleting the descriptions and figures from the recommended form and retaining only the boxes to be

TABLE 6.3 List of data tables in accident reports.

S. No.	Data in Accident Reports	1	2	3	4	5	6	7
1.	Accidents by Month/Day/Time	Y	Y	Y	Y	Y	Y	Y
2.	Casualties by Month	Y	Y	Y	Y	Y	Y	Y
3.	Type of Vehicles involved in Accidents	Y	Y	Y	Y	Y	Y	Y
4.	Investigations of Traffic Accident cases	Y	Y	Y	Y	Y	Y	Y
5.	Enforcement of Traffic Laws and Regulation	Y	Y	Y	Y	Y	Y	Y
6.	Casualties by Type of Road Users	Y	Y	Y	Y	Y	Y	Y
7.	Accidents by Road type	Y	Y	Y	Y	Y	Y	Y
8.	Accidents by Road control	Y	N	N	Y	Y	N	Y
9.	Accidents by Road surface	Y	N	N	Y	N	N	Y
10.	Vehicles Manoeuvre	Y	N	N	Y	Y	N	Y
11	Cross Tabulation of any two variables	Y	N	N	Y	N	N	Y

Note:
1. Royal Malaysia Police (1992).
2. Inter-Agency Road Safety committee (Philippines) 1991.
3. Road Traffic Accident Review: Nepal, presented at IIT Delhi 1993.
4. Srilanka Police (Annual Report) 1993.
5. Delhi Police (Annual Report) 1993.
6. Mumbai Police (Annual Report) 1993.
7. Bangalore Police (Annual Report) 1993.

Y: YES and N: NO

filled by an appropriate number, indicating the valid option. The form is usually used as a guide book or reference guide for choosing the right options. An important insight gained from this is to choose the right options. Another important insight gained from this is that the form designed by experts on the basis of international recommendations does not meet the requirements of the police, who would like to economize on their time and resources. In the process, the accuracy of the data is adversely affected. Examples of reliability and an accurate date are recorded.

6.2.4 Critical variables for identifying causal factors

Formal data collection systems, especially when they are computer based systems, have the capability of generating frequency counts, cross tabulations, and trends of accidents if time series data are available. However, identification of causal factors involves understanding the role of various factors. Often variables which are analysed in accident reports (Table 6.3) are not critical for identifying causal factors e.g. frequency counts of accidents by day of week, time of day, and number of people prosecuted etc (Tiwari 1996). Table 6.3 shows variables which are tabulated because the information is available for them; however, it is not clear how the available information can be used to design countermeasures.

6.2.5 Use of data in recommending countermeasures

A list of causes compiled by the police departments is not based on a detailed analysis of the accident; it is the impression of the person filling the case details. A list of accident causes prepared by the police departments is used as the basis for recommending countermeasures. Table 6.4 lists strategies recommended in all accident reports. It is not clear how the data recorded by the police was linked to the recommended strategies. For example vehicle inspection and driver training procedures are recommended by all. However, the recorded data do not provide reliable

TABLE 6.4 List of recommendations in accidents reports.

S. No.	Recommendations	1	2	3	4	5	6	7
1.	Speed Detectors\video surveillance system	Y	Y	Y	Y	Y	Y	Y
2.	Stricter penalties for Traffic low violation	Y	Y	Y	Y	Y	Y	Y
3.	Improvement in vehicle maintenance	Y	Y	Y	Y	Y	Y	Y
4.	Inspection for road worthiness	Y	Y	Y	Y	Y	Y	Y
5.	Poor road maintenance	Y	Y	Y	Y	Y	Y	Y
6.	Lack of formal driver training	Y	Y	Y	Y	Y	Y	Y
7.	Spot Improvements	Y	Y	Y	Y	Y	Y	Y

Note:

1. Royal Malaysia Police (1992).
2. Inter-Agency Road Safety Committee (Philippines) 1991.
3. Road Traffic Accident Review: Nepal, presented at IIT Delhi, 1993.
4. Srilanka Police (Annual Report) 1993.
5. Delhi Police (Annual Report) 1993.
6. Mumbai Police (Annual Report) 1993.
7. Bangalore Police (Annual Report) 1993.

Y: YES and N: NO

and detailed information which can be used to relate the condition of the vehicle to the cause of accident. Similarly "rash and negligent driving" is listed as the cause of an accident by the police personnel recording the accident details which may not be an accurate and reliable description of the situation.

6.2.6 Black spot analysis

Accident reports which have used a data base created by the MAAP system list locations or streets by the frequency of accidents. This is to identify 'black spots'. This replaces the manual method of marking accident spots on a map. For better understanding of the "black spots" more information and rigorous statistical methods are required (Ayutha and Bohning 1995). Effective counter measures cannot be designed on the basis of a data table produced by data collection systems alone.

6.2.7 RADMS (Road Accident Data Management System) Tamil Nadu

In April 2007, Tamil Nadu became the first state in the country to announce a Road Safety Policy. This was followed, in 2009, by a Road Safety Action Plan. As part of the Action Plan, an easy-to-use bilingual software package – known as the Road Accident Data Management System (RADMS) – was developed, with the help of an international consultant, under the World Bank-supported Tamil Nadu Road Sector Project. The GIS-based RADMS software geographically maps all road accidents that take place on Tamil Nadu's national and state highways, as well as on urban and district roads. The system identifies the most accident-prone spots and displays crash trends and other information at the click of a mouse. The RADMS software, developed after detailed consultations between the police, transport, and highway departments, has been helping the authorities analyze the 'how', 'where' and 'why' of road accidents, and enabling them to plan and implement remedial measures. In the two years since the system has been operational, nearly 3000 accident-prone spots have been identified.

RADMS was established with the cooperation of three stakeholders within Tamil Nadu, namely, the Police Department, Highway Department and the Transport Department. Its design was headed by the Transport Department, and the operations have always been managed by

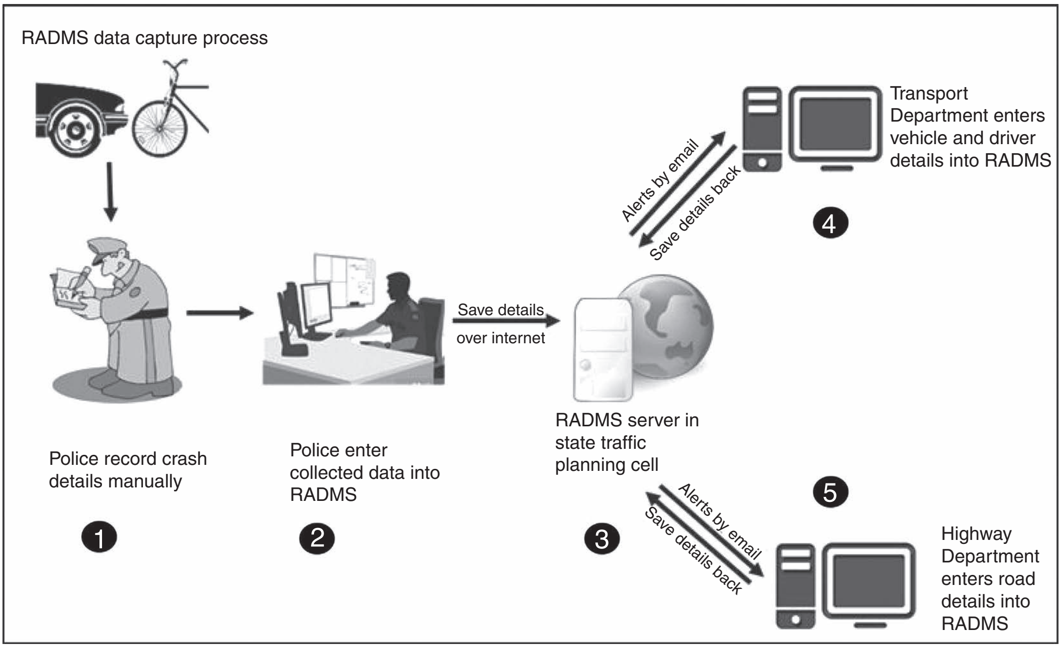

Figure 6.1 Flow of Information in RADMS.

the Police. Thus, for any changes to the system (i.e. any technical or functionality changes), the competent authority to approach is the Transport Department and not the Police.

At the police headquarters, RADMS is managed by the State Transport Planning Cell, which is the central body which regulates the use of the system. Figure 6.1 shows the process followed in RADMS.

6.2.8 Filling out the Accident Recording Form (ARF)

There are seven possible sections which have to be filled out, namely, General Details, Location Details, Collision Details, Vehicle Details, Driver Details, Passenger Details and Vehicle Details. The computer operator first begins by filling in the General Details. There are 150 fields to be filled, of which 68 are marked as mandatory.

First, a unique Crime Number is generated by the police department for the accident, which is fed into the ARF. The police officials are also required to analyse the event before completing the form, to try to identify the major causes of the accident and propose counter remedial measures, which have to be noted in this section. Rash and negligent driving is mentioned as the cause of accident in 90% of the cases.

When the system was started, the location was described using Google maps. Later, GPSs were introduced and provided at all police stations to record the exact location of an accident. Next, the collision details needs to be filled out, where there is a provision for a collision sketch/photograph to be added, which is done only in the case of very severe accidents, since those graphics can then be used for investigatory purposes. There is also a voice recording feature which allows for the views of police officer on site to be recorded.

In the collision details itself, a field by the name of “contributory factor” is to be filled in, where there are four options available, namely Engineering, Human, Natural, and Others. These are filled out on the basis of the judgment of the police. However, accidents are multi-factor phenomena, and it may not be possible for a police constable to identify all the contributory factors. This is a very critical field, since on the basis of the information recorded, the issue is forwarded to the Transport Department or the Highway Department for further remedial action.

The admin cell has been empowered by a set of queries to ensure quality control and robustness of the data. On the vehicle detail form, the operator has to select whether the vehicle belongs to the victim or the accused. Once this selection is done, the registration number of the vehicle and other details are entered. This process, i.e. of entering the car registration number, the details about the vehicle and driver, may be filled automatically by using a central data base – the Wahan Saarthi, maintained by the Ministry of Roads and Highways, which will have an interface with the Transport Department in the near future. The driver parameters are entered manually, since the vehicle may not be driven only by the owner. Once the ARF is submitted by the police department, mail is automatically delivered to the concerned authority in the Transport and Highway Department, since certain form parameters have to be entered by them as well. As per the SOP, they have a variable length of time to complete the task, failing which the issue is reported to senior authorities.

6.2.8.1 Role of the Admin cell

The Admin cell, or the STPC is based out of Chennai. The responsibilities of the STPC are as listed below:

- Monitor monthly tally of accidents and tally with the data collected by State Crime Record Bureau (SCRB) to ensure correctness of data, on every 4th day of the month or first Tuesday, whichever is later.
- On the lines of reports by the IRC, they have to send quarterly and annual reports to the government to discuss the situation of road safety and propose further action.
- Maintain the quality of data by conducting checks on ARFs from time to time. For this, there is a 2 prong strategy that is in practice. First, an ARF is selected at random and a query is run to check if all the mandatory 68 fields have been recorded. If it emerges that not all fields have been entered, the issue is highlighted, and the police station and officer concerned have to immediately take appropriate corrective measures. If however, the 68 fields are all filled, then as suggested previously, the Admin can run certain queries on the system to identify fake reporting. Thus, the system has been designed to overcome the two biggest challenges of data collection, underreporting and false reporting.
- Conduct training sessions for the staff every three months, on using RADMS.

6.2.8.2 Strengths and weaknesses of RADMS

1. The data base does not allow to extract information on impacting vehicles in collision.
2. Kilometer Analysis and Safety Benefit Evaluation features are not operational.
3. There are more than 60 vehicle categories mentioned. This has been done to make work easier for the data collector, while reporting the data and filling out the entire ARF manually. Rather, they can just pick the correct option as per the situation. However, recent analysis shows that most categories are not filled out, and are not used in any analyses.

It is an advanced system when it comes to functionality and its level of service is comparable to most international systems in place. However, there is not much clarity on how to use the system. On the operational front, there is the reliability on human interpretation and judgment, which may lead to incorrect data collation. Though the system has provisions for maintaining consistency in terms of quality of data, the scope for error remains. This problem can be overcome by further standardization and reduction in unnecessary form parameters.

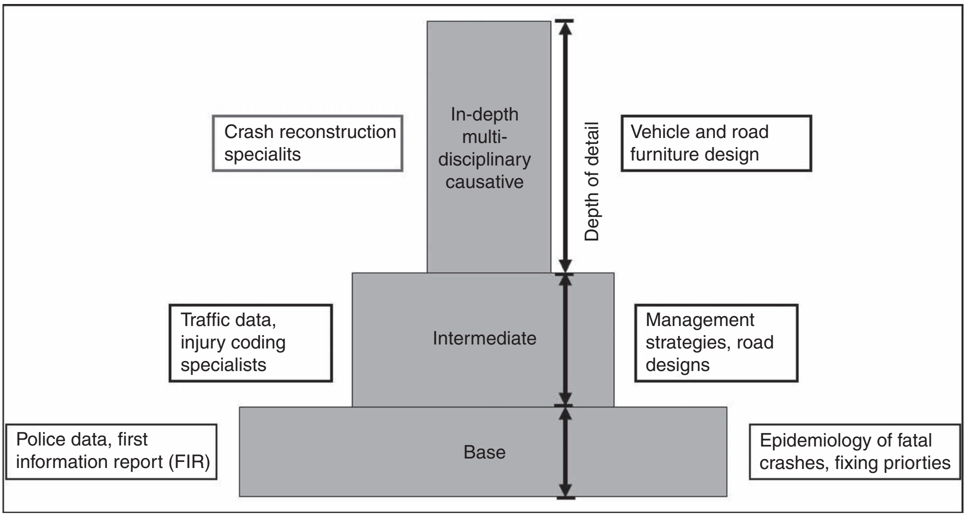

Figure 6.2 Levels of traffic crash data.

6.2.9 National Crime Record Bureau (NCRB) data

The National Crime Record Bureau under the Ministry of Home Affairs publishes *Accidental Deaths and Suicides in India* every year. The data for the report is collected by the State Crime Records Bureau (SCRB) from the District Crime Records Bureau (DCRB) and sent to the NCRB at the end of the year under reference. Data from mega-cities (cities having a population of 1 million or more as per the latest census) is also collected separately. The first edition of *Accidental Deaths and Suicides in India* pertains to the year 1967, and the latest edition of the report pertains to the year 2014. While the total number of fatalities reported by the NCRB can be used for analysis purposes since underreporting is expected to be around 5–10%, the share of road accidental deaths by various modes of transport (NCRB, 2013) shows very low numbers of pedestrians and bicyclists. Figure 6.2 shows a large discrepancy in the number of pedestrian fatalities as extracted from FIR records of city police stations and as reported by NCRB. It seems that NCRB tables are based on identifying the "person/mode at fault"; therefore pedestrians appear to be only 10% of the total victims.

There are other data sources for traffic crashes, such as insurance data bases, road concessionaire records, toll operator records, and hospital data records. However, each source has some bias (Table 6.5) and is not as representative as police records. Therefore, for getting a basic understanding and epidemiology of crashes, police data is the best source.

At present the tables prepared by police are not useful for designing countermeasures, however from the data available from the police (FIRs, case files, vehicle inspection reports and post mortem reports), several useful insights can be gained from FIRs alone. FIR data can be used to fill out the form in Annexure 1 and following useful tables can be made:

1. Number of fatalities, day, time, month, gender
2. Location (at junction or away from junction)
3. Victim type
4. Vehicle type
5. Victim versus impacting vehicles.

TABLE 6.5 Data sources and possible biases.

S. No.	Data Sources	Possible biases
1.	Police FIR	Injury crashes are underreported
2.	Hospital data	Crash details are not recorded, depends on the specialty of the hospital
3.	Special Agencies (concessionaires)	BOT operators or toll operators maintain records of crashes causing damage to the road furniture along with other crashes
4.	Insurance	Depends on what injuries and damage to the vehicles are compensated
5.	Research teams	Misses fatal pedestrian and bicycle crashes where victims are removed quickly

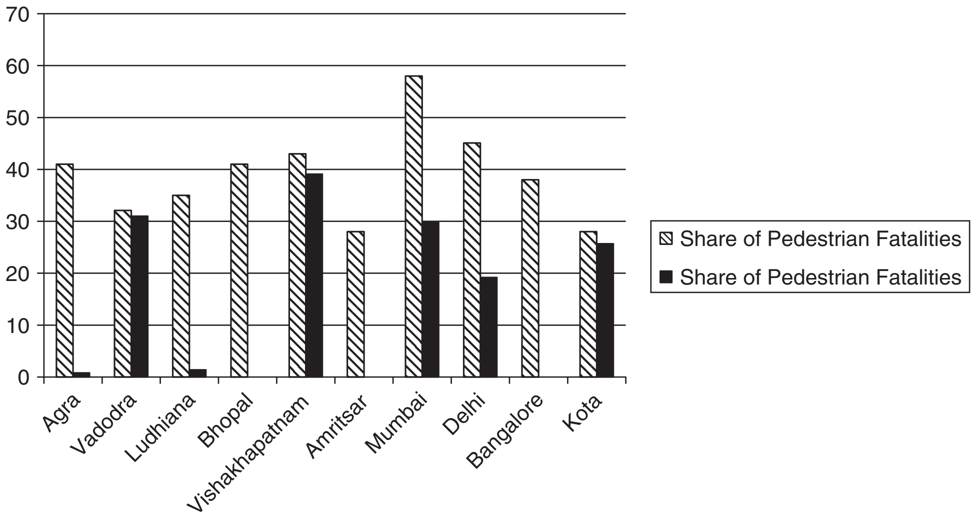

Figure 6.3 Comparison of pedestrian fatalities reported by NCRB and city FIRs.

This information can be used to prioritize interventions and provide a base for drawing samples for investigating secondary and tertiary level data as shown in Figure 6.3.

6.3 CONCLUSIONS

Road traffic crash is a complex phenomenon. It can be explained by understanding the interrelationships between the various components of the system, both hardware and humanware, and the reasons for the breakdown of these interactions that leads to injuries. The level of interactions and complexities increase further in the presence of the heterogeneous traffic mix that exists in most less motorized countries like India. In the presence of the multiple interactions and complexities involved in heterogeneous traffic, it seems difficult to identify a single actor (animate or inanimate) as the initiator of a perturbation that leads to an injury causing event. Therefore, the function of a primary level data base cannot be fulfilled unless the recorded details provide information regarding the complex process involving the association of a number of causal factors. These factors are related to the various components of the traffic system – physical features of the road environment, technical aspects of the vehicles involved, and human behaviour.

This study illustrates that creation of a quality data base requires much more than introducing a standardized format and a computer package. It needs the resolution of the conflicts between recording of information which is easily available and that information which would be useful for designing preventive measures. It is important and difficult to design a form which is clearly understood by those filling out the forms. Terminology used must be understood by all the individuals and agencies involved. Only those variables should be included which suit local conditions. This can be accomplished by modifying the standardized form to meet the local needs; training must be introduced at the training schools; there must be greater interaction between police officials and researchers, and the policy makers who use and analyse the recorded data.

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APPENDIX – I

TRIPP IITD Accident Recording Form

Road Accident Recording Form		
Accident Information		
Form No.		
Filled By	Date filled (dd/mm/yyyy)	/ /
Police Report Available	0=No 1=Yes	If yes, FIR No.
City/Town/Village Name		
Time of Accident		
Date	(DD) (MM) (YYYY)	
Day	01=Monday 02=Tuesday 03=Wednesday 04=Thursday 05=Friday 06=Saturday 07=Sunday 08=Unknown	
Holiday	0 = No 1 = Yes 9=Unknown	
Hit and Run	0 = No 1 = Yes 9=Unknown	
Accident Severity	1=Damage Only 2= Injury 3=Fatal 9= Unknown	
No. of Fatalities		
No. of Injured		
No. of Vehicles Involved		
Collision Type		
01 = Hit pedestrian	02 = Vehicles head on	03 = Vehicle hit from back
04 = Vehicle hit from side at right angle	05 = Sideswipe (same direction)	06= Vehicle Sideswipe (opposite direction)
07 = Overturn	08 = Vehicle hit fixed object	09 = Run off the road
10= Others	99 = Unknown	
Collision Spot	01 = On straight road 02 = Road junction 03 = Other 09 = Unknown	
Type of Road	0= Un-metalled 01=Metalled (Black topped/Concrete) 02=Others 09=Unknown	
Divider	1=Two-Way without median 2= Two-way with median 3= One-way 9= Unknown	

Location 1=Urban 2=Rural 3=Semi-Urban 4=Other 9=Unknown ☐

Light Condition 1=Day light 2=Dark 3= Dark but lighted 4= Dawn 5= Dusk 9= Unknown ☐

Road Category RURAL: 1= State Highway 2= National Highway 3= PMGSY ☐
URBAN: 4=Arterial 5= Sub-Arterial 6= Local Street 7= Local 8= Other 9= Unknown

Distance Km post. In the absence of Km post - from the nearest urban centre ☐ (km) ☐ (m)

From ☐

Global Position ☐ (latitude) ☐ (longitude)

Road 1 ☐ **Road 2** ☐

Road 3 ☐ **Landmark** ☐

Brief Description of Accident

Vehicle Information

Form No. **Vehicle No.** ☐

Type ☐

01 = Multi-Axle Heavy Goods vehicle 02 = 2-Axle Heavy Goods vehicle 03=Light Goods Vehicle 04 =Mini Bus
05= Bus 06 = Car/van/jeep/taxi 07= Ambulance 08= Fire Fighting Vehicle
09= Three Wheeler Passenger 10=Three Wheeler Goods 11 =Thela 12=Electric Cycle
13 = Tractor without Trailor 14= Tractor with Trailor 15 = Cycle Rickshaw 16 = Motorcycle/Scooter/Moped
17 = Animal drawn vehicle 18=Bicycle 19=Pedestrian 20=Others 99=Unknown

Maneuver of Vehicle at Crash Time ☐

01 = Proceeding straight 02 = Turning 03 = Reversing 04 = Overtaking 05=Parked/Stopped

06 = Other 07= Going wrong way 08= Making U turn 09 = Unknown

Loading 1=Normal 2= Overloaded 3= Others 9= Unknown ☐

Disposition 0=Not Roadworthy (needs to be towed away) 1= Roadworthy (can drive away) 9 = Unknown ☐

Mechanical Failure 0=No 1=Yes 9=Unknown ☐

Hazardous Cargo 0=No 1=Yes 9=Unknown ☐

Fire 0=No 1=Yes 9=Unknown ☐

Impact-Vehicle/Object ☐

Vehicle type (If another vehicle impacted this vehicle) 11=Pedestrian 12=Tree 13=Kerb/Median

14= Pole 15= Other 99=Unknown

Make-Model ☐

Model-Year ☐

Form No. **Vehicle No**

Type

01 = Multi-Axle Heavy Goods vehicle 02 = 2-Axle Heavy Goods vehicle 03=Light Goods Vehicle 04 =Mini Bus
05= Bus 06 = Car/van/jeep/taxi 07= Ambulance 08= Fire Fighting Vehicle
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Manoeuvre of Vehicle at Crash Time

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Hazardous Cargo 0=No 1=Yes 9=Unknown

Fire 0=No 1=Yes 9=Unknown

Impact-Vehicle/Object

Vehicle type (If another vehicle impacted this vehicle) 11=Pedestrian 12=Tree

13=Kerb/Median 14= Pole 15= Other 99=Unknown

Make-Model

Model-Year

Victim Information

Road User	1= Passenger, 2= Driver, 3= Pedestrian, 4=Cyclist, 9= Unknown	☐
Occupant Vehicle No		☐
Seating Position	01= Front 02= Back 03= Other 09= Not Applicable for Cyclist/Pedestrian	☐
Location of Non-occupant		☐
Age	In years, 99 if unknown	☐
Sex	1 = Male 2 = Female	☐
Injury	0 = No injury 1= Injured 2 = Fatal 9 = Unknown	☐
Pedestrian/Vehicle Impact by Vehcile No		☐
Mode of Treatment	0=None 01=First aid only 02=Discharge after casualty ward treatment 03=Admitted to hospital 08=Others 09=Unknown	☐
No. of Days in Hospital	Days, Unknown- 999	☐

Injury 1							**Injury Severity 1**	
Injury 2							**Injury Severity 2**	
Injury 3							**Injury Severity 3**	
Injury 4							**Injury Severity 4**	
Injury 5							**Injury Severity 5**	
Injury 6							**Injury Severity 6**	
Most Severe Injury							**ISS**	

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Traffic Conflict Techniques: Some Data to Supplement Accident Analysis

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CONTENTS

ABSTRACT

Successful road safety action requires a systematic assessment and a holistic approach. This in turn requires a thorough knowledge and understanding of how single measures work. Without this knowledge we may implement measures that are poor – or even detrimental – from a safety point of view.

Analysis of accidents is not sufficient as the only tool to be used:

- Accidents are rare events and are therefore associated with random variations.
- Not all accidents are not reported.
- The behavioural or situational aspects of the events are poorly covered.
- Accident analysis is a desk tool, **not** a field tool.

The need for supporting methods is strong. In this chapter traffic conflict techniques are presented – theories as well as validity and reliability issues, and practical examples. A large scale study from Jaipur, India is presented in greater detail.

Key Words: Conflict; serious confict; near accident; safety assessment

7.1 INTRODUCTION

7.1.1 The lack of safety assessments

Successful road safety action requires a systematic assessment and a holistic approach to various single measures. This in turn requires a thorough knowledge and understanding of how the single measures work. Without this knowledge we may implement measures that are poor – or even detrimental – from a safety point of view.

A drastic example – assessed in Sweden – is the safety effect of "ordinary – non- signalised" zebra crossings. More than 50 years after its introduction an evaluation was carried out in the eighties, where different types of crossings were compared; it was discovered that the safety effect for pedestrians was negative (Ekman 1996). This was followed by many years of scepticism; practitioners as well as local and central authorities did not believe that the figures properly described the "true" effects. They tried to find all sorts of explanations (differences in volumes, in width of the road, in speeds, etc.). The researcher had tried all these explanations as well. His only remaining reasonable explanation was that pedestrians felt safer on a zebra than elsewhere, and therefore behaved- less carefully on the zebra crossing.

This illustrates a big problem in safety procedures. We road users feel **we** are the experts, and researchers have great difficulties in cutting through with their expert knowledge. After a decade, the central authorities accepted the results and started trying to overcome the problem. Again expert knowledge from researchers had a low priority; the conclusion was that because drivers did not yield to pedestrians at zebra crossing the rule regarding yielding had to be sharpened. So a law was passed making it mandatory to stop to let pedestrians proceed who were, on or about to enter the crossing. The law was introduced in the year 2001. The result was, however, negative. The number of injured pedestrians increased even further (Thulin 2007). There is reason to believe that the "original problem", namely that pedestrians felt safer when crossing at a zebra crossing, was highlighted to a greater extent. Now (almost) every car stopped, so the reason to be careful when crossing was even less important. The good thing with the example is that it started a completely new discussion about crossing facilities for pedestrians. The National Road Administration started a comprehensive program for removing many zebra crossings, which were felt to be unnecessary. Instead, so-called "safe crossings" were established which were based on the principle of low speeds, below 30 km/h.

This example from Sweden is most certainly not unique. The point is that there were so many measures introduced that were not assessed from a safety point of view **before their** introduction. In the zebra crossing case in Sweden there should of course have been a discussion about introducing zebra crossings: "Why zebra crossing?" "For what purpose?", "What kind of changes do we want to achieve?", "what improvements do we expect?", "Will there be any drawbacks?" And today we would have added questions: "What environmental effects will there be?", "How will it affect car traffic?" etc. There would have been a good chance of having a discussion started about pedestrian safety at that stage. Now, that discussion has started 50 years too late.

This phenomenon of missing safety assessment is not unique. What do we know about the effect on pedestrians and bicyclists of all the new IT-systems, like Electronic Stability Control?

7.1.2 The insufficiency of using only accidents in assessment

The basic problem is the lack of assessment tools that allow a quick, easy and reliable follow up of – both probable and actual – safety effects. Accident analysis has been the main tool. But accident analysis is most often not sufficient, because:

- Accidents are rare events and are therefore associated with random variations. To assess local measures it is not possible to aggregate data, because you then lose all possibility of disaggregation. In the zebra crossing type you may need to disaggregate the type of road, type of intersection, speed, etc. The number of pedestrians quickly falls to quite a small number.
- Not all accidents are reported. Even not all of the fatal accidents are reported, and regarding injury accidents less than half are reported. And we know almost nothing about missing data.
- The behavioural or situational aspects of the events are poorly covered. This is one of the most critical points. In order to know and understand "what is going on **in** traffic in relation to crashes" one needs to know the prehistory, i.e. we need insight into the pre-crash phase. One of the most crucial elements in this phase is of course "speed adaptation". According to most national traffic laws "speed must be adapted to the prevailing conditions in order to be prepared to avoid a collision". The problem is that we do not know how to define that operationally, and, we have no chance of identifying this in real traffic. Simply because we cannot observe it. Strong efforts are of course made to try to identify the pre-crash phase, by interviews with those involved and witnesses to crashes, etc. It does not seem to be reasonable to spend large resources on in-depth analysis by experts. (Hydén et al 2006).
- Accident analysis is a desk tool, **not** a field tool. Engineers are turning into bureaucrats. Instead of being "observers" in – and of – traffic, the Engineers sit at home reading (already very biased) reports. These can only primarily confirm different prejudiced opinions on what has happened, and why. The voice of the weak partners, pedestrians and bicyclists, is easily overlooked.

The conclusion is that we need observational tools that allow us to watch traffic and to be able to do a scientifically sound assessment of what we observe. The result would be a better understanding of the accident causation process. What are the preceding behaviours that will increase the probability of a crash, and what are its relations to infrastructure design, etc. So we need links between accidents and behaviours, so that different (types of) behaviour can be interpreted in safety terms. Thus, we need links between behaviour and conflicts.

7.1.3 Traffic conflicts – an overview

The first attempt to define traffic conflict was made at an international meeting in Oslo in 1977: "A conflict is a situation where two road users approach each other in time and space to such an extent that a collision is imminent if their movements remain unchanged" (Amundsen and Hydén 1977). In operational terms the question was what was meant by "approach each ..." and "imminent".

Research on conflicts started in the sixties. Perkins and Harris (1968) at General Motors Research Laboratories developed a technique to study two categories of conflicts: sudden road users' actions to avoid a collision, and traffic offences. Sudden evasive actions by road users become apparent by braking or changing lanes. Traffic offences are described as behaviour that is deviant from traffic rules.

The US technique made no differentiation between conflicts of differing severity, which meant that there could not be any differentiation at all regarding severity; all conflicts represented the same probability of a collision.

A severity dimension was therefore introduced in research at TRRL in the UK. In a study by Brian Spicer in the beginning of the seventies, all conflicts were measured in which a sudden action took place by braking or swerving between lanes by one or more vehicles to avoid a collision. This simple definition of a conflict did not significantly correlate with collisions. A next step consisted of a five scale severity score to make a clear distinction between severe and slight conflicts. A five degree severity scale was introduced, where degree 1 was "Precautionary braking, while degree 5 was Emergency braking followed by a collision" (Older and Spicer, 1976). Degrees from 3 to 5 (Strong braking, rapidly changing lanes or stopping to avoid a collision, resulting in a near-crash) were defined as serious conflicts.

A new dimension was introduced by Hayward (1972), an objective measure. He proposed to measure the time till the potential collision moment between two vehicles. These times were measured using film recordings. From the analysis of near-accidents, Hayward concluded that a time lower than one second would be a good criterion for near accidents. Other researchers followed up on the 'time-to-collision' approach. This included Hakkert et al (Amundsen, Hydén 1977) and Van der Horst 1982, Kraay 1982. I (Hydén 1975 and 1987) introduced the "Time to Accident" (TA) concept, which is based on the time it would take from the moment one of the road users involved in a conflict starts taking an evasive action (braking, swerving or accelerating) until the predicted collision point is reached, if speed and direction is unchanged. The measure is objective, however – until now – it has been obtained with the help of trained observers. One more developmental line worth mentioning is a Canadian technique that was based on PET – Post Encroachment Time (Cooper 1977, in Amundsen; Hydén 1977). Conflicts were recorded by trained humans. PET and TTC was combined when a new technique was developed in the Netherlands. It is called DOCTOR (Kraay, Horst and Oppe 1986).

From the late 1970s and onwards there was a growing interest in the conflict concept, and different techniques were developed and used. Different definitions were used, as well as different observation techniques. This led to confusion; and international cooperation was felt to be urgently necessary. An international organisation was formed in 1989, ICTCT – International Committee on Traffic Conflicts Technique. ICTCT still exists, but is now called International Cooperation on Theories and Concepts in Traffic Safety – see www.ictct.org.

One of the major efforts carried out by ICTCT was a so-called international calibration study of traffic conflicts. Nine teams participated with different concepts, see Figure 7.1. They all made observational studies in the field at the same location, simultaneously.

Even though there seemed to be a considerable theoretical difference in the scoring of conflicts the main conclusion was that there is one, and only one, severity dimension that is one-dimensional (Grayson (ed.) 1984).

The interest in using traffic conflicts in assessing traffic safety has for many years been rather limited. Very few – primary local – authorities have been using it systematically. The situation has been more or less the same in research. One exception is the Swedish technique. In combination with behavioural and accident analysis it has been used to do research on the design of the infrastructure: design and location of zebra crossings at intersections and design of small roundabouts (Hydén and Várhelyi 2000).

	Definition conflict			Severity dimension	
	Estimation of		Interpretation of evasive action	Based upon proximity	
	TTC	PET		Collision (all types)	Injury acc.
Sweden1 Finland	Fixed threshold			X	
Sweden2	Fixed threshold				Mean speed and type of road user
Sweden4	Threshold as a function of speed			X	
Canada		Fixed threshold	(X)		
England France2			Intensity and result		X
France1 United States Sweden3			Intensity and result		
Germany Austria			Intensity and result	X	
Netherlands	Calculated minimum value			X	

Figure 7.1 Overview of definitions of a conflict and severity dimension by the teams participating in the Malmö calibration study (from: Kraay et al 1986).

The interest and need for information via surrogate safety measures has risen significantly with all new IT-systems in vehicles. As safety is one of the key areas in this new development there is a strong need for finding new ways to assess the safety effects of these new developments/systems. In order to manage this assessment Naturalistic Driving has been introduced: "Naturalistic driving, also known as naturalistic observations, is a new approach among already applied traffic research methods". It can be defined as "A study undertaken to provide insight into driver behaviour during everyday trips by recording details of the driver, the vehicle and the surroundings through unobtrusive data gathering equipment and without experimental control (www.udrive.eu)".

Trent et al (2015) have looked at "Driver Inattention, and Crash Risk" in the Naturalistic Driving project. According to the researchers, risk has generally been calculated for safety-critical events, which group crashes and near crashes. Detailed driving behaviour data recorded in the seconds leading up to crashes and near crashes cannot be obtained from test tracks, simulators, or observational data (e.g., crash databases). The researchers have therefore defined a kind of "conflict technique". They define a serious conflict as: "A near crash involves any circumstance that requires a rapid, evasive manoeuvre by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash. A rapid, evasive manoeuvre is defined as a steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities. As a general guideline, subject-vehicle braking greater than 0.5 g or steering input that results in a lateral acceleration greater than 0.4 g to avoid a crash constitutes a rapid manoeuvre". They ask themselves what crash severity scale is best suited for analysis of risk. The problem is that accident data is scarce even in large-scale trials with naturalistic driving. Therefore, the researchers conclude by stating: "However, further work is necessary to validate these scales" (Trent et al 2015).

7.2 THE SWEDISH TRAFFIC CONFLICTS TECHNIQUE

A conflict, according to the Swedish technique, is an event where two road users are on a collision course, i.e. an accident would occur if none of the involved took an evasive action. The technique is based on two concepts:

TA-Time to Accident: The time that is remaining from when the evasive action is taken until the collision would have occurred if the road-users had continued with unchanged speeds and directions.

CS = Conflicting Speed, i.e. speed of the relevant road user just at the initiation of an evasive action (braking, swerving, acceleration) is taken.

In Figure 7.2a collision is imminent and car A is braking at the moment when the speed of car A is 36 km/h (10 m/s). The distance from this moment **until** he would have reached the collision point is 15 meters. Thus it would have taken 1.5 seconds for car A to reach the collision point, thus TA = 1.5 seconds.

Conflicts are recorded by trained observers who estimate Time to Accident (TA) via estimates of Conflicting Speed (CS) and distance to the Collision Point (d). As a first attempt a severity dimension was introduced by defining $TA \leq 1.5$ seconds as serious conflicts. That meant that only serious conflicts were relevant for the further analysis. The reason for using 1.5 seconds was general observations where an attempt was made to find "critical limits" in the sense that drivers did not want to exceed that limit. It was found that experienced drivers, such as taxi drivers, did not want a limit that was around 1.5 seconds.

7.2.1 Training of observers and reliability

The normal training procedure includes a 5-day session including in- and outdoor training. Initially trainees go through an indoor session where they learn about the basic elements and how to record conflicts. After that there is a first outdoor session where simultaneous training on vehicle speeds is done based on radar measured speeds. The rest of the week is then based on alternative outdoor and indoor sessions. At outdoor sessions all observers are doing conflict studies at the same intersection while there are simultaneous video-recordings. At indoor sessions all events recorded by the trainees are analysed by all the trainees together with an expert, followed by discussions and clarifications. The last day is used for an exam. It has been shown that observers by and large are capable of recording conflicts in a sufficient enough way. The "hit rate" is normally around 80%. One test of trained observers gave the following results:

- The average size of the difference between the observers' result and the true result was in absolute values 0.28 seconds
- In almost half of these conflicts the difference was less than ±0.2 seconds
- In 82% the difference was less than ±0.4 seconds

The conclusion was that observers after training are very capable of scoring "almost to the tenth of a second". The greatest challenge is often to keep fit over an observation period. It is

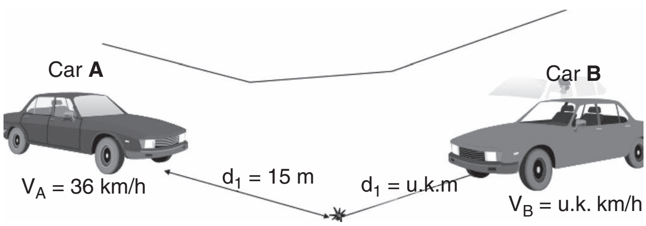


Figure 7.2 TA – Time to accident.

TABLE 7.1 Road-users perceived risk in conflicts related to Time to Accident (TA).

True TA	**TA ≤ 1.0 sec**			**1.0 sec < TA ≥ 1.5 sec**			**1.5 sec ≥ 2.0 sec**		
	EA	**PO**	**HA**	**EA**	**PO**	**HA**	**EA**	**PO**	**HA**
Total #	27	16	54	25	25	133	4	17	52
%	28	16	56	14	14	72	6	23	71

Source: EA: could Easily have ended up as an injury accident
PO: could Possibly have ended up as an injury accident
HA: could Hardly have ended up as an injury accident

TABLE 7.2 Type of evasive action in serious conflicts and accidents, at the same intersections.

Evasive action	**Serious conflicts**	**Accidents**
Braking only	79%	68%
Braking and	14%	20%
Swerving only	5%	10%
Accelerating	2%	2%
TOTAL	100%	100%

easy to lose focus. One of the assisting techniques to manage this is therefore that when observers are doing general screening of the site trying to detect serious conflicts, they are taught to focus on characteristics like suddenness and harshness by any of the road users involved. This is partly done to energise and ease the burden of continuously watching traffic. But this is also because it was found that serious conflicts to a large extent were characterised by behaviours that could be described in such a way. This is partly confirmed by the road users themselves.

In special conflict studies, interviews were made with road-users involved in conflicts. A conflict observer was making regular conflict studies. At every conflict, the observer saw to it that there were policemen at adjacent intersections who stopped car drivers involved, while pedestrians and bicyclists involved were stopped by interviewers. One of the questions road users were asked: "What is your assessment of a situation like the one you just were involved in?" Three alternatives were given, see table 7.1.

The table shows that even though there are no dramatic differences there is still an evident logic in the split of data: the lower the TA-value the higher the proportion of answers "EA: could Easily ended up as an injury accident". This supports the idea that road users clearly react to some kind of Time to Accident-concept and TA should therefore be a relevant concept on which to base a definition of serious conflicts.

Another way of looking at the reliability is to compare evasive action taken by road users in conflicts to accidents collected at the same intersections, see table 7.2.

Braking is by far the most common action, while accelerating is only 2%, the same in both sets. The largest difference is for swerving, which occurs twice as often for serious conflicts as for accidents. The reason may be that in accidents – the most critical type of event – swerving intuitively may be "the last chance", similar to the instinct to cover your eyes when you are about to see something extremely dramatic. All in all, however, the result is very encouraging, and strongly supports the idea of using conflicts based on some kind of TA-concept.

7.2.2 A new definition of serious conflicts

It was felt early on that the definition had to be sophisticated. Particularly, it was obvious that the definition had to be speed dependent. A number of potential definitions were tried in a Ph.D. project (Hydén 1987). In a large empirical study conflicts were recorded in 115 intersections altogether; Malmö, I (1974): 50 intersections, Malmö, II: 15 (1976), and Stockholm: 50 (1976). Police reported injury accidents were collected and analysed for the same intersections, during

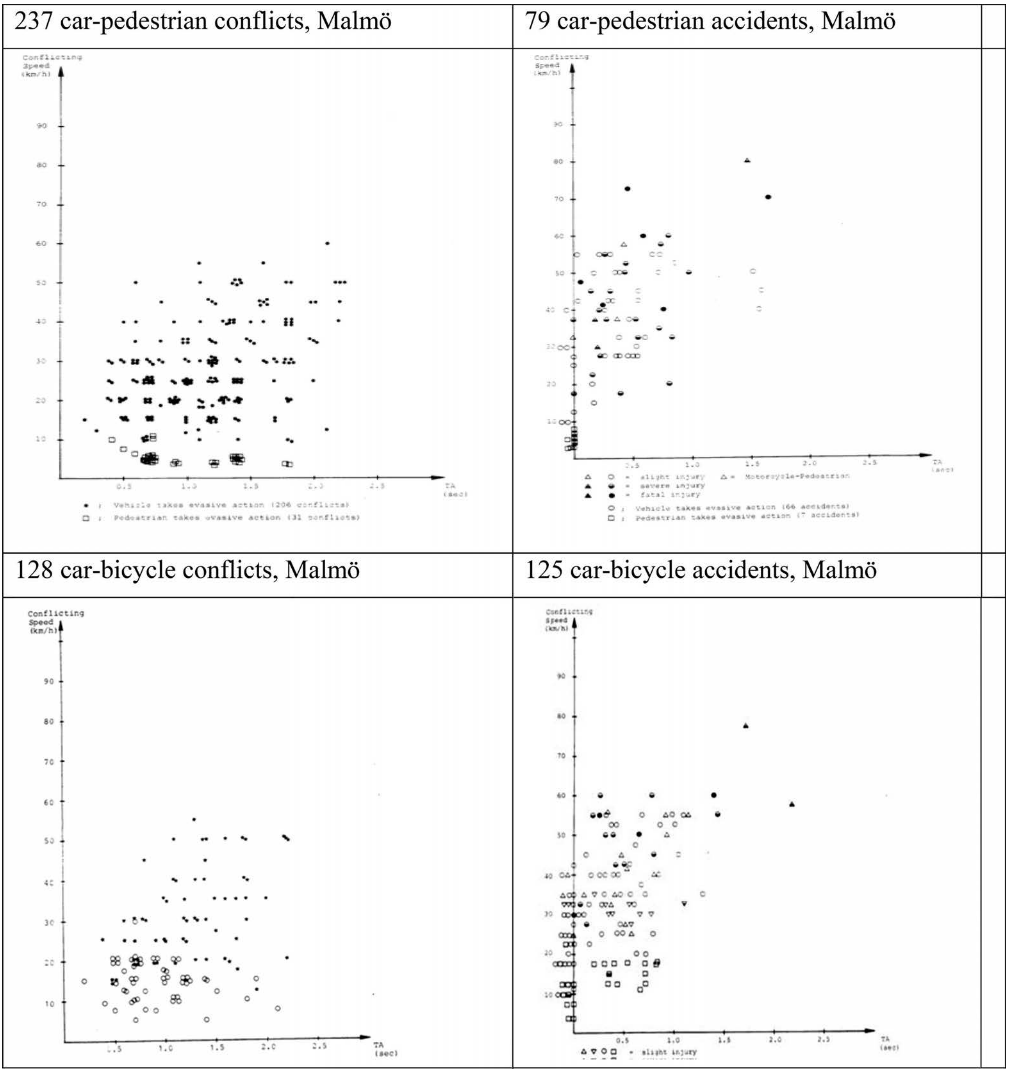


Figure 7.3 Conflicting Speed (CS) and Time to Accident in Car-Pedestrian and Car Bicycle **conflicts** and **accidents**, at the same intersections in Malmö, accidents from same times of the day. (From: Hydén 1987).

times of working days under which conflict studies were made for 7–8 years. For Malmö I: 1968–75, for Malmö II: 1968–75 and for Stockholm: 1970–76.

For all conflicts CS and TA were recorded. In the case of accidents, a researcher made an in-depth analysis of all data that was available; police reports, interviews with involved road users, reports from on-scene investigations, etc. All conflicts and all those accidents that could be scored with regard to CS and TA, were mapped in TA-CS diagrams, see figure 7.3.

The severity scaling of the conflicts was then made in the following way: Five different alternative definitions of severity and severity zones were tested (Figure 7.4). There were two main criteria; 1/the risk in terms of accident to conflict ratio should increase continuously from the "lowest" class. 2/Accident severity, the number of fatal and serious injuries in relation to the total number of injuries should increase with class.

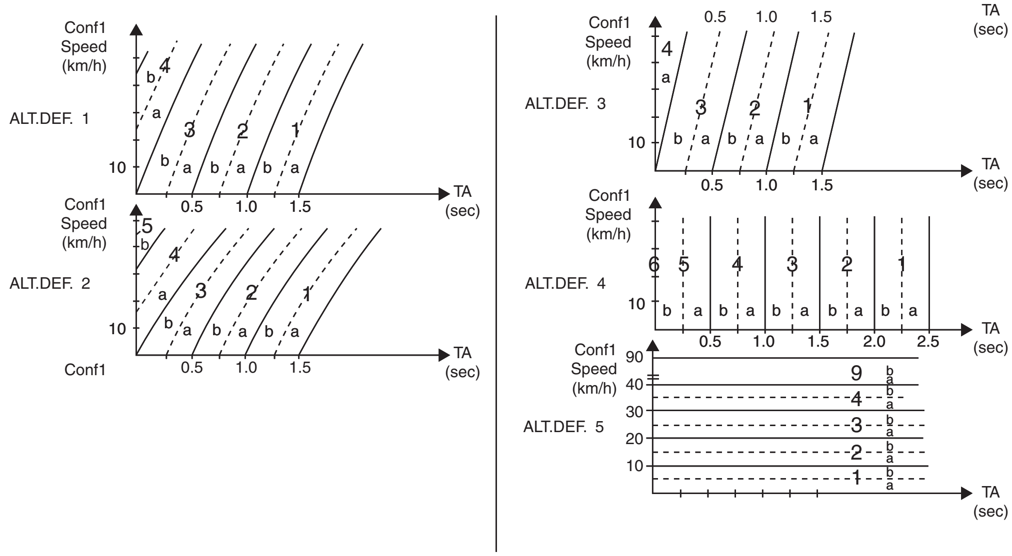


Figure 7.4 Definition of five alternative severities and severity zones for testing. (From Hydén 1987).

TABLE 7.3 Conversion factors (π) for converting serious conflicts to police reported injury accidents.

Car-car	**Car-car**	**Car-pedestrian Car-bicycle**
$\pi = 2.8\,10^{-5}$	$11.9\ 10^{-5}$	$33.9\ 10^{-5}$

A uniform severity level was selected in the first two cases, by defining the threshold between collision and no collision. In ALT.DEF. 1, the uniform severity level starting at TA min = 0 and is calculated from a necessary TA min at different speeds, to allow a vehicle to stop just at the collision point, with the precondition that the vehicle performs maximal braking on dry asphalt.

In ALT.DEF. 2 the uniform severity level is defined by the braking time necessary at the speed in question. This is defined as the time needed to come to a complete stop just at the collision point (Gårder 1982). Thus the braking time is twice as big as the necessary TA-value. Thus Gårder has built in a safety margin which is half the necessary braking time.

If the deceleration is linear then the average speed during the braking is half the initial speed.

The three alternative definitions are "variations" of #1 and #2 for testing purposes.

A large number of tests were carried out on how the Alternative Definitions worked in relation to different quality measures and – primarily – how they fulfilled the basic criteria. It was finally concluded that **ALT.DEF. 2** seems to be the most relevant definition of severity because it fulfils the tested criteria more satisfactorily than any of the other definitions. It was therefore selected as the most appropriate definition (Hydén 1987).

7.2.3 Product validation

In a product validity test, the three data sets (Malmö-50, Malmö-15 and Stockholm-50) were compared with regard to the "accident to conflict"-ratio in each of the three samples. There was no statistically significant difference between the three sets, and it was therefore concluded that they belonged to the same distribution. Hence they were combined and produced one final set of ratios, called "Conversion factors" between accidents and conflicts; see table 7.3. For details see Hydén (1987).

As this is one of the few larger attempts to validate conflicts against accidents, it is included here. It must be observed though, that these conversion figures are old. Lots of conditions influencing the π-values have changed since these figures were produced in the 80s.

7.2.4 Process validation

Based on the selection of ALT.DEF. 2 all conflicts and accidents in Figure 7.3 were analysed and compared to the main criteria. The following important conclusions were drawn:

- Patterns are very alike
- Accidents have a TA-value that is approx. 0.5 seconds smaller and a CS that is approx. 10 km/h higher than serious conflicts
- Conflicts and accidents belong to the same distribution, with different degrees of seriousness (most often)
- Accidents represent a logical continuation of the serious conflicts on a severity **scale**

In some of the accidents the TA-value = 0. That means that road user had not yet started an evasive action. The point is that the driver in one extreme was just a millisecond from starting an evasive manoeuvre. In the other extreme the driver had not even started thinking of making an evasive manoeuvre. In both cases TA = 0. We do not know anything about that; however, we can anticipate that there is some kind of (normal) distribution. That would mean that if we set TA = 0 to those conflicts where the road user was just about to start on an evasive manoeuvre while the other in theory has a negative Time to Accident starting from TA = 0 up till TA = −1 or −2 sec, meaning that the road user had not observed the potential conflict and therefore had not even started to think of any action. TA = 0 is very speed dependent as can be seen from Figure 7.3. The interesting thing is that if we redistribute TA = 0 to "negative" TA-values in the lower speed region in Figure 7.3, we will see that the new accident distributions for pedestrians and bicyclists will be similar to the conflict distributions.

7.2.5 Use of the technique

7.2.5.1 Recording

Recordings are normally made on a special sheet, see Figure 7.5. Normally there is a true sketch of the intersection in question.

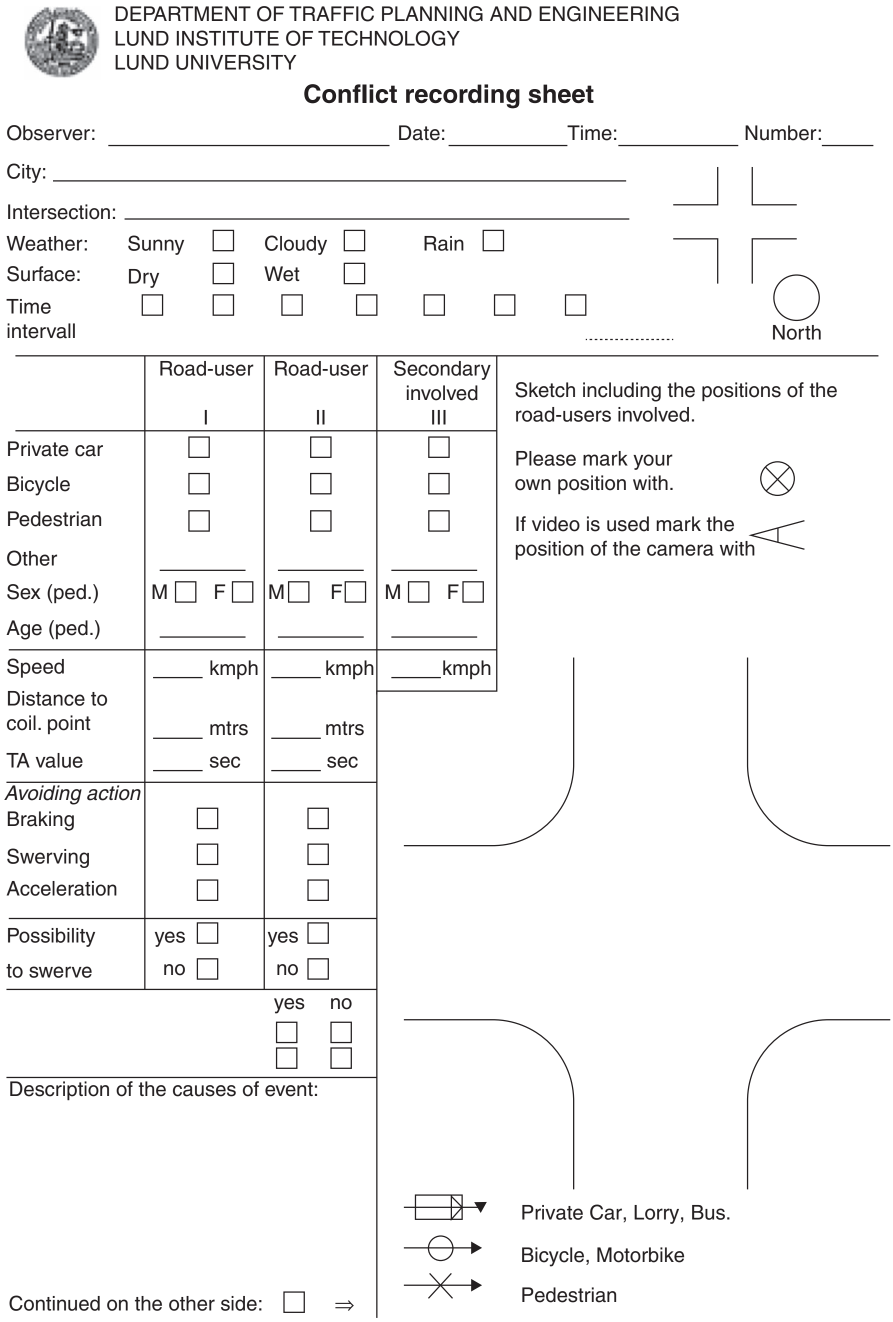
To start with, it is only serious conflicts that are used for the prediction of the expected number of accidents. However, the recording should include some more conflicts (to ensure that all serious conflicts are included). These are skipped in the further analysis.

The most important task for the observer is to estimate TA, with the help of CS and distance. Video is normally only used as a complement and for behavioural studies, counts, or to check the filled in sheet. Normally one observer is sufficient for one intersection, but in large intersections two or more are needed.

Conflict studies are to be carried out at times of day when previous accidents have indicated problems. Most common studies are made during three sessions per weekday, each session two hours, and most common is three to five days of studies at one location.

7.2.5.2 Analysis of conflict studies

Conversion factors ($\boldsymbol{\pi}$) between accidents and serious conflicts are used. In principle, the analysis is made in the same way as an analysis of accidents, with the addition that conflicts are



DEPARTMENT OF TRAFFIC PLANNING AND ENGINEERING
LUND INSTITUTE OF TECHNOLOGY
LUND UNIVERSITY

Conflict recording sheet

Observer: ______ Date: ______ Time: ______ Number: ______

City: ______

Intersection: ______

Weather: Sunny ☐ Cloudy ☐ Rain ☐

Surface: Dry ☐ Wet ☐

Time intervall ☐ ☐ ☐ ☐ ☐ ☐ ☐ ....

North

	Road-user I	Road-user II	Secondary involved III
Private car	☐	☐	☐
Bicycle	☐	☐	☐
Pedestrian	☐	☐	☐
Other	______	______	______
Sex (ped.)	M ☐ F ☐	M ☐ F ☐	M ☐ F ☐
Age (ped.)	______	______	______
Speed	______ kmph	______ kmph	______ kmph
Distance to coil. point	______ mtrs	______ mtrs	
TA value	______ sec	______ sec	
Avoiding action			
Braking	☐	☐	
Swerving	☐	☐	
Acceleration	☐	☐	
Possibility to swerve	yes ☐ no ☐	yes ☐ no ☐	
		yes ☐ ☐ no ☐ ☐	

Description of the causes of event:

Continued on the other side: ☐ ⇒

Sketch including the positions of the road-users involved.

Please mark your own position with. ⊗

If video is used mark the position of the camera with

Private Car, Lorry, Bus.

Bicycle, Motorbike

Pedestrian

Figure 7.5 Conflict observation sheet.

also described in terms of **events,** i.e. what happened in the initiation of the conflict. The Data Base **CDBase** can be used to partly automate the analysis, (Figure 7.6). It produces predictions automatically, as well as other statistics.

It also allows semi-automatic mapping of the conflicts. In a safety assessment in Norway (StatensVegvesen 2003) the CD Base was used in analysing safety at a number of intersections.

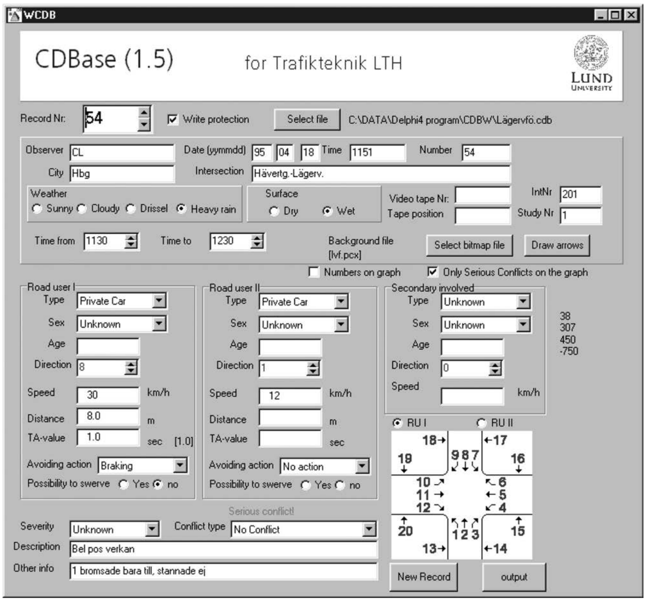


Figure 7.6 CDBase for semiautomatic analysis of conflict studies (Ekman 2001).

The conflict mapping for one of the intersections is presented in Figure 7.7. Based on the observer's notes and the mapping, the conclusion was that the main problem was that the pedestrians were coming from the left in the figure, with cars coming from the north. The main reason seemed to be an unclear situation for cars coming from the north when entering the intersection. The results were used to discuss possible changes of the design and/or regulation of the intersection.

7.2.6 Example of practical use of conflict, behavioural and interactional studies in India

7.2.6.1 Background

In a two-year project – Traffic Calming in India – behavioural and conflict data were used on a large scale (Hydén, Svensson 2009). The main aims of the project were: 1/To understand pedestrian safety problems in a developing country, 2/To identify feasible traffic calming measures. In order to fulfil the aims, comprehensive behavioural, interactional, conflict studies, and volume counts were carried out at selected sites in the city of Jaipur, Rajastan. The project was a collaberation between the University of Lund, Sweden and CUTS in Jaipur, and financially supported by SIDA, Sweden. For the project, team members in Jaipur were trained to do behavioural and conflict studies.

Selection of sites was based on accident data collected from the police. Accident-prone locations for pedestrians were primarily selected. The aim was also to produce a before study so that the effects of implemented countermeasures could be followed up. Conflict studies were carried out using recorded video data – in the first step from seven sites. Teams in both Lund, Sweden and in Jaipur, India analysed the videotapes. Those tapes were also used to do volume counts and behavioural studies.

7.2.6.2 Results

All in all, 847 serious conflicts were recorded, see table 7.4.

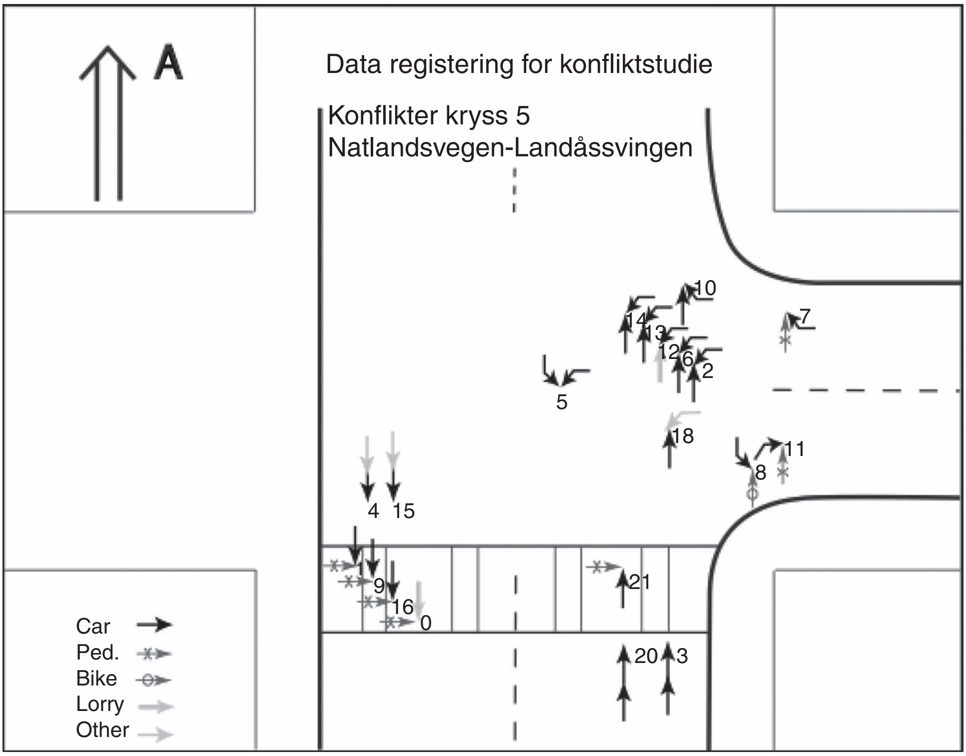


Figure 7.7 Conflict mapping, example at an intersection in Bergen, Norway.

Figure 7.8 Selected sites in Jaipur, example.

Pedestrians represent one third of all serious conflicts, and bicyclists represent one tenth; in total they represent almost half of the safety problem.

Based on the (old) conversion factors from Sweden the average **predicted** number of **injury** accidents per year per location is: Pedestrians: 1.9 accidents, Bicyclists: 0.7 accidents, Motor Vehicles: 0.6 accidents; for these three groups 3.2 accidents per year. Even though the conversion figures are old, there is a great similarity between observed and predicted. This is of course accidental. The main message is that the number of accidents seems to be fairly small and in the same range for similar intersections in Sweden.

As can be seen from table 7.4 motorcycles are involved in more conflicts than cars. Table 7.5 below shows that one main reason for this is their exposure.

The table indicates clearly that motorcycles seem to be much less of a problem than is claimed in the media. Especially in pedestrian conflicts, the car-share is much smaller than

TABLE 7.4 Serious conflicts at the seven sites (from Hydén, Svensson 2009).

	Pedestrian conflicts				**Bicycle conflicts**				**Other**	**Total**	**Obs.**
Counter part	**Car**	**Mc**	**Other**	**Tot**	**Car**	**Mc**	**Other**	**Tot**	**conflict**	**Conflict**	**hours**
Total	87	158	34	279	50	45	5	100	470	847	274
Ser.confl. per hour				1.0				0.4	1.7	3.1	274

TABLE 7.5 Involvement in serious conflicts in relation to volumes at the seven sites.

	Car/Motor Rickshaw	**Motor Cycles**	**LCV/ Truck/Bus**	**Total**
Total volumes per site	800	1852	363	3015
Share (%)	27	61	12	100
Striking vehicles in pedestrian conflicts	31	57	12	100
Striking vehicles in bicycle conflicts	50	45	5	100

TABLE 7.6 Car driver behaviour in interaction with pedestrians (from Hydén, Svensson 2009).

Road user/ type/behaviour	**Show no reaction to pedestrian**	**Brakes**	**Swerves**	**Total**
Motor Bike	73	3	4	80
Car/Motor Rickshaw	69	2		71
Truck	23			23
LCV	7			7
Bus	8			8
Other	3	1		4
TOTAL	183 (95%)	6 (3%)	4 (2%)	193 (100%)

their representation in conflicts. One reason for the difference is most probably their speeds. Private cars have a higher approach speed to these intersections than motorcycles, 43 km/h and 42 km/h respectively. The difference became even bigger when we compared speeds of vehicles involved in conflicts, where the speed of private cars is between 3 and 15 km/h higher than that of motorcycles.

One very interesting observation when analysing the videotapes is that conflicts mainly occurred in the central parts (middle) of the intersections. This is particularly true for pedestrian conflicts. Another finding is that vehicles (including bicycles) are quite often involved in conflicts at locations in the intersections where they "are not supposed to be" regarding driving direction. Generally the situation at these intersections was very chaotic and "disorganised". This was strongly supported by the behavioural and interactional studies. It was, for instance, found that half of the pedestrians walked "diagonally" through intersections, and at some of the intersections at least half of the pedestrians were crossing in the middle of these intersections. Car driver's behaviour is shown in table 7.6.

As can be seen, in principle no motorised drivers showed any reaction in order to interact with pedestrians. All in all, the conclusion is that there does not exist the kind of interplay one is used to from developed countries. Still – as was shown in connection to table 7.4 – the safety of pedestrians does not look too bad if the frequency of serious conflicts per hour in Jaipur is compared with the "Swedish figures". There are two main reasons: 1/Pedestrians have learned

TABLE 7.7 Comparison of Indian and Swedish conflict scorings Site no. 23.

	Pedestrian conflicts				Bicycle conflicts					
	Car	Motor Bike	Other	Total	Car	Motor Bike	Other	Total	Other conflict	Total
Indian Team	2	7	2	11	3	3	0	6	15	32
Swedish team	4	2	1	7	0	0	1	1	25	33

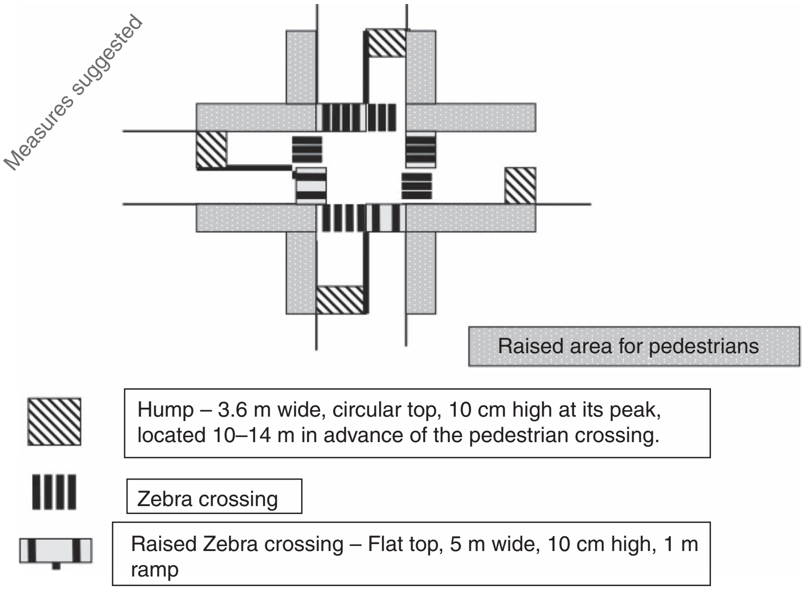


Figure 7.9 Traffic Calmed Standardised Intersection.

to cooperate with this car driver behaviour and accepted being the weaker and have learned to avoid being involved in serious conflicts. 2/Speeds are often low at this type of intersection, lowering the risk of serious accidents considerably.

In order to compare the scorings by the Indian team and Swedish team respectively one day of analysis from the same video recordings was done in India and in Sweden.

The table shows a high degree of similarity, but only on the total level. At a detailed level one can see that there are quite large discrepancies. However, the figures are small and the differences are likely due to random variation. In any coming project, however, a more comprehensive comparison has to be done.

7.2.6.3 Output of the project

One important output of the project was to recommend traffic calming measures to be tested. Based on the findings, the optimal solution would be to test a "standardised" traffic calmed intersection, where low speeds would be ensured all through the intersections. The reason for this is that cars exiting the intersections are likely to encounter more pedestrians; it is therefore particularly important to ensure low speeds at exits.

For different reasons – and in spite of big efforts from the Indian team – there were no measures implemented during the project time. So, unfortunately, proper testing of the measures proposed had to be done later. The project has clearly demonstrated the urgent need for "starting on a changing process" to safeguard Vulnerable Road Users. Still, it can be concluded that the conflict studies were of great importance in assessing the problems and in proposing solutions. Hopefully the experiences gained during the project can be followed up in a later project.

7.2.7 A novel approach to the severity concept

The aim of this study is to extend the traffic safety assessment concept to include normal road user behaviour, and not only exceptional behaviours such as accidents and serious conflicts (Svensson 1998). The goal is to provide a framework for a more thorough description and analysis of safety related road user behaviour in order to better understand the traffic safety processes. All events in traffic are more or less related to safety and it is logical to assume that encounters between road users can be described as events in a safety hierarchy.

To be used for practical applications the safety hierarchy has to be made operational. The aim must be to construct a severity hierarchy for traffic events so that for each event the severity can be estimated. The severity should be related to the probability of a serious injury accident. The severity hierarchy can be used for analyses of the traffic safety process, describing the relationship between accident related events. The severity of the process is described by the Time-to-Accident and Speed values, defined as in the Swedish Traffic Conflicts Technique.

The study includes interactions between vehicle drivers and pedestrians. Only manoeuvres where the vehicle driver either drives straight ahead or makes a right turn, and interacts with a pedestrian, are included. Road user behaviour is studied at two signalised intersections and at one non-signalised intersection with the right hand rule.

The general conclusions are:

1. All distributions decline in both ends of the severity scale; towards the high and towards the low severities, which can be explained by the fact that road users not only avoid the most severe events (accidents) but also the least severe ones.
2. For the interactions involving vehicles driving straight ahead, there seems to be a difference between the distributions with regard to whether the intersection is signalised or not. At the non-signalised intersection the distribution is located towards higher (but not the highest) severities as compared to the signalised intersection. The distribution at the signalised intersection has more widely spread severities covering several levels. One interpretation of the results is that the production of "higher but not the highest severities" may produce a learning process on how to avoid accidents in that type of non-signalised intersection while the signalised intersection, however, does not produce the same kind of feedback. Accident data from these two types of intersections support this theory.

The concept is novel and not explored enough yet, but there is definitely a potential. As the author expresses it: "For traffic safety research, the concept will hopefully serve as a possible framework for exploring different traffic safety theories by taking the whole severity hierarchy into consideration".

7.2.8 Image processing – more conflicts, more information

7.2.8.1 Background

The Swedish conflict technique has proved useful. However, in many cases the number of conflicts is too small. It is too expensive to collect data in sufficient numbers. The way forward is to make conflict studies from automated video analysis. It is, however, a very demanding task. Development started two decades ago. The first attempts in employing computer aid for analysis of video records were semi-automated systems. For example, a German system VIVA traffic (Rudolph, 1996) provided a user-friendly interface for navigation through the film frame by frame, and an operator had the opportunity to take interactive measurements of road users'

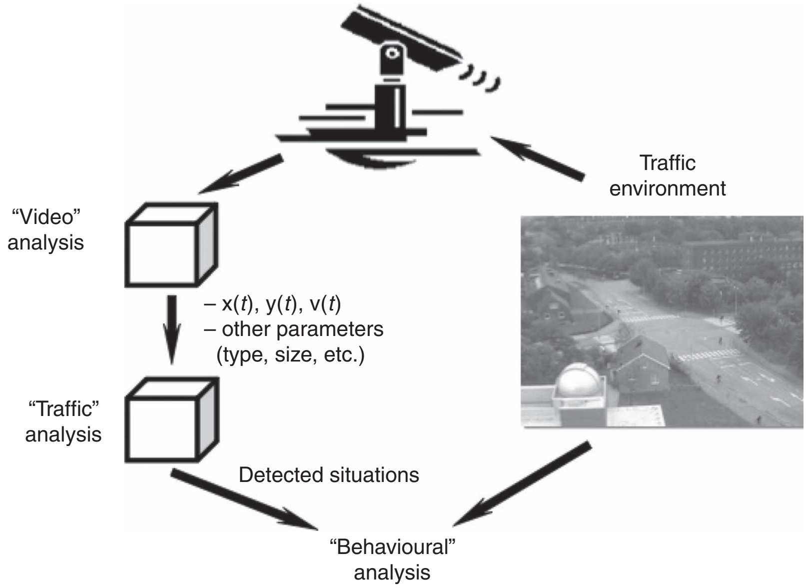


Figure 7.10 The principle scheme of the automated video analysis system at Lund University.

position, speed, distances between a road user and other objects by "clicking" on them on a screen with a mouse.

7.2.8.2 Video analysis system at Lund University (*Laureshyn 2010*)

The principle scheme of the automated video analysis system developed at Lund University is shown in Figure 7.10. A video camera (or a set of several cameras) is installed at a site and makes recordings of the traffic environment. The recordings are processed by video analysis algorithms that detect road users and extract their position and other relevant data like speed, size, and orientation. This data is further analysed, and based on some traffic-related criteria (e.g. certain types of manoeuvre, an interaction, intensive braking or acceleration) the situations of interest are detected. These situations create the raw material for the behavioural analysis itself, and in an ideal case each event is described by detailed data on the trajectory and the speed of the involved road users, and illustrated by a video sequence from the original film, which allows reconstruction of the events and a study of the interactions between the road users in detail.

Video analysis systems, existing at the moment, are capable of performing to a certain degree tasks like detection of road users in a certain area ("virtual loops"), detection of congestion and passages in pre-defined directions (incident detection), tracking of road users, detection of encounters between road users, potential collisions, etc. The quality of the performance, however, varies a lot depending on the complexity of the task. As for the detection of very specific and complex situations like traffic conflicts or complicated interactions, there are still only prototypes tested on small amounts of data.

7.2.8.3 Video analysis system at University of British Columbia (*Ismail et al 2009*)

At UBC in Vancouver there is another team of researchers dealing with automated analysis of behaviour. They have developed an automated video analysis system, that can (*a*) detect and track road users in a traffic scene and classify them as pedestrians or motorized road users, (*b*) identify important events that may lead to collisions, and (*c*) calculate several severity conflict indicators. The system seeks to classify important events and conflicts automatically but can also be used to summarize large amounts of data that can be further reviewed by safety experts. The functionality of the system is demonstrated on a video data set collected over two days at an intersection in downtown Vancouver, British Columbia, Canada. Four conflict indicators are automatically computed for all pedestrian-vehicle events and they provide detailed insight into the conflict process. Simple detection rules on the indicators are tested to classify traffic events. This study is unique in its attempt to extract conflict indicators from video sequences in a fully automated way.

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CHAPTER 8

Statistical Considerations in Road Safety Research

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CONTENTS

ABSTRACT

Statistical methods are concerned with ways to 'control' uncertainty, i.e. reduce variability and reduce sampling uncertainty, in order to understand estimates of characteristics or relationships among quantitative factors in a population. The issues presented in this chapter are meant as an introduction to some of the statistical considerations that engineers, road safety experts and policy makers must take into account as they try to understand the factors involved in reducing the burden of disease from road accidents. The focus is not on presenting specifics of various statistical methodologies, but on providing some understanding of key concepts and principles – basic issues of sampling, probability distributions, understanding uncertainty and variability, common research study designs, and concepts of statistical inference. The unique characteristics of road transport research data are highlighted and their impact on statistical methods is discussed.

Key Words: variability; sampling; study design; statistical inference; significance

8.1 INTRODUCTION

Understanding how the discipline of statistics, and specifically, some of its principles and concepts, plays an integral part in our scientific endeavors of acquiring knowledge, is an essential requirement for researchers in all fields. Statistical concepts are relevant in the design of research studies, and statistical methods are essential for the analysis of data.

Statistics is the science of understanding quantitative information in the presence of uncertainty.

The science of statistics helps researchers understand the role of uncertainty in the observed quantitative data. Uncertainty arises from many sources – the inherent variability in a process, measurement error due to imprecision, sampling error from not observing the entire population, and chance occurrence. The tools of statistics allow researchers to explore the various sources of variability or uncertainty in the data, and to control or adjust for them in the design or in the analysis, in order to 'observe the signal amidst the noise.'

Uncertainty comes from the inherent variability in the processes one is observing (i.e. what we observe is not static, it is changing in time and space), but also from how we measure the observation (i.e. measurement variability or random error). The largest source of uncertainty usually comes from the process of sampling, where a sample or subset from a population of interest is obtained, and one hopes that the process of selection provides one with a 'representative' sample from that population, i.e. one that is like the population it came from. When trying to understand quantitative information, how it is distributed in the population or how different variables are related in the population, we study these aspects in the sample observations and make inferences from the sample information to the likely behavior of the variables in the population (see Figure 8.1). Since the population is usually never observed, there is always uncertainty about the inferences made. We quantify our uncertainties with confidence intervals or estimates of the risk of false positive (p-values) or false negative decisions related to hypotheses about the relationships in the population.

Researchers must realize that statistical methods, while useful in all research endeavors, are not the answer to all research needs. Statistics cannot tell researchers what research question to study, or help decide if the results observed are meaningful. While statistical methods can inform the researcher if what they have observed is likely or not likely to be due to chance variability (with p-values or confidence intervals), 'statistical significance' is not related in any way to a result's importance (Bangdiwala 2009a).

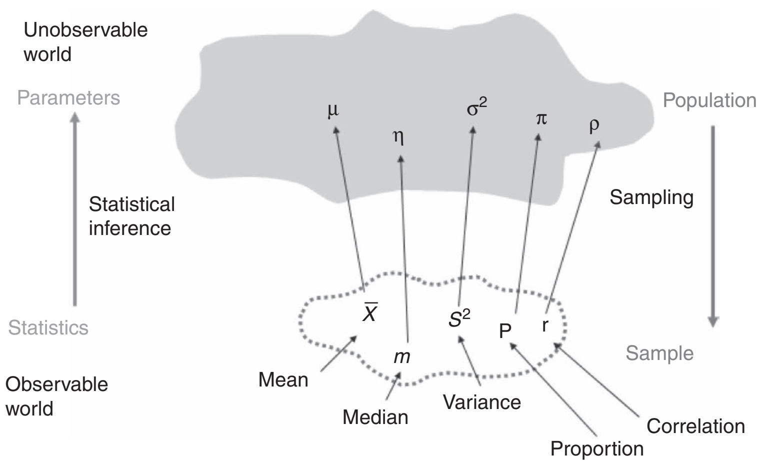

Figure 8.1 Schematic diagram of sampling from a population and statistical inference from the sample: sample statistics are related to population parameters.

Many of the techniques of statistical analysis are common to all disciplines. Most areas of research are concerned with the relationship between an exposure variable and a response or outcome variable. When a relationship is observed in the sample, one wishes to know if the relationship observed is likely to be true in the population, i.e. rule out other reasons, whether systematic errors (biases) or random errors (variability, uncertainty), that may be explaining what has been observed. We thus have standard epidemiological observational and experimental research designs to rule out these potential reasons at the study design stage, and standard analytic methods to control or adjust for the potential reasons at the study analysis stage. However, every applied area of research has its peculiarities that require unique approaches to design and to analysis. Research in road safety also has its special issues.

Researchers in road safety collect vast amounts of quantitative information, on multiple outcomes of interest and on large numbers of potential explanatory factors. We typically study all events in a given time period and place. Typical outcomes studied are numbers of crashes, collisions or conflicts, and numbers of injured, hospitalized or dead individuals. Surrogate outcomes that sometimes are considered as antecedent potential explanatory variables may include behaviors (e.g. seat belt use, speeds, pedestrian crossing behavior), attitudes (e.g. road rage or aggressiveness) and knowledge (e.g. driver experience). These are summarized and described using statistical descriptive analysis methods. They are presented in a given time period or trends are examined over a time period. Often we measure how they are associated with some potential explanatory variables from various dimensions – the vehicles involved (e.g. motorized and mon-motorized road users, speeds, vehicular mix and density), the physical environment (e.g. road infrastructure, the built environment, weather, lighting, signaling), the social/political environment (e.g. laws, enforcement, social attitudes, behavioral norms) and human factors (e.g. age, experience, attitudes, behaviors, knowledge).

The typical research questions in road safety research are why, when, and how accidents occur. Studying the occurrence leads to estimating measures of risk, and understanding the probability distributions of individual variables. Studying the why and the when leads to studying risk factors, associations between variables, and for complex situations, doing multiple factors regression to quantify uncertainty or to rule out the role of chance (statistical testing).

The issue faced in road safety research, like in many other disciplines, is that relationships among potential explanatory variables and outcomes are complex, involve multiple variables in complex ways, and are not necessarily linear. In describing the complex system or when evaluating interventions carried out in the complex system, we make assumptions that enable us to simplify how we go about understanding the relationships.

The design and analysis tools must account for the unique aspects of the data in road safety research. We tend to not sample from a population, but attempt to study all events in a given time period and place. Outcome data of interest are usually counts of relatively rare events in a given time period; exposure is not constant and is conditional on past experiences; potential explanatory factors vary in pre-crash, during crash and post-crash phases of an event (Bangdiwala 2000). Interventions are implemented and evaluated in non-randomized study designs, often with multiple dynamic interventions that overlap in time and space, so that assessing the effectiveness of a particular intervention is not straightforward. Outcomes and exposures often act in multiple dimensions, and this multiplicity leads to complexities among the variables that require complex modeling approaches. This chapter does not pretend to be an exhaustive coverage of all possible statistical issues for considerations that may impact road safety research, but mainly to highlight a few of the key issues unique to this field of research.

8.2 SAMPLING WHAT WE STUDY

The typical units of analysis in research are individuals in a population, defined in a given place and over some time period. In the road safety field we do study individuals – victims of motor vehicle crashes, deaths, injured, disabled; but in addition, we also study vehicles, crashes, road sectors and other places as units of analysis. Interestingly, what we study is typically all units in a given time period and place, i.e. the population of victims or of crashes or all the road sectors in some community. When all units of a population are studied, there is no need for statistical inferential methods since one already is studying the population, so that the only tools required are those for summarizing the information and describing the results. This is the case when using data from a registry or surveillance system, or from police records, that collect information on all cases or crashes.

Sometimes, given the size of the population of interest, one could consider sampling methods. The argument against sampling is that some crashes are so unique, that they all need to be studied. Here comes the need to understand that statistics helps when aggregating data and by focusing on many similar situations to understand the behavior of characteristics in large groups. Studying individual cases is meritorious, but is best done by in-depth analysis and not statistical analytical methods that work on the entire group. Thus, if one wishes to study an unusual bus crash or a unique accident involving three large trucks, these 'outlier' situations are best studied separately and not aggregated into the group of 'typical crashes'. Studying the large group looking for trends and relationships is where statistical methods are useful, and here is where sampling can reduce costs and effort while still obtaining valid and precise estimates of characteristics in the population.

There are several methods used to sample units – from truly simple random sampling to complex multi-stage probability sampling. Each member of the population has an equal chance of being in the sample with simple random sampling, while multi-stage sampling has a known probability of selection for each member of the population. If one is concerned that representativeness of certain subgroups may not occur with random sampling, restriction on the sampling process such as stratification can be used. Adequate numbers from each stratum can be specified, but usually only for a few strata so that the overall sample is not too large and costly.

8.3 NON-CONSTANT EXPOSURE

A special feature in road safety is that an event cannot occur unless one is engaged in an activity that exposes one to its occurrence. For example, one cannot be an 'occupant death' if one is not riding in a motorized vehicle; one cannot be injured in a crash if one is not on the roadway. This is unlike other diseases or conditions such as cancer or cardiovascular disease, where one assumes one is constantly exposed to developing those diseases. Thus, in road safety research, it is not straightforward how to obtain the exposure data. A proper denominator for calculating risks of an event on individuals would be a 'number of individuals exposed over the period of time,' i.e. total number of person-time units, as in person-years or person-days. A proper denominator for calculating risks of an event on vehicles (such as number of crashes) would be a 'number of vehicles exposed over the period of time,' i.e. the total number of vehicle-kilometers in a given time period (Bangdiwala et al 1985). While numerator data such as counts of crashes and victims may be available from police, hospital or other sources, the denominator data of exposure is not available and is also not easily collected, thus making the appropriate estimations of risks hard to obtain.

Note that numerator data may not be necessarily measured similarly in different settings – for example, 'death due to motor vehicle crash' is not uniformly defined by all countries – only 80 of the 178 countries use the same definition – died within 30 days of the crash – as reported by the World Health Organization (WHO 2004). This makes comparability across countries difficult.

A further complication in assessing exposures is that the risk of an event is conditional on exposure factors that change over time, and that these factors are related to previous occurrences of events. For example, prior experience with a crash or near-crash will likely impact the risk-taking behavior of a driver and thus the risk of the occurrence of future events.

Quantifying risk or probability of events is thus complicated by the need to quantify exposure. One uses theoretical derivations to quantify these event probabilities. Statistics, like all sciences that try to understand nature, relies on theoretical assumptions and models to simplify the complexities observed in nature. For example, the observed or empirical distribution of outcomes from collisions of only two motorized vehicles may be obtained from a sample, but that is subject to uncertainties. However, using arguments and theories derived from physics, mathematics, engineering and other sciences, one can postulate a theoretical distribution for the outcomes. The possible values and frequency of occurrence of the outcome is thus described by its theoretical probability distribution. Several well-known theoretical probability distributions have been postulated for studying injuries or incidents.

8.4 COUNTING RARE EVENTS

Data in road safety are rarely the measurement of an attribute, but comprise the counting of events or units; for example, the number of motor vehicle crashes, the number of injuries or deaths, the number of pedestrians, the number of motorcyclists, etc. Count variables have particularly unique behaviors – they are non-negative integers, and their likely values are limited if restricted to a period of time or to an area of space. Their distribution in a given time/space period is not characterized by a continuous probability distribution, but rather a discrete probability distribution. Such probability distributions are specified by providing the possible values and the probability that they occur, with the condition that the sum of all probabilities is 1. A common theoretical probability distribution that can apply to count data is the one proposed by Poisson to describe the distribution of the number of occurrences of an event in a given time interval (Bangdiwala 2010a). It was proposed as a distribution for rare events, and thus it is considered as a good theoretical option to model road safety count data. The Poisson probability distribution is characterized by the following equation:

$$\Pr(Y = y) = \frac{\lambda^y e^{-\lambda}}{y!}, \quad y = 0, 1, 2, 3, \ldots,$$

where λ is the mean value of the distribution and e is the constant base of the natural logarithm (2.71828...). The properties of this theoretical distribution are that its mean λ equals its variance λ and it is right-skewed. Figure 8.2a illustrates the theoretical Poisson distribution function for several specific values of the mean λ.

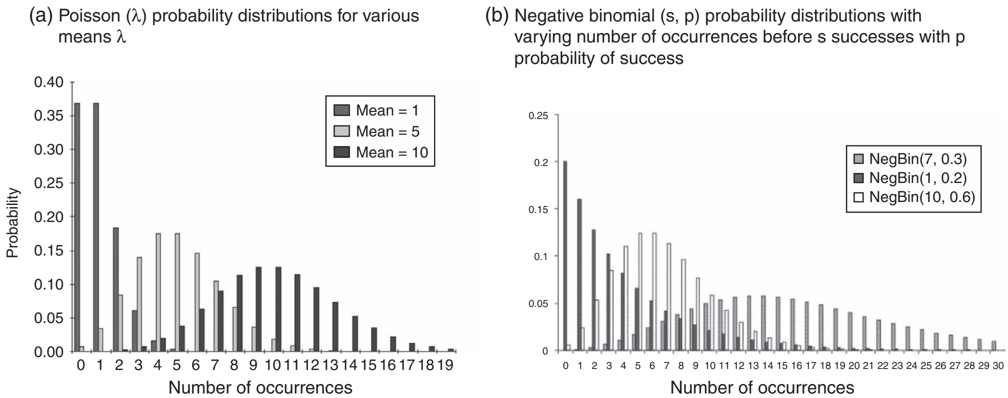

Figure 8.2 Illustrative probability distributions for Poisson and negative binomial distributions, for various parameter values.

The usefulness of using a theoretical probability distribution such as the Poisson is that one can calculate the predicted probabilities of the number of occurrences of the event based on the theoretical probabilities. Another use is in studying the effect of some other variables on the number of occurrences of the event. For example, there may be other factors such as average age of drivers, road conditions, and so forth, which may explain the number of collisions of only two motorized vehicles in a given community in a given year. Thus, a regression modeling approach is needed. In this case, a standard multiple regression model that assumes a Normal (or Gaussian, bell-shaped) dependent variable is not appropriate, and a Poisson regression model (Kleinbaum et al 2007) can be used.

The Poisson distribution may not always be a good fit for a count variable. This may occur for a variety of reasons. For example, the variance may be larger than the mean, what is called *over-dispersion*. The distribution function that is often better suited for over-dispersed data is the right-skewed *negative binomial* distribution. Figure 8.2b illustrates the theoretical Negative binomial distribution function for several specific values of the number of occurrences needed before s successes are achieved, when the probability of success is given by p. Another common situation is when an event is so rare, that most of the times a zero count is observed. In this case, an adjustment to the Poisson distribution may work better, the so-called *zero-inflated Poisson*, where a combination of modeling the zeroes and the non-zeroes is used (Johnson et al 2005).

The Poisson and the negative binomial discrete probability distributions can be approximated by the well-known Gaussian (or Normal) continuous probability distribution under certain situations, and in those cases, the analysis of the data can benefit from the properties of the bell-shaped curve.

8.5 MULTIPLE FACTORS OPERATING IN DIFFERENT PHASES

Lumping together multiple types of injuries into a single broad category called ‘motor vehicle related injury’ leads to a heterogeneity of types of events within the category, which in turn makes it difficult to identify the specific causal mechanism and thus develop targeted preventive countermeasures. Actions that may prevent a pedestrian from being run over by a car in a city intersection may be quite different from actions that would reduce the likelihood of a two-vehicle crash, but both events are lumped as ‘motor vehicle death,’ for example.

Multiplicities arise not only from the multiple types of events in aggregated categories, but in multiple ways. A given event, for example a road traffic crash, can occur under multiple circumstances; a single or multiple vehicles may be involved, as are multiple individuals per vehicle or individuals not in motorized vehicles. Even for a limited and defined specific event such as ‘collision of only two motorized vehicles,’ each of the multiple individuals involved may suffer multiple types of injuries. The types of injuries from such events can include all traumatic/acute transfers of energy, from fractures, penetrating or blunt object injuries, to burns and multiple trauma injuries. The injuries that an individual suffers may affect multiple body parts/sites – as in multiple fractures to different extremities. Each body site may also be affected at different severity levels (Bangdiwala 2009b). The common practice of aggregating all or several types of injuries has potentially serious statistical implications. Relationships between potential causal factors and the outcome may not be readily interpretable.

Having such multiplicities is potentially exciting from a statistical quantification standpoint. One may have k collisions, but j individuals with m total injuries, where $k \leq j$ and m is likely to be much bigger than j. So if one is studying ‘collision level variables’, information on individuals and on injuries must be aggregated or summarized to the collision level; or if one is studying ‘individuals’, information on injuries must be aggregated or summarized to the individual level. In addition, if studying injuries, one must account for the fact that the multiple injuries in a given individual are related statistically (correlated) because of individual and collision characteristics; and when studying an outcome on individuals, one must account for the fact that

		FACTORS		
Pre-crash	Crash prevention	Information attitudes impairment police enforcement	Roadworthiness lighting braking handling speed management	Road design and road layout speed limits pedestrian facilities
Crash	Injury prevention during the crash	Use of restraints impairment	Occupant restraints other safety devices crash protective design	Crash-protective roadside objects
Post-crash	Life sustaining	First-aid skill access to medics	Ease of access fire risk	Rescue facilities congestion

Figure 8.3 The Haddon Matrix for road safety (WHO 2006, *Road Safety Training Manual*, Unit 2).

an individual's overall outcome is correlated with the outcome of other individuals involved in the same collision! These correlations, from the hierarchical nature of the data, can be quantified using traditional variance component analyses if the data are 'balanced and complete,' but also by using more advanced regression models such as mixed effects multiple regression models and generalized estimating equation (GEE) models. Failure to account for these correlations in the design may lead to underpowered studies, and when not considered in the analysis, one can obtain false positive results.

The analytic framework advocated for understanding road transport relationships is the Haddon matrix (Haddon 1972), a matrix presentation of the multiple risk or explanatory factors that operate in the different phases of a crash (pre-crash phase, crash phase, post-crash phase) and involving the multiple dimensions in the crash event – the individual, the vehicle/equipment, and the environment (sometimes broken into physical and social environments) (see Figure 8.3). The Haddon matrix is useful as a planning tool to identify which factors are operating in the different phases and dimensions of the event under study. The next stage is to select interventions to address the modifiable risk factors, based on feasibility of modification, resources available and costs, and potential impact of the interventions.

The use of the Haddon matrix, extended to a third dimension with inclusion of assessments of feasibility and resource considerations, is a valuable planning tool that enables one to identify, prioritize and make policy decisions on interventions by identifying modifiable risk factors and the feasibility of intervening on them (Runyan 1998).

8.6 INTERVENTION APPROACHES – TACKLE THE WORST CASES

When deciding to intervene to reduce the negative outcomes of road transport conflicts, one usually identifies localities that suffer unusually high or extreme rates of injuries or motor vehicle crashes. Blackspot or 'hotspot' analysis is used to identify road sectors and intersections that 'are dangerous' and 'need attention.' Typically, places that have unusually large or extreme problems, beyond what is expected, are then subjected to some 'corrective measures' to lower their injury rates, and the effectiveness of the countermeasure is assessed using a 'before-after' study design. The effectiveness is calculated as the percent change in the measure Y of interest, relative to the 'before' situation (Bangdiwala 2010b):

$$\%\text{Eff} = \frac{Y_{\text{obs-after}} - Y_{\text{obs-before}}}{Y_{\text{obs-before}}} \times 100. \tag{8.1}$$

The calculation in (8.1) is based on the assumption that if no intervention were applied or if the intervention were not effective, the observed 'before' value would be the expected value 'after' and could then be considered as the proper counterfactual for the intervention. However, if the places selected for the intervention are chosen based on their high level of the outcome variable of interest, it is well-known that even if the intervention has no effect, the expected Y_{after} will be smaller than the observed Y_{before}, thus leading one to believe that the intervention was more effective. This arises because the expected value 'after' is not the appropriate counterfactual if one has purposively selected the extreme cases for intervention. This statistical anomaly is called 'regression to the mean,' and one needs to consider it in order to avoid reaching erroneous conclusions. It arises because by selecting those localities with the higher values in the 'before' period, one is essentially taking a sample from a 'truncated' probability distribution, while in the 'after' period, the probability distribution is no longer restricted. This issue was first noted in the injury field by Hauer (1980) who called it 'bias-by-selection.'

From a purely common sense standpoint, it makes sense when dealing with a problematic situation to deal with the worse cases. Thus, for example, it makes sense that interventions be considered at those intersections in a community with the highest numbers of crashes, since resources are limited. This, however, has statistical implications, as illustrated in the following example.

Example: Let C be the number of crashes per year at intersections as our variable of interest, and let N be the number of intersections that are 'similar' in a given community. One is interested in the distribution of the variable C – it is a non-negative count variable, possibly skewed, as hopefully most intersections have a value of '0' but some may have a large value. Assume the true population mean is 3.4 accidents per year. In a given year, suppose we observe a random sample of $n = 10$ intersections and get the following values of C: 8, 6, 4, 3, 3, 3, 2, 1, 0, 0. There is funding to intervene on the 'most critical' black spots, so that we intervene in the 3 with 8, 6 and 4 accidents. Their mean is $(8 + 6 + 4)/3 = 6$, so the question is whether in the future their expected future mean with no intervention is it likely to be 6 or 3.4? The statistical correct answer is 6, because observations in a sample will tend to *regress to the mean* of their distribution. In our example, suppose we do intervene, and that after the intervention, we observe the following number of accidents in the 3 selected sites: 6, 3, and 0, so that the observed mean after the intervention in the 3 sites is $(6 + 3 + 0)/3 = 3$. The apparent relative efficiency is $(6 - 3)/6 = 0.50$ or 50%, while the real relative efficiency is $(3.4 - 3)/3.4 = 0.12$ or only 12%.

8.7 INTERVENTION APPROACHES – DESIGN OPTIONS

Research study design must be appropriate to rule out potential explanations for observed relationships or behaviors in the data. Bangdiwala (2001) suggests necessary elements of good study designs:

- Sample selection that is objective and uses probability (random) criteria (to avoid selection bias),
- Sufficient sample size to rule out the role of chance (low false positive and false negative probabilities),
- Appropriate and similar comparison (or counterfactual) group to help address trends in the absence of the exposure.

Standardization and control over potentially important confounding factors.

TABLE 8.1 Observational study designs in road safety research.

Type of study	What they consist of	What information they provide	What statistics they provide
Case series	■ In-depth examination of a few number of cases	■ Presence or absence of multiple factors in cases	■ Descriptions of distribution of risk factors
Cross-sectional study	■ A sample from a population at a given moment in time	■ If sample is population based, estimates of the prevalence of the outcome ■ Measures of the association among concurrently measured variables	■ Correlations for continuous variables; odds ratio of exposure or of outcome for categorical variables
Case-control study	■ Two samples – one of cases, and one of controls ■ Retrospective assessment of exposure in both samples	■ Measures of the strength of the association between 'caseness' and multiple potential exposure variables	■ Odds ratio of exposure
Case-crossover study	■ Within individual or group sample of times prior to the event	■ Estimates of the effect of immediate exposures on the occurrence of an acute event or outcome	■ Odds ratio of exposure
Cohort study	■ Two samples – one of exposed individuals, and one of unexposed individuals ■ Prospective assessment of occurrence of outcome in both samples	■ If samples are population based, estimates of the incidence of the outcome over time ■ Measures of the risk of multiple outcomes in exposed and unexposed individuals	■ Relative risk of outcome
Surveillance and registries	■ All events occurring in a defined population in an extended period of time	■ Since population based, incidence rates for events	■ Descriptions of distributions of events

There is a well-known hierarchy of methodologies to establish the existence of a relationship or the effectiveness of an intervention, coming from the Evidence-Based Medicine movement, whether they are observational or experimental approaches. The more common observational study designs used in road safety research include case series, cross-sectional or prevalence studies, case-control studies, and prospective studies such as cohort studies and surveillance or registries. Each observational study design makes an important contribution towards understanding the relationship between a potential explanatory variable and the outcome of interest (see Table 8.1).

Measures of the association between exposures and outcomes are obtainable from designs that do have counterfactuals, such as case-control and cohort studies. Case-crossover designs are interestingly quite applicable in road safety research, as they look at exposures that were proximal in time to an acute event such as a crash and compare the presence or not of the exposure to prior times within the individual (see Figure 8.4).

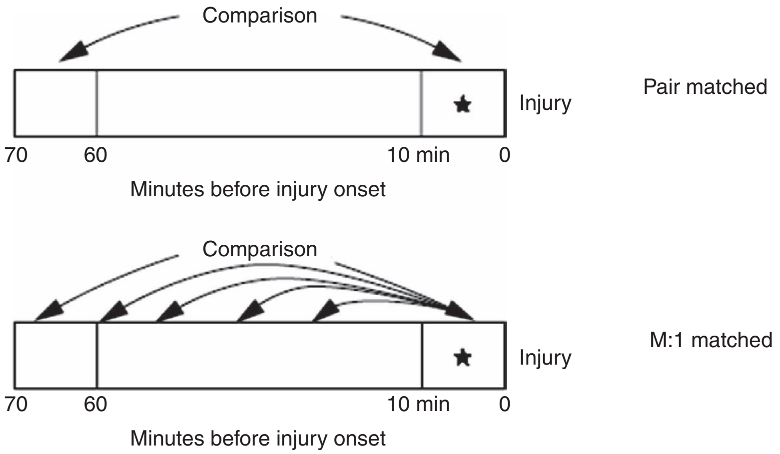

Figure 8.4 Diagram of pair-matched and M:1 matched case-crossover design (adapted from Sorock et al 2001).

Observational study designs may provide some evidence and quantify the strength of the association between an exposure and an outcome, but they are subject to various forms of biases, and thus experimental designs are preferred (see Table 8.2). Within experiments, some designs are considered more robust than others. For example, individual randomized controlled experiments (trials) are considered as stronger than group or community randomized controlled experiments. Non-randomized comparison intervention studies, and within-person or group before-after studies (see Figure 8.5), are considered as poor experimental designs. However, in the injury research field, often it is unethical or impractical to do individual randomized controlled experiments. Many interventions are policies or infrastructure changes that affect entire countries or communities, while others, such as the use of seatbelts or airbags, cannot be ethically denied to individuals. Thus, often specific interventions are carried out in groups of individuals while the outcomes of the interventions are examined in individuals. These types of experimental study designs are called group or cluster randomized controlled experimental designs, and one must account for the intra-cluster correlations in these study designs. They are often called ‘quasi-experimental’ designs since individuals are not assigned to the interventions but rather groups are assigned. The evidence from these studies is not considered as strong as the evidence from individualized randomized controlled studies, but often they are the only ones possible in the injury field, and a well-done group randomized design should be considered as providing strong evidence of the effectiveness of an intervention.

8.8 UNDERSTANDING RELATIONSHIPS – STATISTICAL ANALYSIS

Given the above special considerations impacting road safety research, statistical analysis must account for the particular circumstances. In establishing the causality of a relationship, there are seven considerations as listed by Bangdiwala (2001):

1. *Strength of the association*, as quantified by some statistical measure of association. If the association measure is strong, chance can be ruled out.
2. *Dose-response effect*, i.e., the more of the causal factor, the larger the effect.
3. *No temporal ambiguity*, i.e., the disease follows exposure to the risk factor.
4. *Consistency of the findings*, as shown by external validity or confirmation in other studies.

TABLE 8.2 Experimental study designs in road safety research.

Type of study	What they consist of	What information they provide	What statistics they provide
Individual randomized controlled trial	■ Individuals are randomly assigned to intervention and control arms; standard protocols are uniformly implemented	■ Valid estimate of the effect of the exposure (intervention) on primary and secondary outcomes	■ Relative risks for binary outcomes; effect on means for continuous outcomes
Group or community randomized controlled trial	■ Groups of individuals are randomly assigned to intervention and control arms; standard protocols are uniformly implemented	■ Valid estimate of the effect of the exposure (intervention) on primary and secondary outcomes ■ Since intervention is at the group level, one is not assured individuals actually received the intervention, so that effects are usually smaller ■ Clustering effect leads to correlated data at the individual level that must be accounted for in the analyses	■ Relative risks for binary outcomes; effect on means for continuous outcomes ■ Effects are usually less statistically significant due to the variance inflation from correlated data
Non-randomized comparison intervention study	■ Groups or individuals receive different interventions, but are not randomly assigned; they are self-selected to exposure	■ Biased estimate of the effect of the exposure (intervention) on primary and secondary outcomes	■ Relative risks for binary outcomes; effect on means for continuous outcomes
Within-person or within-group before after study	■ A single individual or group acts as its own counterfactual – the outcome after the intervention is compared to the outcome before	■ Within-person or within-group changes due to the exposure (intervention) ■ If there are multiple measures before or after, trends before and after	■ Mean change score for continuous outcomes; McNemar's test for binary outcomes ■ Regression trends before and after

5. *Biological plausibility*, i.e., the hypothesis is reasonable given what is known in science.
6. *Coherence of evidence*, i.e., consistency and plausibility of findings internally and externally.
7. *Specificity*, i.e., the causal factor causes the disease, and disease is due to the causal factor."

The main consideration is to examine the strength of the association. When quantifying the association to establish effectiveness of an intervention to prevent or reduce incidents or injuries, one must consider the scale of measurement of the variables involved. Intervention (yes/no) is a binary discrete variable, while the outcome of injury or incidents is usually a count discrete variable or binary variable for the occurrence of an event. Thus it is necessary to understand how to quantify the strength of the association between two discrete variables, specifically when both are binary or when one is binary and the other is a count variable.

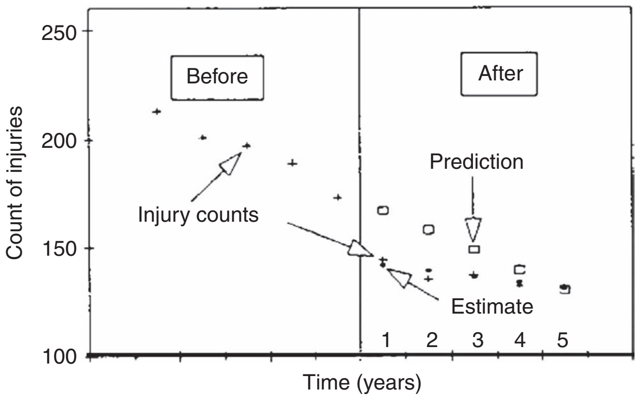

Figure 8.5 Hypothetical diagram of a before-after study data, with multiple measures before and multiple measures after the intervention.

TABLE 8.3 Tabular display of exposure and outcome data, when both are binary discrete variables, by sampling in time situations

(a) Single sample with concurrent measurement of outcome and exposure (e.g. cross sectional study)

	Cases	Controls	
Exposed	a	b	a+b
Not exposed	c	d	c+d
	a+c	b+d	n

(b) Two samples defined by outcome with retrospective measurement of exposure (e.g. case-control study)

	Cases	Controls	
Exposed	a	b	a+b
Not exposed	c	d	c+d
	n_{ca}	n_{cn}	n_{total}

(c) Two samples defined by exposure with prospective measurement of outcome (e.g. cohort study, controlled experiment)

	Cases	Controls	
Exposed	a	b	n_{exp}
Not exposed	c	d	n_{notexp}
	a+c	b+d	n_{total}

8.8.1 Comparing binary variables across groups

Quantifying association is an essential aspect in injury and safety research. Data when both the exposure and the outcome variable are binary is captured in a 2×2 table (see Table 8.3). Depending on the type of sampling used in the various study designs for obtaining the data, the appropriate measure of association is calculated.

Prospectively, we talk about the probability or 'risk' of an event, which is estimated by the proportion of events that occur in a given set of individuals over a given time period. Another name for this is the 'incidence rate' of the event. Given that the risk is a proportion, it ranges from 0 to 1. If one calculates the proportion or estimates the risk of events in the exposed group and in the unexposed group, the relative risk is the appropriate measure of the strength of the association between exposure and outcome. It is given by

$$\mathrm{RR} = \frac{\Pr(\text{event} = 1|\text{exposure} = 1)}{\Pr(\text{event} = 1|\text{exposure} = 0)}.$$

TABLE 8.4 Hypothetical data to illustrate calculation of Odds Ratio and Relative Risks, and how they are related in different study designs

(a) Cross sectional study

		Cases	Controls	
OR of exposure = [(32/40)/(8/40)]/[(38/60)/(22/60)] = 2.32	Exposed	32	38	70
OR of outcome = [(32/70)/(38/70)]/[(8/30)/(22/30)] = 2.32	Not exposed	8	22	30
		40	60	100

(b) Case-control study

		Cases	Controls	
OR of exposure = [(32/40)/(8/40)]/[(38/60)/(22/60)] = 2.32	Exposed	32	38	70
	Not exposed	8	22	30
		40	60	100

(c) Cohort study or controlled experiment)

		Cases	Controls	
RR of outcome = [(32/70)/(8/30)] = 1.71	Exposed	32	38	70
	Not exposed	8	22	30
		40	60	100

(d) When cases are rare

		Cases	Controls	
RR = [(8/70)/(2/30)] = 1.71	Exposed	8	62	70
OR = (8*28)/(62*2) = 1.81	Not exposed	2	28	30
		10	90	100

As a ratio of proportions, it is non-negative and can take on values from $[0, +\infty)$. If the RR equals 1, it means that the risk of the event is the same regardless of the value of the exposure; i.e. there is no association of the event with the exposure.

When a prospective study is not possible, it is common to estimate the 'odds' of the event rather than the probability (or risk) of the event. The 'odds' of an event are defined as a ratio of two probabilities:

$$\text{odds(event)} = \Pr(\text{event} = 1)/[1 - \Pr(\text{event} = 1)].$$

The odds are an estimate of the risk of the event occurring relative to the risk of the event not occurring, and it is especially close to the risk of the event occurring if the Pr(event=1) is small and close to 0, since then $1 - \Pr(\text{event} = 1)$ will be large and close to 1. Now, the odds is a ratio of two probabilities, and thus can range in the interval $[0, +\infty)$. Similarly, the ratio of odds, or the odds ratio OR, is given by the ratio of two odds:

$$\text{OR} = \frac{\Pr(\text{event} = 1|\text{exposure} = 1)/[1 - \Pr(\text{event} = 1|\text{exposure} = 1)]}{\Pr(\text{event} = 1|\text{exposure} = 0)/[1 - \Pr(\text{event} = 1|\text{exposure} = 0)]}$$

As a ratio of non-negative quantities, the OR can range from $[0, +\infty)$. The value of 1 is interpreted to mean that the odds of the event occurring are the same whether exposure = 1 or exposure = 0, i.e. that there is no association of the exposure and the odds of the event.

Table 8.4 illustrates the calculation of the OR and the RR for the different study designs, using fictitious data. The choice between using an OR or a RR is based on the study design and the research question. In Table 8.4b and 8.4c we notice how different they can be for the same data, since the probability of the event is large. What confuses many is the mathematical property due to the feature of 'rare' events, as seen in Table 8.4d. With low incidence or probability of an event, the OR and RR for that event can be very similar.

8.8.2 Comparing count variables across groups and over time

Counts are discrete variables, so that when comparing the distribution of counts across two or more groups, methods for categorical data, such as the chi-squared statistic or Fisher's exact test, can be used. However, if the mean number of counts is large, or if collected over a long period of time, the count data can be approximated by the Gaussian bell-shaped distribution and standard methods for analysis of continuous Normal data are often used.

8.9 STATISTICAL TESTING AND THE ROLE OF CHANCE

In addition to quantifying the association between exposure and outcome, there is keen interest in establishing whether the observed association in the sample is true (in the population) or whether it could be explained by chance. Truth unfortunately is never known, but statistics provides a process to understand the uncertainty in the measurements observed. One such method is to construct a confidence interval, a range of values around the observed estimate that defines an interval of possible values for the true association. A quantity based on the variability in the data as well as on the desired precision of the interval is added and subtracted from the observed value of the effect in order to create the interval. For effects that are based on differences between groups, one focuses on whether the value of '0' is in the interval or not, since it implies 'no difference,' while for effects that are based on relative values between groups, such as the OR or the RR, the 'no difference' value is '1.' If the 'no difference' value is in the interval, we say that the two groups could likely not be different in reality.

Another method to understand uncertainty is through a formal statistical hypothesis testing process.

If we take for example the OR or RR when establishing the association between a binary exposure variable and a binary outcome variable, the formal testing of the association is performed via the process of a statistical test of the following hypotheses:

H_0: OR or RR = 1 'null' hypothesis
H_1: OR or RR ≠ 1 'alternative' hypothesis

The principle behind the specification of the hypotheses in a formal statistical test is based on the method of indirect proof. That is, one first formulates two hypotheses in such a way that one, and only one, is true. Usually, one of the hypotheses is a claim that one is making about the population characteristic (e.g. "exposure and outcome are associated"), and so the other is the opposite situation that is the current belief (e.g. "exposure and outcome are not associated"). The claim is labeled as the 'alternative' hypothesis, while the current belief is called the 'null' hypothesis. For the indirect proof method, one assumes the opposite of the claim is correct, and then proceeds to examine the data for information that favors the claim, similarly to the judicial system of assuming 'innocence' when faced with an accusation (claim) until proven guilty (see Bangdiwala 1989). The evidence in the data is judged by calculating the probability of the observed association if there indeed were no association (i.e. under the null hypothesis). If this probability of chance association is small, we say that the association is not likely due to chance and label it 'statistically significant.' If the probability of chance association is large, we say that the association is likely to be due to chance, and label it 'not significant.' The probability of chance association under the null hypothesis is called the 'p-value' and can be thought as the probability of a 'false positive,' i.e. that one states that there is an association when there is not one.

What is large and what is small for deciding statistical significance? The standard (arbitrary) threshold or cutpoint of 0.05 is attributed to the famous statistician Sir Ronald A. Fisher, who stated in 1926: "*... it is convenient to draw the line at about the level at which we can say: 'Either there is something in the treatment, or a coincidence has occurred such as does not occur more than once in twenty trials.'...*" [Fisher (1926, p. 504)]. This completely arbitrary threshold value has been universally accepted and we thus use the term 'significant' or 'statistically significant' if the 'p-value' observed is less than the level 0.05 at which 'significance' is considered (arbitrarily) to be achieved.

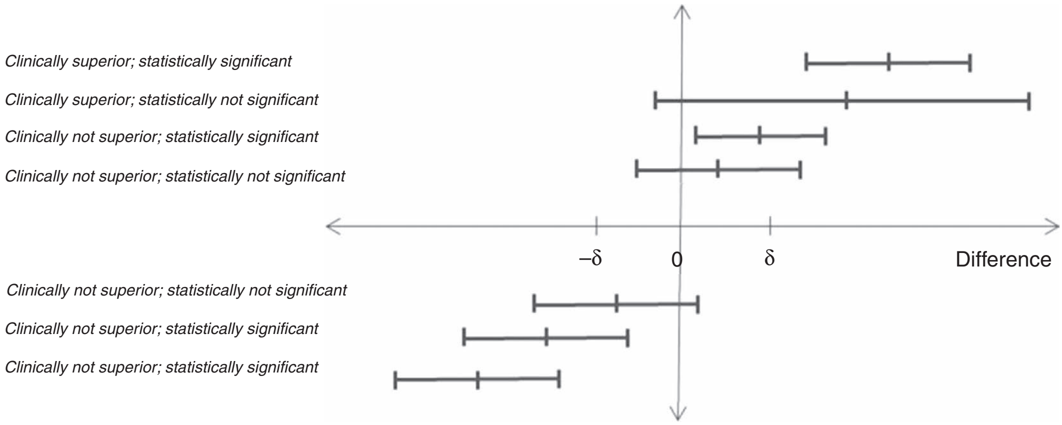

Figure 8.6 Schematic diagram for interpretation of observed intervention differences using confidence intervals: statistical significance versus clinical importance when testing for superiority.

Unfortunately, the term 'significant' is one we also use in non-statistical contexts to mean 'important' or 'meaningful.' These terms are by definition subjective, and have no standard interpretation. What is important or meaningful to an individual may not be so to another. The problem arises then when the term 'significant' is used in scientific writing for a finding that is interpreted by the authors as important or meaningful, but that may not be statistically significant. Some authors prefer to use the term, 'clinically significant,' but often simply state 'significant,' which leads to potential confusion.

When comparing two interventions, many researchers focus only on the significance of a formal statistical hypothesis test. It is more informative to examine the confidence interval, since it provides not only the estimate of the mean difference, but the range of possible values of the true difference. The interpretation of the confidence interval includes not only whether it contains the 'no difference' value, but also if it contains the 'important difference' value of δ. This is a subjectively value chosen by the researcher, usually the smallest difference between the groups that would be considered to be meaningful or important from a research or clinical reason. Thus, looking whether the confidence interval includes the 'no difference' value is to focus on statistical significance, while looking at whether the confidence interval includes the 'important difference' value is to focus on clinical importance (see Figure 8.6). Statistical significance or not is simply a measure of whether the observed difference can be due to chance given the hypothesis stated a priori, but interpretation of the confidence interval may be more meaningful.

8.10 CONCLUDING REMARKS

This chapter has highlighted a few key basic statistical issues that may impact injury prevention and control research. The focus has not been on presenting specifics of various statistical methodologies, but on providing some understanding of concepts and principles. Basic issues of sampling, probability distributions, understanding uncertainty and variability are key to all research activities. Unique characteristics of road transport research data are highlighted and their impact on statistical methods discussed.

Statistical methods are concerned with ways to 'control' uncertainty, i.e. reduce variability and reduce sampling uncertainty. This is usually achieved by restrictive sampling, studying more members of the population, restricting the research question to less variable situations, or by choice of appropriate research designs – experimental (more control) vs observational (less control). Observational and experimental studies provide useful information on the effects of an intervention, in terms of impacts and outcomes. Impact indicators are changes in knowledge, attitudes or behaviors, considered as precursors to outcomes. Outcome indicators address changes in injury events (e.g. frequency, type, pattern), morbidity (e.g. frequency, severity, type), mortality (e.g. frequency, time to death) and cost (e.g. direct and indirect).

Some experimental designs are quite rigorous in providing a valid measure of the effect of an intervention as they control many potential confounders. However, not all uncertainty can be controlled by design, and we use statistical analytical methods such as multivariate regression modeling to further adjust for potential confounders of the studied relationships.

All models, whether probability models of variable distributions or multivariate regression models of variable relationships, are simplifications of reality. However, reality is complex. There is a multiplicity of factors interacting in complex ways, and some factors may cause or be related to others. The limitations of regression models are many, but include

- Assuming you have identified all the relevant factors
- Assuming you measure the factors properly
- Assuming you specify relationships correctly
- Assuming probability models for errors are correct.

The issues presented in this chapter are meant as an introduction to some of the statistical considerations that engineers, road safety experts and policy makers must take into account as they try to understand the factors involved in reducing the burden of disease from road accidents.

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CHAPTER 9

Speed and its Effects on Road Traffic Crashes

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CONTENTS

ABSTRACT

The speed at which motor vehicles move in traffic is at the base of the road injury problem. Speed influences both the probability of the occurrence of a crash and the crash consequences in terms of the severity of injuries and the extent of property damage. There is overwhelming evidence that increase in speeds is always accompanied by an increase in the number of crashes and in the average severity of road traffic injuries. Fatalities tend to change disproportionally with change of average speed in a double quadratic way. For example, an average speed reduction by a factor .95 gives an expected reduction of fatalities by a factor $(0.95^2)^2 = 0.815$ or 5% reduction of average speed gives 18.5% reduction in expected fatalities. Speed control and traffic calming appear to be the most effective and promising ways to reduce injuries and deaths in road traffic crashes.

Key Words: Road traffic injury; speed; speed limits; injury severity

9.1 INTRODUCTION

The speed at which motor vehicles move in traffic is at the base of the road injury problem. Speed influences both the probability of the occurrence of a crash and crash consequences in terms of the severity of injuries and the extent of property damage. However, since the motorcar provide the opportunity to travel at higher speeds, and that was seen as the main benefit of vehicle use, speed was not considered to be a major risk factor in the early decades of car use.

Many of the papers published in the 1960s that attempted to understand the various factors associated with incidence of road traffic crashes included variables such as: hourly traffic volume, age and sex of drivers, width and curvature of roads, weather, driver error, etc., but most did not include speed as a possible risk factor (Pfundt 1969; Knoflacher 1969; Allsop 1969).

An influential report published in 1964 in USA reported that, "One of the important findings of this study is that the greater the differential in speed of **a** driver and his vehicle from the average speed of all traffic, the greater the chance of that driver being involved in an accident. The accident-involvement, injury, and property-damage rates were highest at very low speeds, lowest at about the average speed of all traffic, and increased at the very high speeds, particularly at night. Thus, the greater the variation in speed of any vehicle from the average speed of all traffic, the greater its chance of being involved in an accident." The study also concluded that "The fatality rate was highest at very high speeds and lowest at about the average speed" (Solomon 1964). In general, in the early years of traffic safety work most professionals believed that crash rates were higher at speeds greater and lower than the average speeds on a road, and that if the drivers were more careful and law abiding the problem of traffic safety would be largely resolved.

One of the earlier papers suggesting that vehicle speeds played an important role in crash incidence and severity appeared in 1971 in which the author suggests that, "Surprisingly, the imposition of a lower speed limit is two to three times more effective in reducing overtakings than an equivalent upper speed limit. It can be argued therefore, that a lower speed limit is in the self interest of the misinformed slow driver as well as in the interest of all other drivers. This is a rather unique situation and a strong point in favour of the imposition of lower speed limits on rural roads" (Hauer 1971). Another study in 1972 concluded that, "As is well known, the primary factor affecting the likelihood of driver injury is speed" (White and Clayton 1972).

Sometimes occurrences of natural events that bring about change in society suddenly, help us to study complex issues. In October 1973 the members of the Organization of Arab Petroleum Exporting Countries (OAPEC) announced an oil embargo. By the end of the embargo in March 1974, the price of oil had risen from US$3 per barrel to nearly US$12.[1] Because of the increase in fuel prices and a general recession in the economy, the US government decided to reduce speed limits to 55 mile per hour (mph) on intercity highways that had higher speed limits (generally 65 mph or greater), to reduce fuel consumption and import of oil. The 55 mph national maximum speed limit was enacted in January 1974 and by March 1974 all states in the USA were in compliance with the law (Chatfield et al 1980). Kemper and Byington at the Pennsylvania State University examined the effect of this reduction in speed limits nationwide on traffic crashes and published their report in 1977 (Kemper and Byington 1977). They concluded that there was a reduction in speeds, brought about by the 55 mph law, and the interstate rural system had a 30% reduction in fatality rates, which prevented 4,700 fatalities and 81,000 injuries in 1974. The outcome of this natural experiment gave us reliable evidence that reduction in average speeds of traffic reduces both the incidence of traffic crashes and average severity of injuries suffered by road users.

9.2 THE EVIDENCE

There is overwhelming evidence that increase in speeds is always accompanied by an increase in the number of crashes and in the average severity of road traffic injuries (Peden et al 2004; Elvik and Vaa 2004). However, there are still some sceptics who suggest that increasing speed limits does not result in a greater loss of lives: "All of the evidence thus far indicates that Americans have not responded to higher speed limits by converting the highways into stretches of the Indianapolis 500. Any loss of life has been very minimal and at most a tiny fraction of what had been predicted by the safety lobby. Meanwhile, Americans have saved some 200 million man hours in terms of less time spent on the road. The net economic benefit of raising the speed

[1] 1973 oil crisis. https://en.wikipedia.org/wiki/1973_oil_crisis. Accessed 21 May 2015.

limit has been between $2 and $3 billion a year" (Moore 1999). Such views generally originate from those groups who consider personal freedom in thought an action as an inalienable right independent of consequences or those who try to balance the benefits of perceived savings of time with other harmful consequences. However, all carefully done studies and meta analyses show conclusively that there is a very strong statistical relationship between speed and road safety – when speeds go up the number of crashes and severity of injuries increase and when speeds go down the numbers and severities reduce (Clarke et al 2010; Carlson 1977; Hoskin 1986; Garber and Graham 1990; Wagenaar, Streff, and Schultz 1990; Engel and Thomsen 1992; Vis, Dijkstra, and Slop 1992; Mohan 1995; ETSC 1995; Johansson 1996; Anderson et al 1997; Taylor, Lynam, and Baruya 2000; Garder 2004; Aarts and van Schagen 2006; Peden et al 2004; Koornstra et al 2002; Koornstra 2007). Here we summarise the results of these studies.

Koornstra et al (2002) compared traffic fatality rates in Sweden, United Kingdom, and the Netherlands and concluded that:

- Fatalities tend to change proportionally with change of average speed in a double quadratic way. For example, an average speed reduction by a factor .95 gives an expected reduction of fatalities by a factor $(0.95^2)^2 = 0.815$ or 5% reduction of average speed gives 18.5% reduction in expected fatalities. This relationship has been verified by Nilsson (2004) and (Elvik, Christensen, and Amundsen 2004).
- The simplest explanation for the lowest car occupant fatality rate and lowest total rate of Britain, is that Britain has a lower speed level due to higher traffic density than in Sweden.
- It is clear from the comparisons that an important factor in achieving the low fatality rate per vehicle kilometre in Britain is the higher traffic level; this leads to both lower speeds and also to risks being distributed among more road users. Britain needs to find engineering solutions and speed and traffic management policies that will enable pedestrians and vehicle traffic to coexist at lower casualty levels on these streets.

Though there is no clear evidence regarding the effect of "improvements" in road infrastructure on road safety, there is adequate evidence to show that design features that limit speeds, prevent destructive impacts, and provide safer mobility to vulnerable road users do result in injury reductions. A guiding principle in this respect is that the road environment and infrastructure must be adapted to the limitations of the road user (Van Vliet and Schermers 2000). Some measures for which there is reasonable evidence regarding effectiveness in promoting road safety are traffic calming techniques, use of roundabouts and provision of bicycle facilities in urban areas (Elvik 2001; Hyden and Varhelyi 2000). The concept of *traffic calming* comprises the combination of road and infrastructure measures that reduce the negative effects of motor vehicle use, alter driver behavior and improve conditions for non-motorized street users. The goal of such measures is to improve the quality of life by giving importance to the requirements of people living, walking and bicycling in the area, by creating safe and attractive roads and streets. One of the main features of such streets is the control of vehicle streets by infrastructure design.

There is enough evidence to show that lowering of speed limits on expressways and urban roads results in fewer fatalities and injuries (ETSC 1995). The data presented show that the increase in speed limits from 55 mph to 65 mph on interstate highways in the USA resulted in 2–4 mph increase in mean speeds and 19%–34% increase in fatalities. Reduction of speed limits by 10–20 km/h on motorways and rural roads in Switzerland and Sweden resulted in 6%–21% fewer fatalities. In 1987 the state of Illinois in the USA raised the speed limit from 55 to 65 mph on rural highways. A study shows that this has resulted in 300 extra accidents per month in rural Illinois (Rock 1995). Some have argued that changes in speed limits also leads to changes in exposure rates on those particular roads, and this change should be taken into account before calculating benefits or losses. This argument is important for understanding the theoretical issues involved, but not of much consequence for assessing the detrimental public health effects of higher speeds on injuries and deaths.

Effects of speed limits in urban areas have also been studied by several researchers. Fieldwick and Brown studied effects of speed limits on casualties in 21 countries and concluded that reducing speed limits from 60 to 50 km/h would result in a reduction of 25% in fatalities and casualties (Fieldwick and Brown 1987). A reduction in the speed limit from 60 to 50 km/h in Zurich has been reported to have resulted in 24% fewer pedestrian fatalities.

Small reductions in traveling speed result in large reductions in injuries and fatalities both in urban and rural areas. This is because of the following reasons:

- When anticipating a crash, a driver has to take correctional or evasive action. At higher speed the time available for such reactions reduces.
- The stopping distance of a vehicle under braking is proportional to the square of the original velocity.
- As the energy involved in a crash is proportional to the square of impact velocity, and the severity of injury is related to the energy transferred to the human body, the damage to human beings is related to the square of the impact velocity.

9.2.1 Reaction time

Lower initial speeds mean that the driver has better control of the vehicle and the vehicle can stop much earlier and reduce the probability of a crash. Studies show that time to initial steering (defined as the point at which the driver first begins to use the steering to avoid the crash) can be about 1.7 seconds and the period between the point at which the driver begins to release the accelerator pedal up to the maximum brake application point can be 2.2–2.3 seconds (Summala 2000; Green 2000; Fisher et al 2011). This means that a driver driving at 80 km per hour will have travelled 14 m extra before a corrective steering manoeuvre than one driving at 50 km/h. Similarly, at 80 km/h a driver will cover an extra 19 m before applying the brakes compared to a driver going at 50 km/h.

9.2.2 Braking distance

The stopping distance of a vehicle under braking depends on the square of the original velocity. When this is combined with the extra reaction time, we see that distances covered at higher speeds are much higher than those at lower speeds. These relationships are shown in Figure 9.1.

Figure 9.2 shows that vehicles traveling at higher speeds continue to travel at high speeds and the effect of braking manifests itself later and later, the higher the speed. The vertical dashed line shows that if a pedestrian is detected at 35 m distance by a driver traveling at 20 km/h or 30 km/h, the driver will be able to bring the vehicle to a halt a few metres before the pedestrian, thus avoiding a crash completely. However, vehicles traveling at speeds of 50, 60, 70 and 80 km/h will hit the object at velocities of 32, 53, 70 and 80 km/h respectively. Thus, in this case, an increase of 10, 20 and 30 km/h in speed over 40 km/h can have the effect of an increase in impact speeds of 32, 53 and 70 km/h respectively. This shows how increases in speed affect the outcome in proportions that are disproportionately higher. The effect of this on the severity of injuries is even more disastrous. This is shown in the next section.

9.2.3 Relationship of speed to severity of injury sustained by crash victims

In the event of a crash, the injuries are less severe at lower impact velocities. This is because the severity of injuries depends to large extent on the energy transferred to the human body during an impact. The relationship between speed and energy is given below:

$$E = \tfrac{1}{2} * M * V^2 \tag{9.1}$$

where, E – energy, M – mass of the object, V – velocity of the object.

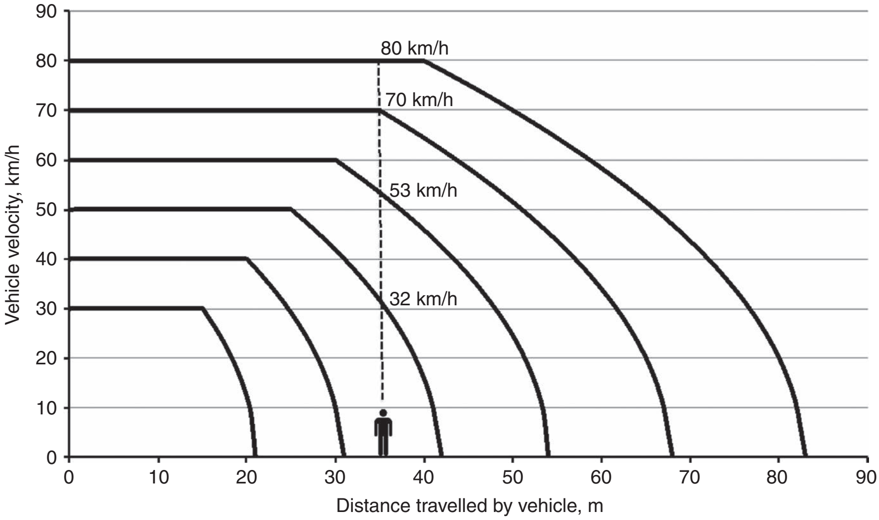

Figure 9.1 Relationship of speed with braking distance for a car on a dry road. Horizontal parts of the lines show the original cruising speed of the car and the curved part shows the braking section (Assumption: driver reaction time: 1.8 s, and average braking deceleration: 5.8 m/s^2).

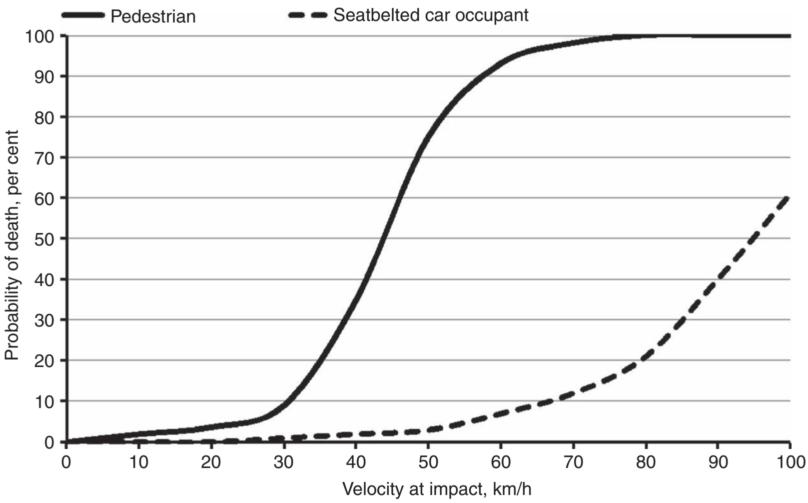

Figure 9.2 Probability of pedestrian and seat-belted car occupant fatality at different impact velocities (adapted from References Peden et al 2004; Anderson et al 1997; Green 2000; Fisher et al 2011, 1987; Evans 1996).

In such a situation small increases in velocity effect much larger increases in energy:

Velocity increase	*Energy increase (related to severity of injury)*
10%	21%
20%	44%
50%	125%
2 times	4 times
3 times	9 times

This theoretical understanding is verified by real life experience. Figure 9.2 shows the probability of death for pedestrians and seat-belted car occupants impacted at different speeds (Anderson et al 1997; Peden et al 2004, 1987; Nilsson 2004; Evans 1996). This shows that the probability of death for a pedestrian being hit at 50 km/h is about 10 times more than being hit at 30 km/h. For car occupants in crashes at 80 km/h the likelihood of death is 20 times more than at 32 km/h (ETSC 1993).

The above data show that speed control can result in enormous savings in deaths and injuries on rural and urban roads. It is clear that impact speeds above 30 km/h are unacceptable for pedestrians and above 60 km/h for belted drivers in frontal collisions, for preventing fatalities. For control of injuries needing hospital treatment crash speeds greater than 50 km/h for belted drivers and over 10–15 km/h for pedestrians would be unacceptable.

The above data seems to suggest that human beings reach their tolerance limits of sustaining severe injury in blunt impacts with hard surfaces at velocities of about 10–15 km/h and fatalities at speeds as low as 30 km/h. The limits for elder individuals would be lower. Belted car drivers are able to withstand impact speeds of 50 km/h as the belt and car interior design prevents impact with hard surfaces.

9.3 SPEED LIMITS

The European Transport Safety Council has recommended maximum limits of 50 km/h in urban areas with limits of 30 km/h on residential roads (ETSC 1995). On motorways, limits of 120 km/h and less have been recommended. However, according to Noguchi the speed at which a driver travels depends on many factors such as the vehicle's engine power and stability, road and traffic conditions, perception of safety, speed limits, and the level of enforcement, travel motivations, personal characteristics, and behaviour of other drivers (Noguchi 1990). Out of these factors, we can have significant influence by policy only over setting of speed limits and enforcement, road design, and vehicle design. It is possible that low-income countries may not be able to adopt all the road design policies and enforcement levels as those present in high income countries because of resource constraints. This makes the issue much more complex and the solution may lie more in innovative approaches to road and vehicle design rather than enforcement. The data on speed and risk suggests the following:

- Wherever there is a significant presence of pedestrians and bicyclists, motor vehicles must not exceed speeds of 30 km/h.
- In locations where bicyclists and pedestrians may be present frequently, speeds may be limited to 50 km/h.
- Speeds greater than 50 km/h may be allowed where interaction between pedestrians and motor vehicles is unlikely and there are very few intersections.
- Speeds greater than 80 km/h should be allowed only on limited access motorways.

Speed limits are difficult to enforce if the design speed of a road is much higher than the speed limit and the road has low density of traffic. This is particularly true for rural roads. Red light cameras have also been found to be very useful in controlling speeds (Retting et al 1999; Lum and Wong 2003), especially in urban areas, but it may not always be possible to use them. It is very necessary that city police departments place a great deal of importance on apprehending speeders so that the drivers are made aware of the existence of speed limits. However, enforcement, especially on rural roads, is very difficult. The police departments can have regular drives on urban roads and periodic drives to apprehend speed limit violators on rural roads, but this has a limited effect. Fleet owners can also be forced to have trip times so regulated that the drivers do not have to exceed speed limits on business trips by using modern trip data recorders.

9.4 ROAD STRUCTURE AND SPEED

A recent study on the effectiveness of road structure on road traffic crashes concludes the following (Noland and Oh 2004):

- Results strongly refute the hypothesis that infrastructure improvements have been effective at reducing total fatalities and injuries.
- In general, infrastructure 'improvements' have led to an increase in total traffic-related fatalities.
- Urban arterial road lane widths of 3 m are associated with a decrease in fatality rates and lane widths of 3.7 m with increase in injury rates.
- Collector road lane widths of 3 m or less are associated with a decrease in injury and fatality rates and wide lane widths with an increase in fatality rates.

In India less than 10 per cent of the fatalities comprise vehicle occupants. Therefore, seat belt and airbag use, while very effective and desirable for car occupants, will not result in major overall fatality reductions. Since a vast majority of fatalities in Indian urban areas and rural highways include pedestrians, bicyclists and motorized two-wheeler riders, that we have to focus on safer road design and speed control for reducing road traffic deaths and injuries.

It is important that rural roads be designed in such a manner that the speed is kept below 100 km/h. Use of roundabouts at intersections and visual cues which do not give the driver a feeling of great expanses helps in controlling speeds. These include advisory speed limit signs, and reflecting surfaces on the side of the road (painted trees, reflectors mounted on posts, etc.). When rural roads pass through built up areas physical measures are necessary to slow down the vehicles. These include constructing very conspicuous "gates" at the entrance of the village/town, use of speed breakers, and even putting up barriers to make the road less negotiable at high speeds (Kjemtrup and Herrstedt 1992; Jazcilevich et al 2015; Hyden 2013; Ewing 1999; Allpress and Leland Jr 2010).

In urban areas speeds are controlled by the presence of intersections and the high density of traffic on the roads. Roundabouts are very effective in controlling speeds on arterial roads in urban areas and some modern designs are also very effective in channelizing traffic. One great advantage of roundabouts over traffic lights is that they are very effective in the absence of policemen and at night-time.

In residential and shopping areas maximum speeds of vehicles have to be kept below 30 km/h and this can only be done through traffic calming methods. Experiences in traffic calming have been well documented elsewhere in this volume. With well designed traffic calming measures road fatalities can be brought to almost zero levels in residential areas.

9.5 CONCLUSIONS

The speed at which motor vehicles move in traffic is at the base of the road injury problem. Speed influences both the probability of the occurrence of a crash and crash consequences in terms of severity of injuries and extent of property damage. There is overwhelming evidence that an increase in speeds is always accompanied by an increase in the number of crashes and in the average severity of road traffic injuries. Fatalities tend to change disproportionally with change of average speed in a double quadratic way. For example, an average speed reduction by a factor .95 gives an expected reduction of fatalities by a factor $(0.95^2)^2 = 0.815$ or 5% reduction of average speed gives 18.5% reduction in expected fatalities. Speed control and traffic calming appear to be the most effective and promising ways to reduce injuries and deaths in road traffic crashes. The effects of lower speeds on vulnerable road users would be more significant than safer vehicle design. Speed control methods which depend mainly on policing are less inefficient and expensive. Any money spent on research to develop vehicle and road designs which control speeds automatically would be money well spent.

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CHAPTER 10

Human Tolerance to Injury: Role of Biomechanics and Ergonomics

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CONTENTS

ABSTRACT

Biomechanics is an interdisciplinary field which combines physics, mechanical engineering, and life sciences to understand the relationship of physical forces to the functioning of the human body. A very important concept of biomechanics is that of human tolerance: there are quantifiable limits to the human's ability to withstand physical forces without harm. If these limits are exceeded, reversible or irreversible injury will occur. Vehicles and equipment can be designed such that even if a vehicle is involved in a crash the resulting injuries are minimized or eliminated. Principles of ergonomics can be used to make equipment easier to use, more efficient, less tiring, and therefore safer.

Key Words: Biomechanics; Human tolerance; Ergonomics; Vehicle safety

10.1 INTRODUCTION

Biomechanics is an interdisciplinary field which combines physics, mechanical engineering, and life sciences to understand the relationship of physical forces to the functioning of the human body. A very important concept of biomechanics is that of human tolerance: there are quantifiable limits to the human's ability to withstand physical forces without harm. If these limits are exceeded, reversible or irreversible injury will occur. Human tolerance limits vary with different types of physical input–impact, acceleration, vibration, compression, stretch, bending and twisting of tissues and body segments. Much of biomechanics research – both basic and applied – investigates what kind and severity of injuries are caused by what magnitude and kind of physical inputs. This information can then be used to design both protective devices and environments.

Biomechanics is valuable in studying all three phases of injury: pre-event, event, and post-event. In the pre-event phase, biomechanics often overlaps with ergonomics in designing products and environments that improve working postures and movements; and minimize the likelihood of injury during work or leisure. In the event phase, the role of biomechanics is to provide human tolerance data to prevent injuries or reduce their severity in the event of a crash or fall, or as a result of forces released in the course of occupational or sports activities. For example, biomechanical knowledge has been used to design:

- Laminated windshields, padded dashboards and knee bolsters, collapsible steering columns, air bags and seat belts in cars;
- Child car safety seats and safety helmets;
- Vibration reduction seats in tractors and trucks.

Ergonomics is a body of knowledge which helps us design our artifacts and the environment such that:

- Energy use is minimized.
- Probability of errors while performing a given takes is minimized.
- Comfort is maximised.
- Probability of injury to muscles or any other organ of the body while performing a task is eliminated as far as possible.
- The task requirements are made as clear as possible to the operator.

The above goals are accomplished by understanding the functioning of the human body and by obtaining physical data regarding the body.

10.2 METHODS OF BIOMECHANICS RESEARCH

A great deal of useful information about mechanical forces and injuries can be obtained by studying "real-life" injury events. An example is Hugh DeHaven's pioneering work on falls from heights (DeHaven 1942). DeHaven measured the "drop height" of humans in non-fatal falls from high buildings. By correlating the drop height, the properties of the object struck, and the indentation, he was able to show that the human body can survive relatively high decelerations when the resulting forces are widely distributed over the surface of the body. Also in the early 1940's, Sir Hugh Cairns studied fatalities and head injuries among army dispatch riders (Cairns 1941, 1946). He found that many of the head injuries occurred at the sides of the head; and that those riders who wore helmets had less severe injuries. Such studies provided the basis for modern-day motorcycle helmets, which provide protection for the entire head and face.

10.2.1 Use of artificial systems

Anthropomorphic (human-like) dummies are widely used in experiments on crash protection. Helmets are tested using an artificial head fitted with accelerometers. Seat belt studies use a dummy with an artificial thorax whose deflection characteristics simulate those of the human body. Of course, the extent to which a particular dummy simulates its human counterpart is of enormous importance (and often a point of considerable debate). A great advantage of these "artificial humans" is that they can be reproduced in quantity and fully standardized, making comparison studies possible (Foster et al 1977).

10.2.2 Use of volunteers

One of the first and classic studies involving the use of a human volunteer in biomechanical research was conducted by Colonel John Stapp. Stapp subjected himself to high accelerations in a rocket sled (Stapp 1955). He kept increasing the acceleration of the sled until he suffered retinal hemorrhage and unconsciousness. His studies proved conclusively that many car crashes are survivable *if* the human body can be prevented from hitting hard structures inside the car. These principles led to the design of life-saving lap-and-shoulder belts and air bags for cars.

The advantage of using volunteers is that human physiology and anatomy can be studied under real-life conditions while physical parameters are simultaneously measured. The drawbacks are that there are clear limitations on the kind of measuring devices that can be used (e.g., they must not themselves injure the volunteer or increase the risk of an injury). Also, the forces to which volunteers can be subjected have to be kept much below injury levels (tolerance thresholds are approached from the "bottom up"). However, such studies can give very valuable data that lead to formal safety policies and regulations:

> To determine the strength needed to hold an infant during an automobile crash, an adult subject was seated on an automobile bench which was rigidly fixed. A lap-and-shoulder belt was locked in position. The adult held an infant dummy weighing 7.9 kg with anthropometric dimensions of a 6-month old infant. In dynamic tests, a cable was pulled by a piston to simulate crash forces. Force transducers ("load cells") were attached to the lap belt, shoulder belt, and the cable; a displacement transducer was attached to the cable to measure cable position. Results clearly demonstrated that an infant in a 50 km/hr crash would almost certainly strike the dash or windshield of the car, even when held tightly by a restrained adult (Mohan and Schneider 1979).

10.2.3 Use of human cadavers

Research involving human cadavers makes it possible to fill in gaps in knowledge obtained from animal experiments, reconstruction of "real-life" crashes, and human volunteer studies. Since cadavers have almost the same dimensions and geometry as living human beings, and because bone properties do not change appreciably after death, data from cadaver research can be used to validate computer models and to design test dummies, for example. Research with cadavers has other advantages: a wide variety of measuring devices can be used; and testing can be done to the point of destruction (which is especially important in the study of fractures or internal injuries).

An example of the value of postmortem human subjects (cadavers) is their use in studying motor vehicle crashes. Highway crashes in which people were killed or injured can be simulated in the laboratory using cadavers and mechanical sleds accelerated to varying velocities. Impact forces can be measured by attaching accelerometers to the cadavers. The injuries sustained in the laboratory are then compared to those which occurred in the "real-life" crashes. The different sets of data then give an indication of what kind of physical damage can be expected with a given range of forces, accelerations, sitting positions, and so on.

There are several disadvantages to injury research using cadavers. Observation of secondary effects – such as development of cerebral edema after a skull fracture – is often impossible. Distortions are introduced because post-mortem anatomy differs from living structures (e.g., muscle tone is absent). Large biological variations among cadavers means that considerable caution must be exercised in applying the research results. Cadaver research obviously can be done only in the relatively few countries that have legislation governing the donation of human bodies to science.

10.2.4 Animal experiments

Experiments with animals allow researchers to study physiologic processes and the responses of living tissues to biomechancial forces. Many of the early studies on tolerance to impact involved research with animals. Animals are used less often for injury research today. Knowing that a small monkey can withstand a peak acceleration of 2000g is of limited applicability to humans, especially when there is now available a great deal of human-specific tolerance data. Also, growing public support for the protection of animals in laboratories places increasing constraints on experiments. Only when other types of research cannot produce the data essential for protecting humans should animal studies be considered.

10.2.5 Computer models

Computers have been used, for example, to study the kinetics of motor vehicle/pedestrian collisions. Computer simulations can model how different parts of the anatomy will be impacted when a person is struck by a vehicle. The model can be changed for persons of different ages, heights, and weights and for different vehicles at varying speeds. The value of the computer simulation depends largely on the accuracy of the designer's data about the real-life situation. It is just as easy to run an unrealistic model as an accurate one! The use of computer models therefore depends on continuous matching of results against data from the real world.

Many of today's computer crash/injury models have taken a long time (almost twenty years) to develop and are very complex (Society of Automotive Engineers 1984 and Ward 1982). They are being used to refine biomechanical experiments and to improve the designs of vehicles and protective devices. Computers are especially valuable in sensitivity analyses – predicting injury outcomes under a variety of crash conditions. For example, computer modelling revealed that in most crash situations, crash forces on both the neck and head decrease when a motorcycle rider is wearing a helmet (Bowman 1981).

What follows are examples of how biomechanical research has already led to dramatic reductions in injuries.

10.3 BIOMECHANICS AND MOTOR VEHICLE OCCUPANT INJURIES

The most important factors in determining the severity of injuries in a frontal car crash relate to the host, agent and environment: design features of the car and roadside, the speed of the vehicle (or vehicles) at the time of the crash, and whether the occupants are restrained by protective devices. Car features that can increase occupant injuries are protruding knobs on the dashboard, windshields that shatter into tiny fragments, rigid steering wheels that can impale drivers, seat backs without head supports, and exterior bodies made from plastic or inexpensive steel. Rigid and sharp objects (such as hood ornaments or metal "bumper guards") attached to the front of motor vehicles can inflict severe injuries on pedestrians and two-wheeler riders.

There has been extensive research on the biomechanics of motor vehicle occupant injuries (Nahmu 1984; Aldman 1985 and King 1973). Consider the situation where a driver is not wearing a seat belt, swerves to avoid an animal on the highway, and the motor vehicle crashes into a tree. The crash – which occurs in less than one-tenth of a second – involves more than one collision. The first collision is between the vehicle and the tree. As the front end of the car is crushed, the car decelerates. The driver, however, continues to move forward inside the vehicle at the car's initial speed. The second collision – the human collision – occurs a fraction of a second after the first, when the driver strikes the interior of the car at the windshield, dashboard, and steering wheel. The collision of internal organs against each other – brain against skull, spleen against rib cage – can be considered a third collision.

The impact energy increases in proportion to the square of the car's velocity. Impact forces are also roughly proportional to the square of the velocity. Impact forces can be twice as great when a car hits a barrier at 110 km per hour compared to 80 km per hour. As a car's impact speed rises above 30 kph the likelihood of death in a frontal crash increases sharply; at 65 kph it is ten times greater and at 80 kph it is twenty times greater.

Crash force on an unrestrained adult occupant can be over 60,000 Newtons (9.81 Newtons is the force exerted by 1 kg acting under the influence of gravity). Yet, these forces on the body can be reduced by distributing them over time (reducing the amount of deceleration) or by distributing them over a wider area of the body. Seat belts perform both functions and can actually prevent the second collision.

For children too small to use seat belts, special restraint devices are needed. Adults cannot protect children from injury in a crash by holding them tightly on their laps. Also, if the adult is not wearing a seat belt during a crash, the child can be crushed between the adult and the car's interior.

An air cushion system is also very effective in protecting occupants from injury as a result of frontal impacts (Mohan 1976; Gillis 1989 and Crandall 2001). Unlike manual seat belts that require occupants to buckle them up before driving, air cushions protect automatically. When a frontal crash occurs, electrical or mechanical sensors trigger an inflator filled with inert gas. The air bag is then inflated in a fraction of a second. The occupants move forward into the bags, which cushion them from the forces of impact. The air cushions deflate rapidly after reaching their maximum inflation.

10.3.1 Bus safety

During an accident, passengers suffer serious injuries because the seats get uprooted and bodies of passengers hit sharp corners and pointed objects. Specifications regarding anchoring of seats must be adopted. We can also evolve standards for inside surfaces and furniture so that there are no sharp corners and pointed objects. In time, interior padding standards should also be evolved.

10.3.2 Safety of road users outside the bus

Buses in India are involved in almost one third of road crashes, especially with pedestrians, bicyclists and motorcyclists. While designs for making the fronts of cars safer for pedestrians have been evolved abroad, the same is not true for buses. Therefore it is important to develop safer bus fronts which are less aggressive for the vulnerable road users.

Safer bus fronts developed for pedestrians would be of benefit to bicyclists also, because impact forces are not like to be very different in the two cases. As use of bicycles and walking becomes more popular in the highly motorized nations, safer bus front designs would be beneficial there also. In addition, similar designs could be incorporated on trams.

The safer bus fronts would have to optimize for head, chest, pelvis and lower limb impacts. Details of impact velocities are not known but traffic surveys from various Indian studies indicate that urban bus speeds vary between 15–45 kph. In the absence of any further data a start could be made by optimizing for bus-pedestrian impact velocities of 20 kph.

10.3.3 Crashworthiness of Country Specific Motor Vehicles (CSMV)

Many countries have vehicles which are assembled locally. These include Tuk-Tuks in Thailand, Jeepneys in the Philippines, three-wheeled scooter taxis in India, and a host of other vehicles designed and made locally. The construction methods, materials used and economic considerations will not allow for the imposition of car safety standards on these vehicles. It will also not be easy to design very efficient crash attenuating frontal structures for CSMVs. However, design changes can be attempted in the following areas: (i) improvements in roll-over characteristics of the vehicles (ii) Body designs which restrict passenger ejection from vehicles, (iii) Removal of all pointed and sharp objects (e.g., bolts, rivets, etc) from the inside surfaces of the cabin, and (iv) provision of impact absorbing padding in areas whereas passengers are likely to hit the vehicle surfaces during a crash.

The type of changes mentioned above will not require heavy investments in research and can be done with largely local initiative. Cooperation and involvement of biomechanics experts from around the world as short term consultants can make a significant contribution in making CSMVs safer.

Biomechanics research has produced improvements in windshields, dashboards, steering columns, and restraint systems in cars (Schimt et al 2004). These improvements have saved tens of thousands of lives and prevented hundreds of thousands of injuries to vehicle occupants (Robertson 1981). Among the priorities for biomechanical research in injury prevention are the design of vehicles that can protect occupants in high-speed crashes (Dole 1988; Peden et al 2004), motorcycle helmets that are crash-effective, inexpensive, and comfortable to wear in hot climates; and more "forgiving" fronts of vehicles (such as buses and trucks) to minimize injuries to pedestrians and two-wheeler riders.

10.4 ERGONOMICS

The earliest work which led to the formation of ergonomics as a formal field of study was the time and motion studies done by F.W. Taylor and L. M. Gilbreth (Greenbeerg and Chaffin 1977). Since then a great deal of work has been done to make the shop floor more productive and the products we use safer and easier to use. The following is one of the many definitions of ergonomics:

- Ergonomics studies men at work, with the objective to achieve an optimum man-task system, in which a proper balance can be maintained between the worker and the working conditions.
- Ergonomists make optimum designs, they evaluate and compare designs and, they also try to predict workers' loads and the performance of systems. The knowledge base of the ergonomist comes from physiology, psychology, anthropometry, biomechanics, and which ever physical science is relevant.

This helps in setting limits on work procedures, work environment and working hours, and rest periods. The knowledge also helps us design better controls on equipment, more comfortable shapes of furniture and machines, and safer and more convenient shapes of tools. This helps in reducing the probability of injury. An example of manual handling is given below, describing how work practices are regulated to make them safer.

10.4.1 Manual handling

Most activities involve lifting, pulling, pushing and carrying of heavy loads which result in sprains, falls, cuts and bruises, spinal injuries and abdominal hernia. In addition fatigue also results in a lack of coordination and an increase in frequency of accidents. Many countries have set standards for the maximum weight to be lifted by men and women, ranging from about 60 kg to 80 kg. A distinction is made between lifting loads from the ground and lifting those from higher surfaces. Loads to be lifted from the ground are generally limited to 30–40 kg. In general it can be emphasized that loads heavier than 15–20 kg should be lifted only with the assistance of another person. Containers can be designed so that there are always two handles when the weight is more than 10 kg. Guidelines for ergonomic design of containers, tools, and handles, are also available (Balgun 1986).

Many attempts have been made to improve shoulder load carrying techniques, designs of wheel-barrows and even improved designs of bicycle trailers. The success of these is very dependent on the technical skills, equipment and materials locally available. A recent study (Balogun 1986) indicates that load transportation methods using transverse yoke and head pack were more efficient than the frontal yoke. The authors have suggested that the frontal yoke system is physiologically and perceptually unacceptable.

10.5 CONCLUSION

- Vehicles and equipment can be designed such that even if a vehicle is involved in a crash the resulting injuries are minimized or eliminated.
- The most important vehicle features for the safety of passengers during a crash are: laminated windshield, collapsible steering column, padded dashboard and other interior surfaces, seat belts, air-bags, and child safety seats.
- As far as possible children should never be transported in the front seats of cars.
- Vehicles should also be less "aggressive" for road users outside of cars. Fronts of vehicles should not have any sharp, pointed or hard objects and should have cushioning properties.
- Principles of ergonomics can be used to make equipment easier to use, more efficient, less tiring, and therefore safer.

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CHAPTER 11

Safer Vehicle Design

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CONTENTS

ABSTRACT

This chapter presents some basic principles used in the design of safer vehicles. There are two distinct segments at risk. There are people in the vehicle, and people outside of the vehicle. Research over the last 40 years has lead to the evolution of seat belts, air bags and crush zones which are able to protect the users of four wheel vehicles fairly effectively. The state of the art is to use finite element simulations in conjunction with crash testing to design vehicles.

Key Words: Kinetic energy; seat-belts; air-bags; crush-zones; Finite Element Simulation

11.1 INTRODUCTION

A typical modern lathe machine has a five horsepower motor and stores a kinetic energy of about 1 kiloJoules. The operators of these machines wear helmets, wear eyeglasses, and undergo three years of fulltime training, and their skills are constantly upgraded by retraining programs. In contrast, a modern vehicle is a 100 to 600 horsepower machine weighing 800 to 4000 kg without load. When travelling at 40 km per hour it stores kinetic energy of the order of 100 kiloJoules. The operators of these machines are mostly untrained at their jobs, operating them part time for maybe 1 hr a day. Acceptance of these facts, and engineering for safety is the first step towards a safer vehicle design.

There are two distinct segments at risk. There are people in the vehicle and people outside of the vehicle. Research over the last 40 years has lead to the evolution of seat belts, air bags and crush zones which are able to protect the users of four wheel vehicles fairly effectively. In our environment, there is a large segment of people outside of the vehicle who are exposed catastrophically to 100 kJ of energy over durations as short as 10 ms. Users of two-wheeled vehicles are also ineffectively protected in spite of the helmet laws. Here the aim is to elucidate some basic principles used in the design of safer vehicle designs. To the end, we will have a look at some of the latest tools being used at IIT Delhi for the design of safer vehicles.

11.1.1 Safety must be engineered

One of the questions often asked is if safety has to be engineered or if it can be done actively by the operators or passengers. Let us start by computing the time we have on hand. We can convert a typical speed of 40 km/h to 11 m/s. If the dashboard is 1m away (any closer and you will not be able to open the glove compartment) and the car comes to a dead halt, if unobstructed, you will cover the distance in 1/11 sec. This is about the time taken for the flick of an eyelash. It is known that the time taken for one human synapse is about 1/30 sec. Three synapse cycles is too little a time for the human brain to take any cognitive action. So any preventive measures have to be based on reflex action.

Now that seatbelts are compulsory in India, I often see parents sitting strapped in holding on to their children. The 5 kg baby has a kinetic energy of $\frac{mv^2}{2}$ or $\frac{5\times 11^2}{2} \cong 302$ Joules. To dissipate the energy, and to bring the baby to rest, the effort required is equivalent to lifting a 60 kg mass by half a meter in a tenth of a second, which is beyond the capacity of humans. Parental instinct in case of a crash will just not be backed by parental muscle power.

Even worse is the case of the parent who is not strapped in. After the child hits the dashboard and dissipates 302 Joules, the parent will hit the child. If the parent weighs 50 kg (ten times), an additional 3000 Joules of energy will crush the child against the dashboard. Clearly, safety has to be engineered and cannot be the result of conscious or reflexive evasive action.

11.1.2 Newton's means of safety

With a little poetic license, I aim to demonstrate how the basic issues of safety can be assessed by the 400 year old formulae of Issac Newton. The simple understanding of the nature of impact is to derive an equivalence of impact when travelling in a vehicle at 40 km/h or approximately 11 m/s. Recounting our high school physics, realize that this is the velocity attained by a body under free fall from a height of $\frac{v^2}{2g}$ or $\frac{11^2}{2\times 9.8} \cong 6.2$ m which is a height of two floors, very close to the vaulting record of Sergei Bubka. As a kid, I (some of you as well) jumped down from one floor height and I am still healthy, but not from two floors. Mr. Bubka however, vaults this height and survives because of the cushioning. So the obvious solution that comes to mind is to provide cushioning. For Mr. Bubka, the International Olympic Committee recommends a cushioning of 1 m depth! This is one of the best possible safety devices. The problem is that most car users would not like to strap one on the moment they sit inside vehicles. It is however, used in the expensive cars; the cushion appears only when there is an impact, is an air cushion and is called an airbag! The requirement of rapid deployment and providing cushioning requires a sophisticated system design involving accelerometers, ignitors, jets and an intricately folded membrane structure.

What are the other options? Bungee jumping allows people to drop the height of a few stories and still survive. The bungee rope is specially designed to limit the load experienced by the human to tolerable levels. This is the most popular measure for car safety, and it is called a 'seat belt'. It is important to understand that as one cannot buy rope off the street and go bungee jumping, the same is true of seat belts. Any belt used to strap in the rider cannot provide safety. A device called a centrifugal clutch is used to allow the belt to extend when the motion is slow. This allows the user to adjust the belt. For rapid movement, of the type of 1 m in 1/11 of a second, the clutch locks up, and restrains the user. That is not all. If the belt were

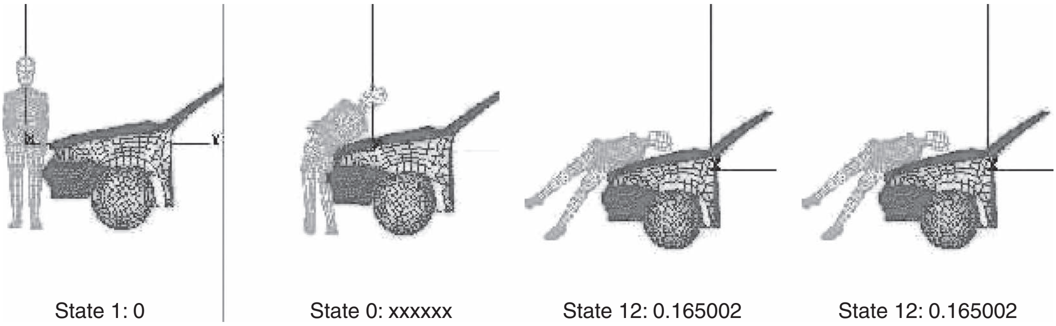

Figure 11.1 Simulation of pedestrian impact.

rigid, there would be no bungee jumping, but a hanging. It would be as good as hitting the dashboard. The belt is a result of precision engineering that brings the occupant to rest not with zero travel, but only after a travel of maybe half a meter. This ensures that we do not have lacerated necks and completely crushed ribs. Needless to say, for the seat belt to save lives, it has to be a precision-engineered system.

11.1.3 Slow it down

Slowing down is a good safety principle. For example, if the vehicle speed is 20 km/h, the energy which varies as a square of the velocity, becomes a fourth. So the survival height becomes 1.5 m in place of 6 m, a drop that many of us expect to survive. However, this is a social solution. An engineered crushing mechanism can provide an equivalent slowdown. The bonnet of a car typically has a length of over a metre. If the design of the vehicle allows the bonnet to compress on impact, then the dashboard of the vehicle does not stop instantaneously but travels forward. This gives additional space to the designer of the airbag and seatbelt to bring the rider to rest with less damage. It does not, however, help the rider who is not strapped in, or in the absence of an airbag. It is not sufficient to have a crush zone. The crushing must be supported by appropriate seat belt design to save lives.

11.1.4 Design for VRU

There are many more people outside the vehicle than inside the vehicle in developing countries. The riders of vehicles are reasonably safe due to the effort of engineers in the US, Europe, and Japan. The principles used in protecting the riders are applicable in protecting the road user as well. One design would be to mandate a crush boundary layer of half a meter. Bonnets that fold on impact, rounding of the front profile, and sinking the hard pivots of the windscreen wiper below the bonnet, are some of the measures that have been taken. However the present-day bumpers and bonnets with small clearance to engine are not VRU friendly designs. Similarly, bus and truck front designs can be improved to make them more pedestrian and two-wheeler friendly. Figure 11.1 shows simulations being conducted on pedestrian impact.

11.2 ADVANCED METHODOLOGIES

The basic principles of the common safety design methods have been discussed. In reality, very sophisticated experimental and simulation tools are used to achieve the goals in the earlier sections. The snapshots below show a car-motorcycle crash test carried out, and Finite Element Simulations.

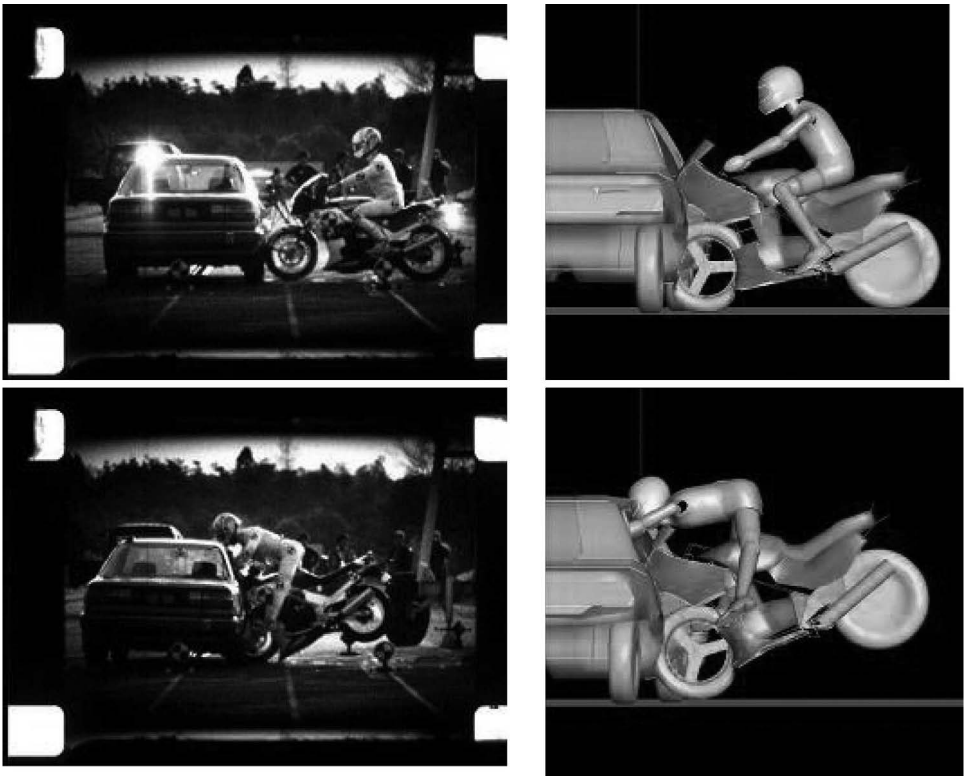

Figure 11.2 Car-motorcycle crash test and simulation.

Figure 11.3 Crushing of honeycomb, test and simulation.

Honeycomb materials are often used to design crush zones as they have good energy absorption characteristics. They can be designed to fit stress corridors on demand and are lightweight structural materials. Figure 11.3 above shows a crushed honeycomb and the simulated crush.

Airbag deployment has to meet stringent requirements, as the bag has to be fully deployed within 5 ms to avoid 'slapping' the rider. The airbag mass is about 200 gm. and moves at a peak speed of around $0.5\,\text{m}/.005\,\text{s} = 100\,\text{m/s}$! Energy content is about 1000 Joules! The slap can be strong enough to break the rider's jaw, following which it has to deflate as the rider impacts the surface to minimize the injury to the rider.

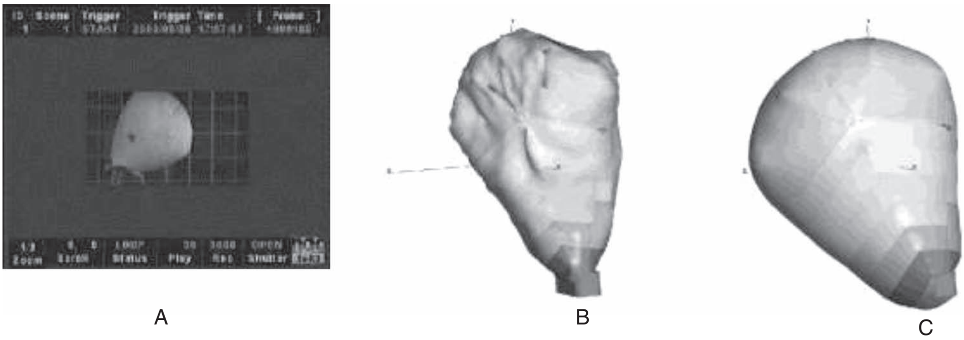

Figure 11.4 Airbags a) Experiment, b) Intermediate simulation and c) Full blown simulation.

Figure 11.4 above shows simulation of the airbag inflation process that is used to study the inflation and iterate on the design of airbags. Needless to say, the driver side and passenger side airbags are of completely different designs because of the space availability.

11.3 CONCLUSIONS

Basic issues in design for vehicle safety have been discussed. The state of the art is to use finite element simulations in conjunction with crash testing to design vehicles. Both these activities need substantial infrastructure and skilled manpower to execute.

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Risk Evaluation and Road Safety

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CONTENTS

ABSTRACT

Risk can be defined, following the reliability and epidemiology literature, as a probability of sustaining an injury more or less severe in a road accident. The main risk indicators used in public health and transportation, such as the mortality and fatality rates, are described with their theoretical background from the survival theory, and their common estimates based on accident, injury, and mobility data. The factors affecting the risk indicators: demographic, geographical, mobility, and economic, are reviewed with their main effects, especially on the mortality rate with the relevant statistical risk models, including some advanced statistical models useful to tackle some deficiencies of the classical models such as Smeed's law or Kopits World Bank model.

12.1 INTRODUCTION

We live in a risky society. What does it imply? It implies that as a road user we are subject to a potential adversity or threat, the vectors of which are the moving vehicles on the road. The accident can occur as an unwanted and unexpected event, such as a collision or a crash, which has consequences such as injuries because of the release of mechanical energy.

Risk has different meanings; here we treat risk as a probability of an adverse event leading to consequences. In this chapter, we are more interested in the objective rather than the subjective

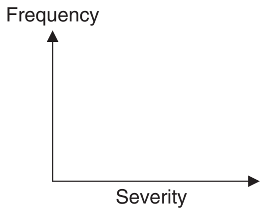

Figure 12.1 The two dimensions of risk.

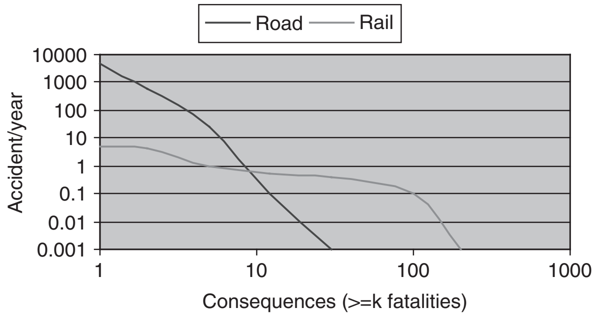

Figure 12.2 Farmer's curves for road and rail (source: Evans 1994). The scales are logarithmic. The y axis gives the frequency in number of accident/year and the x axis indicates the number of fatalities, and the curve indicates the number of accidents per year with more than a certain number of fatalities.

measure of the risk. According to this definition coming from epidemiology and reliability, risk has two dimensions: frequency/severity forming a plane in which accidents take place, some being very severe and less frequent, others rather frequent but slight.

On this risk surface, we can draw the Farmer's curve which gives the pattern of risk in the plane frequency/consequences. If the consequences are expressed as the number of fatalities per accident from 1 fatality to more than 100 fatalities per accident, in the case of a catastrophic accident, we can compare the risk curve of two systems of transport: road and rail. In the UK according to Evans (1994), the road risk is diffuse with a lot of fatal accidents with few deaths per accident. The rail risk is more concentrated on accidents with a high number of fatalities but with much less frequency. In the developing world, the road risk can be catastrophic, with accidents involving buses having more than 20 to 30 deaths in a single accident.

12.2 RISK INDICATORS IN PUBLIC HEALTH

We define the Individual Risk as the probability of occurrence of an adverse outcome during a stated period of time which leads to consequences such as death or injuries. This probability is related to the instantaneous failure rate, for a human an instantaneous death rate, for example by means of the hazard function

$$\text{Hazard function} = h(t) = \lim_{dt \to 0} \frac{P(\text{death between}[t,\ t + dt]/\text{live before } t)}{dt}$$

For a human, the death rate depends on age, according to a bath-tub curve. There is a strong risk at birth, then the risk decreases, then increases again at old age due to uncertainty. In the developed world, there is a peak around 20 years old due to road accidents, especially for men.

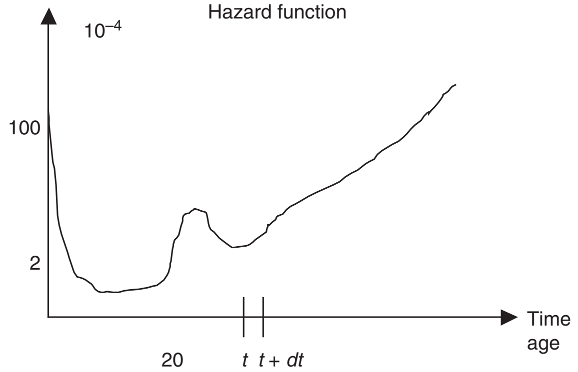

Figure 12.3 Death rate for a human in the western world (unit 1/10000 on the y axis).

From the cumulative failure (death) rate, which is equal to the integral of the instantaneous rate

$$\int_0^t h(u)du$$

we can calculate the risk of death during a certain duration or up to a certain age.

$$\text{Risk} = P(Y < t) = 1 - P(Y \geq t) = 1 - \exp(-\int_0^t h(u)du) \approx \int_0^t h(u)du$$

For example, the risk of dying between 20 and 21 for a young French male in the 1980s was equal to 2/1000, that is to say, two chances over one thousand to die.

$$P(\text{death}[20,\ 21]) = P(20 < Y \leq 21) \approx \int_{20}^{21} h(u)du = (21 - 20) \times \frac{2}{1000}$$

It is also possible to calculate by integration the life expectancy from this curve at different ages: at birth, at 20, 40, 60, . . .

12.2.1 Mortality rate and number of years of life lost

When we select traffic accidents as the cause of death, we get the mortality rate due to road accidents, which has a peak around 20 years old with young males, and starts to increase with age due to the physical vulnerability of old persons in the case of a crash.

We used to characterize the risk in public health by the **Mortality rate** expressed as a number of fatalities/person ∗ year. It is estimated by the ratio

$$\frac{\text{Number of fatalities in a year}}{\text{Number of inhabitants exposed during a year}}$$

This mortality rate due to traffic accident is very low. In France in $2000 = 13.5 * 10^{-5}$, in $2003 = 10 * 10^{-5}$

These figures are based on an actuarial estimation relying on population statistics by gender and age and on statistics on fatalities due to traffic accidents. Such estimates are subject to the migration effect, as some foreigners may die on the road and some residents may die by accident abroad.

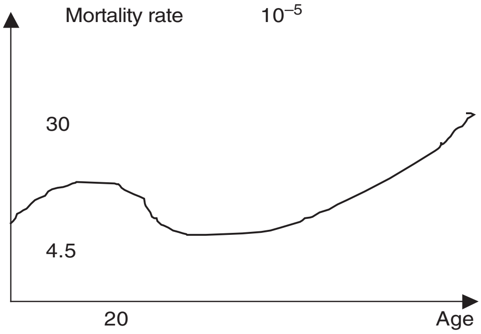

Figure 12.4 Mortality rate pattern due to traffic accidents in western world (unit 1/100000 on the y axis).

By aggregating individual risks, we obtain the burden as number of deaths or injuries that results from the exposure of the population to the risk of traffic accident during a period of one time unit, one year for example, as the summation over the whole population of n individuals of the indicator of death, which is a random variable taking the value 1 for death with probability $\lambda \times 1$ equal to the mortality rate over one year, and 0 with the probability $1 - \lambda \times 1$

$$N_{t,t+1} = \sum_{i=1}^{n} D_i\left([t, t+1]\right) \quad \begin{matrix} P(D_i = 1 \text{ (death)}) = \lambda \times 1 \\ P(D_i = 0 \text{ (life)}) = 1 - \lambda \times 1 \end{matrix}$$

The collective risk, which is similar to the average burden, is equal to the product of the individual risk by the total exposure equal to the total number of individuals exposed during one year to risk

$$E\left(\sum_{i=1}^{n} D_i\right) = \sum_{i=1}^{n} E(D_i) = \lambda \times n \times 1$$

The burden can be expressed as a number of fatalities by using the mortality rate or by the number of injuries (severe and light) by using the morbidity rate.

When we compute the number of fatalities, each death has the same value. We can choose to put a value on each death according to some criteria. In public health, the value corresponds to the number of years of life lost because of premature death due to a traffic accident. Their summation leads to another risk indicator used in public health, the total **Number of years of life lost**. It is equal to the product of the life expectancy taken at the average age at death for traffic accident by the total burden. If the age at death for 910 killed pedestrians is 24 years and the life expectancy at 24 is 40 years, then the number of years of life lost is equal to $40 * 910 = 36400$ years. As young people are much more involved in fatal accident than adult or old people, the ranking of road accident as a cause of disease increases from rank 10 to 3 by using the number of years of life lost instead of the mortality rate.

This risk indicator is completed with the Number of years lived with disability which is estimated from the burden of injured people. When we add both indicators, we end with the Number of disability adjusted life years (= YLL + LLD). 1 DALY = Loss of 1 healthy year is the unit used in The Global burden of diseases by WHO.

12.2.2 Factors influencing the mortality rate

In epidemiology, we are interested in the variations of the accident risk according to age and sex to explore the differences between male and female and between young and old, as well as the spatial and temporal distribution of the accident risk among different spatial units.

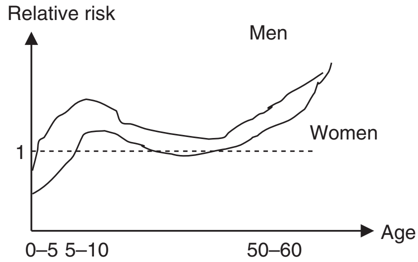

Figure 12.5 Mortality ratio (reference male 0–5 years old) of pedestrian according to age and sex.

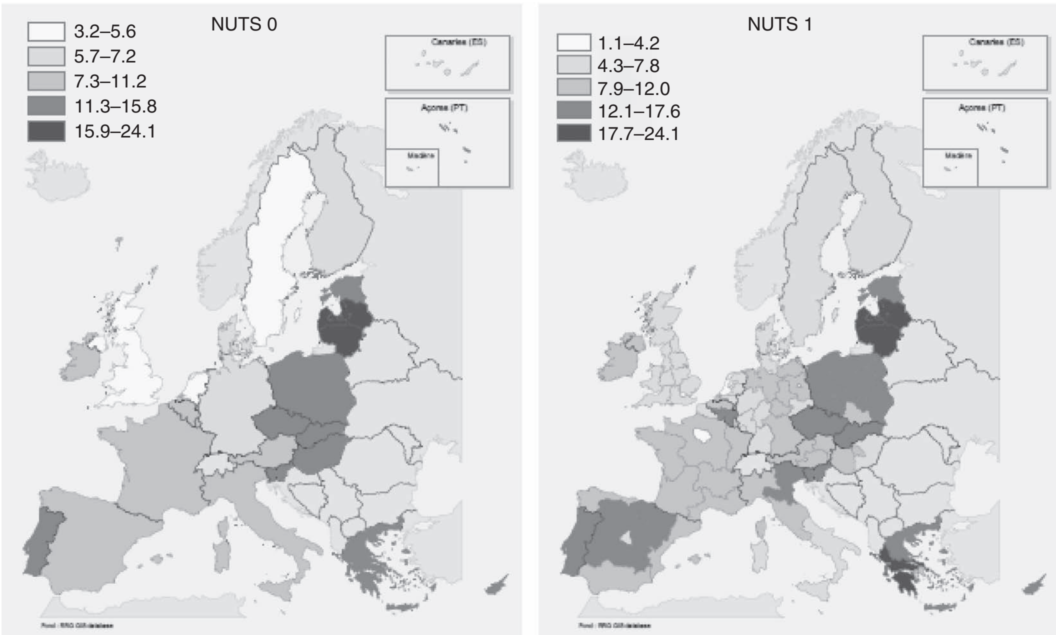

Figure 12.6 Mortality rate in Europe (source: Eksler et al 2008) (unit 1/100000).

12.2.2.1 Demographic factors

The mortality rate varies according to gender and age. The patterns of variation are not similar among road users. The peak of risk is around 10 years old for pedestrians and around 20 years old for car drivers or occupants in the western world. A comparison of the relative mortality rate according to age and sex for walking reveals that there are two main vulnerable groups: young boys (5–10) and old women (>65).

12.2.2.2 Geographical factors

The risk can be estimated on different geographical areas. Most of the time we follow some administrative division of the territory, as in regions. The spatial distribution of the mortality rate is useful to compare countries or regions as in Europe. The risk is smaller in northern Europe than in southern Europe (Eksler et al 2008).

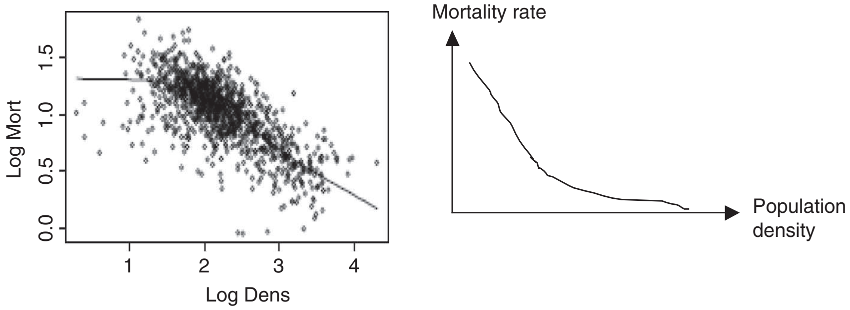

Figure 12.7 Mortality rate and population density (source: Eksler et al 2008) (unit 1/100000).

Some of the differences between regions or countries are due to the differences in the population density, which influences the mortality rate. The mortality rate decreases with the population density when we consider regions as spatial units. Rural regions have an higher rate than urbanized regions.

The estimation of such a relationship relies on the modelling of the number of fatalities by a Poisson distribution

$$Y_i \sim \text{Poisson}(\lambda_{\text{i}}\ N_i)$$

where λ_i is the parameter of the Poisson law, equal to the mortality rate for a spatial unit i, and N_i the number of inhabitants in the spatial unit i. We use a generalized mixed regression model by introducing some co-variables (the logarithm of the population density and a fixed effect "country" β_c with c the country index) plus a spatial non structural random effect ν_i on the mortality rate, which follows a normal distribution with zero mean:

$$\log(\lambda_i^{\nu}) = \beta_{\text{c}} + \beta(\log(\text{PopDens})) + \nu_i$$

12.2.2.3 Mobility factors

The most well-known relationship is the Smeed's curve relating the mortality rate to the motorization rate, equal to the number of motorized vehicle per inhabitant (car, lorry, bus, moto, and moped). The motorization rate increases with the economic development and tends to stabilize in developed countries. The curve was fitted originally with data for G-B from 1907–1947 (Smeed 1949) and for a panel of 68 countries between 1960–1967 (Smeed, 1968). From this curve, by regression, Smeed's law has obtained in which states the mortality rate increases with the motorization rate, with an elasticity of 1/3.

$$\frac{\text{fatality}}{\text{inhabitant}} = \text{c}\left(\frac{\text{motorised vehicle}}{\text{inhabitant}}\right)^{\frac{1}{3}}$$

$$\frac{\text{fatality}}{\text{motorised vehicle}} = \text{c}\left(\frac{\text{motorised vehicle}}{\text{inhabitant}}\right)^{-\frac{2}{3}}$$

$$\text{fatality} = \text{c}\ \ (\text{motorised vehicle})^{\frac{1}{3}}\ (\text{inhabitant})^{\frac{2}{3}}$$

It is in fact a Cobb-Douglas production function of the number of fatalities with two factors: the population and the fleet of motorized vehicles.

This law has some defects; first of all, it has been estimated by a regression over two highly correlated variables: population and vehicle fleet; secondly, it does not integrate the socio-technical progress of the road transportation system due to the improvement of vehicles and of drivers. Due to this failure, the law is not able to reproduce the peak in the trend of the number of fatalities in the western countries around the seventies.

Another class of road risk models developed by Koornstra and Oppe (1989, 1991) is able to predict this change from positive to negative of the number of fatalities. The model is based on a time series analysis of the number of fatalities on an annual basis and the number of vehicle ∗ kilometers (equal to the number of motorized vehicles multiplied by the average of the number of kilometers driven in one year by a motorized vehicle). They model separately the fatality risk equal to the ratio of these two numbers by a decreasing exponential function over time and the number of vehicle ∗ kilometers by a logistic function because there is a phenomenon of saturation about the motorized mobility in the developed world.

The evolution of mortality rate is nearly proportional to the number of vehicles (or vehicle ∗ kilometers) mediated by a socio-technical factor, which is related to the safety of the road transportation system, and decreases the rate of the risk over time because of the socio-technical improvement of the system.

$$\frac{\text{fatality}_t}{\text{inhabitant}_t} = c\, e^{-bt}(\text{motorised vehicle})^{[0.8-1.2]}$$

There is a competition among the three components of the road transportation system: safety/mobility/demography. The rate of variation in the number of fatalities is the sum of the rate of variations of these three components:

$$-\text{b} + \frac{\text{dmotorisation}}{\text{dt}} + \frac{\text{dpopulation}}{\text{dt}}$$

It is positive, and the number of fatalities increases over time, if the rate of socio-technical progress is lower than the sum of the increase in motorisation or mobility plus the increase in population. It is negative, and the number of fatalities decreases, if the safety progress is greater than the increase in mobility and population. In that case, safety outweighs mobility, in the former case mobility outweighs safety. What happens is that when the motorisation starts growing in a country, the growth rate is very strong, around 8%. With an increase in population of around 2%, it means that the safety rate has to be greater than 10% to counterbalance the effect of mobility. Usually the safety rate is around 5% per year and we have to wait for a slowing down of the mobility due to saturation to get a decrease in the number of fatalities.

In France (Lassarre and Hoyau 2009), the number of vehicle ∗ kilometers increased at a rate of 7.5% up to 1973, the year of the first world oil crisis, which reduced the increase to 2.5% . The safety index measured by the number of fatalities per vehicle ∗ kilometers decreases according to an exponential function at a rate of 5.4% per year. It follows that the number of fatalities rises steadily at a rate of 7.5–5.4 = 3.1% per year up to 1973, then decreases at a rate of 2.5–5.4 = 2.9% per year after 1973. On the fatality risk curves we can observe the impact of important national safety measures taken in 1973 (speed limits on national roads and motorways plus seat belt use) and 2002 (Speed cameras) which immediately reduced the number of fatalities by 14% and 17% respectively.

12.2.2.4 Economic factors

Many attempts have been made at an aggregated level (country level) to relate an economic indicator such as GDP or unemployment rate to the mortality rate. On the basis of an analysis of a macro-panel of countries from all over the world over a twenty year period, Kopits and Cropper (2005) end with a Kuznets curve relating GDP to mortality rate. The mortality rate

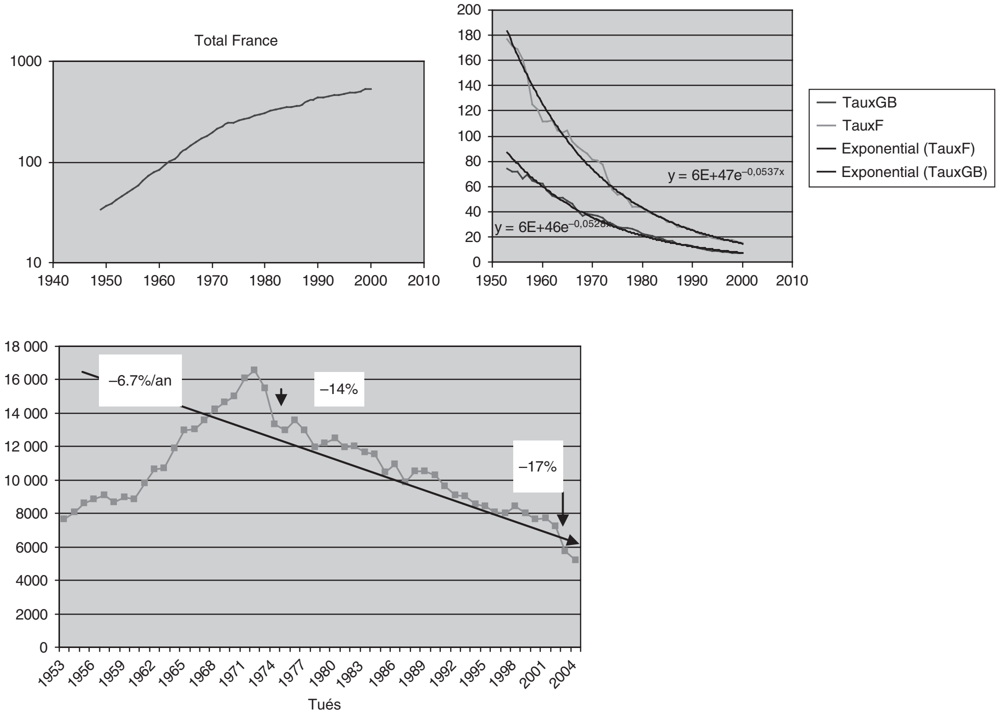

Figure 12.8 Evolution in France of the number of vehicle ∗ kilometers (logarithmic scale, unit 10^8), fatality risk (unit 10^{-8}) and the number of fatalities (source: Lassarre and Hoyau 2009).

increases with the economic development up to a turning point at a value of 8500 US$ then starts decreasing. At the country level, one needs to attain a certain degree of development in order to invest in safety for reducing the burden of road accidents, in the same way as for reducing environmental pollution.

Such models have to be examined carefully, as they rely first of all on the quality of the data collected (with uncertainty about the counting of fatalities in developing countries) and on the validity of the model and of its estimation techniques.

The long-term model of the mortality rate and the GDP can take a linear form after a logarithmic transformation; the coefficient β_0 is the elasticity which is constant but could differ among the countries

$$\log FAT_{it} = \alpha_i + f_i(t) + \beta_{0i} \log GDP_{it} + u_{it}$$

It includes a fixed effect of a country or a region, and a trend translating the socio-technical progress, depending on the country or region if necessary, which could be

– a linear trend $\beta_i\mathrm{t}$,
– a linear trend plus interventions (national road safety measures taken) $\beta_i\mathrm{t} + \omega_i\mathrm{I}_{it}$,
– a parabolic trend $\beta_i\mathrm{t} + \eta_i\mathrm{t}^2$.

In the Kopits model (2005), the elasticity is no more constant with the introduction of the square of the logarithm of GDP

$$\log FAT_{it} = \alpha_i + f_i(t) + \beta_{0i} \log GDP_{it} + \beta_{1i} \log GDP_{it}^2 + u_{it}$$

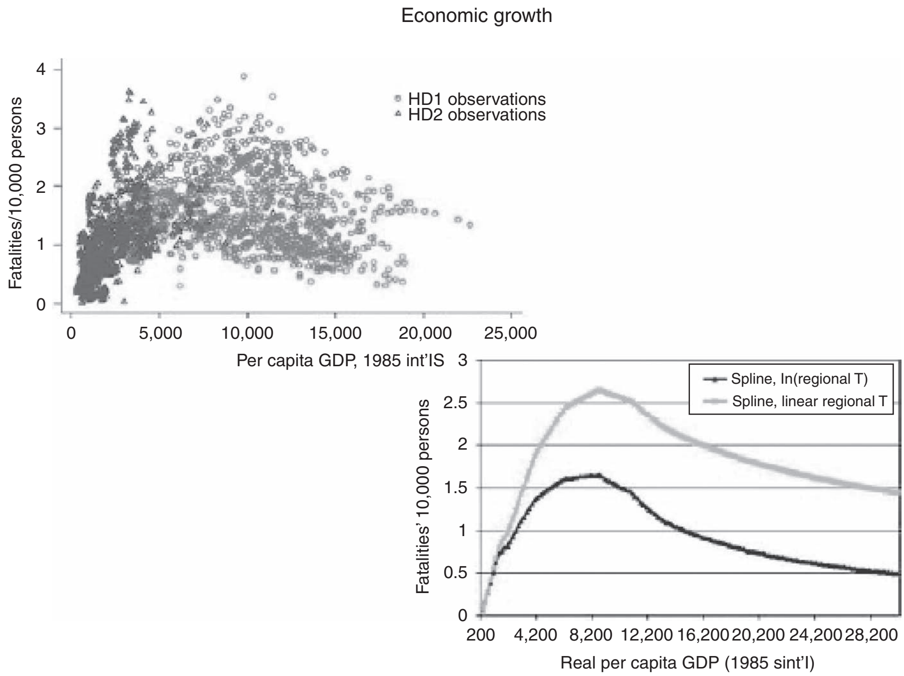

Figure 12.9 Data points and curves fitting per capita GDP and mortality rates according to Kopits (source: Kopits and Cropper 2005).

We get the Kuznets curve (an inverted U curve) with a concave parabola if $\beta_{0i} > 0$, $\beta_{1i} < 0$. In this case the elasticity is a linear decreasing function of the GDP

$$\frac{\text{dlog } FAT_{it}}{\text{dlog } GDP_{it}} = \beta_{0i} + 2\beta_{1i}\text{log}GDP_{it}$$

Some precautions have to be taken in the regression by introducing some proxy variables playing the role of common factors among the macro-panel and some structural models of the variances (autoregression and heteroscedasticity). Furthermore, the hypothesis of homogeneity of the elasticity (same value for all countries) has to be tested before applying such a hypothesis as in the Kopits model. The same applies for the test of a hypothesis of the same type and value of trend. And finally one has to consider the possibility of cointegration between these time series as we know that over more than twenty years the number of fatalities is not a stationary time series but could be integrated of order 1 or 2 (combining a deterministic and a stochastic linear trend) and that the deflated GDP is integrated of order 1 (Dupont et al 2014).

One has to be cautious about the results coming from such models on macro-panel data. Nevertheless from an analysis made by an IRTAD (International Road Traffic and Accident Database) working group (ITF 2014), we could admit a positive relationship between GDP and mortality rate and fatality risk. As we expect, a relationship between GDP and the mortality rate (because GDP influences the motorization rate or the mobility rate and acts as a proxy for this variable), the relationship between GDP and fatality risk is more informative in the sense that it shows a direct effect on the number of fatalities through the risk, plus an indirect effect through the mobility. The unemployment rate is negatively related to the mortality rate or the fatality risk, maybe because unemployment affects mainly the young people who are more at risk.

12.3 RISK INDICATORS IN ROAD TRANSPORT

People are not exposed permanently to the risk of traffic accident. In fact they are exposed to the risk when they are on the road or on the street as a pedestrian, cyclist, driver or passenger of a motorized vehicle. Note that some people, because of their jobs (policemen, street cleaners, or professional drivers), are more exposed to the risk.

The exposure is no more 24 hours long but limited to the duration of the presence on the road or street network. This exposure can be measured either by an amount of time, like a number of hours spent in the traffic, or by the distance driven on the network. The information on these exposure indicators comes from mobility surveys for persons (households) or goods (companies) or from counts on the road network by vehicle categories. In addition to the internal traffic of local people and companies, one has to consider the transit traffic from abroad coming or passing through the territory. We can also use the gas sales as a proxy for estimating the number of vehicle ∗ kilometers driven by motorized vehicles in a country, knowing the consumption rate of liter per kilometer.

We end with a series of individual risk indicators:

– Rate of implication in an injury (fatal) traffic accident per hour or per kilometer,
– Rate of being injured or killed in an injury (fatal) traffic accident per hour or per kilometer.

The second one is called the fatality risk in terms of number of deaths per million of hours or kilometers. Such rates can be calculated for each road user type: driver of a car, motto, lorry, bicycle, passenger in a car, motorcycle, lorry, bicycle, public transport such as a bus, or pedestrian.

These rates can be related to the vehicle as done by the insurance companies. See by example the premium related to the number of kilometers driven. Usually a premium is calculated relative to the power and age of the vehicle, the residence of the owner, and the age and sex (beware of discrimination) of the main driver. We end with a new series of individual risk indicators which are:

– rate of implication in an injury (fatal) traffic accident per vehicle ∗ kilometer
– rate of being injured or killed in an injury (fatal) traffic accident per vehicle ∗ kilometer.

Sometimes these indicators can be downgraded by taking the number of vehicles, that is to say the size of the fleet of motorized vehicles in a country, as exposure. When calculating these risk indicators for each type of motorized vehicle, we could distinguish between an internal and

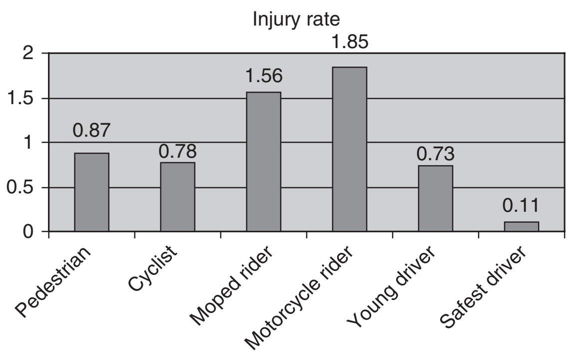

Figure 12.10 Injury rate in Norway (injuries per million person kilometres of travel) (source: Elvik 1999).

TABLE 12.1 Fatality rates per hour or kilometer in Great-Britain for transport modes and other activities (source: Evans 1994).

Great-Britain	**Fatality rate per 100 million hours**	**Fatality rate per 100 million kilometres**
Passenger travel by		
Bus	1.4	0.06
Rail	6	0.1
Car	12.4	0.4
Water	16	0.8
Air	20	0.04
Foot	27	7
Bicycle	64	4.6
Motorcycle	342	11.4
Employment		
All work	0.9	
At home		
All ages	2.6	
People over 75	22	

an external risk by taking into account either the individuals inside the vehicle, like the driver and the passengers of the car, or the individuals involved in the collision with that type of vehicle but situated on board another vehicle or as vulnerable road users such as cyclists or pedestrians. The fatality risk for the driver of a lorry is 15 to 20 times less than the fatality risk for the occupants or a car hit by a lorry. The internal risk for trucks is very low, but the external risk is rather high because of the mass of the vehicle, which causes a lot of damage.

These indicators are considered to measure the safety performance of the road transportation system. The fatality rate per billion of vehicle ∗ kilometre is a classic risk indicator which decreases regularly along an exponential function over time due to socio-technical learning, as has been shown previously. The fatality rate per vehicle ∗ kilometre decreases with GDP as shown by Kopits with a regression model on a macro-panel of OECD countries.

We can compare the performances of different modes of transport which are not by road, such air and rail, and also the transport risks with other risks generated by other activities, such as going to work or staying at home (Evans 1994).

12.4 MODELS OF ACCIDENT FREQUENCY AND SEVERITY

In the Insurance industry, the practice in risk evaluation is to separately model the frequency and the severity of crashes of the vehicles that are insured. The number of accidents is supposed to follow a Poisson distribution. The number of victims in an accident or the cost of an accident is a random variable Z, which could be a Pascal distribution for the number of injuries or a log-normal distribution for the cost of an accident.

Then, the number of victims or the total cost in a set of accidents is a random sum of random variables which follows a compound Poisson distribution

$$N_g(t) = \sum_{i=1}^{N_a(t)=n} Z_i = Z_1 + Z_2 + \cdots + Z_n \qquad \begin{array}{l} E(N_g(t)) = E(N_a(t))E(Z) \\ Var(N_g(t)) = E(N_a(t))E(Z^2) \end{array}$$

It means that the number of fatalities or injuries is an overdispersed Poisson distribution because the variance is not equal to the mean but greater.

For the number of accidents, especially for counts on road section or junction, a negative binomial distribution is used instead of the Poisson distribution. Some other specific distribution such as the zero inflated Poison distribution could also be used.

12.5 CONCLUSION

Risk of road traffic has been extensively described and analyzed through probabilistic and statistical risk models coming from epidemiology and reliability theories. Individual and collective risks are measured and estimated to assess the importance of the burden of accidents through classic risk indicators such as mortality and fatality rates, as well as morbidity and injury rates. The estimators are subject to the exhaustivity of the counts of accidents and victims and of the precision of the mobility indicators used as measures of exposure to the risk. The relationships between the risk indicators and the main risk factors are rather well documented by means of aggregated risk models, but the exactness of the form of the relationships requires advanced statistical technics and not just simple linear regression fits.

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CHAPTER 13

Investigating Driving Failures and Their Factors by In-Depth Accident Studies: The Example of Powered Two-Wheelers

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CONTENTS

ABSTRACT

In-depth accident study is a method useful as a complement to more quantitative accident approaches, to further the research in malfunctions in the driving system and their determinants. They help to precisely define the adapted countermeasures to address the right targets. The road users are considered central in such an analysis, to understand the nature and the reasons for the difficulties and malfunctions they encounter when on the road. This paper presents some key elements on in-depth accident data collection and elaboration, on the sequential analysis of the accident process; the functional analysis of human failures and their factors. As part of the traffic system, the powered two-wheelers have become a component both crucial and critical. In the second part of the paper, they are taken as an application example of what can bring an in-depth accident approach to the understanding of the difficulties faced by road users.

Key Words: Accident Analysis; Human Failures; Human Factors; Systems Approach; Powered Two-Wheelers

13.1 INTRODUCTION

The aim of this chapter is to show a thorough analysis of accident mechanisms, for their prevention and the mitigation of their consequences. It presents a number of key data used to carry out such an analysis with particular emphasis on the role that the data has to take in this analysis as a central component in the traffic system: the road users. It will be shown that considering the road users as central to the analysis is not to blame them, but to understand the nature and the multi-factorial reasons for the difficulties and malfunctions they encounter. As a matter of fact, understanding comprehensively the mechanisms of an accident requires not only that we go beyond a common sense analysis oversimplifying things, but also avoid the bias of a "responsibility" approach, which confuses the accident study with the work of a judge or a policeman who looks for the guilty party. In order to seek countermeasures well adapted to the problems at hand, it must be kept in mind that the traffic system as a whole is dedicated to road users. So a thorough review of these road users' difficulties and frailties is needed to improve such a system, through actions that aim to adapt at best this system to their characteristics and capacities.

Among road users, the drivers of powered two wheelers (PTWs) take a special place in the field of concern because of their intrinsic vulnerability, their current development in the world of individual means of transport, and their absence in road safety policies (ITF 2015). That is why the second part of this chapter will focus on a detailed analysis of their accidents, viewed as an example of how the method described in the first part can be applied in practice.

Beforehand, it must be remembered that the "accident approach" is complementary to the other approaches to road safety. Its interest relies on focusing directly on attested problems; its drawback is to show only what is not working well. As such, this approach will often require being associated with observations, surveys, and experiments to develop certain issues or to investigate the influence of such-and-such variables further upstream. Road safety analysis as a whole seeks to understand the malfunctioning mechanisms in a way to define solutions on an informed basis not subject to presuppositions. Knowing that the solution to a problem is not necessarily where the cause is located (for example, it is often efficient to act appropriately on the infrastructure to modify the behaviour of the drivers), and keeping in mind that understanding the role of the different factors and of the different actors in the system is needed to define the most appropriate solutions.

Two complementary aspects are to be considered in accident analysis: 1) the quantitative (statistical, epidemiological) approach that allows for the defining of the stakes of the problems in terms of safety specific to such-and-such a jurisdiction, on the risk faced by such-and-such a part of the road user population (young drivers, the elderly, motorcycles), and 2) the in-depth approach that allows us to go further in the research of malfunctions and their determinants; the latter being the object of the present essay.

13.2 IN-DEPTH ACCIDENT STUDY AS A COMPLEMENTARY TOOL FOR ROAD SAFETY

As mentioned by Elvik and Vaa (2004), the reporting of road accidents in official statistics is incomplete and biased. These data are most generally produced from information collected by the police, whose work consists of defining the respective faults and responsibilities rather than understanding the combination of elements involved in the different steps of the accident process. The result is that a large number of potential data elements of importance are not 'still according to Elvik and Vaa' correctly reported.

The fact is that one of the limitations of the statistical approaches is the focus on the final phase of the accidents: the collision, so as to find out the most directly determining element. This is what led to the very widespread conception that the great majority of accidents are caused by "human error". It is nevertheless useful to question the various successive stages which preceded this error and contributed to it. It is also essential to understand well the nature of this error and to identify the combination of factors which contributed to it in order to widen the scope of countermeasures, not limited to enforcement but also addressing, on a well-documented basis, driver training, improvement of infrastructure safety, improvement of vehicle and equipment, communication campaigns, and so on.

13.2.1 Data collection and elaboration

In-depth accident investigation can cover a wide range of activities according to the purpose of the data collection. This is reflected by the vague definition by OECD (1988) as an accident investigation which goes much deeper into in-depth than the data currently available. The present description is mainly based on the In-Depth Accident Studies data collection method conducted at IFSTTAR – Accident Mechanism Laboratory. But references are also made to the European projects TRACE (2008) and DACOTA (2012).

The general principle of the method is to collect, as soon as possible, as much information as possible on the three components of the driver-vehicle-environment system. A multidisciplinary team of investigators (a technician and a psychologist) is automatically alerted and takes action at the same time as the emergency service on the scene of the accident. They make their own data collection (material clues, witness statements) focusing on the process of the accident and its circumstances. The collected data concerns the involved persons, the vehicles, the road, and the environment. The data collection can be processed in two steps:

On the scene of the accident the priority is to take pictures and films of the final positions of the vehicles, of the tracks on the ground, of the vehicle deformations and every other relevant element that can help to understand the accident. A careful examination of the vehicles involved is made to collect information such as the position of the gear lever, the weight of a possible loading, the presence of a mobile phone ... The interviews conducted with the involved road users will be specifically orientated towards the course of events and the people's own perceptions and difficulties during the events.

A second step of data collection is performed to answer some questions and statements that remain unclear. This can involve complementary interviews with the drivers in quieter conditions allowing the data collection to go deeper into the investigation.

Once the information needed is collected, a kinematic reconstruction is performed, usefully with the help of specific software, being based on final and impact positions, skid marks, the

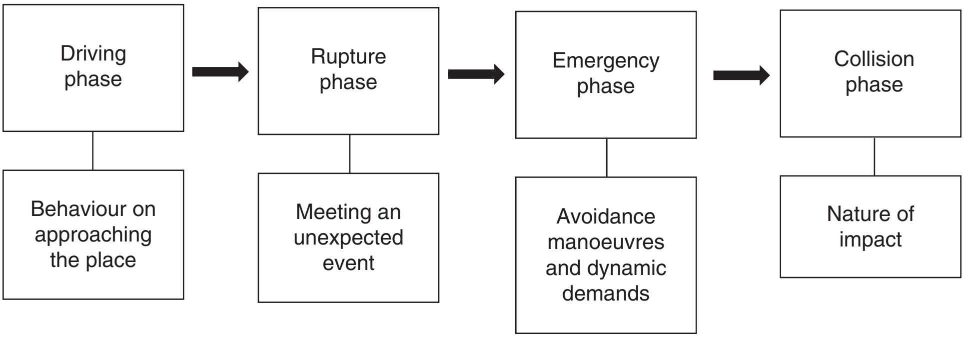

Figure 13.1 Major steps to consider in a sequential analysis of accidents.

impact angle, impact locations of the vehicles, the testimonies from the involved persons, the victims' injuries, etc. The purpose of the reconstruction is to build a spatiotemporal description of the accident process, consistent with the entirety of the data collected.

A precise description of the data collection protocols and of the elements of the method of kinematic reconstruction can be found in the DaCoTa project on-line Manual (DaCoTa 2012).

13.2.2 A sequential analysis

Driving activity has often been defined as a complex and sequential task. Being an output of a driving malfunction, nearly every accident is also the result of a complex and temporal process. It is necessary to consider this complexity and sequential feature to consider each intervening element in the overall process and to clarify the role it plays in the accident process.

Accidents are not only "crashes", meaning by that that they cannot be limited to the last step of their development: the collision. If one were considering only the crash situation to understand the accident, it is important not to mix causes and consequences, and to provide useful analysis, using both scientific and operational angles. In the resulting crash situation it is essential to analyse, from a secondary safety point of view, safety; but the earlier steps of the accident genesis must also be taken into consideration from a primary safety perspective, with the purpose of improving prevention.

So the first stage of analysis consists of drawing up the accident scenario in terms of the sequence of events and, in particular, by describing the initial state of the system before a problem has occurred, by identifying the triggering event and by reconstructing the emergency manoeuvre. The second stage is to identify the mechanisms that contribute to the production of this sequence of events: these mechanisms are found in the interaction between the system components. To achieve this, each individual scenario is divided into four phases, connected one to the other (Figure 13.1). The description that follows made use, notably, of the following papers: Girard (1993), Van Elslande et al (2008), Ferrandez et al (1995), Fleury and Brenac (2007) and Hill et al (2012).

13.2.2.1 The driving phase

The driving situation represents the state of the driving system before a problem arises. It is the 'normal' situation, which corresponds for the driver to the performance of a specific task in a given context, with certain objectives, certain expectations, and so on. It is 'normal' because up to this point no unexpected demands are made upon him. The driver can adapt effectively, the events occur in line with his/her anticipations. He/she is not overloaded with information. He/she controls his/her speed and course; he/she is 'master of the vehicle'. In more general terms, there is a balance between the demands and ability of the system components to respond one to another: road alignment, skid-resistance, sight distance, tyre wear and pressure, the condition of the shock absorbers, road surface quality, speed, degree of driver awareness, etc. It should be noted that "normality" in this case refers to effectiveness and controllability, but not necessarily to compliance with traffic regulations.

The study of this situation indicates what the drivers involved considered to be both desirable and feasible in a particular place, given a particular context.

13.2.2.2 The rupture phase

The so-called "rupture" consists of an unexpected event that interrupts the driving situation by upsetting its balance and thus endangering the system. That event could be an unforeseen presence or manoeuvre by another user, the advent of an infrastructure configuration which takes the driver by surprise or provokes a sudden high workload, and so on. The effect of the rupture situation is to suddenly switch the system components from a bearable level of demand to an excessive demand in terms of the ability to respond.

It should be noted that an "unexpected event" does not necessarily mean "unpredictable", which raises the question as to what extent it really was unpredictable, and if not, why it was unexpected. Information about the previous driving situation is of considerable use when seeking an explanation.

13.2.2.3 The emergency phase

The emergency phase covers the space and time between rupture and collision. It is the period during which the driver tries to return to the normal situation by carrying out an emergency manoeuvre. A particular feature of this phase is that the driver faces very severe constraints (both temporal and dynamic) regarding the options open to him. The emergency situation can be so characterized by the sudden excessive demand level imposed on the system components. The driver must solve, within a given time, a problem that he did not expect. The range of solutions depends on the environment in terms of the space available for evasive action and also in terms of obstacles. The capacity of the vehicle to perform the required manoeuvre depends not only on its design and mechanical state but also, due to vehicle-ground interaction, on the state of the infrastructure. The emergency situation reveals the insufficiencies or defects in one or the other of the system components, weaknesses that remained tolerable when faced with normally moderate driving situation demands. Of course, this phase of the emergency may not be manifest when the driver is unaware of the danger until the impact.

The emergency manoeuvre is an attempt to solve a problem. It sometimes succeeds, but if an accident has occurred, this manoeuvre has failed. So the emergency situation is followed by the collision phase.

13.2.2.4 The crash or collision phase

The collision phase comprises the crash and its consequences. It determines the severity of the accident in terms of material damage and bodily injury. Once again, the situational circumstances depend on what has occurred previously and also on the interaction between the three components: thus an elderly person is more vulnerable to injury, modern vehicles are better designed for crashworthiness, a protective rail prevents impact with a hostile obstacle, etc.

The identification of these phases (or 'situations') enables the different sequential stages of the accident to be reconstituted in a homogeneous manner, which makes it possible not only to analyse each case from the viewpoint of the process that engenders it, but also to set up horizontal studies of several accidents by comparing the successive stages in their development.

This can lead to the definition of homogeneous typical accident-generating scenarios, useful for action (Fleury and Brenac 2001).

We are particularly interested in the analysis that follows in the so-called 'rupture' situation, which is a key stage that pitches the driver from a normal driving situation into an impaired one. This transitional phase is a good place for comparing accidents, to the extent that it forms the pivotal moment of the accident generation. The human functional failure occurring at this moment will be essential to consider for the purpose of primary safety development. In the sequence of failures that follows the accidental impact, we thus identify those which characterize this moment of rupture and explain why the driver suddenly finds himself in a critical situation.

13.2.3 A functional analysis of human difficulties

13.2.3.1 Driving as a complex task calling for system adjustment

Despite the apparent simplicity of the partly automatic (skilled) way in which drivers operate, driving a car can be considered a difficult activity performed in a dynamic and complex environment in which drivers' regulating functions are sometimes over requested, so that their adaptation capacities are eventually pushed to their limits (Van Elslande 2003). Accidents are the most evident symptoms of this capacity overflow in compensating for driving system demands. Insofar as drivers are not willing to have an accident 'even when they take risks' every accident case necessarily proceeds through a failure of one or another regulating function which usually renders the road users able to compensate for the driving difficulties they meet at the wheel. Consequently, an important way of obtaining knowledge about the relevant mechanisms behind road dangers is to analyse these human functional failures, their factors, and the characteristics of the contexts in which they occur. For this purpose, in-depth accident studies make it possible to understand more precisely these operating malfunctions, in relation to both the situational driving context (interaction with the vehicle, the road, and with other users) and the internal driving context (state, intentions, motivations, etc.).

13.2.3.2 Human functional failures

The Human Functional Failures (HFF) model has been elaborated through a cross-referenced use of many studies of accident cases, making use of the data in the literature on human error (e.g. Reason 1995, Rasmussen, Hollnagel) in order to elaborate on an operational grid for classifying human errors and deficiencies that are found in deteriorated driving situations (Van Elslande 2003). This classification model has been used in numerous accident studies published in scientific papers and has notably been validated in the framework of the European TRACE (Traffic Accident Causation in Europe) project (Van Elslande, Naing, and Engel 2008).

Human failures are not defined as "faults", because failures can also be found for "not at fault" road users. The aim is to use the failures to identify the limits (physical and mental) of human capacity and therefore be able to better understand the types of countermeasures that would assist in overcoming these human limitations.

The HFF model distinguishes five major functional categories within which can be identified the incapacity of a function (perceptive, diagnostic, prognostic, decision, motor) to overcome a difficult encountered by the driver. A sixth heading deals more with the problem of a temporary general aptitude to drive than the specific capacity to handle a difficulty: these "generalized failures" correspond to an alteration to the entire functional chain (i.e. on the perceptive, cognitive and psychomotor levels) making the driver unable to manage the slightest difficulty encountered on his route, (e.g. falling asleep). These different categories of failure are delineated in 20 types of failure which are further detailed in table 13.1.

TABLE 13.1 Distribution of Human Functional Failures.

Failures Categories	Types of Failures
Perception	Per1: Non-detection in a situation of limited visibility Per2: Information acquisition focused on a partial component of the situation Per3: Cursory or hurried information acquisition Per4: Momentary interruption in information acquisition activity Per5: Neglect of information-seeking requirements
Diagnosis	Diag1: Poor evaluation of a temporary road difficulty Diag2: Erroneous evaluation of the size of a time/space gap Diag3: Mistaken understanding of how a site functions Diag4: Mistaken understanding of another user's manoeuvre
Prognosis	Pro1: Expectation by default of no manoeuvre by another user Pro2: Active expectation of adjustment by another user Pro3: Expectation of no obstacle
Decision making	Dec1: Violation directed by the characteristics of the situation Dec2: Deliberate violation of safety rule Dec3: Violation by automatism
Action taking	Exe1: Poor controllability when faced with an external disturbance Exe2: Guidance problem
Overall failure	Gen1: Total loss of psychophysiological capacities (e.g. falling asleep) Gen2: Alteration of all sensorimotor and cognitive capacities Gen3: Overstretching cognitive capacities

1. *Perceptive failures* (Per1 to Per5) cover the different kinds of problems in detecting and identifying certain parameters essential to the situation, depending on the reasons behind it (see table 13.1).
2. *Diagnostic failures* (Diag1 to Diag4) describe information processing problems which keep the driver from evaluating the physical parameters identified during the previous step so as to estimate the feasibility of the planned manoeuvre; and also from understanding the information gathered concerning the type of situation the driver is confronted with in his/her interaction with the environment and traffic.
3. *Prognostic failures* (Pro1 to Pro3) correspond to another information processing step, characteristic of all activities with a dynamic component: developing expectations as to the potential development of a situation.
4. *Decision failures* (Dec1 to Dec3) correspond to an ill-suited "choice" of a manoeuvre by the driver among the driving strategies he/she could have adopted in the situation, notably from the point of view of its safety demands.
5. *Failures in the psychomotor step of executing the action* (Exe1 to Exe2) deal with weaknesses in the last link in the functional chain involved in the driving activity: action on the vehicle's controls to guide it along the trajectory followed.
6. *Generalized failures* (Gen1 to Gen3) are distinguished from the previous driving failures in that they deal with an alteration, not of one function, but of the entire functional chain described or a large part of it. The problem thus is situated at the upper level of the individual's general ability to control the situations, both in terms of the information to be gathered, the processing operations to be applied, the decisions to be taken or the actions to be undertaken.

13.2.3.3 Factors of human failures

In this methodology, a clear distinction is made between human failures and human factors. Human failures are defined as "the unwanted outcome of a confrontation of the driver with a task in which a difficulty was met". They are the result of a combination of factors, involving human, vehicle or road parameters; these factors being defined as "characteristics of the system which have weakened its capacity to function safely". So the functional failures are explained by different patterns of factors linked to the driver's condition motivations and experience, to the layouts (e.g. complexity, visibility), to the driving conditions (e.g. presence of an unlit obstacle, atypical manoeuvre by another user) and to the vehicle parameters (e.g. technical condition of the safety equipment, obstacles to visibility).

It must be noticed that different factors can act at different steps of the accident process. Some factors can play a role in the driving phase, contributing to the human failure to come (e.g. a road infrastructure allowing or favouring speeding behaviour), some can directly trigger the failure at the rupture stage (e.g. an erased stop line), some can act at the emergency phase by impeding the possibility to recover the failure (e.g. non-practicability of the pavement edges), and last, some elements can be the aggravation of the consequences of the crash at the collision phase (e.g. an aggressive obstacle).

A detailed presentation of the factors possibly acting on driving failures can be found in Van Elslande et al (2008).

13.3 IN-DEPTH STUDY OF POWERED TWO-WHEELER ACCIDENT MECHANISMS

The powered two-wheeler (PTW) population, which includes motorcycles, scooters and mopeds, has been constantly increasing in the traffic and it plays a significant role in mobility in many countries, particularly in many of the world's large cities where PTWs have become a real alternative to passenger cars, given the level of traffic congestion. Indeed, PTWs present a number of advantages, including flexibility, reliability of travel time, and lower cost of use compared to a private car. Some riders use PTWs as their primary form of transport, others for recreation. For many it is the only affordable or practical means of individual motorized mobility (ITF 2015). It is estimated that there are more than 300 million powered two-wheelers in the world, with a relatively uneven distribution across regions: around three quarters are found in Asia, 16% in North America and Europe, 5% in Latin America, 1% in Africa and 1% in the Middle East (Rogers, 2008). In the various OECD countries, PTWs account for between 2 to 31% of the motorized fleet; the highest percentage generally being found in countries with a mild climate. They can even form the dominant motorized transport mode in some developing and emerging countries, comprising up to 85% of motorized vehicles. In most countries, the motorcycle fleet increased much faster than the passenger car fleet from 2001 to 2010 (ITF 2015).

But at the same time, PTW riders have not benefited at the same pace as car occupants from safety improvements. Per kilometre driven, PTW riders have a much higher risk (between 9 and 30 times, depending on the country) of being killed than car occupants. PTW riders are also more likely to be very seriously injured, with long-term disabilities, in a road crash than other motorized road users.

Growing PTW traffic and the repercussion in casualties makes it imperative to adopt safety interventions targeting this mode of transport, addressing the different facets of the problems by a combination of actions directed towards the road users, the infrastructure, and the vehicles. Aiming at such a target involves going beyond a too general or preconceived approach of the PTW travelling safety issue. There is a need for a detailed investigation of the difficulties encountered by PTW riders and those who interact with them on the road. It must be acknowledged that PTWs have a special place in traffic, with a template, performance, and driving that may raise specific difficulties of interaction with other users of the road space; it must be taken into account that they have a specific dynamic behaviour that can sometimes cause greater control difficulties; and of course, the vulnerability inherent in this mode of transport must not be forgotten. All this leads to specific accident mechanisms that have to be elucidated.

In addition to statistical and epidemiological analyses that describe the stakes of the problems, the risk levels and the people concerned, the thorough analysis of PTW accidents can characterize the malfunctions and specific factors affecting them, particularly in comparison with those of other road users. This section outlines the results of previous works (Van Elslande 2009; Jaffard and Van Elslande 2012) from in-depth analysis of PTW accidents following the method described above. These results are presented under two headings showing different malfunctions; the first one deals with loss of control of the PTW; the second one corresponds to wrong interactions with others.

13.3.1 PTW losses of control

In-depth analysis of loss of control accidents (without the intervention of another road user) shows a marked differentiation of failures observed for PTW drivers compared to the other drivers. For the latter, loss of control is highly correlated to a general deterioration of driving ability (following a decrease in vigilance, because of a significant impregnation of alcohol or other drugs), a phenomenon which is less represented in the PTW sample. Two main categories of human failure represent the principal challenges for PTW drivers:

- At the stage of Diagnosis of the situation, the evaluation by the rider of a difficulty in the infrastructure that corresponds most generally to the negotiability of a bend, but also includes losses of adhesion of the road surface. The human failure type “Wrong evaluation of a difficulty relative to the infrastructure” is found in one third of the PTW losses of control, which is significantly more than the others.
- At the stage of executing the driving act, PTW riders show more difficulty in controlling their vehicle than other drivers. These difficulties often occur in encounters with environmental constraints (poor adhesion, surface defects, wind, rain, etc.); which gives us cues of a certain sensitivity of these two-wheeled vehicles to external disturbances (the human failure type “poor controllability of the vehicle” appears in nearly 35% of PTW losses of control versus 14.5% for other vehicles). On the other hand, the loss of control involving more endogenous reasons – a lack of attention or vigilance – does not specifically characterize PTW users.

Thus, PTW losses of control partly involve the sensitivity of such vehicles to constraints and difficulties from infrastructure and environment: what is easily controlled by the four-wheel vehicle drivers can become critical for two-wheeler drivers. As such, PTW accidents sometimes bring latent malfunctions (Reason 1995) of the traffic system to the foreground, malfunctions that are usually masked by the lower impact they have on the majority of circulating vehicles. This shows in particular, the need to address infrastructure elements such as pavement degradation problems, adhesion conditions, the road alignment, etc., taking into account the sensitivities of motorcycle riding.

But this type of accident often also involves behavioural parameters that contribute to make a small road difficulty into an insurmountable ordeal. Speed is an undoubted factor in loss of control. However, different mechanisms of involvement of speed must be distinguished. The accident analysis shows, in more than a quarter of the cases, an inappropriate behaviour that can be described as risky: a playful attitude, competitive, euphoric, etc., that pushes the driver to his limit and causes a loss of control when facing the slightest disturbance. But generally, a less caricatured behaviour is observed. In the most frequent cases, inadequate speed upstream comes from a problem of too great a trust shown by the PTW drivers in their evaluation and control capabilities. These two categories of problems must be distinguished in the analysis.

In summary, it follows from these analyses that there are several action vectors to fight PTW loss of control: a management of infrastructure that better integrates PTW characteristics; the enforcement of inappropriate behaviour; PTW driver training, not in performance, but in the identification of boundaries of skills, and the adoption of a necessary regulating margin for unexpected events. The improvement of vehicles is also an crucial aspect, notably improved brakes for emergency situations: combined front-rear braking, and anti-lock braking systems (see ITF 2015). But these different actions mag expressly reinforce the feeling of confidence of PTW drivers in their mastery of driving situations, and achieve the opposite effect.

13.3.2 Wrong interaction with others

Here we analyse accidents that originated from a bad interaction with another road user (this other user being hit or not). Again, the in-depth analysis of these accidents shows a marked distinction between failures observed for PTW users and those of other drivers in non PTW accidents.

It is first noted that the Perceptual failures are found less for PTW riders than for the other road users. The PTW drivers' failures, in accidents which confront them with other road users, affect essentially the "prognosis" step (anticipation) for motorcycles riders, and the "decision" stage (manoeuvre undertaking) for moped drivers. So, the in-depth analysis of accidents also shows strong differentiation within the population of PTWs, between motorcycles and mopeds.

Failures of Prognostic functions characterize almost 40% of the motorcycle accidents studied and 27% for mopeds (23% for other road users). These erroneous expectations are specified in three types of riders' prognosis failures in a fairly balanced way:

- The "active expectation of adjustment by another road user" characterizes riders who become aware of a critical situation but who leave to the others the care of correcting it, by simply trivializing the danger or on the basis of a priority feeling;
- The "by default expectation of no manoeuvre by another user" characterizes drivers who have been surprised by a manoeuvre they had not anticipated.
- The "expectation of no obstacle on the path" refers to the implicit bet that is made by some riders of a clear road despite the lack of visibility (e.g. vegetation on a bend), to the point of sometimes spilling over into the space reserved for others ...

The Decision problems characterize 23% of the moped accidents sample (7% for motorcyclists, 9% for motorists). They relate mainly to the "wilful violation of a safety rule" when the decision to commit a specific manoeuvre (overtaking, turning, etc.) is taken, while the safe conditions for its realization are not met.

Such results from a detailed analysis of accidents attest to the fact that it is necessary not to drown the different facets of the problems with an overall vision. There are accidental configurations which clearly differentiate the different PTW users and these features must be clearly identified so as to put in place the correct measures on the right targets.

Motorcyclists are thus much less characterized in the sample studied, than the mopeds' users, by the decision to deliberately commit manoeuvres violating the rules. It must be noted, however, within the upstream factors of driving failures, a higher incidence of the parameters: "adoption of a too high speed for the situation" (even if legal) and "ludic driving" (playful, competitive) for the motorcyclists than for motorists. It is not a question here of a functional failure in the strict sense since these parameters have not directly conditioned the occurrence of the accident, but they have nonetheless contributed in combination with other factors to the genesis of a failure of perception, information processing, or control of the action.

It must be remembered that human failures differently particularize motorcycles and mopeds drivers; the first fail by overconfidence in their expectations about the situations changing and in their forecasts about obstacles that may be encountered; the latter more often manifest inappropriate decisions of manoeuvres engagement in unsafe conditions, to the detriment of socially shared rules. Motorcyclists are far more marginal than "mopedists" for this last kind of malfunction.

Note finally that the PTW riders as a whole are less often involved in accidents for which they are exempt of failure (7.4% vs. 14.2% for the control sample). This is a surprising result while PTW riders are in majority considered non responsible in the accidents they have with car drivers (ACEM 2009).This suggests that they often actively participate, on a secondary basis, in the accidents of which they are victims, notably by putting forward some kind of atypical behaviour surprising for the others and pushing them at fault.

However, to conclude, it must be kept in mind that all the results presented here emerge from a specific sample of accidents, illustrative of PTW accidents occurring in France. Such an analysis should be updated according to the particularity of PTW situations in different jurisdictions. As shown in the ITF (2015), the stakes are not the same in all regions of the world, according to the road safety laws that are more or less developed, and the role that the different populations of PTW riders occupy within the overall traffic. The implementation of specific in-depth studies of accidents, inspired by the method described here, will allow better understanding of these regional specificities.

13.4 CONCLUSION

The thorough analysis of accidents is a longer process and more expensive both financially and temporally than the analyses which are based on the work of the police. But it has the advantage of not confining itself to the establishment of responsibilities, and not being limited by the findings of police investigation. Scientific approaches have converged on a multi-factorial concept of accidents, which are considered the product of interaction between several factors related both to the state and the behaviour of the road users involved, the design and maintenance of roads and streets, as well as the design and maintenance of vehicles. These analyses led to the "safe system approach" whose purpose is to avoid the most severe traffic crashes by integrating human limitations and frailty in the system functioning. This is done by acting on the different components of the road system in a way to promote safe behaviour on the part of the road users, to offer them the capacity to correct their eventual errors, and to protect them in case these errors cannot be corrected.

Analyzing in-depth the accidents according to the methods described in this chapter provides an understanding of the mechanisms of the entire genesis of accidents and the plurality of factors that contribute to functional failures of road users – whether they are held responsible or not. It thus gives the opportunity to identify broader preventive actions through training activities for road users, a better adaptation of road and street features to their functioning and capabilities, along with enhanced safety characteristics of vehicles and equipment.

Applying this method to a sample of PTW accidents has helped to identify a number of critical points that correspond to them. Such data came in addition to the results from quantitative approaches that highlight in particular the primacy over all other measures on motorcycling safety, of the obligation for all PTW users of a (correct) wearing of the helmet, as indicated by the ITF (2015). It could be said that for PTW riders who are intrinsically vulnerable, protection is the first step to prevention.

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CHAPTER 14

Human Body Models

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CONTENTS

ABSTRACT

Experimental studies with human subjects, volunteers or post mortem human subjects (PMHS) help us understand the biomechanics of the impact during a traffic crash. Anthropometric crash test dummies (ATDs) were developed to provide tools for the development and assessment of safety systems to address the variation in human anthropometry. ATDs are available with varying specifications of gender, age, and body sizes. Still, due to persistant limitations associated with ATDs and the advancement in computer based simulation capabilities, the human body computer models have become more popular in recent times. Their ability to simulate both pre-crash and post-crash scenarios, including active muscle response, has made them invaluable to crash analysis. This chapter discusses basic methodological considerations regarding human body models, includes a limited review of recently published whole body models, and briefly presents the biomechanical properties of human tissue. The chapter concludes with a discussion on future outlook and recommendations for targeted research on the aspect of injury predictability and making human body models more numerically robust.

Key Words: Human body models; crash simulations; tissue properties; numerical methods

14.1 INTRODUCTION

To prevent human injury in traffic it is necessary to understand the biomechanics of impact. This can be done through experimental studies with human subjects, volunteers, or post mortem human subjects (PMHS), after ethical approval. Volunteer studies can only be performed in a non-injurious loading regime, while PMHS can be subjected to injurious loading, with the major limitation that the mechanical properties of biological tissues change with death. The individual variation is large in experiments with human subjects, due to the wide spread of anthropometry and material properties that depend on factors such as gender, age, and health status. The mechanical anthropometric crash test dummies (ATDs) were developed to provide repetitive tools for development and assessment of safety systems. Over time, many different ATDs have been designed for specific loading conditions representing mid-size males, large males, small females and children of different ages. With the development of advanced safety systems, the ATDs can no longer adequately distinguish between the protective benefits of different modern safety systems. The need for a repetitive tool with increased bio fidelity and anatomical resolution initiated development of numerical human body models. With increasing computer capacity, human body models have become popular tools for traffic safety research and crash simulations.

Recently, collision avoidance systems have seen a rapid introduction on the market. These systems help the drivers, through warnings and autonomous interventions. Pre-crash maneuvers can influence the occupant posture prior to an impact, and thereby increase the protective potential of crash safety systems. Human body models have the potential to simulate occupant responses in both the pre-crash and crash phases if the active muscle response is included. To do so, a human-like control strategy of the muscle activity should be included in the human body models. This is not as relevant for crash simulations since the muscle forces are typically very small compared to the forces in the crash, and the duration of a crash is so short that there is hardly any time for the muscles to contract.

In recent years, development of human body models has increased and many papers are presented each year on new or enhanced models. Therefore, it is impossible to write a review of human body models that does not become outdated immediately. This paper aims to go through the basic methodological considerations regarding human body models, provide a limited review of recently published whole body models, briefly present biomechanical properties of human tissue, and finally provide a future outlook in the discussion.

14.2 MODELING AND METHODS

> "All models are wrong, but some are still useful."

This statement by Box and Drapper (1987) is essential for simulation engineers and anyone who makes decisions based on simulation results. This chapter introduces the challenge of creating useful human body models that increase our understanding of impact biomechanics and traffic safety.

The first critical step in any simulation is the problem of definition. If a problem is not correctly defined, then the simulation results will not be reliable. To set up a reliable simulation, it is necessary to have a thorough understanding of the problem at hand. For crash simulations with human body models, this means understanding among other things:

- How impact energy is transferred through a vehicle structure,
- How occupants are loaded by restraint systems, and
- How human tissues deform under impact loading.

The best quality simulation is set up if the answers are known. However, that is not the most useful simulation. The tricky question is how to set up simulations that provide reliable results when the answers are not known.

A problem definition should clearly state the objectives of the model. For example, a model with the objective to analyze pedestrian crash kinematics (Figure 14.1) will have very different

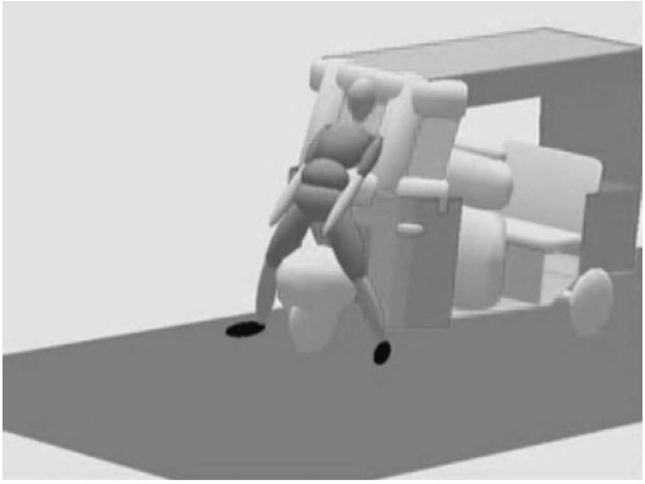

Figure 14.1 A multi-body simulation of a pedestrian to three-wheeler impact to analyze pedestrian kinematics such as head impact speed using a MADYMO multi-body human model (TNO 2012). Courtesy of Sudipto Mukherjee, Indian Institute of Technology, Delhi.

Figure 14.2 A finite element simulation of a frontal crash to analyze the thoracic injury risk for an occupant loaded by seat belt and airbag, here visualizing the shear stress in the ribs with THUMS (TMC 2008). Reprinted from (Mendoza-Vazquez 2014) with permission from Manuel Mendoza-Vazquez.

requirements compared to a model for predicting thoracic injury in frontal impacts (Figure 14.2). The first model mainly needs biofidelic joint motions and inertia properties of the body parts, while the second model has to have biofidelic rib cage deformation and a prediction of the stress and strain on the thoracic tissues. A model should not be more complicated than necessary, as additional details may also introduce additional limitations and errors. Hence, to analyze overall kinematics it is neither necessary nor beneficial to model the stress distribution of internal organs.

There are two major numerical techniques used for human body simulations: multi-body dynamics and the finite element method. Multi-body dynamics connect rigid or flexible bodies through kinematic joints that can constrain a number of degrees of freedom. Hence, it is well suited to study occupant or pedestrian kinematics. Explicit finite element methods divide the structure into a number of elements (volumes, surfaces or lines) that are connected by nodes and provide for example the stress and strain in the elements. Therefore, finite element simulations are more computationally expensive and well suited to study tissue deformation and predict injury. Explicit finite element methods provide approximate answers to partial differential equations, i.e. solving the equilibrium equation: $KU + C\dot{U} + M\ddot{U} = F$, where U are nodal displacements ($\dot{U}, \ddot{U}$ the nodal velocities and accelerations), K the stiffness matrix, C the inertia matrix and M the mass matrix of the structure at hand. For more theory and details of the explicit finite element methods, interested readers are referred to one of the many books on the topic of finite element analysis such as Sazbo and Babuska (1991) and Cook (2002).

For traffic safety applications, frequently used codes are; MADYMO (TASS, Rijswijk, The Netherlands) for multi-body dynamics, and LS-DYNA (Livermore Software Technology Corporation, Livermore, California, US), RADIOSS (Altair Engineering Inc, Troy, Michigan, US), and PAM-CRASH (ESI Group, Paris, France) for explicit finite element simulations.

Developing human body models requires a systematic methodology, such as exemplified here.

1. State the objective of the model clearly, including mandatory requirements and justified limitations. Describe the experimental data sets and criteria that are to be used for validation.
2. Acquire the geometry based on medical imaging. Computer tomography typically provides a good resolution of hard tissues (bones) while magnetic resonance imaging gives better resolution of soft tissues (muscles, internal organs, flesh). External measurements on volunteers can provide the outer geometry with good accuracy. There are a number of other imaging techniques that can be used as well, and anthropometric data bases that can provide a representative geometry rather than an individual's.
3. Create the finite element mesh using a pre-processor, either directly based on the medical imaging or through an intermediate step where surfaces are created. There is plenty of available commercial software capable of providing good quality mesh. It is recommended to keep track of the element quality since distorted elements can reduce the accuracy of the numerical calculations.
4. Choose material models (constitutive equations) based on biomechanical characteristics of tissues and the intended objective of the simulation. To make a good choice, an understanding of deformation rates and magnitudes is necessary. A simple material model has the advantage that it requires few material parameters to be measured. A complex and more biofidelic material model requires many parameters to be measured, which may not be feasible, and can result in a less biofidelic result if many parameters are based on engineering judgment alone.
5. Define contacts between different organs and body parts that will interact during the simulation. Other boundary conditions or restraints are added at this stage if needed.
6. Validation is a very important and usually time consuming step. During the validation, simulation results are compared with experimental data. If the result does not compare favorably to the experimental results (passes the specified criteria from step 1) it is necessary to go back to earlier steps in the methodology and revise the assumptions made. In many cases where material data are scarce the model responses are tuned to one or multiple sets of experimental data. If so, new data sets are needed to validate the model.

Model validation should be an essential part of any simulation strategy. For example, vehicle models are preferably created based on already existing and validated models of subsystems and then compared to full vehicle crash tests. Validation of human body models is more complex than validation of engineering structures, mainly because of:

- The difficulty of obtaining human test data,
- The experimental challenges connected to testing of biological tissues, and
- The wide individual spread of mechanical properties and anthropometry for humans.

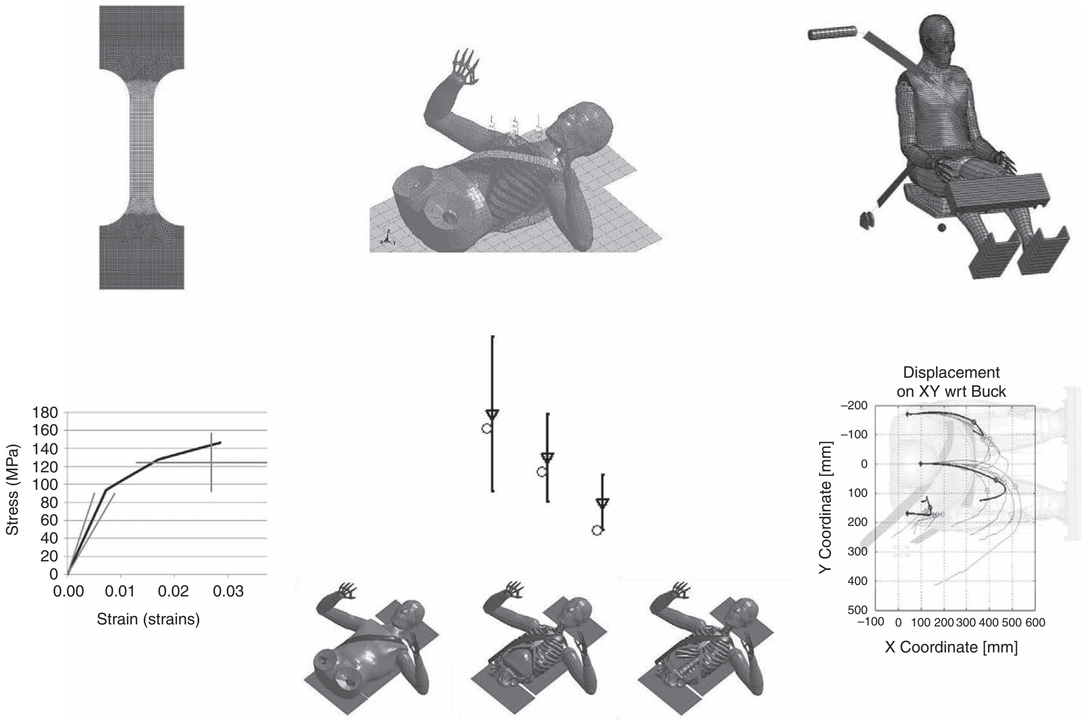

Figure 14.3 Illustration of the validation process with an example of thorax validation from Mendoza-Vazquez (2014). From left to right: Coupon test with rib cortical bone (Mendizabal Dones 2010) (experimental data from Kemper et al (2005)), Rib cage loaded with shoulder belt in intact, denuded and eviscerated states (experimental data from Kent (2008)), and Full body sled test (experimental data from Shaw et al (2009)). Reprinted with permission from Manuel Mendoza-Vazquez.

However, a useful and biofidelic human body model can be created with a structured validation process where the material models are compared to material testing (animal or human tissues), organ models are compared to human specimen testing, then compiled and compared to experimental data on body parts or regions, and finally the complete human model is compared to a relevant whole body test with volunteers or PMHS (Figure 14.3). The objective of the model and study determines if a model is valid or not. It is usually necessary to perform further validation before applying existing human body models to the development of safety systems.

14.3 OVERVIEW OF WHOLE BODY MODELS

This paragraph gives a brief overview of published human whole body models, multi-body and finite element models, starting with models for crash simulations and continuing with pre-crash simulations. There are numerous models of isolated body parts or regions that were not included in this review.

14.3.1 Crash models

The first human body models were based on multi-body modelling; an excellent review of the developments up to the 1980s was presented by Prasad and Chou (Prasad and Chou 1989).

Figure 14.4 Mid-size male models, cut in the sagittal plane to visualize the internal structures: THUMS v3 (TMC 2008), THUMS v4 (Watanabe et al 2011), GHBMC (Vavalle et al 2013).

In 1998, an omni directional model of the mid-size male was presented (Happee et al 1998) with skin surface, body mass and inertias defined based on the anthropometry database RAMSIS (Geuß 1994). In 2000, a mid-size male pedestrian model (Yang et al 2000) was developed with anthropometry, body mass, and inertias from the GEBOD database (Baughman 1983) and joint stiffness from experimental tests with post mortem human subjects. It was validated for car impact and lower extremity injury predictions (Yang et al 2000). Today, some of the most frequently used multi-body models are combined with finite elements for contact interaction and have been developed for the MADYMO code (TNO 2012). These adult models represent the small female, mid-size male, large male and scalable models of the mid-size male and small female (TNO 2012). They have been applied to a wide range of studies on topics that range from motorcycle safety to pedestrian impacts and crash simulations.

The first whole body child model was presented in 1979 (Wismans et al 1979), a 2-D model validated with one PMHS experiment. In 2002, multi-body child models representing pedestrians of 3, 6, 9, and 15 years of age (Liu and Yang 2002) were developed by scaling a mid-size male model (Yang et al 2000). These models were validated by reconstructing two accidents with child pedestrians (7 and 9 years of age). The overall trajectories and head impact locations correlated with the accident data. A year later, two pedestrian models of 3 and 6 years of age were published (van Hoof et al 2003) similarly scaled from a mid-size male model (Happee et al 1998). Validation data has not been published for these child models. In 2005, occupant models of 1.5 and 3 years of age were presented (van Rooij et al 2005) and then extended to occupants 6 and 10 years of age (TNO 2012). These models were based on a mid-size male model (Happee et al 2000) with facet elements on the skin surface to provide a contact interaction with finite element models of seat belts and other restraint systems. The occupant model 6 years of age was validated to adult data that was scaled to represent a child (Neathery 1974) frontal thoracic pendulum test with pediatric PMHS (Ouyang et al 2006), abdominal loading of porcine specimen (Kent et al 2006), and quasi-static neck tension test with pediatric PMHS (Ouyang et al 2005). This illustrates well the challenges of validating human body models where it is often necessary to compensate for a lack of validation data by combining PMHS, volunteer and animal test data.

Finite element models of the whole human body were first presented in the late 1990s and early 2000s. The most frequently used and published model represented the mid-size male occupant. Table 14.1 presented here shows the HUMOS (Robin 2001), THUMS (TMC 2008, Iwamoto et al 2002 and Watanabe et al 2011), and GHBMC (Vavalle et al 2013) models. In 2001, a European consortium presented the HUMOS (Human Model for Safety) with geometry acquired through physical slicing of a frozen PMHS (Robin 2001). A year later, the first version of THUMS (Total Human Model for Safety) was developed based on the Visual Human Project data set (Iwamoto et al 2006). In 2008, it was updated to version 3 with a detailed model of the brain (TMC 2008). In 2010, the THUMS version 4 was published (Watanabe et al 2011); it was a fresh

TABLE 14.1 Finite element models representing the mid-size male occupant.

Model	HUMOS	THUMS version 1.4	THUMS version 4	GHBMC	50th percentile male
Reference	Robin 2001	Iwamoto et al 2002	Watanabe et al 2011	Vavalle et al 2013	Schneider et al 1983
Codes	LS-DYNA, PAM-CRASH, RADIOSS	LS-DYNA	LS-DYNA	LS-DYNA	–
Weight [kg]	80	77	77	76.9	75.5
Standing height [m]	1.73	1.75	1.75		1.75
Sitting height [m]	0.92		0.85*	0.90*	0.915
No. elements	~100,000	~80,000	~1,710,000	~2,180,000	–

Source: *Measured in driving posture with LS-PREPOST (LSTC, Livermore, USA).

model meshed based on a set of detailed computer tomography images from a selected individual and the model had a higher level of detail than previous versions. The GHBMC (Global Human Body Modeling Consortium) mid-size male presented in 2013 was developed based on a multi-modality imaging approach (Vavalle et al 2013); using surface laser scanning, magnetic resonance imaging and computer tomography of one volunteer in supine, upright, and driving postures. All the models mentioned have been validated on the segment level and compared to whole body PMHS test data. The more recent models have gone through a larger set of validation data with many different load cases (Kitagawa and Yasuki 2014, Gayzik et al 2014).

Models that represent the population beyond the mid-size male are rare. There is no published model of the mid-size female, while the THUMS and GHBMC will have models that represent the small female (Kitagawa and Yasuki 2014, Gayzik et al 2014). Based on the THUMS version 4 mid-size male occupant, pedestrian and occupant versions representing the mid-size male, small female, and large male have been developed (Kitagawa and Yasuki 2014). The GHBMC has ongoing work to create a small female occupant using the multi-modality approach based on one female subject, a large male occupant by scaling the GHBMC mid-size male occupant, a mid-size male pedestrian based on the occupant model and subsequently by scaling the mid-size male pedestrian model to create pedestrian models representing a large male and a small female (Gayzik et al 2014). There is ongoing work to scale the mid-size male model to represent more of the human population, such as obese and skinny individuals, although not published to date.

Finite element whole body child models are rare. In 2005, the first version of THUMS was scaled to represent a child 3 years of age (Mizuno et al 2005), then further improved with respect to the pelvis (Mizuno et al 2006) and the head-neck complex (Zhang et al 2009) based on medical imaging of a child of 5 years of age. This model has been compared to dummy models and cadaveric data (Zhang et al 2007) and is to date the only published whole body child model that accounts for age dependent anthropometric details (Brolin et al 2015). The interested reader is referred to a recently published review of child anthropometry and human body models (Brolin et al 2015).

14.3.2 Pre-crash simulations

Techniques to simulate muscle contractions have been developed, mainly for models of the neck (Dang and Goldsmith 1987; de Jager 1996; Wittek 2000; Brolin et al 2005). Active muscle forces are usually modelled with Hill-type (Winters and Stark 1985) line elements although some models have superimposed the Hill-type line elements with solid elements to include the bulk properties of passive muscle tissue (Behr et al 2006; Hedenstierna et al 2008; Iwamoto et al 2009, 2011 and 2012).

The first whole human body models that simulated active muscles to some extent came in the 2010s (Iwamoto et al 2011, 2012; Iwamoto and Nakahira 2014; Meizer et al 2012, 2013a, 2013b; Osth et al 2012, 2014, 2015). The mid-size male THUMS was enhanced with muscle activity through combined Hill-type line elements and solid elements (Iwamoto et al 2011, 2012; Iwamoto and Nakahira 2014). This implementation controls the muscle activity with an open loop control approach where the levels of activity were determined prior to the simulation based on volunteer electromyography measurements (Iwamoto et al 2011; Iwamoto and Nakahira 2014) and a simplified model (Iwamoto et al 2012). The open-loop control approach has the limitation that for each new load scenario a new set of data for muscle activity has to be determined, implying either new volunteer experiments, simplified simulations with other models or basing the muscle activity on engineering judgment alone. To avoid determining the muscle activity prior to the simulations, an alternative closed-loop approach was first suggested for a mid-size male multi-body model (Meizer et al 2012) in simulations of autonomous braking, frontal, lateral, and rear end impacts. This model was further developed with respect to the neck, hip, and elbows and compared to more scenarios (Meizer et al 2013a, 2013b). It is available in sitting and standing versions for the MADYMO code (TNO 2012). A similar closed-loop approach was developed for the mid-size male THUMS model with a focus on autonomous (Osth et al 2012, 2015) and voluntary driver braking (Osth et al 2014), in the LS-DYNA code. For both these closed-loop implementations the levels of muscle activity were determined with proportional, integral, and derivative controls striving to maintain specified joint angles at their initial values. This approach seems to be very promising to create human body models with muscle control that changes its response with the level and direction of loading, based on sensory information about the current state in the model (Osth et al 2015).

14.3.3 Biomechanical properties

It is essential to understand the biomechanical properties of human tissue in order to develop and use human body models. This chapter will briefly introduce constitutive models and material properties. The interested reader is referred to a text (Fung 1993; Park and Lakes 2007) for further details. There are specific challenges with biological tissues, for example the large individual spread of mechanical properties that depend on for example, age, gender, hormones, and health status. Biological tissues are living materials surrounded by bodily fluids, which makes testing difficult. They can be considered as composite structures with complex material models; typically featuring nonlinearity, visco-elasticity, and anisotropy. The human body is made up of ground substances with polysaccharides, ionic fluid, and a network of polymeric fibers (mainly elastin and collagen) where the living cells are attached. The hard tissues are reinforced with minerals similar to hydroxyapatite (calcium phosphates).

14.3.4 Hard tissues

Compact or cortical bone is mainly composed of mineral salts (more than 2/3 of the mass) for hardness and collagen (almost 1/3 of the mass) for ductility. The remaining mass is mainly water. The spongy or trabecular bone consists of plates or rods of compact bone that in the long bones are intermixed with bone marrow. Hence it is a highly anisotropic and inhomogeneous material. The properties of bone depend on the bone mineral content, the micro structure, the load mode (tension, compression, shear), direction of loading, and load rate. Generally speaking, stiffness and strength increases with increased rate of loading. In human body models intended for crash simulations, the bone micro structure is rarely modelled. Instead, anisotropic material models represent the overall mechanical response. The stiffness curve for bone is fairly linear compared to most other biological tissues and many models use piecewise linear material models.

Bone is a tissue that remodels under the influence of forces. That is the reason why astronauts have do exercises on space journeys and why bone fracture sites should be subjected to forces (but not movements) to enable healing and regrowth of bone. Hence, the mechanical properties

TABLE 14.2 Example of material models and properties for the rib cortical bone in three models.

Model	HUMOS	THUMS v. 4	GHBMC version 4.1.1	Experimental data (Kemper et al 2005)
Material model	Elasto-plastic behavior with failure	Plasticity with damage	Piecewise linear plasticity	
Density [kg/m^3]	6,000	2,000	2,000	
Young's modulus [MPa]	14,000	13,020	11,500	$13{,}900 \pm 3{,}700$
Yield stress [MPa]	70	80	88	93.9
Failure strain [%]	4	2	1.8	2.71 ± 1.3
Poisson's ratio	0.3	0.3	0.3	

of bone can vary substantially between individuals based on their life styles. For example, elderly occupants who have been sick and lying in bed for long periods will have weak bones compared to young athletic occupants.

14.3.5 Soft tissues

The structural composition of soft tissues is a mixture of water, cells, ground substance, collagen and elastin. The mechanical properties of collagen and elastin fibers are very different. An approximate value for the Young's modulus of collagen is 1000 MPa compared to 0.6 MPa for elastin (Park and Lakes 2007). Similarly, the tensile strength of collagen is 50–100 MPa while it is around 1 MPa for elastin (Park and Lakes 2007). However, the strain at failure is higher for elastin (100%) than collagen (10%) (Park and Lakes 2007), Elastin fibers are well represented by linear elastic material laws up to 60% stretch, according to Y.C. Fung (Fung 1993); it is the most "linearly" elastic biosolid known. Collagen, on the other hand, provides strength to the soft tissues and the way it is structured determines the properties of the tissues. Depending on the tissue, the proportions of the constituents and the fiber arrangements vary. In ligaments and tendons, the fibers have a wavy parallel orientation that provides slack initially and increases in stiffness as the fibers are stretched, thereby creating the non-linear material response for the intact ligament. Fibers oriented in a two dimensional random order are seen in organ capsules and for example in the dura mater membrane that surrounds the brain. In the skin, fibers have a three dimensional weave structure, although at the skin surface there is a predominant orientation parallel to the surface. In cartilage, the collagen fibers are strictly parallel at the joint surface to reduce friction, and are perpendicular at the bone interface to provide damping and support. These examples of fiber orientations for different tissues highlight the importance of non-linear material models with anisotropy.

In finite element human body models the joints are usually modelled with sliding contacts to simulate the cartilage interface, solid elements for the damping in the cartilage, and either line elements or shell/membrane elements to simulate the ligaments that restrict joint motion. If the ligaments are implemented with linear elasticity instead of non-linear, it will not be possible to simulate the joints' neutral zone with low stiffness and simultaneously capture the range of motion with adequate stiffness responses. The neck, and especially the upper cervical spine, is an example of a body region where the neutral zones of the joints are relatively large, and for models that target both low and high energy impacts it is necessary to use non-linear material models for the ligaments. The intervertebral discs play an important role in damping, and if these are modelled with linear elasticity the human body model will have an oscillatory response. To conclude, it is the intended application of the human body model that determines the complexity needed in the material models.

14.4 DISCUSSION

Human body models can be used to explore how parameters like seated posture, anthropometry, and age influence the protective capacity of safety systems. To take traffic safety beyond the mid-size male and small female, human body models should represent the human population in terms of age, gender, and body dimensions. Whole human body models were developed for multi-body and finite element methods, with a majority of the models representing the mid-size male. There exist a few models of the small female and some interesting child models are on the way. However, there is still work needed to be done before human body models can represent the population at risk for injury or death in traffic, considering both vehicle occupants and pedestrians.

Another important aspect is injury predictability, where some human body models may predict injury with more detailed criteria based on tissue stress or strain that are closer to the real world injury mechanism than the criteria currently used with ATDs. However, more work is needed on constitutive material models with biofidelic failure and experimental data to validate these injury criteria. Additionally, human body models must be numerically robust for a large range of load cases and computationally efficient, in order to become powerful tools for the automotive industry and to be part of virtual product development and assessment.

Before human body models can be used in legal certification and consumer testing there are several obstacles to overcome. Two of the most important are how to assess the quality of simulations and if the quality requirements should be on the model or as a competence criteria for the simulation engineers.

Finally, the human body is a challenge and a source of inspiration. Therefore, there are many interesting questions still waiting to be tackled by researchers, numerical as well as experimental, that can improve the biofidelity of human body models for a multitude of applications.

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CHAPTER 15

Highway Safety in India

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CONTENTS

ABSTRACT

This chapter presents the trends of traffic crashes on Indian highways. Highways can be made safer by adopting appropriate geometric design standards and speed control by design. This chapter presents a summary of various geometric standards including the effect of guard rails, lane width, shoulder width and median designs on speed and traffic safety. The final section presents the principles of road safety audits. Road safety audits should be adopted for all highway projects and road-related urban projects in order to ensure that all identifiable risks to human life have been avoided. Road safety audits should be generalized on existing roads as a planning tool for road safety improvement as well as to provide feedback on current road construction and maintenance practices.

Key Words: Highway safety; Safety Audit; Indian highways

15.1 INTRODUCTION

The government of India has launched a major programme to expand and improve highways in India since 2000. Seventy thousand kilometers of National Highways (NH) are maintained by the National Highway Authority (NHAI). Through the National Highway Development Programme (NHDP), NHAI is upgrading nearly 49,000 km of NH. Twenty four thousand km of highways have been upgraded. Upgrading includes expanding existing four lanes to six lanes, existing 2 lanes to divided four lanes, and improving 2 lanes with paved shoulders. The major motivation behind highway upgrades has been improving inter-city and interstate connectivity through capacity enhancement, as well as to improve highway safety.

This chapter presents trends of traffic crashes on Indian highways. Section 15.2 discusses traffic crash patterns on Indian highways. Section 15.3 presents a summary of risk factors identified for highways internationally, research results of different geometric features – lane widths, shoulder rumble strips, etc. Section 15.4 presents safer road principles adopted by different countries and a list of good practices. Finally Section 15.5 lists important issues for future research.

15.2 TRAFFIC CRASHES ON INDIAN HIGHWAYS

Highway safety remains a major concern after nearly 50% of completion of NHDP projects. Figure 15.1 shows the number of fatalities since 1970. This includes fatalities on all roads; however, as per the Ministry of Road Transport and Highways (MoRTH) records, 40% of traffic and fatalities are on highways. Traffic fatalities have continued to rise at a rate of 8–9% per annum since 2000, when NHDP was launched. As per the NCRB report (2013) nearly 1,37,000 people lost their lives in road traffic crashes in India in 2013, a majority of them on highways.

Figure 15.2 shows traffic fatalities in different states from 2010 to 2013. Almost all states show an increase in the number of fatalities from 2010 to 2013; however, in Andhra Pradesh, Tamil Nadu, and Uttar Pradesh the increase is much higher than in the other states.

Figure 15.3 shows the number of fatalities per hundred thousand persons in different states. Tamil Nadu has the highest rate amongst all states. Fatalities per hundred thousand population in smaller states like Puducherry, Goa, and Daman & Diu are higher than other states. States

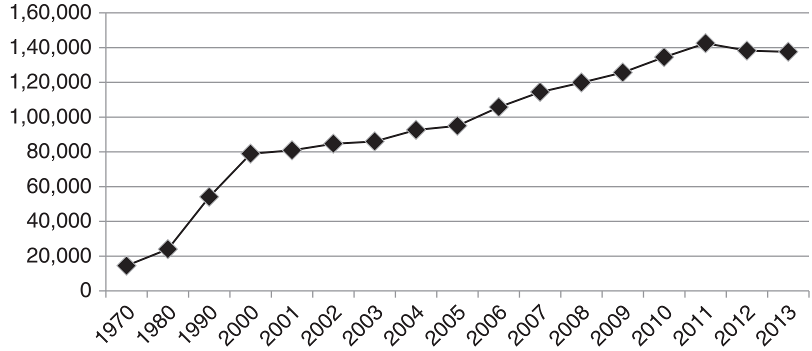

Figure 15.1 Traffic fatalities in India 1970–2013, (NCRB, 2013).

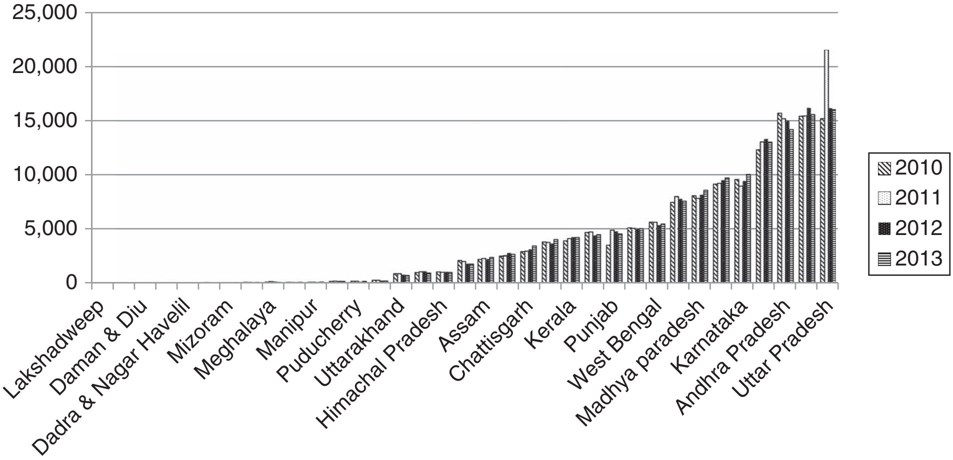

Figure 15.2 Traffic fatalities in different states in India (NCRB, 2013).

which are considered more prosperous, like Haryana, Andhra Pradesh, and Karnataka also have high rates.

Recent studies (Naqvi and Tiwari 2015) have shown fatal crash rates (fatalities per kilometer), among the studied sections of three NHs (NH 8, NH 24 and NH 1) are the highest i.e. 3.08 crashes/km/year on six-lane NH-1, followed by 2.54 crashes/km/year on four-lane NH-24 bypass, and 0.72 crashes/km/year on two-lane NH-8. The same study also found that the share of collisions involving pedestrians (hit pedestrians) are the highest i.e. 45% on six-lane NH-1, 31% on four-lane NH-24 bypass and 21% on two-lane NH-8 sections.

This pattern is similar to the one observed in an earlier study (Tiwari et al 2000) where traffic crashes at 35 locations on different highways were analysed. Thirty per cent of the total victims were pedestrians.

Vehicles using National and State Highways (NH & SH) in India have wide variations in operating characteristics, and tractors and animal carts often share the carriageway with fast moving motorised traffic. NH & SH passing through villages and towns are used by local traffic also, resulting in wide variations in direction, speed and vehicle mass. Pedestrian activity is also high in these stretches. There have been attempts at making limited access highways/expressways in some selected highway corridors (Mumbai Pune, Delhi Agra, Bangalore, Mysore) using raised embankments with fencing all along, however, tractors, bicycles and other vehicles used for local

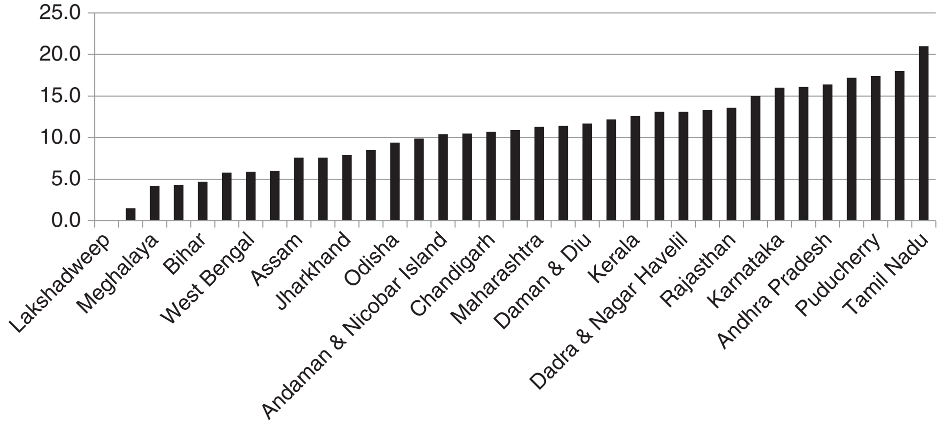

Figure 15.3 Fatalities per hundred thousand persons in states (NCRB, 2013).

rural commutes continue to be present in small numbers. This demands that when NH & SH pass through villages and towns, safe passage must be ensured to through traffic consisting of trucks, buses, and cars, as well as local traffic consisting of bicyclists, pedestrians and other non-motorised traffic.

Road construction and maintenance consume a large proportion of the national budget, while the costs borne by the road-users are often neglected. According to the study sponsored by the MoRTH, road accident costs alone accounted for at least 0.69 of the GDP of India. Estimated costs of traffic crashes was revised later to 2–3% of GDP (Mohan 2009). This cost does not include human suffering and pain due to injury and loss of life, which defies valuation in monetary terms. These issues demand equal attention in designing counter measures to mitigate the various risks. It is, therefore, vitally important that policies be pursued which, within financial and other constraints, minimise total transport costs for the individual road links and for the road network as a whole. To do this meaningfully, particularly when dealing with large and diverse road networks, various options for shoulder designs, median designs, guard rails, and active and passive speed control measures have to be evaluated carefully.

These issues have assumed more importance in recent years because of the conflicting demands expressed by those who want speedy through traffic conditions on the NH & SH on the one hand, and the inhabitants of towns and villages who demand safety for themselves on the other. The latter have been successful in constructing speed breakers, usually by force, on the NH & SH passing through their villages all over the country. Though construction of speed breakers on the NH & SH is illegal, the authorities have been unsuccessful in curbing this practice. The speed breakers so constructed do not follow any standards and the design is based on forcing vehicles to slow down as much as possible. Though this serves the objectives of the local inhabitants, these speed breakers cause a great deal of annoyance to the drivers of vehicles and can even be hazardous at high speeds if not seen early enough. In such a scenario, it becomes necessary to look at the issue in a scientific manner and evolve traffic calming guidelines that suit all of the stakeholders.

15.3 TRAFFIC ON NATIONAL HIGHWAYS AND STATE HIGHWAYS

The NH & SH together carry more than 70% of the total road traffic and safety has become a major concern on these roads. The problem is especially serious and difficult when NH & SH pass through villages and towns. The local traffic and activities around the highways cause congestion in the daytime and these locations can become bottlenecks for fast through traffic. However, at night and when the volume of local traffic is low and vehicle speeds high, these road sections become a major safety hazard, especially for the local population. In the light of present commitment of the government to upgrade NH & SH sections, these corridors which pass through villages and towns present a challenge which must be addressed to develop a safe and efficient highway network in the country.

The NH & SH pass through many different sizes of small towns and villages. The density of these settlements varies depending on the region. Since these are not limited access roads, they are intersected by other categories of roads forming intersections on the main highway. Upgrading of the network must ensure that the needs of long distance traffic be addressed along with the needs of local traffic, which includes slow moving vehicles like bicycles, animal carts, tractors and pedestrians. Capacity and speed enhancement strategies for the NH & SH must address the safety concerns of others and not just those of the long distance road users present on the network.

15.4 SAFETY ON NATIONAL HIGHWAYS

Improvement of national highways in India is being given a great deal of importance as a part of national efforts to become economically competitive globally. However, the guidelines for highway development generally follow specifications which are not yet tailored to our specific situations as far as road safety is concerned. A study by Tiwari et al (2000) reported traffic crash patterns from 35 selected locations on highways. Two different methods were used to collect road crash data for the sections under study:

(i) Analysis of road accident First Information Reports (FIRs) for a period of one year from the police stations in the area.
(ii) Analysis of data collected by specially trained informers for a period of three months for a 50-km section of the highway. The informers were instructed to travel over the section every day and collect information on accidents occurring on that stretch.

The two methods of data collection resulted in the following insights:

(i) The data available from the police records misses out many minor injury and single vehicle accidents.
(ii) The data collected by the informer missed out many fatal accidents involving pedestrians and bicyclists. This is probably because the vehicles involved in these cases are able to drive away in many cases, as they do not suffer much damage, so there is no evidence left behind and the informer may miss the case when he travels on that stretch of the highway after a day.
(iii) The informer recorded details of the crashes involving damaged or overturned trucks on the side of the highway, as they were available for inspection and questioning. It is interesting that a majority of these crashes did not result in fatalities to the truck occupants.

The above finding suggests that the perceptions about highway accidents formed by highway users may not reflect the reality about the problem. All of us see damaged vehicles stranded on the highways and so are convinced that these kinds of accidents would constitute the main problem. However, our findings suggest that though these types of accidents do cause large economic, time, and efficiency losses, they do not result in a majority of the deaths. Table 15.1 and table 15.2 show the type of road users killed on highways and the impacting vehicles respectively. Data from Mumbai and Delhi are included to compare the situation in urban areas with that on highways.

TABLE 15.1a Proportion of road users killed at different locations in India (1997–2000).

	Type of road user, per cent								
Location	**Truck**	**Bus**	**Car**	**TSR**	**MTW**	**HAPV**	**Bicycle**	**Pedestrian**	**Total**
Mumbai	2	1	2	4	7	0	6	78	100
Delhi	2	5	3	3	21	3	10	53	100
Highways+	14	3	15	~	24	1	11	32	100

Notes: TSR: Three-wheeled scooter taxi; MTW: Motorised two-wheelers; HAPV: Human and animal powered vehicles; +: Statistics summary of 11 locations, not representative for the whole country (tractor fatalities not included).

TABLE 15.1b Proportion of road users killed on different highways (2010–2014).

	Truck	**Bus**	**Car**	**M2W**	**Tractor**	**Bicycle**	**Pedestrian**
2 lane NH8	13	9	14	42	1	2	20
4 lane NH24	4	7	8	44	4	5	27
6 lane NH1	41	5	6	10	1	3	34

TABLE 15.2a Proportion of impacting vehicle type in fatal crashes (1997–2000).

	Vehicles involved, per cent					
Location	**Truck**	**Bus**	**Car**	**TSR**	**MTW**	**Total**
Mumbai	52	16	24	3	5	100
Delhi	40	33	16	4	7	100
Highways	65	16	15	1	3	100

*Only those cases included where details were known, totals for these vehicles only, others not included.

TABLE 15.2b Proportion of impacting vehicle type in fatal crashes (2010–2014).

	Vehicles involved, per cent						
Location	**Truck**	**Bus**	**Car**	**TSR**	**MTW**	**Others**	**Total**
2 lane NH1	47	5	17	1	5	25	100
4 lane NH24	54	8	9	4	3	2272	100
6 lane NH6	72	3	12	1	2	10	100

Table 15.1 shows that in urban areas motor vehicle occupants constitute 5–10 per cent of the fatalities and the rest are vulnerable road users. On highways the proportions are 32 and 68 per cent respectively. Though the motor vehicle fatalities are higher on highways than in urban areas, as would be expected, the differences are not as high as in western countries. A vast majority (68%) of those getting killed on highways in India comprise vulnerable road users, and this fact should be the guiding factor in future design considerations. Data from three highway segments from 2009–2013 show a similar pattern. Pedestrian and motorised two-wheeler (M2W) proportions are very high except on six lane highways where the proportion of truck victims is much higher.

Table 15.2a and Table 15.2b show the involvement of different kinds of vehicles in fatal crashes in urban areas and on highways. This shows that as far as vehicle involvement is concerned the patterns are very similar in both cases. Trucks and buses are involved in about 70 per cent of

TABLE 15.3a Crash types by type of highways (1997–2000).

	Crash type in per cent						
Highway Type	**Overturn**	**Head-on**	**Angle**	**Rear-end**	**Pedestrian and bicycle**	**Fixed object**	**Other**
Single lane	50	~	~	~	50	~	~
Intermediate lane	~	13	13	13	~	13	48
2 lane w/o shoulder	7	14	2	31	23	5	18
2 lane + 1.5 m paved shoulder	5	11	~	16	45	11	16
2 lane + 2.5 m paved shoulder	5	17	2	25	19	13	17
4 lane divided	4	19	7	19	35	2	13

TABLE 15.3b Crash types by type of highways 2010–2014.

	Crash type in per cent						
Highway Type	**Overturn**	**Head-on**	**Angle**	**Rear-end**	**Pedestrian and bicycle**	**Fixed object**	**Other**
2 lane with paved shoulder undivided	6	33	6	21	21	~	5
4 lane divided	0	6	2	54	32	~	1
6 lane divided	2	10	9	28	45	~	1
2 lane hill road	77*	4		1	4		13

*Run off vehicles 76% and 1% overturn.

fatal crashes in both rural and urban areas. This is again very different from Western countries where there are significant differences in rural and urban crash patterns.

The above aggregate data indicate that crash patterns on rural and urban roads are more similar than would be expected based on the Western experience. This is probably because of the settlement patterns in our countryside, where there is high density all along the highways which results in the use of many sections of the highway as urban arterial roads. Therefore, safety would be enhanced mainly by separating local and through traffic on different roads, or by separating slow and fast traffic on the same road, and by providing convenient and safe road crossing facilities to vulnerable road users.

Table 15.3a shows the accident types by type of highway and type of accident. The statistics for single lane may not be representative because of the small sample size. It is interesting to note that there are no major differences in the overturn type of accidents in two lane and 4 lane roads. Similarly there are no major differences in head-on collisions on different types of two lane roads. However, it is very surprising that on 4-lane divided roads, head-on collisions comprise 19 per cent of the crashes. Divided 4-lane roads are justified on the basis that these would eliminate the occurrence of head-on collisions. The fact that this is not occurring means that many vehicles are going the wrong way on divided highways. This is probably because tractor and other vehicle owners go the wrong way when they exit from roadside businesses and the cut in the median is too far away. This issue needs to be taken up seriously to develop guidelines for the placement of cuts in the median or for providing under/overpasses for vehicles in convenient locations.

Table 15.3a shows the traffic crash patterns on different highway corridors in 1997–2000 and Table 15.3b shows crash patterns in the last five years (2010–2014). Traffic crash pattern on hill road is clearly different from all other types of highways where run off-the-road type crashes dominate.

Rear end collisions (including collisions with parked vehicles) are frequent on all types of highways including 4-lane highways. This shows that even though more space is available on wider roads rear-end crashes are not reduced. This would probably have to do more with the visibility of vehicles rather than the road design itself. Countermeasures include making vehicles more visible with the provision of reflectors and roadside lighting wherever possible.

Impacts with pedestrians and bicycles have a high rate on all roads including 4-lane and six-lane divided highways. The rate seems to be lower on 2-lane highways with wider (2.5 m) paved shoulders. These findings suggest that wider shoulders reduce conflicts between slow moving traffic and motor vehicles but do not eliminate them. For these type of accidents to be reduced the following countermeasures need to be experimented with: physical segregation of slow and fast traffic, provision of 2.5 m paved shoulders with physical separation devices like cat's eyes, provision of frequent and convenient underpasses (at the same level as the surrounding land) for pedestrians, bicycles, and other non-motorised transport, and traffic calming in semi-urban and inhabited areas.

Collisions with fixed objects are low only on 4-lane divided highways. Provision of adequate run-off area without impediments, and design of appropriate medians are obviously very important on highways.

15.5 LITERATURE REVIEW

Highway design is an important element of the driving environment, and it includes among other things the lane and shoulder width, median width and height, a clear zone, horizontal and vertical alignment, and roadside landscaping. All of these factors of highway design can influence drivers' perception and therefore influence their driving behaviour (Martens et al 1997; Janssen et al 2006). Several studies have shown that highway design is associated with accident rate (e.g., Knuiman et al 1993; Hadi et al 1995; Karlaftis and Golias 2002; Polus et al 2005). A limited number of studies directly investigated the effect of roadway design on driver behaviour (e.g., De Waard et al 1995; Martens et al 1997; Stamatiadis et al 2007).

Safe and well-designed highways should minimize the likelihood of vehicles going off the road and be free of conflicts among different road users (cars, motorcycles, bicycles, and pedestrians). However, safe design may create a situation where drivers feel too safe, and therefore allow themselves to increase speed, reduce attention, and suffer from boredom and drowsiness. Therefore, the road should be designed in a way that will still convey the risk of unsafe behaviours (Shinar 2007).

Driving speed, for example, is one of the behaviours affected by the driver's perception of the road's safety, and it is not necessarily compatible with the road's design speed (Misaghi and Hassan 2005). If a road design is very forgiving – i.e., wide shoulders, wide lanes, and no curves – the drivers' confidence will rise and they will compensate by speeding (Shinar 2007). But, if the speed chosen is not appropriate in a given situation, it may result in loss of control and run-off-the-road accidents (Janssen et al 2006).

Lower speeds can be achieved by several passive measures such as speed limit signs and road markings, and active measures such as speed bumps, roundabouts, and roughness of road surface (Martens et al 1997). However, on well-designed highways in terms of lane width, horizontal curvature, and super elevation, drivers slow down voluntarily. In these cases, the traffic environment and road design are "self- explaining" (Theeuwes and Gosthelp 1995).

A summary of research findings concerning selected important highway design features is presented in the following section.

15.5.1 Shoulder width

A number of researchers have studied the impact of shoulder width and surface quality on traffic crashes. AASHTO (2004, in Stamatiadis et al 2009) defines roadway paved shoulder functions, including emergency stop and pull off, and recovery area for driver errors. Studies have found conflicting results regarding shoulder width. Kraus et al (1993) have reported that narrow shoulders can create a dangerous situation where the driver will not have a recovery area in case of lane deviation and they therefore increase the likelihood of off-road collisions. However, Hauer and Lovelly (1984, in Hauer 2000) have reported that approximately ten per cent of fatal freeway crashes are related to vehicles stopped on shoulders; thus wide shoulders may also create a dangerous situation.

Karlaftis and Golias (2002) found that lane width variable was one of the most important factors affecting accident rates on two-lane roads. In addition, paved shoulder width was also associated with accidents: as the shoulder width increases (up to 7.5 m), the accident rate decreases (Choueiri et al 1994). Shoulder width can also have conflicting effects on driving behaviour.

On the one hand, several studies have found that narrowing roads and lanes – either in reality or perceptually – can be used as a measure to slow driving speed (Shinar et al 1980; Kolsrud 1985; Van Smaalen 1987 in Martens et al 1997; Godley et al 2004), and thus create safer driving behaviour. Ben-Bassat and Shinar (2011) offer two possible explanations for the effect of road and lane width on driving speed. The first explanation is that wider shoulders give the driver a sense of security and space for correcting errors (Hauer 2000; Stamatiadis et al 2009). In contrast, narrower roads are perceived as less tolerant and therefore more dangerous. This leads drivers to use speed control as a means to avoid danger or risky situations (Summala 1996). The second possible explanation for slower driving speeds on narrow roads stems from the increase in driver workload. De Waard (1995) argued that driving in a narrow lane requires less mental effort from the driver than driving in a wide lane, because of the need to keep the vehicle in the lane. Also, higher speeds involve high rates of flow of information and require greater mental effort. These findings, which associate narrow roads with lower speed and safer driving behaviour, contradict studies that found a negative effect of narrow shoulders on safe driving behaviour, by affecting the driver's ability to maintain a safe lane position. An early study, (Rinde 1977, in Dewar and Olson 2001) examined crash rates on 37 two-lane roads in California with three different shoulder widths of 2, 4, and 8 feet. He found that narrow shoulders led drivers to steer away from the right shoulder and drive closer to the center of the road, thus increasing the likelihood of a head-on collision (Rinde 1977, in Dewar and Olson 2001). Some other studies also found that the accident rate decreases as shoulder width increases in a two-lane roadway (e.g., TRB special report 214 1987, in Rosey et al 2009; Hadi et al 1993; Zegeer and Council 1995).

15.5.2 Highway geometry (horizontal curves)

Since a horizontal curve has an effect on driving speed and choice of lane, it has an effect on crash rates also. Horizontal curves reduce the visibility distance, limit a driver's ability to anticipate the course of the road ahead and thus increase uncertainty (Martens et al 1997).

Several authors (Choueiri et al 1994; Takeshi and Nozomu 2005) have found, a negative relationship between curve radius and accident rate, especially for run-off-the-road accidents.

Shoulder width and curve radii can also affect the driver's sight distances (Choueiri et al 1994). Green et al (1994), using the UMTRl Driving Simulator tested the relationship between roadway geometry and driver performance and found that the variability (specifically the standard deviation – SD) of the drivers' lateral position was affected by lane width and by sight distance. They also found that as the lane became wider, the SD of lateral position increased, and when the sight distance increased the SD of lateral position decreased.

Another simulation study that examined the effect of roadway geometry on driving performance found that as a curve's radius decreases, the demands on vehicle control increases, resulting in more corrections, which in turn affect lane position; and inversely, when speed was lowered vehicle control was improved (Van Winsum and Gosthelp 1996). Straight sections are perceived by drivers to be safer, which may lead to higher speeds.

15.5.3 Guardrails

Installation of guardrails has become an important safety element in safe highway design.

Guardrails, placed along the right-hand edge of the paved road surface, are generally effective in reducing both accident rates and accident severity (Michie and Bronstad 1994; Elvik 1995; Lee and Mannering 2002). One possible reason for guardrails' effectiveness in reducing accident rates may be that the guardrail can also be perceived as a roadside hazard (Lunenfeld and Alexander 1990; Michie and Bronstad 1994) and therefore it influences driving behaviour.

Van der Horst and de Ridder (2007), using a driving simulator found that when a guardrail appeared on the side of the road, drivers tended to move away from it, but only if an emergency lane (that can be considered as 3.5 m shoulder), was not present.

Ben-Basset and Shinar (2011), used a driving simulator in order to examine the effects of all three features of roadway design on driving behaviour. The following important observations were reported by Ben-Basset a Shinar (2011):

1. As in previous studies (e.g., Van Winsum and Gosthelp 1996) speed decreased with decreasing curve radii. Thus, driving speed on straight roads was the highest; in shallow curves the speed was medium, and in sharp curves it was the slowest. A similar effect of roadway geometry was also found for 85th percentile speeds and for the subjective evaluations of perceived safe speed and road safety. In all cases the straight road was perceived as the safest and thus allowed a higher speed, while the sharp turns were perceived as the most dangerous and elicited the lowest speeds.
2. The existence or absence of a guardrail in roads with different geometries revealed another aspect of the effect of roadway geometry on speed. When driving on straight roads or around right curves (sharp or shallow), participants drove faster when a guardrail was present than when it was not. But when driving around left curves, guardrails did not induce higher speeds. These findings suggest that guardrails give the drivers a sense of security and therefore they allow themselves to drive faster in their presence on straight and right geometries. In left turns, on the other hand, the driver's gaze is directed into the curve and away from the guardrail (Shinar et al 1977), and therefore its influence diminishes or disappears. Moreover, assuming guardrails are perceived by drivers as a hazard (Lunenfeld and Alexander 1990; Michie and Bronstad 1994), when a guardrail is present, a slight overcorrection for the curvature in a right curve or under correction in a left curve can lead to a collision with the guardrail and not just 'running off the road'. In straight or right curved roads there is a higher chance for colliding with the guardrail than in left turn geometry. Therefore, participants drove at a safer speed (slower) when a guardrail was present in straight or right curved road scenarios.

Guardrails also had significant effect on speed when combined with shoulder width. As in previous studies (e.g., Godley et al 2004), significant differences in actual speed for different shoulder widths was found, but this effect was significant only when a guardrail was present. In contrast, speed remained relatively constant at all three shoulder widths when there was no guardrail. It seems that the guardrail at the edge of a shoulder enhances the appearance of the shoulder width, so that drivers felt more secure and allowed themselves to drive faster in 1.2 and 3 m shoulders with guardrails compared to their speed with the same shoulder widths without guardrails. On the other hand, when the shoulder width was extremely narrow – 0.5 m – the participants drove much slower with a guardrail than without a guardrail. In this case the guardrail served to enhance the narrowness of the shoulder, and the smaller safety margin associated with it. In addition, if the participants perceived the guardrail as an obstacle, they were probably careful not to collide with it. In summary, the effect of a guardrail on actual speed depends on the width of the shoulder that it bounds: it can serve to increase speed when the shoulder is wide, but it can just as well serve to decrease speed when the shoulder is narrow. Similar interaction effects of shoulder width and guardrail existence were also obtained for perceived safe speed. When a guardrail was present, participants estimated the safe speed relative to the shoulder width: safe speed being safer with wider shoulders. However, when there was no guardrail, the estimated safe speed was unaffected by the shoulder width. These findings strengthen the hypothesis that a guardrail heightens the sense of security that wide shoulders are designed to provide.

The effect of shoulder width and guardrail existence on the estimated safety of the roads was not the same as on the actual speed and evaluated safe speed. The estimated safety of the roads with narrow shoulders was the lowest and was essentially unaffected by the presence or absence of a guardrail. As the shoulder got wider, estimated safety was more influenced by the presence of a guardrail: roads with guardrails were perceived as safer than roads without guardrails. On the other hand, actual speed and evaluated safe speed remain relatively stable throughout different unbounded shoulder widths.

Ben-Basset and Shinar (2011) suggested that the guardrail served as a moderating element to actual and estimated safe speed in narrow shoulders, suggesting that the guardrail enhanced the perceived danger of the narrow shoulders. If this were the case, the participants should have evaluated the roads with the narrow shoulder and guardrails as less safe than the same roads without the guardrails. However, instead, the roads with the narrow shoulders were evaluated as unsafe regardless of guardrail existence. Only when the shoulder width increased, did the guardrail enhance the positive security effect of shoulder width. Perhaps the most significant contribution of the results of the Ben-Basset and Shinar (2011) study to understanding the effects of different road design elements on driving behaviour, is that shoulder width in and of itself does not affect actual speed or even perceived safe speed, unless it is delineated by a guardrail at the right edge of the shoulder.

The guardrail has a very strong perceptual effect on the width and safety margin that the shoulder provides, to the point that it affects driving speeds, and hence driving safety. Therefore, guardrails can serve not only as post-crash injury reduction measures, but also as crash prevention devices.

The study (Ben-Basset and Shinar 2011) also demonstrates that roadway geometry can be used to reduce driving speeds, but at the same time it can have a negative effect on maintaining a stable lane position in sharp curves. Thus, controlling the width of road shoulders and the placement of guardrails seems to be a safer approach to speed and lane position control.

15.5.4 Rumble strips

In recent times rumble strips have been installed to mark the edge of the carriage way and sometimes the center line of two lane roads. Rumble strips are a countermeasure aimed at reducing the frequency and severity of run-off-the-road (ROR) crashes specific to driver performance errors. Installed along the edge of a travel lane, shoulder rumble strips produce noise and vibration that alerts drivers when their vehicles are drifting off the roadway. The safety benefit of shoulder rumble strips in reducing the frequency and severity of ROR crashes has been emphasized in many earlier studies (see, Torbic et al 2009; Persaud et al 2004; Gårder and Davies 2006; El-Basyouny and Sayed 2012).

Khan et al (2015) examined the effectiveness of shoulder rumble strips in reducing the number of ROR crashes on two-lane rural highways in Idaho using an empirical Bayes (EB) before-and-after analysis method. The results of this study demonstrate the safety benefits of shoulder rumble strips in reducing the ROR crashes on two-lane rural highways. The state of Idaho 2001–2009 crash data was used as the primary data source for the study. The study finds a 14% reduction in all ROR crashes after the installation of shoulder rumble strips on 178.63 miles of two-lane rural highways in Idaho. The authors (Khan et al 2015) reported that the roadway geometry type and the paved right shoulder width affect the effectiveness of shoulder rumble strips on two-lane rural highways. The results indicate that shoulder rumble strips were most effective in reducing ROR crashes for roads with relatively moderate curvature and right paved shoulder width of 3 feet and more.

Further, Khan et al (2015) suggested since the installation cost of shoulder rumble strips is relatively low, the results obtained in this study suggest that application of the shoulder rumble strip treatment to two-lane rural roadways roads with relatively moderate curvature and right paved shoulder width of 3 feet and more should be continued. Since wider shoulder width (3 feet and wider) provides additional room for non-motorized travel, installation of shoulder rumble strips is also recommended in shoulder widening projects that can potentially help non-motorized traffic in the absence of a designated bike-path. For the roadway sections with sharper horizontal curvature, shoulder rumble strips should be implemented with additional curve delineation treatments to reduce the ROR and other crashes.

15.5.5 Designing safe highways – active speed control on highways

It is well accepted by the experts that differences and variations in the speed, direction, and/or mass of vehicles usually determine the severity of road accidents. In the West, freeways are the safest roads where driving speeds are the highest but relatively uniform. There is little or no variation in direction and vehicle mass. In the last twenty-five years residential areas and inner cities have become safer because of 30 km/h zones in the residential areas, despite considerable variation in the directions and mass of vehicles using them.

Vehicle speed is one of the critical factors associated with road accidents because higher speeds reduce the time available to avoid collisions and make the impacts in collisions more severe. Research studies from around the world demonstrate conclusively that the frequency and severity of accidents usually reduce with reduction in average speed. A decrease in average speed of 1 km/h will typically result in a 3 per cent decrease in fatal accident frequency. Variation in speed between vehicles within the traffic stream is also a factor contributing to accident occurrence.

Management of speed by engineering the road with the purpose of bringing the design of the road into accordance to the desired speed is called “Speed management by design” or “Traffic calming”. These methods have been developed as a result of studies in the Netherlands and Denmark and other EU-countries.

Two main principles for speed reducing measures have been used: visual measures and physical measures. Speed limit signs, painted strips across the road (visual brakes), road surface patterns, plants, etc. are examples of visual measures. These are also known as passive measures. Physical measures include changes in road surface texture, speed breakers, rumble strips, road narrowing, and gates on roads, and these are known as active measures.

The general experience from different European countries indicates that speed limit signs and other visual measures *alone* are not always sufficient to make the drivers choose an appropriate speed. But when used in combination with other physical speed control measures, significant effects can be observed.

With the widespread application of active speed control measures a positive influence on the efficiency of traffic flow, safety, and road capacity utilization is expected because:

1. Reducing the difference in speed between vehicles and between different points along the same road reduces the disturbances in traffic flow and thereby increases the average speed of all vehicles.

2. Reinforcing the road hierarchy by slowing down vehicles significantly on access roads, moderately on local collectors, less on collectors, increases safety.
3. Reducing the number of accidents reduces the number and severity of traffic jams that are caused by accidents.

Seven different types of sections can be identified to address the Traffic Calming (TC) requirement on NH and SH corridors.

15.5.6 Safety management on highway corridors passing through desolate areas

No special treatment (apart from providing delineators and paved shoulders) needs to be provided to improve the safety of straight corridor highway stretches passing through desolate areas. However, at intersections of these highways with village roads, visual and physical warnings should be provided to drivers on the intersecting roads, by providing adequate warning/speed limit signs, rumble strips, bright lighting at intersections and change of colour/texture of roads at the intersection. Apart from these, speed breakers should be provided on intersecting village roads to bring the vehicular speeds down to 30 km/h or below at the intersection. In case of undivided highways, 10 m to 20 m long over-runnable medians should be provided at the intersection, along with adequate road markings (for road obstruction), delineators, reflector studs and signposts, warning of the presence of a divided carriageway ahead.

15.5.7 Speed management on highways passing through agricultural fields

Vehicular traffic on highways passing through agricultural fields conflicts with crossing pedestrians, cattle and farm-vehicle traffic. Service lanes should be provided on both sides of the highway to segregate this traffic from the traffic on the highway. Warnings and speed limit signs should be provided on the highway before each opening in the service lane. In case of undivided highways, where space does not permit construction of segregated service lanes, a 1 to 1.5 m wide over-runnable median and a minimum of 1.5 m wide footpath on both sides of the highway should be provided throughout the corridor, to act as refuge for crossing pedestrian and cattle traffic, along with sign posts enforcing a speed limit of not more than 50 km/h. At intersections with minor roads, warning signs should be provided on intersecting roads, indicating a speed limit of 50 km/h on the highway and 30 km/h on the minor roads along with intersection ahead warnings. Apart from these physical devices such as rumble strips on the highway and speed breakers on the minor roads, signs should be used to warn the driver of the approaching intersection. Visually the intersection should be brightly lit and/or provided with a change of texture and colour.

15.5.8 Speed management on highways passing through industrial areas

Industrial areas generate a lot of demand for parking of heavy goods vehicles. Highways passing through these stretches should be provided with a minimum 6 m wide service lane, segregated from the main carriageway by a footpath/median and/or paved shoulders on both sides of the road. In the case of undivided highways, an over-runnable median should be provided throughout the corridor, with gaps corresponding to the openings in the service lane. Highway traffic should be warned in advance of crossing vehicular traffic at these openings in the medians and the service lane, visually, through the use of speed limit and warning sign boards as well by providing street lighting at these locations, and physically, through the use of rumble strips and rumble areas. Wherever space constraint does not permit the construction of service lanes, a minimum of 2.5 m wide paved shoulders and 1.5 m wide footpaths should be provided on both sides of the highway. Raised pedestrian crossings should be provided on highways (along with warning signs for vehicular traffic) wherever high pedestrian crossing traffic is expected.

15.5.9 Speed control measures on highway corridors passing through residential/commercial areas

Residential and commercial areas generate a lot of demand for cross-pedestrian, cattle and vehicular traffic. Highway traffic approaching such an area should be warned, using gates at the entry of the zone, with the name and length of the village/town corridor marked on it. 50 km/h speed limit signs should also be posted at these locations, along with rumble strips as a physical warning measure. In case of undivided highways a 1.0 m wide over-runnable median should be provided throughout the length of the corridor, with gaps wherever required. These gaps, with intersections at minor roads or service lane entries, should be treated distinctly from the rest of the carriageway. Texture and colour change treatment should be applied, along with bright street lighting or flashing beacons. To alert drivers of cross traffic at these locations, advance warning signs should be posted along the highway indicating the change of speed limit to 30 km/h. Rumble strips may also be provided on the roads approaching the intersections, along with advance warning sign boards indicating ‘rumble trips ahead’. In addition, minor roads should be provided with road humps to bring vehicular speed down to 30 km/h at the intersection, along with advance warning signs indicating ‘road hump ahead’. Wherever it is not possible to provide a continuous median on an undivided highway, 10 m long, 1 m wide over-runnable medians should be provided at locations where high pedestrian cross traffic is expected. All schools, hospitals and institutional areas along the highway, should be provided with raised pedestrian crossings at every 100–150 m. These crossings should be accompanied by advance warning signs stating ‘speed breaker ahead’, ‘school/hospital area’ and 30 km/h speed limit.

In case of high-density corridors where setback from the highway is less than 6 m, traffic calming devices should be used to restrict corridor speed between 30 to 50 km/h. 2.5 m wide continuous paved shoulders should be provided along with minimum 1.5 m wide raised footpaths on both sides of the highway.

15.5.10 Speed control measures on railroad intersections on highways

Highway traffic approaching a railroad intersection should be warned, visually, using 30 km/h speed limit signs, ‘railroad crossing ahead’ warning sign as well by bright street lighting at the intersection, and physically, using rumble strips and speed breakers on both sides of the crossing. In case of undivided highways, a 100 to 200 m long (based on queuing length at the location) over-runnable median should be provided on both sides of the crossing. The gates at the railroad crossing should be provided with a retro-reflective finish, along with flashing beacons for better visibility at night.

15.5.11 Speed control measures on bridges on highways

Highway traffic approaching bridges on Highway should be warned through signposts, indicating ‘Bridge Ahead’. Apart from these, advance indication should also be given using signposts and road markings, of 50-km/h speed limit, and ‘no overtaking zone’. Rumble strips should be used to physically warn the drivers on approach to the bridge. Reflective studs should be used to highlight lane markings on the bridge.

15.5.12 Speed control treatment on hill roads

All bends on hill roads should be provided with delineators, along with crash barriers/guard rails wherever possible. A continuous lane marking should be maintained throughout the corridor, using thermoplastic paint as well as reflective studs. Signposts indicating a corridor speed limit of 30 km/h should be provided at regular intervals.

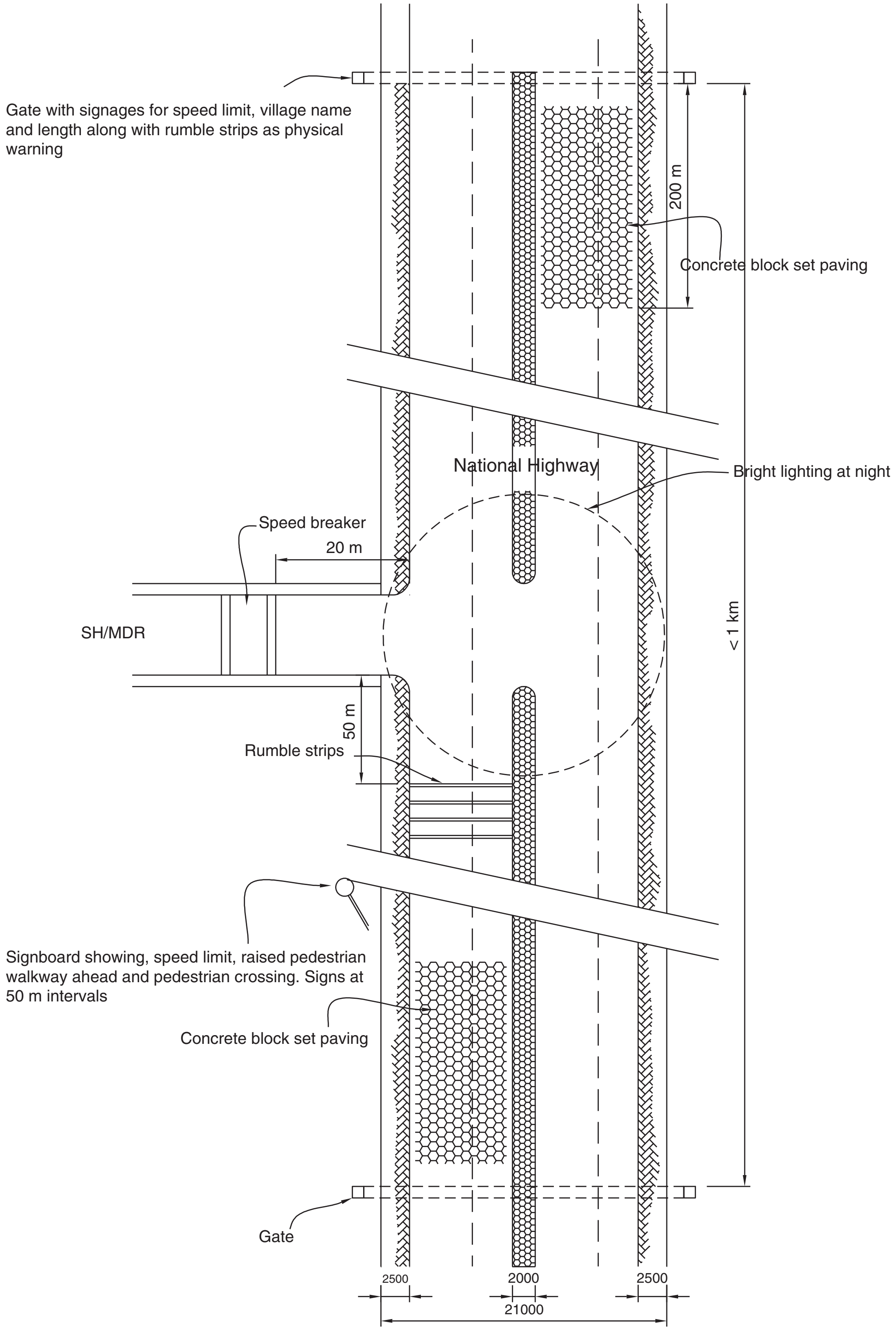

Figure 15.4 Traffic Calming Measures at T junction between State Highway and National Highway.

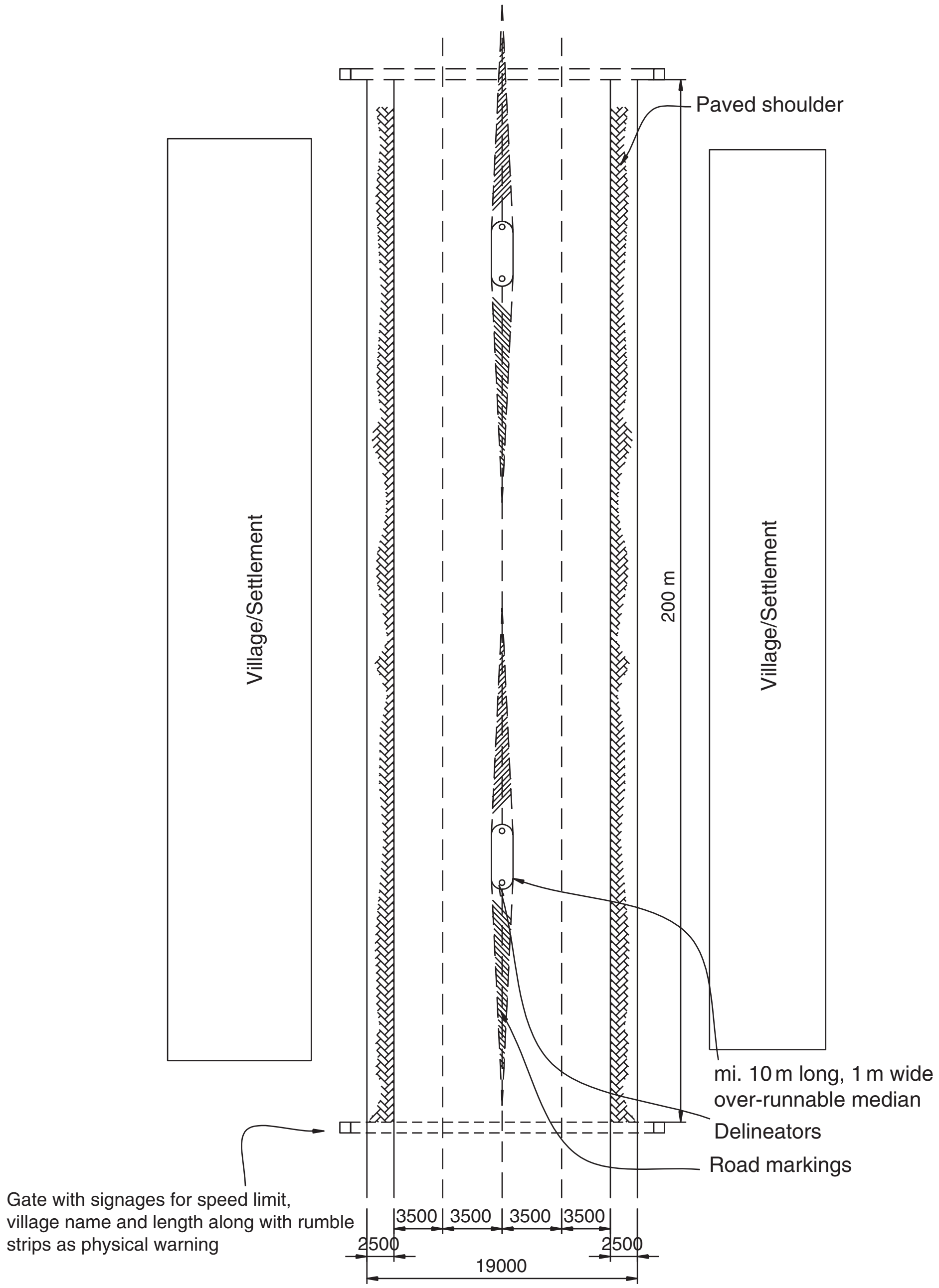

Figure 15.5 Traffic Calming Measures on NH/SH passing through Town/village.

Figures 15.4, 15.5 and 15.6 give examples of speed control measures on a straight highway corridor passing through a village, a T junction between a State Highway and National Highway and a four-way junction between a State Highway and National Highway.

Road safety audits are recommended to identify shortcomings in road design of the existing roads or planned roads. Detailed checklists can be developed keeping in mind following the basic principles of risk reduction.

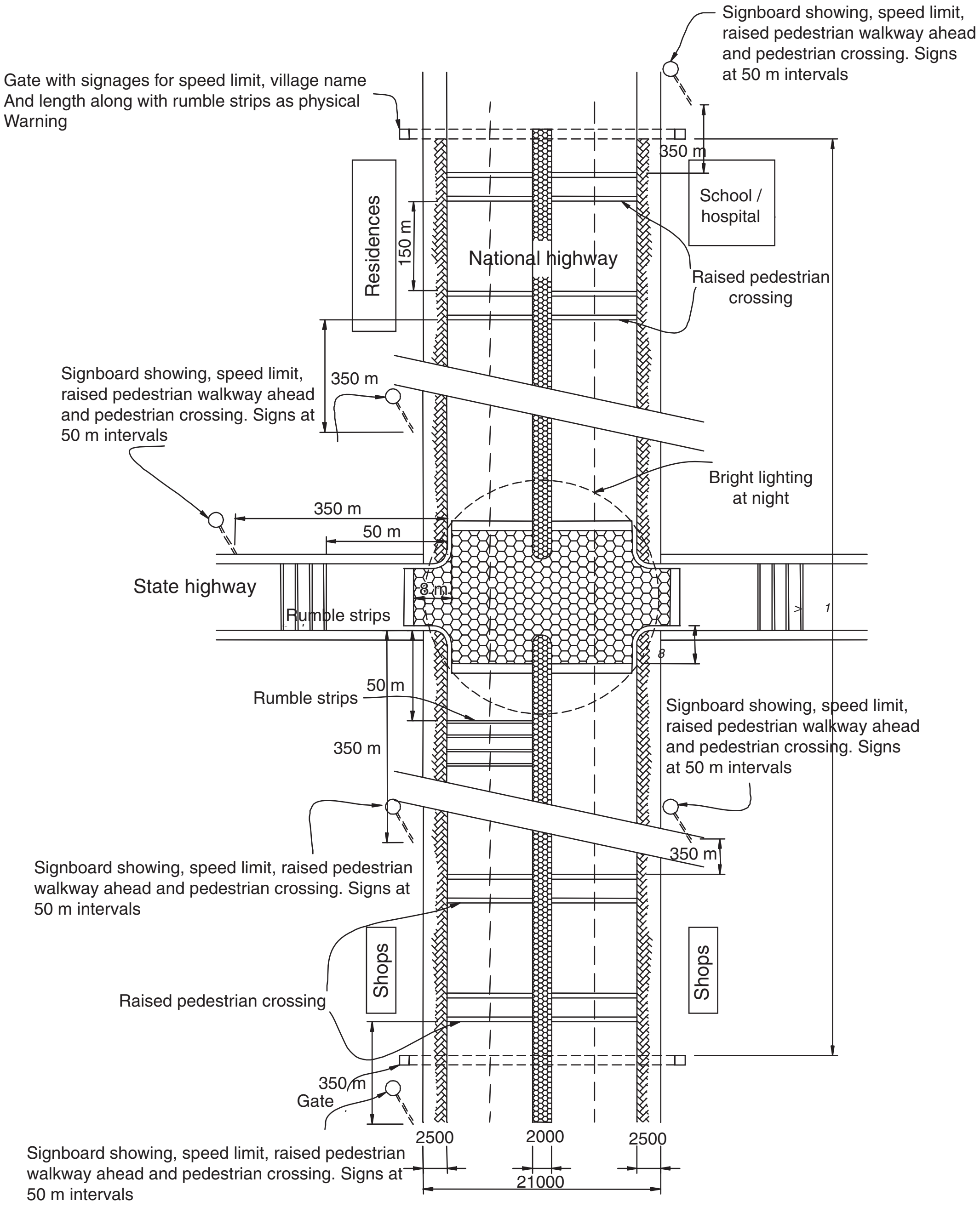

Figure 15.6 Traffic Calming at a four way Junction of NH and SH/NH.

15.5.13 Some principles for risk prevention

Driving, riding or walking on the road is a dynamic activity that involves travelling on a route for a length of time. Perception and management of a local road and traffic situation is influenced by what road users have previously experienced on their route. Accordingly, the effects of road features on risk cannot be assessed punctually, but must be appreciated in relation to their location on the routes followed by drivers and other road users.

15.5.14 Prevention of crashes (primary safety)

15.5.14.1 Adaptation of the road to vehicle dynamics and to pedestrian movements

The road is designed for speeds up to a given level and, provided drivers keep to this level, road characteristics should be compatible with vehicle movements; this applies to the design of curves (radius, super elevation), and to the distance available for braking before any discrepancy in the route requiring lower speeds (in relation to the visibility distance or advanced warning).

The road surface should also be compatible with vehicle types and speeds, given the local climatic conditions (smoothness, state of repair, skid resistance). Pedestrians should have pathways to use which are preferable to the carriageway, which means providing comfortable walking conditions, even when carrying loads, and devoid of features that could cause falls (slippery surface or holes).

15.5.14.2 Error and conflict avoidance

Road design and equipment should facilitate accurate information-taking by all road users: this requires "readability" (road features should provide the right message enabling road users to anticipate a change of situation and modify their trajectories or speeds accordingly), and the appropriate warnings before any otherwise non-perceptible changes in the road or traffic situation or any unremoved hazard. Road "readability" and advance warnings should be as adequate by night as in the daytime.

Visibility distance before any change of the road and traffic situation requiring adaptation from the road users (junction, crossing, change of width, entry to village, etc.) is a key element in "readability" and determines the need for additional warning cues.

Adequate channelization of vehicle trajectories (through markings, islands, medians) is another means of avoiding conflicts, particularly frontal conflicts when overtaking, and lateral or rear-end conflicts involving turning vehicles at junctions. Separation of motorized and non-motorized traffic is essential for safety on high speed roads, as well as appropriate space allocation and organization for non-motorized road users (continuity, capacity, provisions for all necessary movements including crossing the road). Where slow and fast traffic are mixed on the carriageway, adaptation of lane width may be used to allow overtaking of slow road users by cars or lorries without conflicts between them and without frontal conflicts with vehicles approaching from the opposite direction.

Transitory or moving obstacles on the carriageway (parked vehicles, animals crossing, etc.) are potential sources of conflicts that need to be avoided as much as possible through appropriate means (provision of emergency parking facilities, fencing, etc.). Permanent obstacles such as holes in the road surfacing need, of course, to be removed.

15.5.14.3 Facilitation of emergency manoeuvres

When conflicts, or potential accident situations arise, emergency manoeuvres performed by drivers most often involve a combination of braking and swerving. Braking requires adequate road surfacing (smoothness, skid resistance). Swerving requires lateral space free of fixed or moving obstacles, which may be provided by shoulders, given some conditions of level (no difference between shoulder and carriageway), structure, surfacing, and occupancy. Fulfilling such requirements is part of "road forgiveness" that ensures that not all errors or conflicts necessarily lead to crashes.

15.5.14.4 Speed control

The need for abrupt and/or repeated changes of the speed of motorized traffic is conducive to problems of vehicle dynamics and to drivers' errors in information-taking. Road layout should therefore avoid generating such a need, but should ensure only smooth and predictable changes of speed along a route.

From a crash avoidance viewpoint, acceptable speeds depend not only upon infrastructure characteristics, but also upon type and composition of traffic (fast and slow transport modes, cross-directional traffic). Where traffic components change, for example when approaching a junction or entering a village, vehicle speeds need to adapt. It is thus essential that road design and equipment should reflect the necessary adaptation ("readability") and should not induce higher speeds than those compatible with safety or with current regulations.

15.5.15 Injury prevention (secondary safety)

15.5.15.1 Speed control

If a crash occurs, lower crash speeds mean less severe injuries. Where vulnerable road users may get involved, very low speeds are required to avoid fatal and severe injuries. The conditions of speed control through road features as expressed above must thus be made particularly stringent on road sections or locations highly frequented by pedestrians, cyclists or motorcyclists; introduction of speed reducing devices may be necessary, even if the route serves for long distance traffic.

15.5.15.2 Eliminating potential aggravating factors

When a vehicle gets off the road after a first crash or loss of control, any hard obstacle (trees, utility poles, signs) on its trajectory strongly aggravates the injuries sustained by the occupants by causing sudden deceleration. Narrow and deep drainage ditches or trenches have similar effects. Here again, the road should "forgive": roadsides should be cleared of any such obstacles or ditches (2 to 4 m); if some of the "aggressive" features cannot be eliminated, crash protection should be provided (crash barriers, shock absorbers).

15.5.16 The road characteristics to examine

The road features that may be related to risk have been introduced either at the planning stage, or at the design stage, or when finalizing road equipment. When auditing existing infrastructure, all characteristics will be appraised simultaneously, as listed below.

15.5.17 On road sections

- road layout: horizontal alignment, vertical alignment
- cross-section: number of lanes, width of lanes, presence and width of median, local hazards or discrepancies (variations in width of carriageway, variation of the number of lanes, etc.), presence, structure and width of shoulders, presence, structure and width of specific lanes for slow road users or non-motorised traffic
- road surfacing, surfacing of shoulders or roadsides, surfacing of specific low speed lanes, state of maintenance
- signing and marking, road lighting
- occupation of roadsides (hard obstacles, other aggressive features)
- possibility of temporary or moving obstacles (wild animals) on the carriageway.

15.5.18 At junctions

In addition to the general characteristics to be observed on road sections, some features are more particularly related to junctions:

- Junction layout: number of legs, oncoming and outcoming lanes, areas of potential conflicts
- Junction design: channelization of turning movements, traffic islands or roundabouts, crossing facilities, etc.
- Specific signing and traffic regulations, traffic lights.

15.6 CONCLUSIONS

Improvement of national highways in India is being given a great deal of importance as a part of national efforts to become economically competitive globally. However, the guidelines for highway development generally follow specifications which are not yet tailored to our specific situations as far as road safety is concerned. This chapter showed traffic crash patterns on highways extracted from police FIRs. The traffic patterns have remained unchanged since 1997. The majority of the victims continue to be pedestrians, and motorcycle riders. Involvement of trucks and buses is nearly 70%.

Highways can be made safer by adopting appropriate geometric design standards and speed control by design. This chapter has presented a summary of various geometric standards including the effect of guard rails, lane width, shoulder width and median designs on speed and traffic safety. The final section has presented principles of road safety audits.

Road safety audits should be adopted for all highway projects and road-related urban projects in order to ensure that all identifiable risks to human life have been avoided. Road safety audits should be generalized on existing roads as a planning tool for road safety improvement as well as to provide feedback into current road construction and maintenance practices.

Formal procedures need to be developed at the country or state level to ensure that audits are carried out on an objective basis, and that their findings are actually acted upon. The technical content of auditing procedures should integrate internationally available knowledge and should adapt to the conditions of traffic mix and environment concerned.

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CHAPTER 16

Highway Construction Zone Safety Audit

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CONTENTS

ABSTRACT

In this chapter we present some of the issues in highway construction zone safety. Ensuring safety in construction zones for different road users and construction workers is a challenging task and reducing vehicle speeds in such zones is of vital importance. A number of measures are prescribed by various codes of practices and contract specifications to ensure safety in construction zones. A structured audit helps to find the level of compliances achieved by the construction agencies from the provisions of codal practices and contract specifications. There are not many standard procedures available in the literature that suggest the way an audit should be conducted. We present a systematic method to conduct a safety audit in a construction zone for the construction phase only, and illustrate its application with the help of a case study.

Key Words: Construction safety; Road safety; highway safety

16.1 INTRODUCTION

There are two broad categories of highway construction: (1) An altogether fresh alignment and (2) widening of highways along more or less the existing alignment. The first category is not very common these days, while there are large numbers of projects in the second category. The problem in the first category is less severe compared to the second category. In the second category, construction has to be carried out along an existing road which usually carries heavy traffic (the very reason which calls for widening). This poses a number of challenges to various stakeholders in ensuring the safety of road users.

Construction zones are also known as 'Cone zones' in some countries such as the USA, because of the widespread use of cones, barrels, and signs in the work zones. Construction work zones are often associated with reduced lane widths, lane shifts, and varying pavement surfaces. Reduced capacity increases in accident causes, leading to traffic congestions and long queues.

The objective is to provide safety for road users (motorists and pedestrians), and workers are a prime concern. A large number of people are killed when traffic has to pass through road construction. These figures are predicted to climb up further. According to FHWA, the annual number of persons killed in motor vehicle crashes in work zones in the US has increased 45% over the last 10 years. The majority of these fatalities are drivers or occupants, however, 15% are non-motorists-including pedestrians, bikers, and construction workers.

16.2 CHALLENGES IN MAINTAINING HIGHWAY CONSTRUCTION ZONE SAFETY

Highways pose a unique challenge, not only in their construction but also in their safety management. A typical highway passes through different terrains, different climatic conditions and importantly different urban and rural settings. The construction activities do not take place in a well bounded space but they extend linearly in both directions. Getting the required right of way in itself is a challenging task, not to mention enough construction space. Sometimes compromises have to be made in the design of highways due to inadequate right of way. In very rare cases the authorities are able to get the required right of way in a continuous stretch with the result that a number of fronts are open at the same time. Even the basic barricading to demarcate the construction zone is very difficult. On top of that, there are large numbers of stakeholders involved in the construction of highways, and coordination is a big issue. Although it is well known that speeding is a major cause of accidents we still find that there is no statistically significant difference in speeds of vehicles on the road in a construction zone when compared to no construction zone. This has been revealed by a number of experiments conducted by colleagues at the IIT Delhi wherein they measured vehicle speeds in a construction zone and a nonconstruction zone.

IRC recommends a certain system of signage to be used in construction zones to distinguish them from nonconstruction zones, however, in the absence of clear cut construction zones it is very difficult to ensure safe construction. Further, there is the problem of mixing construction equipment and road traffic. This is because a proper system of barricading is not available in most of the highway construction.The presence of workers, materials, and equipment very near to the moving traffic makes it very risky. Also, there is a reduction in space for moving traffic, and a lack of safety features, for example full shoulders, unobstructed clear zones, sidewalks etc., which are available on an otherwise full-fledged highway.

Drivers in the lane adjacent to a construction zone also experience distraction, adding to the stress. Further, there is a competition between normal road users and construction workers for the limited space and this results in specific risks at work zones.

16.3 THE RISKS TO ROAD SAFETY AT CONSTRUCTION ZONES

Construction zones pose risks to road users such as pedestrians and motorists, besides the construction workers engaged in construction of the highway. One of the major objectives of construction zone management is to see that drivers/motorists at construction zones and workers at construction zones remain safe throughout the construction period. Thus it is imperative to manage safety in the construction zone to safeguard the above road users. Adopting proper design and construction strategies helps to save time and cost besides ensuring the safety of road users, and they also provide a safe driving experience during construction. Accelerated construction always is a welcome step. Proper coordination among different stakeholders and utility providers is very important. Experts advise adopting design and build contracts for better coordination and better project management output. The work can be done during night time, and off peak time for users' convenience. Technological solutions such as use of devices that contain and redirect vehicles are also found to be useful. It is also imperative that the risk of vehicle intrusion into the workspace is minimized. In extreme cases, closure of the road/lane also could be an option.

16.4 NEED FOR SAFETY AUDIT

The broad objective of conducting a safety audit is to reduce the level of risks to road users and construction workers. As mentioned earlier, a highway construction zone poses a unique challenge in ensuring safety compared to other construction projects. Works such as earthwork, rebar handling and tying, formwork making, fixing, and removing, concreting, waterproofing, asphalt paving, bitumen work, dense bitumen concrete, granular sub base/wet mix macadam, kerb, road marking/fixing of permanent sign boards, crash barriers etc. which are considered routine work with very minimum risk in normal construction projects, become high risk activities in a highway construction zone. This is because in routine work, construction activities are carried out in a relatively well bounded area, and it is relatively easy to isolate the construction sites from the road users. On the other hand, in structures such as flyovers, bridges, ROB, major and minor bridges, underpasses, and cross drainage work etc., where they can be segregated from the moving traffic and occupy relatively closer spaces, safety is to be managed in the same way as that of any other construction.

Thus in addition to routine safety precaution to be undertaken for various construction activities, some additional safety precautions need to be adopted in a highway construction zone.

According to our estimate, the number of people dying in Indian construction zones is 22,080 annually, based on an estimate of the working population in construction. This translates into a minimum of about 300 fatalities annually in highway construction zones alone. This is based on the assumption that approximately 7000 km of road is constructed in a year and 20% of the cost of road work is the labour component. It is estimated that in any year there would be about 730,000 workers engaged in road construction.

There are different Acts and Laws for ensuring safety of workmen besides a number of contract clauses. In most highway construction, The Building And Other Construction Workers Welfare Cess (BOCW) Act is applicable. It has a number of features to ensure safe work.

The contract has a number of safety clauses addressing the safety concern. The contractors are supposed to comply with them. However, our experience with highway construction even in prestigious projects, shows that the level of compliances (both with the document and physically) are very low.

16.5 TASKS INVOLVED IN SAFETY AUDIT

Safety audits normally commence by reviewing the existing systems being followed/adopted by the contractors including planning, execution, documentation, and reporting, through collection and assessment of primary and secondary data/information.

Subsequently, the major hazards and risks associated with various road construction activities are identified, and a work zone safety audit procedure is established. The safety provisions laid down in the contract are also reviewed. A checklist is then prepared for implementation based on the existing contract document. Missing details which may enhance safety provisions are also identified and incorporated in the revised check list.

A detailed assessment of worksite safety conditions through site visits is carried out. This review and assessment must include, but may not be limited, to the following aspects pertaining to:

- Traffic Management Plan;
- Traffic Safety Measures;
- Safety during construction of structures, including design and suitability of temporary structural arrangements;
- Fire Safety Practices;
- Electrical Safety Practices;
- Mechanical Safety Practices;
- Dust Control and Suppression Arrangements;
- Storage, transportation, handling and use of various toxic and hazardous materials;
- Safety of roadside residents and passers-by;
- First aid;
- Emergency Response Arrangements;
- Accident records; and
- Housekeeping.

Available literature on safety should be reviewed and interviews of the officials with contractors having good safety practices should also be conducted. There should be a safety awareness evaluation, and based on the findings, suitable remedial measures should be suggested. The assessment should not be limited to the contractor's personnel alone but should include the consultants' and clients' personnel as well.

There is very limited literature that describes an objective way to conduct a highway construction safety audit. It would be prudent to present the procedures for conducting a safety audit in the following paragraphs. For the purpose of a safety audit, the entire exercise can be divided into the following broad categories.

(1) Structural safety
(2) Traffic management and safety
(3) Construction safety

(4) Mechanical/Electrical Machinery Operational Safety, Fire Safety, and
(5) Worker/Work Zone Safety (WO)

In order to assess the compliance, based on the labour laws, contract conditions and best practices, checklists can be prepared for document compliance and site compliance.

16.6 AUDIT STEPS

16.6.1 Review and understand various safety provisions in the contract documents

The first step in the audit process is to review and understand various safety provisions as provided in the contract documents for the project concerned. This should include an appreciation and understanding of the safety provisions as given in various acts, rules and regulations of federal government/state governments of the states through which the highway is passing/MoRT&H/Indian Roads Congress (IRC) specifications/codes; safety instructions issued by the client from time to time; and safety provisions under the Environment Management Plan(s) for the project. Subsequently, a review of systems being followed/adopted by the contractors and CSCs including planning, execution, documentation, and reporting through collection and assessment of primary and secondary data/information is carried out.

16.6.2 Review of the major hazards and risks associated with various road construction activities

The major activities in a typical highway construction project are identified. A list of enabling activities is also prepared. The major hazards and risks associated with various road construction activities are identified based on the review of the safety provisions laid down in the available contract document. A check list is prepared based on the existing contract document. Missing details which may enhance safety provisions are also identified and incorporated in the checklist, and thus the final checklist is prepared for implementation.

16.6.3 Conducting the audit

This section outlines the audit procedures. The audit exercise begins with narrating the audit objectives to the representatives of stakeholders, namely: contractor, consultant and client. The objectives of an audit are typically (1) to find out the contractual compliance level in quantitative terms for safety aspects. The safety here covers traffic safety, construction safety, workers' and work zone safety, occupational safety, temporary structures safety, mechanical, electrical, plant and equipment and fire safety. It does not, however, include the safety consideration during the design stage, (2) to identify the good practices, and (3) to identify the poor practices. For conducting such an elaborate audit exercise, the audit team must have personnel experienced in Construction Safety/OSHA, Structural Safety, Worker/Work Zone Safety, Traffic Management and Safety, Mechanical/Electrical Machinery Operational Safety.

The audit protocol can be established based on a checklist developed for each of the activities that affect the safety, as mentioned earlier. The philosophy of preparing the checklist revolves around: (1) the existing contract, (2) the law, and (3) the prevailing best practices observed during the site visit.

16.6.4 Briefing the project team

On the day of audit, the audit team should brief the project team regarding the purpose of audit, methodology of audit, and the terms of reference of the audit team.

16.6.5 Presentations by the project team

After the briefing by the audit team, the project manager of the contract under audit should make a presentation before the audit team. The presentation should cover different topics under two broad headings: (1) general and (2) safety management. Under general, the presentation should consist of: (a) a project description (consisting of project start date, likely completion date, percentage progress, (b) major activities in progress and their location in terms of their chainage, and (c) major plant and equipment deployed by the contractor of the work package. Under safety management, the presentation should cover details of: safety system and procedures, safety policy, safety officer, safety committee, worker's/visitors induction, PPE provision, job safety analysis, method statement, training programs conducted in safety, accident reporting, accident investigation process, safety data, other aspects covering fire safety provisions, electrical safety provisions, mechanical safety provisions, dust control, storage, transportation, handling process, roadside resident safety norms, first aid and emergency response arrangement, construction accident records at the site, details of environmental officers, qualification and experience, details about the safety officers, qualification and experience, and labour camp arrangement.

16.6.6 Verification of sample documents

After the presentation, the audit team should verify sample documents according to the list prepared based on the contract document.

16.6.7 Visiting audit locations with the checklist

After the document verification, the audit team should split into smaller teams and proceed directly to locations where work is being carried out. The audit team members are equipped with the checklist covering different aspects related to safety. Against each of the checklist items, the compliance, or non-compliance is recorded. While some of the activities should be audited at all locations, for some of the audit items only sample auditing may be done for some of the audit subgroups. The sample audit will take place only for plant and machinery items and appliances. The sample size should be about 20% of the existing stock subject to a minimum of two for each of the plant and machinery items and appliances.Besides recording the compliance/non-compliance, the audit team also needs to record the good and bad practices prevailing at the site with reference to safety aspects.

16.6.8 Computing contractual compliance

The audit team will compute the contractual compliance of safety provisions after the completion of an audit of different activities. The contractual and legal compliances are computed in quantitative terms based on the checklist. This is computed in two parts: document compliance and field compliance. The method for computing compliance for each one of them is described below.

16.6.9 Document compliance

The audit team asks for the document as per the prescribed checklist of the respective audit head. For compliance 1 point is awarded while for non-compliance 0 point is awarded. In case some checklist points are not applicable, they are not taken into account in the computation procedure. Based on the number of '1s' and '0s' found, the contractual compliance percentage is obtained. Corresponding to every reading of '1' the audit team also makes further distinction: '1' for 'average compliance' and '2' for 'good compliance'.

16.6.10 Field compliance

The audit team visits sites and as per the checklist of the respective audit head, checks the compliance. For every compliance, '1' is awarded while for non-compliance '0' is awarded. In case some checklist points are not applicable, they not taken into account in the computation procedure. Based on the number of '1s' and '0s' found, the contractual compliance percentage is obtained. Corresponding to every reading of '1' the audit team also makes further distinction: '1' for 'average compliance' and '2' for 'good compliance'.

16.7 ILLUSTRATION OF AUDIT FOR THE LMNHP

16.7.1 Introduction to the project

The illustration of above procedure is provided with reference to the Lucknow-Muzaffarpur National Highway Project (LMNHP), with a total length of 483 kms being executed by the National Highways Authority of India (NHAI), on behalf of Government of India. The work consists of four-laning and strengthening NH-28 as part of the East West corridor development under Phase II of National Highways Development Programme (NHDP). The section between Lucknow in Uttar Pradesh and Muzaffarpur in Bihar forms a part of this corridor and passes through the cities like Barabanki, Ayodhya, Basti, Gorakhpur, Kushinagar and Gopalganj. The project road provides a link for connectivity to Indo–Nepal border cities like Nepalganj, Saunauli and Raxaul as well as important places in the Buddhist circuit like Kapilvastu, Lumbini, Kushinagar and Sarnath. The civil works under LMNHP are being implemented through 12 construction contracts. These 12 contracts are being administered by four Construction Supervision Consultants (CSCs). The IIT Delhi was approached by the NHAI to carry out a detailed systematic safety audit of work sites across all contract packages in LMNHP as an independent consultant. The broad objective of the consultancy service was to facilitate NHAI in overcoming the deficiencies and lapses in worksite safety management in on-going LMNHP and improve/strengthen institutional and contractual framework with regard to work zone safety management in NHDP. This was to be achieved first through establishing a safety audit procedure and thereafter conducting a safety audit for the LMNHP to overcome both project specific deficiencies and help in strengthening safety provisions (including enforcement mechanisms) in future contracts. Further, the IIT Delhi was to review the nature and extent of which compliance is being achieved in the LMNHP in line with the various worksite safety provisions stated in the contract documents, identify the strengths and deficiencies of the existing system (as in LMNHP) and recommend actions that are needed to mainstream safety aspects during construction of road projects in future. The construction activities involved in the project are given in Appendix 1.

16.7.2 Objectives and method statement

The objectives and method statement to achieve these objectives are explained in Table 16.1.

16.7.3 Implementation of audit steps

In line with the objectives mentioned above and the steps for audit described in previous sections, the step wise implementation is explained in the following sections. It is to be noted that the following section presents implementation of audit steps to measure compliances and to list good and bad practices only. The remaining objectives are not dealt with in this chapter.

As mentioned in an earlier section, the compliance was checked in two parts: document compliance and field compliance under the five headings mentioned earlier.

TABLE 16.1 Objectives and method statement for the safety audit of case project.

S. No.	Objective	Method Statement
1.	Carry out a detailed assessment of worksite safety conditions in each of the 12 contracts of LMNHP through site visits in line with the identified risks and hazards associated with various road construction activities. This review and assessment must include, but may not be limited, to the following aspects pertaining to Traffic Management Plan; Traffic Safety Measures; Safety during construction of structures including design and suitability of temporary structural arrangements; Fire Safety Practices; Electrical Safety Practices; Mechanical Safety Practices; Dust Control and Suppression Arrangements; Storage, transportation, handling and use of various toxic and hazardous materials; Safety of road-side residents and passers-by; First aid; Emergency Response Arrangements; Accident records; and Housekeeping.	Review the provisions of Traffic Management Plan; Traffic Safety Measures; Safety during construction of structures including design and suitability of temporary structural arrangements; Fire Safety Practices; Electrical Safety Practices; Mechanical Safety Practices; Dust Control and Suppression Arrangements; Storage, transportation, handling and use of various toxic and hazardous materials; Safety of road-side residents and passers-by; First aid; Emergency Response Arrangements; Accident records; and Housekeeping laid down in the available contract document. Preparation of check list for implementation based on the existing contract document. Identify missing details which may enhance safety provisions and accordingly incorporate them in the revised check list.
2.	Assess the knowledge and awareness of safety requirements at various levels of the Contractors' and CSCs' staff, and make recommendations for improving the same if and where required.	Search safety literature and conduct interviews of the officials with contractors having good safety practices, identify and develop safety awareness evaluation test, conduct the test and based on the results suggest suitable remedial measures.
3.	Assess the role of CSCs and NHAI Project Implementation Units (PIUs) and Headquarter, and performance and response of the CSCs (including approval system, issuing of instructions and record keeping) in ensuring/enforcing worksite safety, and make recommendations thereto as required.	Study the present system, review of best practices and implementation in the context of NHAI.
4.	Identify and make a comprehensive list of items/aspects and areas/sections of safety deficiency in individual contracts of the project.	Perform safety audit of each package with the developed check list.
5.	Recommend specific actions that are required to overcome safety deficiencies and to strengthen/improve safety conditions in the project's contracts.	Based on the safety audit, possible remedial measures for each of the deficiencies would be suggested along with the cost implication of each of the suggestions.
6.	Identify the good practices that are being followed /adopted by various contractors and the CSCs in the project, which can be used as dissemination and learning material.	

(*continued*)

TABLE 16.1 Continued

7.	Identify the safety provisions not covered by the contracts (including technical specifications) and the EMPs, and make recommendation(s) to NHAI regarding implementation of those for LMNHP contracts.	This task will be achieved through safety audit.
8.	Identify and suggest a comprehensive list of items/aspects to be covered in the monthly reviews and reports. Also, identify and prepare a comprehensive checklist of items to be monitored on monthly basis at site for rating the contractors' performance on work sites safety management.	Study the present system, review of best practices and their implementation in the context of NHAI with safety as one of the parameters. Checklist would be developed and implemented and after validation the same shall be given to the NHAI for future references.
9.	Organize a workshop that includes participation from MoSRTH, NHAI, CSCs and Contractors, to present the findings of the safety audit and discuss the recommendations made in the draft report. Each recommendation must be discussed and reviewed in detail in the said workshop. Proper documentation of reasons for acceptance, rejection and modification must be maintained by the consultant and should be included in the final report.	Workshop will be organized and the mentioned aspects would be covered.
10.	Reassess whether the recommendations made in the Audit Reports (contract specific) have been implemented or not (including reasons) in the project sites.	Select sample validation of recommendations will be carried out.

16.7.4 Checklists

The compliances were checked against checklists. The checklists were exhaustive and these are given in the Appendix 2. The checklists were implemented at different locations along the highway for different contracts (there were 12 contract packages as mentioned earlier). The percentage compliances at different chainages were computed.

The check lists are broadly grouped into five groups: Construction safety, Structural safety, Worker/work zone safety, Traffic management and safety, and Mechanical/electrical/machinery/operational safety, as given in Table 16.2. A number of checklists were also prepared to check the document compliance. For this a number of documents were referred to and they are given in Appendix 3.

16.7.5 Findings

(A) Contractual compliance
The following graphics show the level of compliances observed by us during the audit exercise in one of the prestigious projects.

(B) Good and bad practices
Also good and bad practices in each work contract were compiled. These are shown below.

TABLE 16.2 Sample activity for safety.

S. No.	Activity	Example
1.	Construction Safety (CS)	Safety in earthwork etc.
2.	Structural Safety (SS)	Plan for form work at bridge construction site or ROB site etc.
3.	Worker/Work Zone Safety (WO)	Worker safety measures at HMP/ Concrete Batching plant etc.
4.	Traffic Management and Safety (TS)	Traffic diversion plans at road-widening sites
5.	Mechanical/Electrical Machinery Operational Safety (ME)	Machinery working condition and maintenance schedule

16.8 CONCLUSION

Ensuring safety in construction zones is a challenging task. A number of fatal and non-fatal accidents occur in a highway construction zone. In addition to the normal safety management applied at a typical project site, construction zones require some additional effort in ensuring the safety of different road users and construction workers. A construction zone safety audit is a systematic procedure aimed at reducing the number of fatal and non-fatal accidents by applying knowledge of the road construction process. Very few systematic audit procedures are available in the literature. In this chapter, a systematic method of carrying out a highway construction safety audit is presented and it has been implemented on a real life live project. The level of contractual compliance requires a lot of improvement and self-motivation by the construction agencies.

SUGGESTED READINGS

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APPENDIX 1: TYPICAL ACTIVITIES INVOLVED IN HIGHWAY CONSTRUCTION

1. Drilling and Blasting
2. Surveying
3. Earth work – Open Excavation, Trench Work, and backfilling, Embankment/Subgrade
4. Rebar Handling and Tying
5. Formwork making, fixing, and removing,
6. Concreting
7. Waterproofing
8. Asphalt Paving, Bitumen work
9. Dense Bitumen Concrete/Bitumen Concrete (DBM/BC)
10. Granular Sub Base/Wet Mix Macadam (GSB/WMM)
11. DLC/PQC
12. Kerb
13. Road Marking/Fixing of Permanent Sign Boards
14. Crash Barriers/Slope Protecting Works
15. Activities at Height (including aspects pertaining to ladder, scaffolding, working platform, railing safety)
16. Welding and Gas Cutting
17. Material handling, loading and unloading of materials
18. Mastic Asphalt spreading
19. Machinery-Batching Plant, Hot Mix Plant, Crane Operations, Diesel Generator Set, Hydraulic Excavators, Dozers, Transit Mixer, Trailers, Installation of Machine (Boom Placer), Cleaning of Delivery Line and Pump, Tipper, Motor Grader, Poclain & W-20 Loader, Paver, Roller,
20. Lighting
21. Work over Water
22. RE wall
23. Pile driving
24. Tree cutting
25. Storage, transportation, handling and use of various inflammable materials/explosives and
26. Electrical works at plant sites, camp sites and work sites and near habitations

APPENDIX 2

Audit Check Lists: TEMPORARY STRUCTURES SAFETY (SS)

Part A: Documentation Audit

S. No.	Aspect	Reference	Issue	Compliance	Observations	Remarks
1.	Ladder/Stair Safety		Ladders are safe and inspected regularly			
2.	Scaffolds		Has the scaffolding arrangement been designed by competent person?			
			Is the scaffold supported on firm ground?			
			Is the draining available for high scaffold?			
			Has it been checked and approved by competent person?			
			Whether competent person is employed to inspect the scaffold condition periodically			
			Is experienced and trained person employed for erection and dismantling of scaffolds?			
			Is site having a practice of providing suitable and sufficient scaffolds so that the work could safely be done at a height?			
			Is site engaging suitable/properly trained/ experienced workmen for constructing/ dismantling/shifting scaffolding works?			
			Is there a system of inspecting materials of scaffolds on each occasion before erection?			
4.	Formwork Checklist		Whether the approved design, drawing and specifications are available for the formwork system			
5.	Structural Fabrication and Erection		Are lifting tools & tackles tested, inspected and checked before use?			

Part B: Field Audit

S. No.	Aspect	Reference	Question	Compliance	Observations	Remarks
1.	Ladder/ Stairways/ Ramps		Do extension & straight ladders extend $3'$ beyond landing?			
			Are ladders placed on level ground?			
			Are ladders positioned at an angle of apart 1:4?			
			Are ladders adequately secured?			
2.	Scaffolds		Base plates used			
			Soil Condition			
			Scaffold is plumbed up (vertical tubes)			
			Entry restricted into affected area?			
			Are diagonal bracings secured and checked with missing elements?			
			Are lock pins in place and secured?			
			Is scaffold erected in firm ground?			
			Is it free from defective components?			
			Is scaffold tag system in use?			
			Is there safe access to the working platform?			
			Is the width of working platform properly maintained?			
			Is there a provision for anchoring full body harness-lanyards to be tied to life line?			
			Are openings in working platform kept safely covered/fenced?			
3.	Working at Height		Is the area below the workplace barricaded, especially below hot-works?			
			Workmen provided with bag / box to carry bolt, nuts and hand tools			
			Has arrangement for fastening hand tools been made			
			Fabricated makeshift arrangements are checked for quality and type of material welding, anchoring, etc.			
			Is work at more than one elevation at the same segment restricted?			
			Safety nets are in use and maintained clean where height is more than 6 m?			
			Covering of gaps in form work and edge protection?			
			Is entry restricted into affected area during the life cycle of the activity			

APPENDIX 3: LIST OF DOCUMENTS REQUIRED FOR CHECKING CONTRACTUAL COMPLIANCE

1. Latest Monthly and Quarterly Report (i) Contractor to CSC; (ii) CSC to PIU; & (iii) PIU to HQ
2. All sample formats of (1) Non Compliance Reports; (2) supervision consultant reports; and (3) RFIs
3. Locations of approved sources of Fine Aggregate; Coarse Aggregate; and Water along with a map showing various access/ haul roads
4. Locations of major plants viz Crusher, HMP, WMM Plant, Batching Plant, etc.
5. Locations of camp sites, labour camps & workshops
6. Locations of Material Stock Yards
7. Ref. Clause 36.6 -Approved Construction Methodologies for various items of work
8. Temporary Structures/Formwork details of Individual Contractor
9. Ref. Appendix G5 (A & B) of EMP – Filled in Information in the prescribed Formats
10. Details of environmental officers of CSC – qualification and experience
11. Safety Organization chart including names of Contractor and the details of safety officers of contractor – qualification and experience
12. Documentation of Safety Systems adopted by individual contractor
13. Safety Plan of Contractor (Ref. Clause 112.4 of Technical Specifications) and directions given to contractor/actions taken on contractor/notices issued to contractor by CSC/PIU and contractor's replies.
14. Approved Traffic Diversion Plans and Traffic Management Plans of individual contractors
15. Fire Safety Practices, Electrical Safety Practices & Mechanical Safety Practices of individual contractor
16. Dust Control Measures adopted by individual contractor
17. Storage, Transportation & Handling procedures of individual contractor
18. Permissions and Consents (1) For the Storage and use of explosives; 2) Storage and use of diesel, LDOI bitumen material; (3) Mining Permission; (4) Blasting Licence; and (5) Blasting Safety Procedures
19. Road Side Residents safety norms adopted by individual contractor
20. First Aid and Emergency Response Arrangement of individual contractor
21. Traffic Accidents Records with Police
22. Construction Accident Records at Site maintained by Individual Contractor
23. Refer Clause 19.1 of GCC/COPA- Correspondence from PIU/CSC to contractor, vice versa and replies on this clause
24. Refer Clause 24.2 of GCC/COPA- Copies of insurance against accidents to workmen
25. Refer Clause 35.1 of GCC/COPA- Copies of Labour returns
26. Copies of applicable laws of Government of UP/Bihar on worker's safety provisions
27. Refer BOCW Act 1996, Registration and Cess Payment proof
28. Accident Reports filed at work
29. Check-lists of Safety Inspections carried out at worksites and labour camps
30. Minutes of meetings of Site Safety Committees
31. Minutes of meetings of Housekeeping Committees
32. Weekly/monthly/quarterly Monitoring/Review Committee minutes
33. Records of regular Medical Check-Ups
34. Registers of Dispensaries
35. Training Schedules for Health and Safety
36. Register for Issue of Safety Equipment
37. Copies of Independent Safety Audit and Review procedures/Supervision Manual/Training Manuals available with the contractor and the consultant
38. Copies of Safety Instructions issued by NHAI- to be provided by NHAI, PIU

CHAPTER 17

Road Safety in Urban Areas

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CONTENTS

ABSTRACT

The 19th and 20th centuries have introduced modern technical transport modes which have changed the thinking and planning of professionals in a fundamental way. Earlier they had to develop multifunctional urban structures for every neighbourhood, the public space has to be used for nearly all kinds of human activities, mobility, social contact, leisure, playgrounds for children, and meeting places for adults and elderly people. The public space was a scarce good and had to be planned carefully in a socially accepted manner. However, since the advent of the car, former cities have been converted into carriageways for fast car traffic, and are now a barrier for vulnerable road users and a dangerous environment, especially for children. Are vulnerable road users and children the 95% cause of traffic accidents, because of their human errors? The human error which causes deaths and injuries, is brought about by the laws, guidelines, and professional paradigm and thinking of planners, administrators and decision makers. In order to have safe urban areas, the priority is clear: pedestrian safety first, followed by safety cyclists and public transport, far ahead of cars. All traditional standards and cross-sections have to be rewritten and redesigned if we want to live in safe urban areas in the future.

Key Words: Urban Safety; systemic safety; cities

17.1 INTRODUCTION

How road safety became an issue in urban areas

> *'When the past no longer illuminates the future, the spirit walks in darkness'.*
> *– Alexis de Tocqueville*

Although road safety as we know it started with the motoring age, road accidents had long been a problem in the nineteenth century, especially in the **fast growing urban areas** of Britain.[1] Thus in 1875 there were 1,589 fatalities, mostly involving horse conveyance of some kind, and this was actually more than in 1910. Very little research has been done on these accidents and on public policy regarding them, but the legislation of the time does contain measures on the proper use of the highway. Thus the Highway Act of 1835 prohibited riding on a footpath, and has regulations on the control and driving of carts and carriages, including dangerous driving and riding offences. Drinking while in charge of a carriage, horse or cattle, was an offence under the **Licensing Act of 1872, and the Locomotive (Red Flag) Act of 1865 with its speed limit of 4 mph in open country and 2 mph in towns**, which is well known. There must also have been a considerable body of knowledge to do with driving horse-drawn vehicles and presumably safety was included in this.

1897: **THE AUTOMOBILE CLUB**. *(rich and influential people)* Like the cyclists, early motorists were subject to hostile attention from horse riders, local authorities, and the police, and formed themselves into associations to fight for their rights and also to provide services for their members.

The **Local Government Board** was to issue guidelines on the design of road signs, which it did in 1904.

There were three types of signs: speed, prohibition, and caution:

(1) For **10 miles or lower limit of speed**, a white ring 18 inches in diameter, with a plate below giving a speed limit in figures.
(2) For prohibition, a solid red disc 18 inches in diameter.
(3) For caution (dangerous corners, cross roads, or precipitous places) a hollow red equilateral triangle, with 18-inch sides.
(4) All other notices under the Act were to be on diamond-shaped boards.

1905: **First use of bumpers (UK)**.
1916: **LONDON "SAFETY FIRST" COUNCIL**.
1922: **US School Patrol system started**.
1923: **EARLY ROUNDABOUTS**: the work of an American traffic specialist, William Phelps Eno, on traffic movements at junctions.
1931: **THE HIGHWAY CODE. ROAD RESEARCH LABORATORY**: Although the RRL was set up at this time, it was not until 1946 when the Traffic and Safety Division was formed that road safety research got underway.
1934: **ROAD TRAFFIC ACT**: This brought in the **30 mph limit in built-up areas**, (*without any scientific evidence!)* driving tests, pedestrian crossings *(ruthless and fundamental restriction and limitation of people's mobility = pedestrian freedom of movement in public space)* and reflectors for bicycles. Penalties for dangerous driving were increased.

[1] Introduction The History of Road Safety by Gerald Cummins http://www.driveandstayalive.com/Info%20Section/history/history.htm

1939: **ALNESS COMMITTEE**. This was the Select Committee of the House of Lords set up to look at road accidents and is notable for laying down the **three "E's"** *(captures thinking in Engineering, Education, Enforcement)* as the basis for remedial work.
1944: **INTERIM REPORT OF THE COMMITTEE ON ROAD SAFETY**.
1946: The first of a series of Presidential Highway Safety Conferences held in the U.S.A., which created the framework for traffic safety work in the post-war years.
1963: **THE BUCHANAN REPORT**. This was a major and influential study of the impact of the motorcar on society.

17.1.1 Review of road safety in urban areas: TRL-report World Bank 2000

The urban safety problem: 750–880,000 people died prematurely in road traffic crashes in 1999. Some 85% of these occurred in developing countries, and urban road networks contributed to a significant proportion of countries' national road traffic crash (RTC) problems. Between 35 and 70 per cent ++ of all crashes occur in urban areas. Vulnerable road users dominate, with pedestrians being the most vulnerable group in the poorer countries. The majority of the victims come from the underprivileged sectors of society. Urban RTCs involve a high proportion of buses and commercial vehicles. They occur predominately on links rather than at junctions, highlighting the dangers of the current emphasis on capacity expansion, often at the expense of vulnerable road users. No clear link was found between urbanisation and the proportion of accidents occurring in urban areas but this is compounded by the lack of transport in the rural areas of the poorest countries. Data from three countries indicate that at least a third of rural RTCs occur where highways pass through villages or small towns. Urbanisation in the developing world continues apace, thus the relative importance of urban road crashes in the future will increase.

17.2 THE TRADITIONAL 'PROFESSIONAL VIEW' OF TRAFFIC SAFETY IN URBAN AREAS

The recommendations in the World Bank-Report Safety in Urban Areas (Downing et al 2000) reflects the "world view" of experts in the traffic-safety professional world. It shows how the problem is seen and how the "system" is understood. It is the world of the three E's: Engineering – Education – Enforcement. This approach paves the way to the future "*Developing country practice: The way forward"*

- Urban safety improvements should be separately identified even if for practical reasons they are treated as components of national or urban development projects.
- Road safety should be managed effectively as part of the city's overall development strategies and transport plans in line with the planners' vision for the cities. All urban and transport policies have a potential for safety impact and safety should always be considered.
- The management approach is critical to the success of plans and implementation. It should be multi-sectoral and include strong involvement of the stakeholders and community participation.
- Successful implementation of road safety strategies will depend upon public and political commitment, the strength of the implementing agencies and the resources available, and a coordinated multi-sectoral approach. Development projects should devote sufficient resources to these aspects and, in particular, focus on establishing a sustainable road safety unit in large cities.
- A safety culture within the road authority should be developed with other units such as maintenance departments and planning, learning how they can contribute to the reduction of crashes. Road-user safety should be the responsibility of the road authority as a whole, and all units, not just that of traffic/safety engineering departments.

- Road safety management will also require the cooperation of a variety of local government sectors, NGOs and private businesses. A strong coordinating body or lead agency will be necessary to ensure implementation.
- Some element of road user charges should be devoted to the improvement of urban roads and their safety with a rational approach to apportioning of funds.
- Public-private partnerships could have considerable potential, particularly where the private sector has a commitment to the development of their city.
- Road safety measures should be focused on improving the safety of the VRUs who come from the poorest sectors of urban society. Likely measures will include better facilities for pedestrians and two-wheelers, reduced vehicle speeds, traffic calming, and safer public transport. Changes need to be introduced through an understanding of the needs of target groups and not by a top-down approach alone.
- Road safety programmes need to be based on good crash information. Medical databases and secondary indicators should be considered, as well as improved police systems essential for both planning and monitoring purposes.
- Research is needed to develop new approaches to road safety, particularly to change the behaviour of vulnerable communities and the drivers of public service vehicles. Evaluation of approaches is vital, as is its dissemination of the lessons.

Accident data are the basis for the analysis of the urban safety problem. The professionals are looking to the road users, their physical and psychological and social situation, as well as the roads, the traffic code, enforcement, education and training, as the following headlines and recommendations show.

17.2.1 Road safety plans

Coordination of activity by central and local government under the traditional headings of the three Es – **Engineering, Enforcement and Education** – is essential to achieve cost-effective results. The following specific areas are included:

1. Blackspot programmes
2. Traffic calming
3. Area-wide schemes
4. Traffic law enforcement
5. Education and publicity
6. Urban road safety management
7. Crash prevention and casualty reduction on urban roads

Figure 17.1 shows a comprehensive system view – *from the point of The three Es* (European Commission 2000)

It is extremely interesting to find the following paragraph at the end (page 62) of the report[2]:

17.2.2 Urban land use planning

Land use planning aims to reduce the number of motorised trips and also trip length, segregate functions of access and movement to create safer road networks, ensure good local planning of parking and circulation and design to be as self-enforcing as possible:

- Have local plans checked for road safety implications and impacts
- Introduce and strictly enforce access control procedures
- Introduce and strictly enforce development control procedures

[2] Downing, A., Jacobs, G., Aeron-Thomas, A. et al. 2000. Review Of Road Safety In Urban Areas. Project Report Pr/Int/200/00. Transport Research Laboratory. UK.

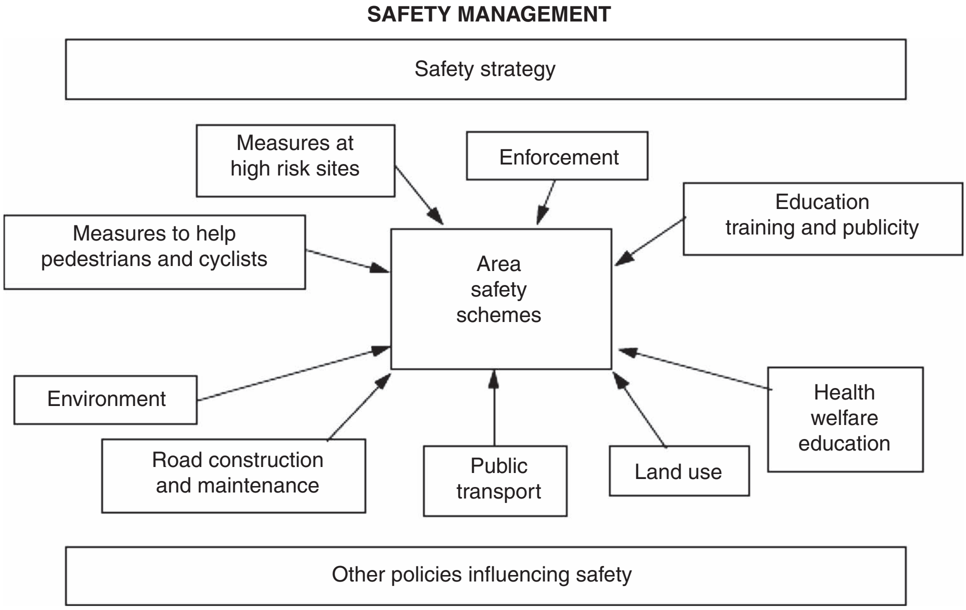

Figure 17.1 From the DUMAS (Development Urban Management and Safety – EU-project 2000).

- Train engineers and planners in safety conscious planning of road networks and land use
- Establish consultation procedures so that traffic safety engineers have the opportunity to comment on any proposed development.

But this chapter was not elaborated further, which proves the traditional view of the problem. Instead of going deeper into land use and urban planning, the report follows the three E path:

Infrastructure improvements,
Traffic Management,
Transport operations and
Institutional strengtheningfor road safety.

The outcome is in principle the same as the Urban Road Safety Programme, carried out by the World Bank in the Asia Technical Department Series for Urban Transport in Asia, by Midgeley (1994).

Midgeley argues that programmes should be drawn up involving: police, engineers and educators and that the importance of adequate funding should be recognised. He lists the Components of an Urban Road Safety Programme as:

1. crash data collection and analysis
2. traffic engineering and control at crash locations
3. vehicle testing and inspection
4. driver training and testing
5. traffic education for children
6. publicity and marketing
7. traffic police enforcement
8. road safety monitoring and research
9. traffic and road safety design standards
10. emergency services and first aid
11. road safety legislation and penalties

So far, the situation has not changed much since 2000 in most of the countries and organizations dealing with traffic safety in urban areas.

17.3 A SYSTEMIC APPROACH: RISK AND ACCIDENTS

Accidents are symptoms of system failures, the effect of risk in the system. Risk can be defined in the simplest way:

$$R = \sum_{\text{(for all accidents)}} \text{(probability of the accident occuring)} \times \text{(expected loss in case of the accident)} \tag{17.1}$$

Probability is dependent on the number of system users with potentially dangerous attributes. We can call them aggressive road users. Aggressiveness has different expressions: ruthlessness, occupation of public space, protected position, powerful appearance, mass, and speed. The counterpart is vulnerability. Aggressiveness is an attribute as well as a kind of behaviour; vulnerability is an attribute. Both are present in an urban society. In human history people have learned to deal with both these attributes, by developing rules in the society. We call that culture, in our case, the urban culture. If the dimension of aggressiveness exceeds human evolutionary experience by technical development, (speed or mass or both), as happened when cars came into common-use, traffic safety – not only in urban areas – becomes a serious problem; because cars and all other modes like pedestrians, cyclists and public transport are mixed in the public space, without clear rules.

17.3.1 Cities and urban areas

It is important to distinguish between those two terms. Both are man made, but they have different structures; we can say they have different DNAs. Cities have been developed hand in hand with the social evolution of people over the last 10,000 years. They are artificial, man-made complex structures, built on a human scale and operated by people using mainly local energy. The dominant and most significant transport system was pedestrians, the only transport mode of mankind for which everybody has enough evolutionary experience to move safely. The trips are short, most of them across the street. This keeps urban structures together, which are rich in variety. Goods are transported in these cities by foot, horse- or ox-drawn vehicles, today with small lorries with electric or combustion engines. The dominant speed is the pedestrian speed. Roads are safe and traffic accidents are very rare and seldom fatal.Where these cities have survived the industrial revolution of the 19th century and the disaster of the motorization period, it is easy to re-establish a high quality of life for people, rich business, and a safe environment. The urban-DNA is based on people, and starts to work as soon as cars and car-traffic is removed from the body of the city. In Vienna, where the author was able to remove more than 120.000 cars per day from the city center and more than 8000 parking places from the streets and historical places[3], road traffic safety was not an issue any more. Since then, the turnover of shops has increased substantially, 3000–4000 vehicles are on the roads every day during the time of delivery.

Urban areas are the parts of settlements, built after the 19th century. The invention of street cars during the period of industrial revolution solved the mobility problems for longer distances in the fast growing cities of that time. These urban structures are in general densely populated, have rather narrow streets, flanked by urban buildings with four to five levels, and shops and workshops on the ground level. As long as the streets were free of car traffic, these urban areas were a safe environment for everybody. Children could play on the streets as ever before in urban areas. When the car came into use as a mass-transport-mode for everybody it occupied not only the urban space, but also the brains of architects and urban planners.

[3]Knoflacher H. Verkehrsorganisation Wien 1. Bezirk, Wien 1971

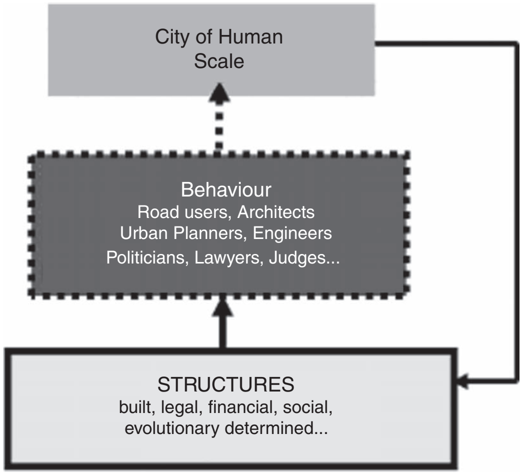

Figure 17.2 Cities are artificial, man-made, complex structures, evolved over 10,000 years. Road traffic safety in these cities was historically not a big issue.

The Athens Charter, published by Le Corbusier[4], influenced the work and thinking of generations of architects and urban planners. The new city became a place for convenient and easy car mobility. This transformed cities into urban areas, and big cities into agglomerations. In these urban areas the risk of a road traffic accident is present in the public space. Treating traffic safety on the road is only dealing with the symptoms of a deeper malady.

17.3.2 Traffic safety – Behaviour – Structures

Traffic accidents are the visible effects of system failures and not only of human errors.[5] How could humans survive with this percentage of human error in a hostile environment over 6 million years? The environment was much more complex than the carefully planned new technical, highly developed artificial one of today. Unfortunately, most people have no chance of escaping from using public space. Each part of the built up area was planned by skilled and educated architects, urban planners and engineers, approved by a qualified administration doing the business on a legal basis – and finally built. If these structures kill people, doing their daily ordinary business and activities, something unplanned must have happened if we assume that the planners and decision makers did not intend to build these risks into their structures and infrastructures. What is very often not considered are the relationships and feedbacks in the following diagrams in which the road users are the only black sheep?

If the human errors of road users are the cause of road traffic accidents, the manmade urban environment should not produce more risk than the indoor mobility of people. If human error is extended to everybody's behaviour in the system, if experts and decision makers, who are involved in planning, building and operating the urban system and transport and traffic are also suspected of producing risk and accidents in the system, then we are forced to admit that human error is built into the urban fabric, the urban system.

If this is the case we have to suppose, that standards, building and land use codes etc. might also contribute to the causes of road traffic accidents. Most of the urban and transport regulations and standards have no sound scientific background. Many are agreements or extrapolations of individual experiences at the system level. If this were not the case, no traffic calming measures would be necessary to enhance road safety.[6]

[4] Athens Charta 1943, Le Corbusier 1887–1965
[5] http://cyberlaw.stanford.edu/blog/2013/12/human-error-cause-vehicle-crashes
[6] http://en.wikipedia.org/wiki/Traffic_calming

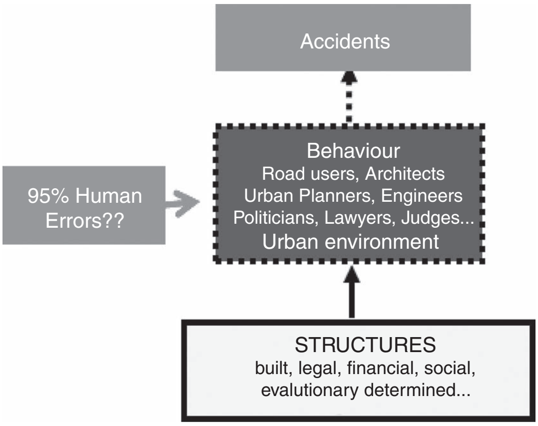

Figure 17.3 Basic relationship between effects (accidents), behaviour and structures. Is it true, that 95% of accidents have their cause in human errors? Is road user behaviour really the main cause of accidents?

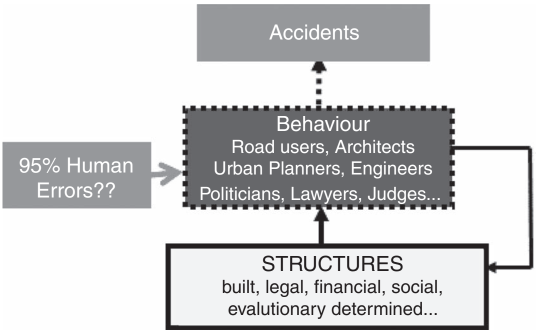

Figure 17.4 If "human errors" are built into the urban structures, these structures can cause errors in human behaviour and finally accidents.

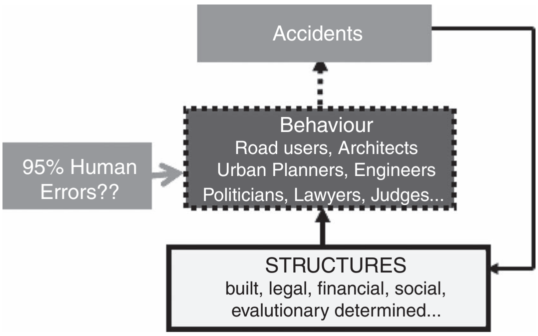

Figure 17.5 Traffic safety experts change structures to reduce the risk built into the urban road structure by traditional educated engineers, architects, land use and urban planners.

Roads are converted into pedestrian areas, lane width is reduced to a scale far from the minimum standard lane width. Speed limits of 20 km/h or 30 km/h prevent separation between cycling and car traffic. Parking restrictions have positive effects on local business. To prioritize public transport, car lanes are cut. Nearly everything which is forbidden in traditional standards, regulations and rules, has become a success in traffic safety on urban roads.

17.4 THE URBAN AREA – A PRODUCT OF THE HUMAN BRAIN

Everything man-made is produced in the human brain. If the approach to urban and transport planning has had such fundamental changes, as history shows us, something must have happened in the human brain. When technical vehicles came into common use, (especially the car), planners, civil servants and decision makers did not continue to plan and build cities for people; instead they built an urban environment for and around the needs of cars. It is remarkable, that even the elementary principles of logic were ignored.

The car must have changed the brains of people. Instead of planning and building the urban environment for people, they designed and shaped urban areas for the needs of cars and motorists.

That mystery could be solved in the mid-seventies of the last century. I discovered a similarity in diagrams derived from observations in two totally different fields of science: the behaviour of humans in the artificial environment of a city, and the information system of honey-bees about distances to sources of food (Knoflacher 1981).

The cause of this homology is body-energy consumption in both cases. The level in our brain controlling body energy, is the deepest and oldest one. The car is the product of our technical civilisation, but it goes into the deepest level of our brain and changes everything above that level. It moves the world view toward the needs of cars, it changes the value system of experts, decision makers, and society.[7]

Infected with the car-virus[8], society started planning the world for these vehicles and tolerates killing and injuring people in the public space of urban roads (and in rural areas) as never before in human history. The result is 1.2 million victims in road traffic accidents globally per annum (WHO 2014). The people don't see the urban environment as humans because the car in their brain is controlling their perception of the world.

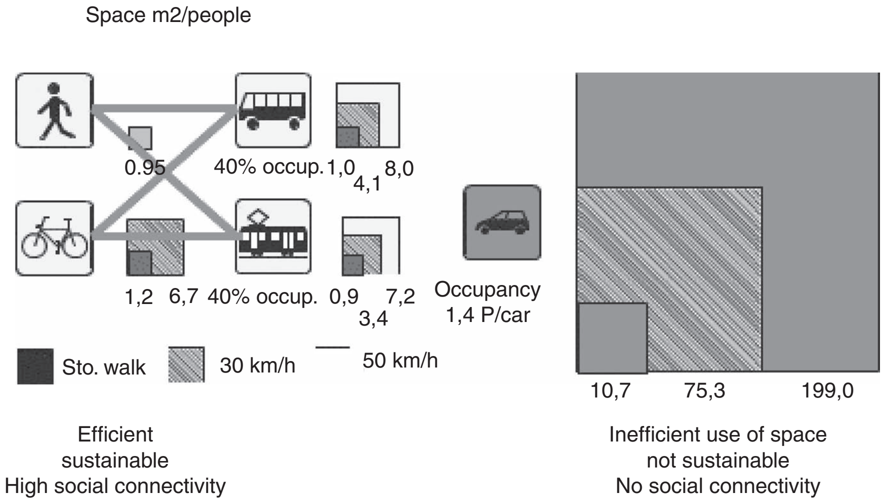

Figure 17.6 With the city-agreeable modes, pedestrians, cyclists, and public transport were subordinated to the needs of cars in physical, legal, financial structures, which is in total contradiction to fundamental engineering and planning principles of efficiency or sustainability.

[7]Riedl R. Die Spaltung des Weltbildes, 1985, H. Knoflacher Verkehrsplanung für den Menschen, Böhlau 1985

[8]Knoflacher H. Virus Auto, Böhlau, Wien 2009

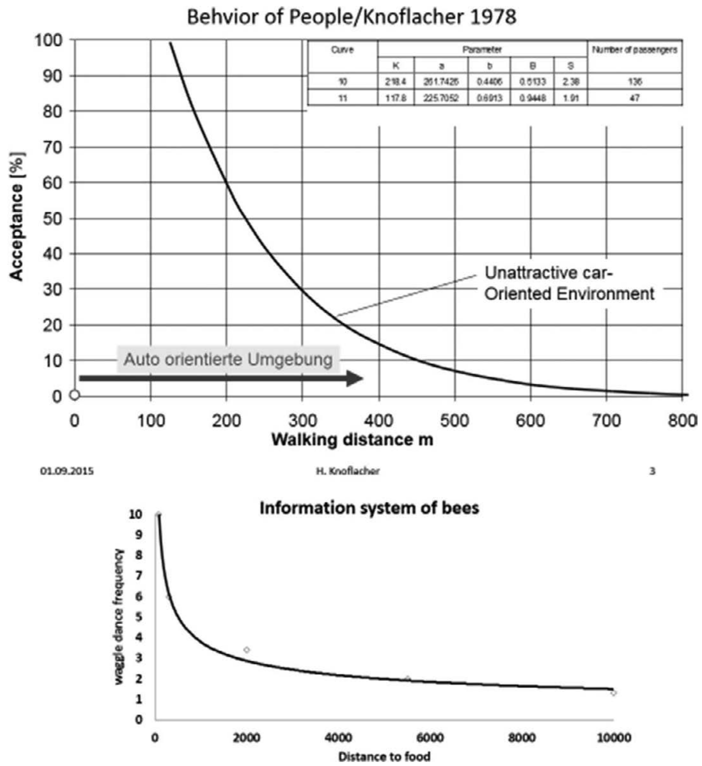

Figure 17.7 Diagrams, expressing the sensation (perception) of distance for humans and honey-bees. In both cases the curve has an e^x-shape.

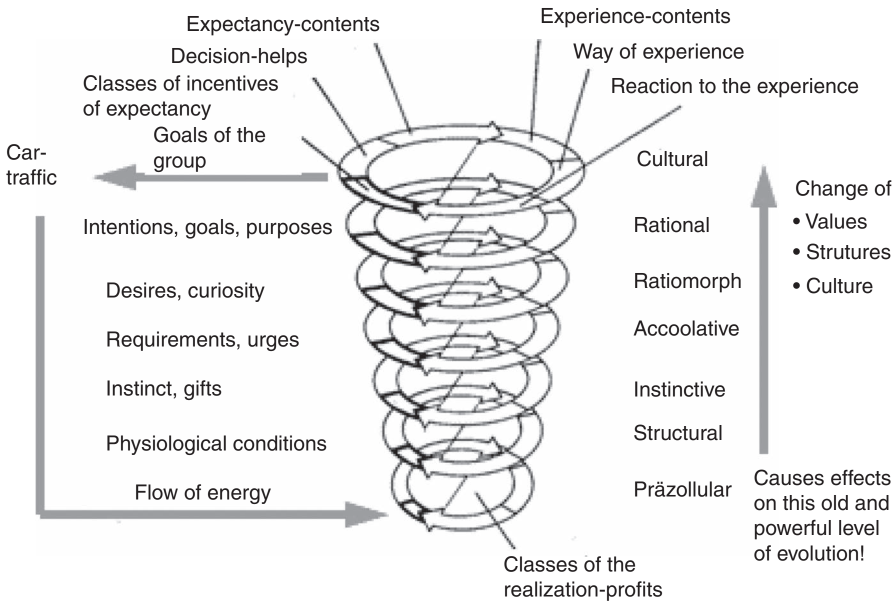

Figure 17.8 The effect of cars on human brains.

Figure 17.9 The same place. The left slide with the car is accepted by the society, the right side with a frame of the same size of the car (Gehzeug = walking-tool), is seen as unsocial behavior.

Figure 17.10 The “congestion-problem” and the “parking-problem” in a rational view. This tool was invented to open up new vistas for students and professionals.

17.5 THE DIFFERENCE BETWEEN SAFE AND UNSAFE ROADS IN URBAN AREAS

Figure 17.11 reflects the reality of human behaviour on urban roads. If cars can park close to homes, shops, workshops, schools, sport and leisure activities, people are becoming car drivers and each road is becoming a dangerous place for everybody, especially for vulnerable road users. If the building code forces people to provide parking places at their homes or other places of activities, this law is the cause of road traffic accidents in urban areas. If planners, architects, engineers, and experts in administration execute such a law or guideline, they are responsible for the consequences of their decision.

Parking places everywhere are the cause of accidents in urban areas – everywhere – They are the cause of traffic congestion, the damage to local shops and workshops, environmental degradation, and air and noise pollution.

17.5.1 Effects on safety on urban roads

If cars can be parked close to every human activity, carriageways for car traffic must be built for each building. This both enhances cost for the municipality and brings the danger of death and/or injury for all vulnerable and urban-compatible road users. For thousands of years, public

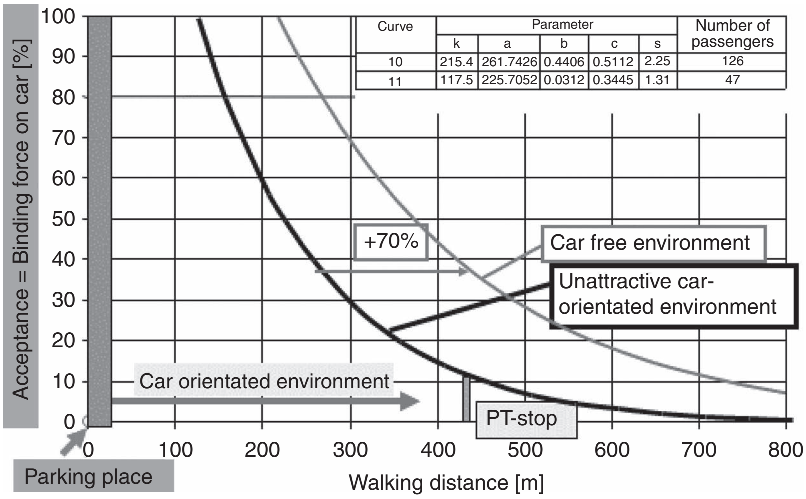

Figure 17.11 Acceptance of walking distance to public transport stops in a car-free-environment and on car-dominated urban roads.

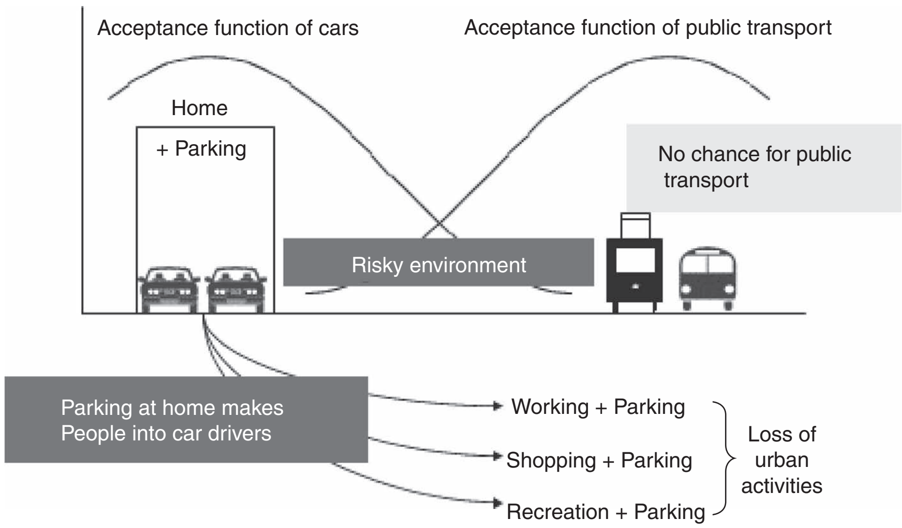

Figure 17.12 The urban structure, which causes risk and accidents in urban areas.

space was a shared space for everybody. This precious part of the former city was converted into carriageways for fast car traffic and is now a barrier for vulnerable road users and a dangerous environment, especially for children. Can we call this kind of urban and transport planning progress when the outcome is an environment in which we have to warn our children about the peril of death in the urban public space, well designed, based on approved road design standards? Is this the future urban area we want? Are vulnerable road users and children 95% of the cause of traffic accidents, because of their human errors? Or are human errors in the professional society, responsible for planning, building, approving, drafting and deciding about laws, regulations and standards, managing the urban transport system also a cause for road-danger in urban areas?

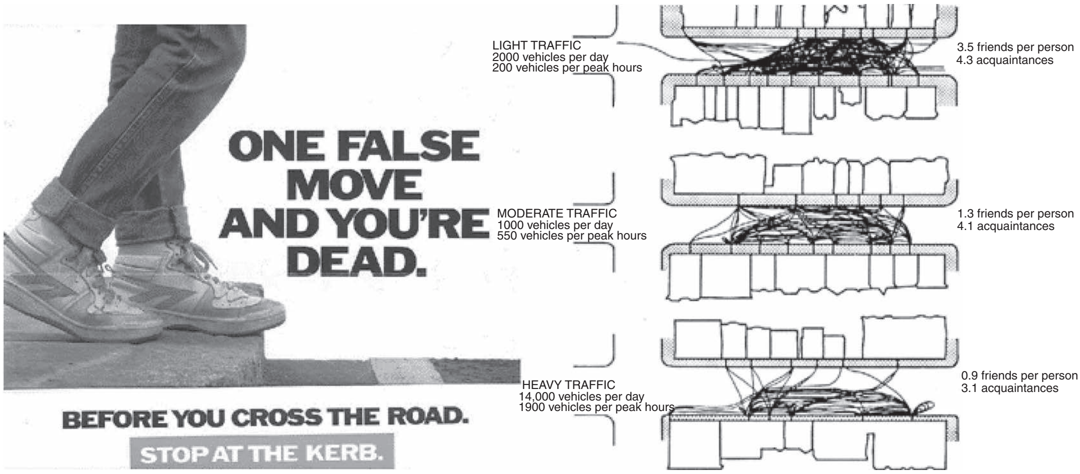

Figure 17.13 Traffic safety campaign in urban areas, left side. Loss of neighbourhood and local social contacts – right side.

The human error which causes the deaths and injuries, is implemented by the laws, guidelines, and professional paradigm and thinking of planners, administrators, and decision makers, who have not been aware that the car in their brain is controlling their activities. Some of them have a crisis of conscience when they try to do something for vulnerable road users.

Besides ignorance about human evolutionary constraints and abilities in the traditional engineering and planning disciplines, the urban areas have been developed on focussing on mobility, speed, and time, which dominate our society.

17.5.2 The additional contribution to unsafe urban areas: Traditional urban and transport planning paradigm

The 19th and 20th centuries have introduced modern technical transport modes which have changed the thinking and planning of professionals in a fundamental way. Earlier, they had to develop multifunctional urban structures for every neighbourhood, the public space had to be used for nearly all kinds of human activities, mobility, social contact, leisure, as a playground for children and a meeting place for adults and elderly people. The public space was a scarce good and had to be carefully designed, in a socially accepted manner. Now the high speed of electric, steam and combustion engines occupies the easily accessible space around the compact cities. Growth of Mobility, Time Saving by Speed and Freedom of Modal Choice became the pillars, the paradigm, on which urban areas and the road system were designed. Motorways were planned in and around urban areas, but the effect on urban traffic safety was never analyzed. It was therefore an opportunity to analyse the effect of a motorway on the traffic safety of a whole city, when two motorways in the City of Vienna were opened in 1978 (Knoflacher 2004).

The motorways opened in Vienna in 1978. It relieved the urban roads from car traffic and enhanced the speed in the system. The effect can be seen clearly in the diagram. The downward trend was stopped, and more than 15,000 additional accidents that injured people happened, till the system stabilized itself after 16 years. These kinds of solutions are the result of the traditional paradigm of transport planning, based on mobility-growth, time-saving, and freedom of modal choice. Unfortunately none of those exist in reality; they are myths. Mobility was defined as movement of vehicles without any purpose. Each trip has a purpose, independent of the mode. The increase of car trips was and is accompanied with a decrease of trips in all other modes.

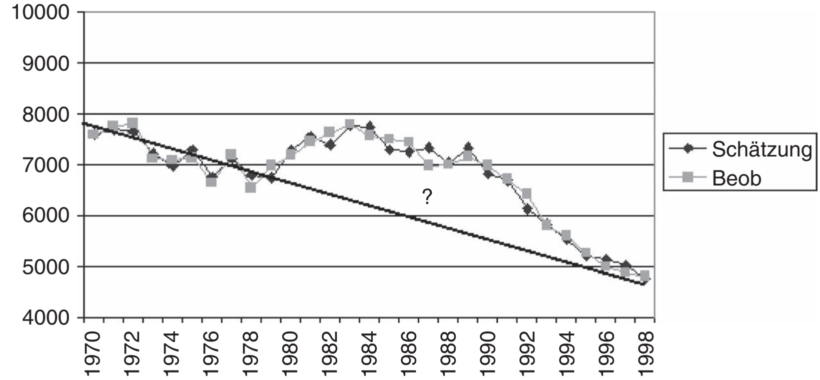

Figure 17.14 The effect of a motorway on the accidents of a big city.

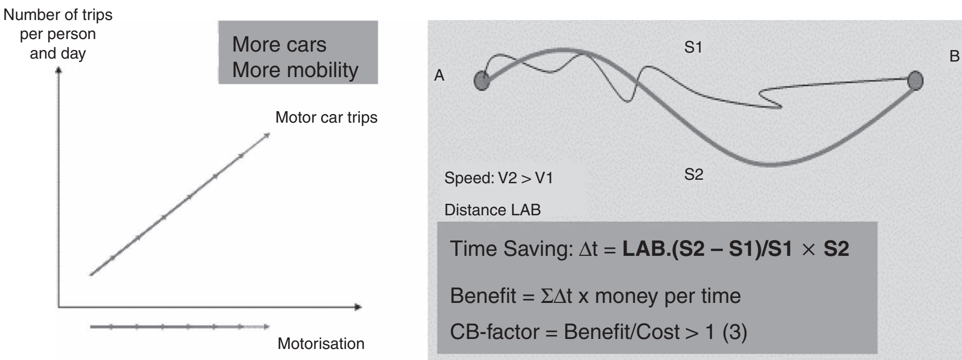

Figure 17.15 and 17.16 "Growth of Mobility", left, and Time Saving by Speed, right figure, are core pillars of traditional urban and transport planning theory and practice.

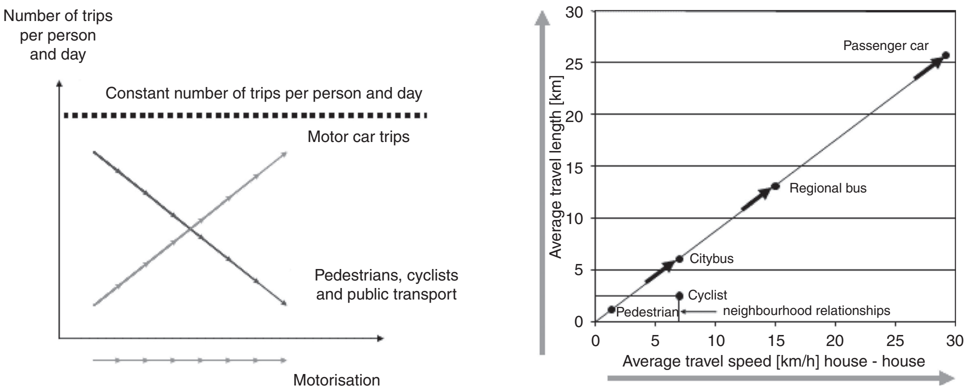

Figure 17.17 and 17.18 The reality of the system is different: There is not "growth of mobility", the average number of trips per person per day is constant, left figure. Only the kind of mode is changing. Average travel time in the system is also a constant. If speed increases, distances increase.

Time Saving does not exist in the system. For decades we have known (Knoflacher 1986) that travel time budgeted in the system is a constant. If speed increases, distances also increase. The transport changes urban structures. Speed of car traffic dissolves the city into the surrounding landscape; big cities become agglomerations. In transport economics, travel time saving as a benefit has finally been accepted by some researchers (Metz 2008). Trip distance and energy consumption for mobility increases with decreasing urban density.[9]

17.5.3 How to make urban roads safe?

Terms specify and manipulate thinking, since they are mental models of something. When we are thinking about urban areas, does the term "road" fit into our perception of a city? The dictionary distinguishes between road and street: A **road** usually runs between two more distant points, such as between two towns. A **street** is described as being a paved road or highway in a city, town, or village, especially one lined with houses, shops, or other buildings. The implication is that if a **street** does not have these things, it will probably be called a **road**. When a town expands, sometimes what was formerly a **road** will become a **street**. The word **road** is the more general term, though, and can be applied to a **street**. **Street** is the narrower term[10]. What is narrow and what is wider depends on the point of view. From the broader system-planning and system-understanding view, street is a much wider term, since it has to take into consideration the whole built up area, the social, economic and ecological circumstances which specify the conditions as to how the street has to be designed for optimal use by all. Road is from the urban – human and not car-addict – viewpoint a much narrower term. Therefore we should use the term street in the urban context.

Streets are safe, if aggressive road users, the car drivers, are a minority, under control of the society and/or made insecure by the environment. Streets are safe when no cars are parked on public space or on private ground along urban roads or in private garages. Roads are becoming a dangerous environment, if cars are parked at every origin or destination of trips. Risk comes into the urban space with every car moving more than 20 km/h. Risk comes into the urban space with every car parked in public space, since a parked car reduces the visual distance especially for children crossing the road, or pedestrians forced to use the carriageway, when cars are parked on sidewalks.

What needs to be done: Figure 17.19.

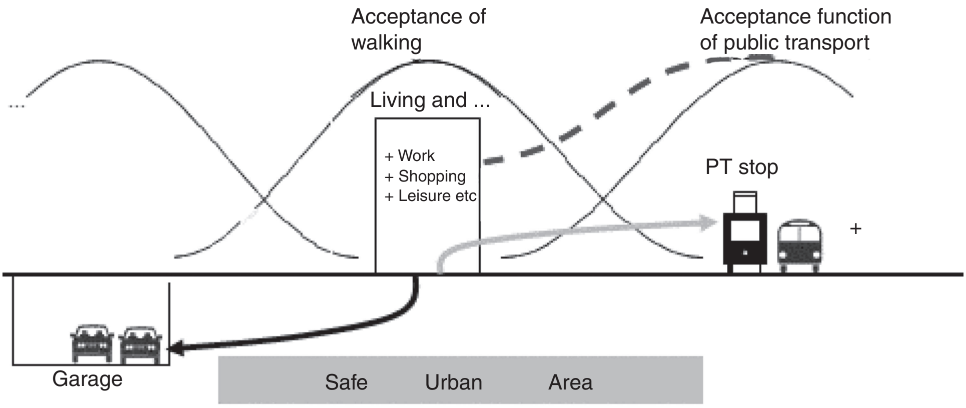

Figure 17.19 Reorganisation of parking makes unsafe urban areas safe.

[9] http://www.uitp.org/publications/Mobility-in-Cities-Database.cfm
[10] http://dictionary.reference.com/help/faq/language/d01.html

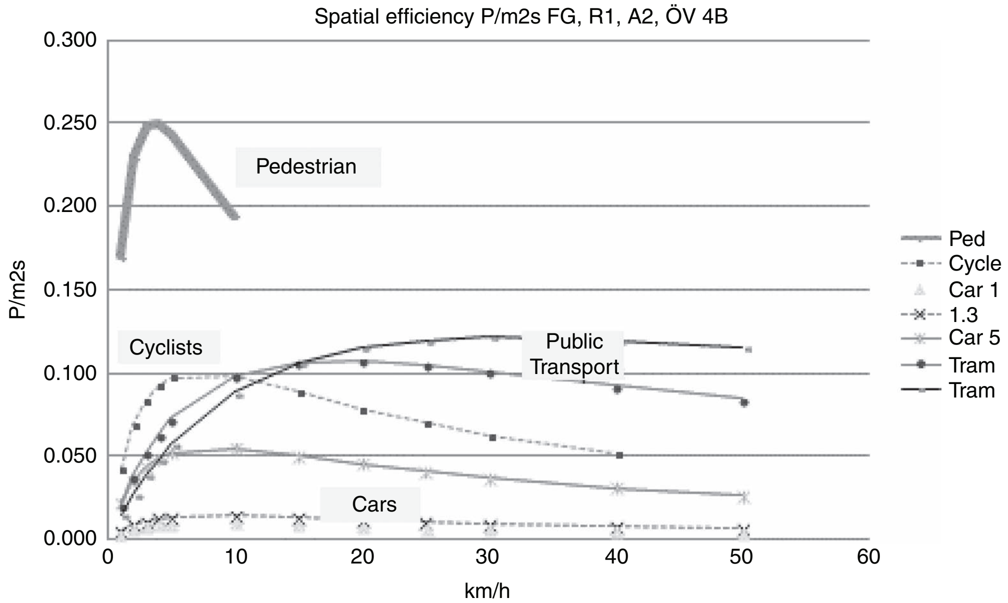

Figure 17.20 Spatial and temporal efficiency of urban transport modes.

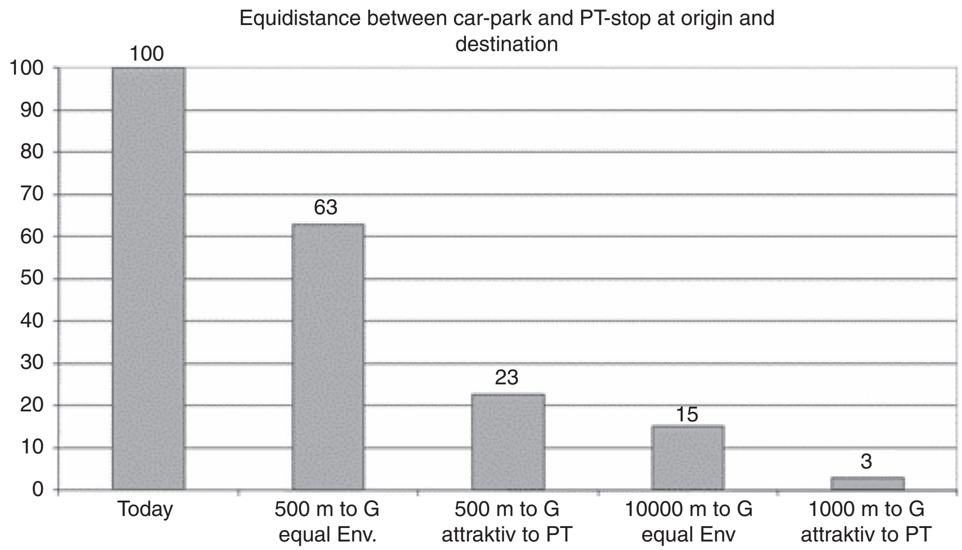

Figure 17.21 Effects of different structures on use of cars. The distance to parking and the quality of environment are the decisive variables for the choice of mode.

In combination with the system behaviour, explained above briefly, more than 70% of the downgraded urban roads of today become urban streets, since it is the traffic system which decides the location of shops, meeting places, or quality of life. Less than 30% of the roads remain in the car traffic regime and can be designed and managed in a safer way than today.

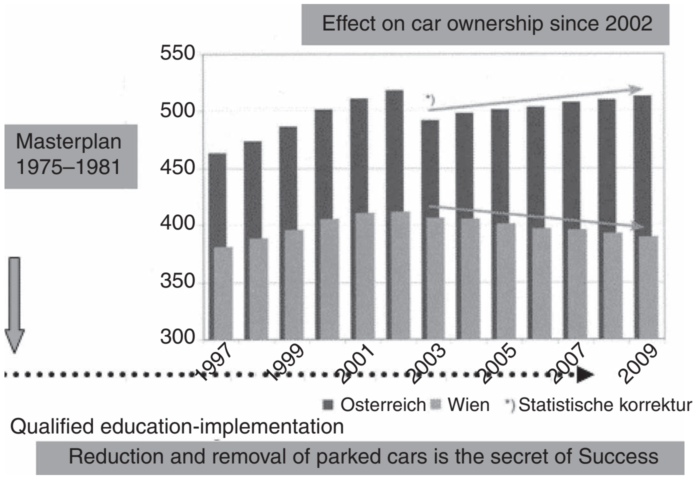

Figure 17.22 Change of structures change human behaviour – in Vienna toward less cars, more public transport, cycling and walking – and a much safer urban area.

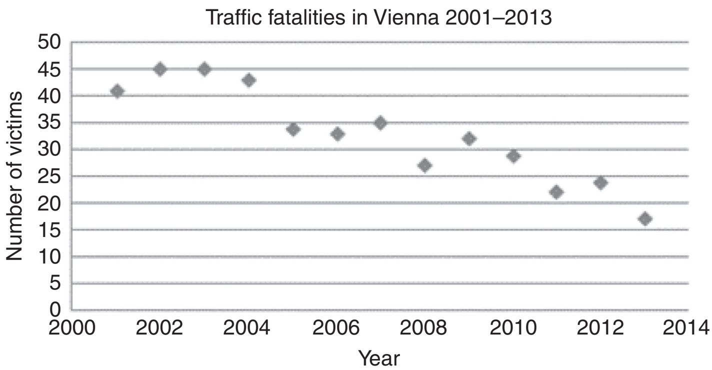

Figure 17.23 Traffic accident fatalities in the urban area of Vienna 2001–2013.

Pedestrians, cyclist and public transport on the surface, become the dominating traffic modes in this safe environment of the future.[11]

The priority is clear: pedestrian first, followed by cyclists and public transport far ahead of cars. Based on these rational facts, all traditional standards and cross-sections have to be rewritten and redesigned if we want to live in safe urban areas in the future. Traffic calming would not be necessary on roads anymore, if car traffic is managed in the right manner from the beginning. Delivery vehicles and cars for handicapped people, as well as public service and emergency vehicles appear in these areas. The effects of this organization can be calculated. Figure 17.21 shows the results.

The city of Vienna has been at least partly following certain principles for decades. For more than five years the city has been number 1 in quality of life globally; Viennese households, have reduced car ownership since 2002, and the share of public transport has gone up since 1999 from

[11] Knoflacher H. Bedeutung des öffentlichen Verkehrs im öffentlichen Raum. Wien 2014

28% to 40%. Fatalities from traffic accidents were reduced from 45 in 2002 (30 fatalities per million) to 17 in 2013 (10 fatalities per million inhabitants).

The cause of the decrease of car ownership is the reorganization of parking space in the city: removal of parking places from historical sites and many streets, no free parking on streets any more between 9 h and 22 h, parking permission for residents, without the guarantee of a parking place, etc.

The accident analysis for the city of Vienna is shown in Figure 17.22. The similarity to Figure 17.21 can be seen: since car ownership is decreasing, the number of severe accidents is decreasing too. The built environment was changed (see the effects of the motorway going in the opposite direction), the legal and the financial structures have changed during the last three decades. There are no cost-free parking opportunities in the city any more. 75% of tram- and bus-lanes are separated from car traffic, 1400 cycle lanes were organized, more parts of the city became pedestrian areas, and a 30 km/h speed limit has been implemented in most districts. There are less aggressive road users in the urban area. We have to challenge the background, the existing paradigm of urban and traffic planning, if we want to enhance safety in urban areas.

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CHAPTER 18

Urban Safety and Mobility

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CONTENTS

ABSTRACT

Of the total 1.25 million people dying in road traffic crashes annually, at least 30% are in urban areas (WHO 2013). This number is expected to increase with the increase in urbanization in Asia and Africa. The largest number of victims in road traffic crashes in urban areas are pedestrians, bicyclists and motorcycle riders in most countries. Therefore urban traffic safety requires special focus on making the urban environment safer for pedestrians, bicyclists and motorcycle users. Most public transport users are also pedestrians, because access and egress trips of a public transport system are walking trips. This chapter presents a discussion of urban streets, and their functions, followed by important principles for making urban traffic safer for pedestrians, bicyclists, and public transport users.

Key Words: urban safety; traffic calming; roundabouts; safe streets

18.1 INTRODUCTION

The importance of urban traffic safety can be judged from the fact that this century is called the 'Urban century' since in 2007, for the first time in human history, 50 per cent of the global population lived in urban areas. Only a century ago, this figure stood at 13 per cent, but it is now predicted to reach 69 per cent by 2050 (Population Division UN 2008 and 2010). In some regions, cities are expanding rapidly, while in others, rural areas are becoming more urban. At present urbanisation is taking place in low income countries as a result of natural growth within cities and large numbers of rural-urban migrants in search of jobs and opportunities. Rapid urban growth tends to overwhelm cities where the struggle to develop infrastructure, mobilise and manage resources, has negative consequences for the environment (UNEP 2011). Urban traffic safety has become a major concern in cities in low income countries in Asia, and Africa where a significant proportion of the urban population lives in informal settlements. The scale of the problem comes into sharp focus in India and China. India's urban population grew from 290 million in 2001 to 340 million in 2008 and it is projected to reach 590 million by 2030 (McKinsey 2010). China's urban population is expected to increase from 636 million in 2010 to 905 million by 2030 (UN Population Division 2010).

18.2 URBAN STREETS

Urban streets offer opportunities for a range of human activities. They enable necessary activities like commuting to work, school, shopping etc. The majority of these activities are necessary for survival; therefore the physical framework influences their incidence only slightly. These activities are more or less independent of the physical environment. The presence of bicyclists and pedestrians on the main carriageways in Asian cities is an example of this. Since for a large section of the population in these regions any other mode of travel is too expensive, they continue to use the roads despite the hostile physical environment. These road users are exposed to a high-risk environment and suffer a huge cost in terms of getting involved in fatal and injurious crashes. However, there is a range of optional activities, for example walking, enjoying the outdoors, socializing, playing, etc. which take place only when exterior conditions are optimal, safe, pleasant, etc. Social activities depend on the presence of others in public spaces. They are indirectly supported whenever necessary and optional activities are given better conditions in public spaces. The disintegration of living public spaces and the gradual transformation of the street areas into an area that is of no real interest to anyone is an important factor contributing to vandalism and crime in the streets. Are most Asian cities moving in this direction, or can we arrest this trend by creating an inclusive street environment?

The urban street network is the basic building block which defines the physical as well as socio-economic characteristic of a city. It can be one of the most powerful statements of recognizing or ignoring the existence of heterogeneous socio-economic structure in the society. The street environment can make an inclusive city which is economically prosperous, culturally vibrant, socially equitable, clean, green and safe, and in which all citizens are able to live productive lives.

The inclusive street environment also has bearing on other safety issues in the city. When all traffic is slow, there is life in the streets, in contrast to what is found in car-friendly cities, where the speed of movement automatically reduces the activity level. The present mix of traffic in Asian cities results in varied activities on the streets. Bicycles, pedestrians, and bus traffic attract street vendors. Vendors often locate themselves at places which are natural markets for them. A careful analysis of the location of vendors, the number of vendors at each location and the type of services provided demonstrates the need for their presence. If the services provided were not required at those locations, then they would have no incentive to continue staying there. However, road authorities and city authorities view their existence as illegal. Often the argument is given that the presence of street vendors and hawkers reduces road capacity. If we apply the same principle that is applied for the design of road environment for motorised traffic, then vendors have a valid and legal place in the road environment. Highway design manuals recommend frequency and design of service areas for motorised vehicles. Street vendors and hawkers serve the same function for pedestrians, bicyclists, and bus users. As long as our urban roads are used by these modes, street vendors will remain inevitable.

Street vendors also enable integration of various activities and functions in and around public spaces. The mixing of various functions and people makes it possible to interpret how the surrounding society is composed and how it operates. What is important is not the formal integration of buildings and primary city functions, but whether the people who work and live in the different buildings use the same public spaces and meet in connection with daily activities. An inclusive street environment requires pedestrian, bicycle and public transport friendly streets. Inclusive streets ensure not only safe mobility – reduced risks of traffic crashes – but also reduced street crimes and better social cohesion. Streets must be returned to pedestrians not only because they are the majority the road users, but also, the efficiency of the overall system, including the performance of motorized vehicles, depends on meeting the demand of 'captive pedestrians'. The experience from environments where 'captive pedestrians' are present makes a very strong case for rethinking the conventional hierarchy of road users. It is clear that the present investment patterns, focussed on improving conditions for cars, is not leading to desirable results. Congestion, continues to worsen along with shift away from walking, bicycles, and public transport – the desirable modes for environment sustainability. A well functioning road infrastructure must fulfill the requirements of all road users.

The following issues are important for understanding urban safety and mobility:

- Vulnerable groups lack mobility, which also means accessibility to income generation opportunities and most of all contributes to exclusion from urban life.
- Exclusive urban environments or exclusive streets create violence at different levels.
- Survival compulsions force people to defy laws: often they are exposed to higher risks in traffic and are victims of fatal road traffic crashes. This violence or injury is created by insensitivity of state planners and infrastructure designers who ignore the existence of pedestrians, bicyclists, and public transport users.
- Cities where authoritarian administration is successful in implementing the laws against vulnerable groups, i.e., banning pedestrians, cyclists and rickshaws, along with hawkers and street sellers, often create streets that are reduced to areas which are of "no interest to anyone". Street crime is highest on such streets.
- Millions of people in the cities of Africa, Asia, and Latin America cannot find work in the formal sector and have to create work themselves. Streets provide opportunity for self-employment and honest living with dignity. However, when this is denied, what options is left for survival?
- Not surprisingly safety is of growing urgency as cities in many countries are becoming more violent, which further restricts access and mobility in the city, including to women children, and high-income residents.

18.3 DESIGNING SAFE URBAN STREETS

Road transport is understood as a complex sociotechnical system (Larsson et al 2010; Salmon et al 2012). Road infrastructure design, environment and vehicles, interact with multiple road users having different requirements. Complex sociotechnical systems can only be understood and countermeasures can only be effective when the entire sociotechnical system and the interactions between its components are taken into account through the use of systems-based analysis methodologies (Cornelissen et al 2015). The need for a systems approach is recommended by the high injury rate amongst some road users, including pedestrians, cyclists, and motorcycle riders (Elvik 2010). The terms 'vulnerable' or 'unprotected' road user, used to describe this group, highlights the growing design incompatibility between different types of vehicles and road users (Elvik 2010; Walker et al 2011; Wegman et al 2012). The safe systems approach adopted by The Netherlands is based on three important principles:

1. Road environment with an infrastructure adapted to the limitations of the road user;
2. Vehicles equipped with technology to simplify the driving task and provided with features that protect vulnerable and other road users; and
3. Road users that are well informed and adequately educated.

The basic premise behind these principles is the acceptance of the limitations of road users – impatient pedestrians, risk taking attitudes amongst young drivers, bicyclists and pedestrians always looking for the shortest and easiest path, etc. Road environments must be designed in such a way that despite these limitations, the probability of injury and severity of injury can be reduced. Elvik (2010) discusses how despite impressive progress in road safety in many countries in the last few decades – The Netherlands 80% reduction since 1970, France, Great Britain and Nordic countries 50% – young drivers continue to have a considerably higher risk of accident involvement than middle-aged drivers, and the injury rate for pedestrians, cyclists, and riders of mopeds or motorcycles continues to be higher than the injury rate for car occupants. A considerable proportion of drivers continues to exceed speed limits. To address these problems priority has to be given to creating designs which encourage 'safe behaviour from high risk groups of road users.'

Urban road environments can be adapted to the limitations of pedestrians and bicyclists by appropriate speed management and segregation from fast motorised traffic that imposes higher risk due to higher kinetic energy.

Speed is the most important factor governing the design of various features of urban roads such as lane widths, sight distance, radius of horizontal curve, super elevation, extra widening of pavement, length of transition curve and the length of summit and valley. Design speed of urban roads must fulfill the safety requirements of different types of roads. An efficient urban road network follows a hierarchy. The hierarchy is based on the function that the road is expected to perform, and the type of traffic and the road users present on the road. The design speeds, road widths and other geometric features are adapted to suit the road function. Most road design manuals recommend the following road classification.

18.3.1 Arterial roads

These are the primary roads for ensuring mobility function. Arterial roads carry the largest volumes of traffic and offer the longest trips in a city. These roads are characterized by mobility, and cater to through traffic with restricted access from carriageways to the side. In such cases, special provisions should be introduced to reduce conflict with the through traffic. These roads have the maximum right of way amongst the four categories and cater to a speed limit of 50–60 km/h and a ROW of 50–80 m.

18.3.2 Sub arterial roads

This category of roads follows all the functions of an Arterial road and are characterized by primarily carrying through traffic with restricted access from the carriageway to the side. It carries similar traffic volumes as the arterial roads. Due to the overlapping nature, Sub arterial roads can act as arterials; however, this is context specific and is based on the land use development it passes through and it caters to a speed limit of 50 km/h (same as arterial roads). The ROW of this category of roads varies from 30–50 m.

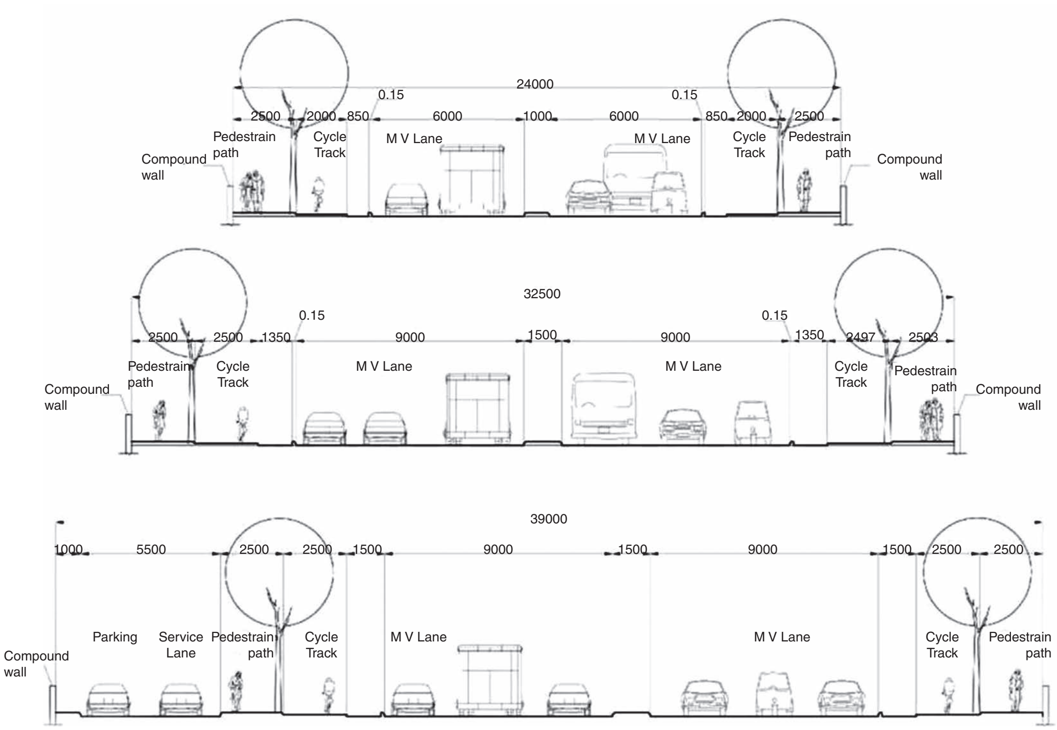

Figure 18.1 Road cross sections for different roads.

18.3.3 Distributor/collector roads

As the name suggests, these are connector roads which distribute the traffic from access streets to arterial and sub arterial roads. They are characterized by mobility and access equally. These roads should be designed for 30 km/h, since the access function is combined with the mobility function. It carries moderate traffic volumes compared to the arterial roads.

18.3.4 Access streets

These are used for access functions to adjoining properties and residential areas. A majority of trips in urban areas usually originate or terminate on these streets. They cater to a design speed of 15–30 km/h and have a road right of way of 15 m–30 m. They carry relatively lower volumes of traffic at low speeds. They are characterized predominantly by access.

Based on the function the classification of the roads is decided and an appropriate design speed is adapted. The design speed governs the geometric design of the right of way and the cross section elements of the road, based on the function and land use type. The code of practice for Urban Roads (IUT 2013) and Planning and Design Guidelines for bicycle facilities (2014) suggest several alternate road cross sections (Figure 18.1).

Table 18.1 presents recommended design speed and specifications for geometric elements of different categories of roads. Some of the key elements include the following:

Lane Widths: The lane widths of a carriageway affect the safety and driving behaviour of drivers. Wide lanes encourage higher speeds.

TABLE 18.1 Design speed and carriageway width recommended for different road categories.

	Arterial Roads	**Sub Arterial Roads**	**Distributory Roads**	**Access Roads**
Carriageway				
Design speed	50 km/h	50 km/h	>30 km/h	15 km/h
ROW	50 m–80 m	30 m–50 m	12 m–30 m	6 m–15 m
Horizontal curve	30 m or more	30 m or more	10 m or more	5 m or more
Gradient	2%	2%		
Number of lanes	Minimum 6 lanes divided (using a raised median);	Minimum 4 lanes divided (using a raised median);	Maximum 4 lanes of 3.0 m width each (excluding marking) or 2 lanes of 3.0 to 3.3 m width each (excluding marking) with or without an intermittent median	1 to 2 lanes, (undivided); of 2.75 to 3.0 m width each
Minimum width for car lane	3.0 to 3.5 m width each	3.0 to 3.5 m width each	2 lanes of 3.0 to 3.5 m width each	2.75 to 3.0 m width each
Minimum width for bus lane	3.5 m-(segregated)	3.5 m-(segregated) or painted lane	Mixed traffic	

Source: IUTa, 2013.

Horizontal clearance: For urban arterials, sub arterials, collectors, and local streets where curbs are utilized, space for clear zones is generally restricted. A minimum offset distance of 500 mm [18 in] should be provided beyond the face of the curb, with wider offsets provided where practical. However, since most curbs do not have a significant capability to redirect vehicles, a minimum clear zone distance commensurate with prevailing traffic volumes and vehicle speeds should be provided where practical.

18.3.5 Infrastructure for non-motorized vehicles

Cycle infrastructure width requirements are based on vehicle dimensions, volume and clearance requirements of moving vehicles (cycle rickshaw, freight rickshaw). These requirements vary for cyclists riding straight and those maneuvering a bend at a cruising speed.

Exclusive lanes for slow moving vehicles – bicycles and rickshaws and pedestrians, along with spaces for street vendors, are also essential. Hawkers and roadside vendors provide services to bus commuters and pedestrians; therefore designed spaces would discourage them from occupying the carriageway. This improves the capacity of the lanes designed for motorized vehicles and increases safety for bicyclists and pedestrians. Table 18.2 shows design specifications for non motorized vehicles.

18.3.6 Pedestrian paths

The pedestrian paths should be continuous as well as segregated unless at stretches where a narrow right of way rules out the possibility of segregated paths. At such locations visual continuity should be maintained using texture and pavement markings.

Paths should be shaded, and space for facilities such as service providers (hawkers), benches, street light poles etc., should be provided outside the pedestrian path, the edge of which needs

TABLE 18.2 Infrastructure for NMV.

	Arterial Roads	**Sub Arterial Roads**	**Distributory Roads**	**Access Roads**
Non Motorised Vehicle	Segregated cycle track	Segregated cycle track	Cycle lane	Mixed traffic
Location	Between carriageway or street parking and footpath on either edge of the carriageway	Between carriageway or street parking and footpath on either edge of the carriageway	On the edge of the carriageway, adjacent to the footpath or parking.	
Gradient	1:12–1:20	1:12–1:20	1:12–1:20	1:12–1:20
Lane width	2.2 to 5.0 m	2.2 to 5.0 m	1.5 to 2.5 m	Mixed with motorized vehicular traffic
Minimum width	2.5 for a two lane cycle track and 1.9 m for a common cycle track and footpath	2.0 for a two lane cycle track and 1.7 m for a common cycle track and footpath	1.5 m	1 m (painted)

Source: IUTa, 2013.

to be clearly defined. Benches for the disabled as well as the general public should be provided along the pedestrian path. Design specifications for pedestrian paths are given in Table 18.3.

Accessible footpaths should meet the mobility needs of people with physical and visual disabilities. These are shown in Table 18.4.

18.3.7 Bus shelters

- Bus stops must be located where it is safe and convenient for bus commuters to reach the bus stop. Bus stop locations must minimize the delays faced by commuters (pedestrians) and motorized traffic at junctions. Bus stop platform design should minimize boarding and alighting time.
- A minimum distance of 500 m is recommended between the bus shelters. Shorter distance maybe required for specific locations like schools or offices. The distance between the bus stops should not exceed more than 1 km, because access distance for bus commuters exceeds 500 m.
- Bus stops at junctions can be located on the near side of the junction or the far side of the junction. Bus stops located on the near side of the junction can utilize the red light phase for boarding and alighting, and improve the performance of the bus operation. Also, when the volume of buses is high, (more than 3 bus/signal cycle), queue on the far side bus stop may spill over at the junction. Therefore, the near side of the junction is the preferred location for bus stops.
- A bus stop can be located before the junction itself or at some distance away from it. It has been observed that as a bus shelter is brought nearer to a junction the flow of traffic improves. However, it also increases interference with turning traffic. It has been found in simulation experiments that bus shelters located at 20 m before the junction provide the best results.

TABLE 18.3 Design Specifications for Pedestrian Paths.

	Arterial Roads	**Arterial Roads**	**Distributor Roads**	**Access Roads**
Pedestrian Paths				
Criteria	50 km/h 50 m–80 m	50 km/h 30 m–50 m	30 km/h 12 m–30 m	15 km/h 6 m–15 m
Gradient	1:20	1:20	1:20	1:20
Sight Distance				
Lane width	1.7 (including curbs) to 5.5 m each. However where secondary footpaths are available along service lane, the minimum width of secondary paths can be 1.5 m (including curbs)	1.7 (including curbs) to 5 m each. (including curbs)	1.5 to 3.0 m (including curbs) each	0–2.5 m (including curbs) each
Effective capacity as per LOS C in persons per/min counted over 15 min			Effective width of footpath (m)	
23–50			1.5	
58–83			2.5	
81–116			3.5	
115–165			5.0	

Source: IUTa, 2013.

TABLE 18.4 Components of Accessible Footpaths.

Footpath	The minimum clear width should be 1.2 m in order to accommodate wheelchair users. Comfortable minimum width is 1.8 m. The footpath surface should be even and without any irregularities. The use of guiding and warning blocks should be used.
Paving	The use of guiding and warning blocks should be used along the footpath
Road Markings	It is essential to designate areas in parking lots to make them comply with accessibility standards.
Road Signs	All signs should be visible, clear and consistent. All accessible places should be clearly identified by the International Accessibility Symbol. They should be in contrasting colours. Also, for the visually impaired it is essential to use braille.
Audible Signals	The use of audible signals or auditory signals is beneficial to the visually impaired to cross a road with minimum or no assistance. Also called a pedestrian access system, it is mountable onto signal poles at crossings and a push button system makes its use easier. It also gives an audible alert signal to Vehicle Users about Pedestrian Crossings.

Source: IUTa, 2013.

- On distributory and access roads bus shelters can be on the far side of the junction because the volume of buses is not as high as on the arterial roads.
- If the distance between the junctions is more than a km, bus stops have to be provided at the mid blocks. This should be combined with a pedestrian signal to ensure safe crossing for bus commuters.

18.4 INTERSECTIONS

The road intersections are the critical elements of the road sections and the function of a designed intersection is to control conflicting and merging streams of traffic, to minimize the delay including pedestrian and bicycle traffic.

Intersection design influences the capacity of the corridor and the safe movement in conflicting directions. The pattern of the traffic movements at the intersection and the volume of traffic on each approach, during one peak period of the day, determine the lane widths required including the auxiliary lanes, traffic control devices, and channelization, wherever necessary. The arrangement of the islands and shape, length of the auxiliary lanes also differs based upon the type of intersection.

Intersections are complex and dangerous parts of the road transport system because they represent a point where two or more roads cross and road user activities include turning left, right, and crossing over. This presents many potential conflict points between road users (Federal Highway Administration 2000). This level of complexity and risk is exemplified in road crash statistics, where intersections are over-represented. For example, in Victoria, a jurisdiction in Australia, approximately 50% of all road crashes occur at intersections (VicRoads 2011a) and similar figures are reported worldwide (c.f. Kuciemba and Cirillo 1992; The Highways Agency 1995). Despite interventions (c.f. Archer and Young 2009; Chiou and Chang 2010; Shin and Washington 2007), there has been little reduction in casualties and serious injuries at intersections over the past decade (Hoareau et al 2011). Detailed data from selected Indian cities also shows concentration of fatal crashes near intersections (Mohan et al 2014).

The function of an intersection is to enable safe interchange between two directions or two modes. The design of an intersection must be comprehensible to all road users. This aim is best achieved with a well-organized situation with a minimum number of conflict points. The basic principle to limit the number of conflict points as much as possible can be at odds with other requirements; for example in relation to traffic flow. If additional lanes are built for this reason, the result can be that the traffic situation is no longer sufficiently comprehensible and 'aids' (such as traffic lights) are needed.

It is important that the speed of the various road users is minimized during interchanging. In collision with a car at low speed, the chance of survival is significantly greater than when the car is traveling at a higher speed (Rogers, 2003).

Intersections function to control conflicting and merging traffic and to achieve this, intersections are designed on certain geometric parameters and are broadly classified into three main types. Designers are often faced with tough choices of prioritizing the conflicting requirements of one mode over another. The three main types of junction solutions are:

1. Unsignalized intersection
2. Signalized Junctions
3. Roundabouts

18.4.1 Unsignalized intersections

Uncontrolled intersections can create dangerous situations for NMVs conflicting with crossing or turning motorized traffic. At uncontrolled junctions with distributor roads, all turns may be permitted, where vehicular traffic volume is considered low and enough safe gaps are available. At higher volume distributor roads, and on arterial roads where high volumes are combined with the high speeds of motorized vehicles, restrictions on right turns for motorized vehicles should be enforced through a continuous median on the primary road.

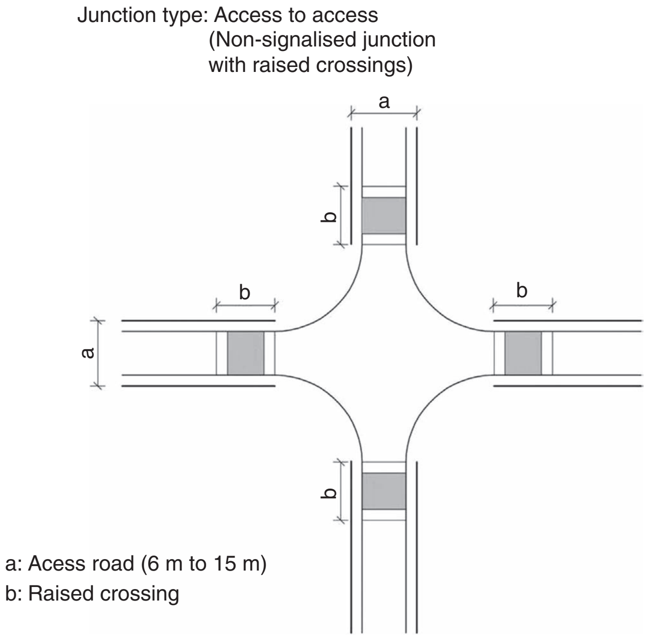

Figure 18.2 Example of unsignalized junctions.

At such locations where alternative safe crossings are more than 200 m away, ‘NMV and pedestrian only’ (no motorized vehicles allowed) crossings should be considered ‘signalized at-grade’, especially at locations where high crossing demand exists. On low volume distributor roads where all turns are permitted, NMVs may turn, as vehicles by gap acceptance. Here speeds of 30 km/hr or less should be achieved at the junction by introducing traffic calming devices on all conflicting streets, including the primary road.

NMVs moving along primary roads conflict with vehicular traffic while crossing secondary streets at uncontrolled junctions. Similar conflicts are also created at property entrances requiring vehicular access (such as residences and petrol stations). Adequate treatment along NMV paths at junctions is required to resolve these conflicts and ensure safety and coherence for crossing bicyclists. Design requirements for such treatment include speed reduction for vehicles on secondary roads, design ensured continuation of the NMV path/track, and warning NMVs about expected vehicular conflicts. All of these requirements can be bundled in a single junction design known as the raised crossing design. Raising the motor vehicle lane or crossing by a set height achieves raised crossings. This is typically equivalent to the height of the footpath so that the design allows pedestrians and others with special mobility needs (such as wheelchairs) to move across unhindered while crossing vehicles slow down (due to the steepness of the ramp access to the crossing as on a speed breaker) and are forced to yield to them. In this arrangement however, cyclists need to be accommodated to ensure a similar quality and level of service as the pedestrian. Figure 18.2 shows examples of unsignalized junctions.

18.4.2 Signalized intersections

Signalized intersections are a less (sustainably) safe solution than roundabouts or grade separated intersections and must therefore be regarded as second best in terms of safety. Often signal

TABLE 18.5 Elements of Design and Criterion of use.

Element	Criterion for Use
Signal Design	
Signal Cycle Design	Minimize delays to waiting cyclist and improve directness
Signal Pole Location and aspect design	Ensure safety of crossing cyclist
Geometric Design	
Segregation at or Near Intersection	Ensure safety and directness for cyclists
Bicycle Holding area (stacking spaces) or boxes	Ensure flow capacity and directness
Grade separated crossing for cyclists	Ensure Safety and directness for cyclists
Intersection Crossing Path	Ensure safety of cyclists

Source: IUTa, 2013.

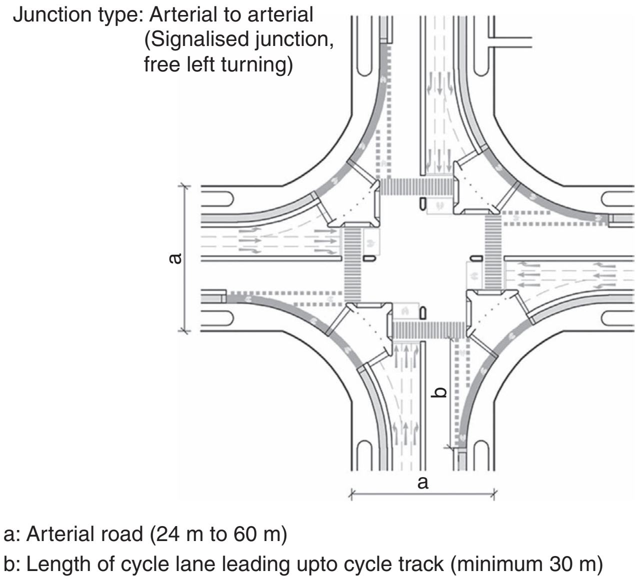

Figure 18.3 Example of Signalized junctions.

engineers prioritize motorized traffic over bicyclists in the phasing plan. Selected geometric and signal phase design elements can be used in a signalized intersection, which significantly improves the crossing conditions for cyclists and pedestrians. The list of these elements their selection and use has been described in Table 18.5.

Segregated lanes for left-turning vehicles at an intersection are usually kept signal free in an attempt to reduce vehicular delays. This denies cyclists and pedestrians any safe time to cross the junction, and adds to their delays and risks. It is also known that in most cases signal free left-turning lanes do not provide any significant benefit or relief to waiting motorists; on the contrary, they cause friction and reduced flows for motorists merging after the junction. Keeping this in mind, one of the following designs for left-turning vehicular lanes should be adopted in the order of priority. Figure 18.3 shows examples of signalized junctions.

TABLE 18.6 Round about options for different category roads.

	Arterial Roads	**Sub Arterial Roads**	**Distributory Roads**	**Access Streets**
Arterial Roads	1. Roundabouts (3,4 arm) 2. Signalized Crossings (3,4 arm) 3. Grade separated crossing for motor vehicles 4. Grade Separated Crossings for cyclists, along Arterial road (in case of 4 arm only)	1. Roundabouts (3,4 arm) 2. Signalized Crossings (3,4 arm) 3. Grade separated crossing for motor vehicles 4. Grade Separated Crossings for cyclists, along Arterial road (in case of 4 arm only)	1. Roundabouts (3,4 arm) 2. Signalized Crossings (3,4 arm) 3. Grade Separated Crossing for cyclists along Distributor road (4 arm only)	1. Traffic calmed crossing (3 arm only – access street opening on to an arterial road) 2. Grade Separated Crossing for cyclists along access road
Sub Arterial Roads	1. Roundabouts (3,4 arm) 2. Signalized Crossings (3,4 arm) 3. Grade separated crossing for motor vehicles 4. Grade Separated Crossings for cyclists, along Arterial road (in case of 4 arm only)	1. Roundabouts (3,4 arm) 2. Signalized Crossings (3,4 arm) 3. Grade separated crossing for motor vehicles 4. Grade Separated Crossings for cyclists, along Arterial road (in case of 4 arm only)	1. Roundabouts (3,4 arm) 2. Signalized Crossings (3,4 arm) 3. Grade Separated Crossing for cyclists along Distributor road (4 arm only)	1. Traffic calmed crossing (3 arm only – access street opening on to an arterial road) 2. Grade Separated Crossing for cyclists along access road
Distributory Roads	1. Roundabouts 2. Signalized Crossings (3,4 arm) 3. Grade Separated Crossing for cyclists along Distributor road (4 arm only)	1. Roundabouts 2. Signalized Crossings (3,4 arm) 3. Grade Separated Crossing for cyclists along Distributor road (4 arm only)	1. Roundabouts 2. Signalized crossing	1. Roundabout 2. Unsignalized/ Traffic Calmed Crossing (3,4 arm)
Access Streets	1. Traffic calmed crossing (3 arm only – access street opening on to an arterial road) 2. Grade Separated Crossing for cyclists along access road	1. Traffic calmed crossing (3 arm only – access street opening on to an arterial road) 2. Grade Separated Crossing for cyclists along access road	1. Roundabout (3,4 arm) 2. Unsignalized/ Traffic Calmed Crossing (3,4 arm)	1. Unsignalized/ Traffic Calmed Crossing (3,4 arm) 2. Mini Roundabouts

TABLE 18.7 Fundamental elements of Roundabouts on Urban Roads.

Design element	Mini	Urban compact	Urban single lane	Urban double lane
Recommended max entry design speed	25 km/h	25 km/h	35 km/h	40 km/h
Max no of entering lanes	1	1	1	2
Inscribed circle diameter	13 m to 25 m	25 m to 30 m	30 m to 40 m	45 m to 55 m

Source: IUTa, 2013.

18.4.3 Roundabouts

A roundabout is a type of circular intersection with a specific design and traffic control features. Roundabouts can be designed to suit most site conditions, traffic volumes, speeds, and all road user requirements. This is one versatile solution, which combines the benefits of safety and efficiency in an attractive package. Safety is achieved by reduced speed (less than 40 km/h) within the roundabout and efficiency by high directness in time and distance or minimal delays for all users.

Roundabouts, on higher traffic intensity junctions, requiring complex crossing decisions by cyclists, require segregated bicycle infrastructure along with safer crossing provisions for pedestrians, whereas lower intensity junctions may rely more on mixed conditions and traffic calming techniques.

Roundabouts are used to control merging and conflicting traffic flows at an intersection, by performing two main functions:

1. They define the priority of the traffic streams entering the junction, so as to ensure that the traffic entering should not be a hindrance to the already existing traffic circulating in the roundabout.
2. They cause the diversion of traffic flow from its straight path, ensuring slow speeds of vehicles as they enter the junction.

Various design options recommended for different situations are summarized in Table 18.6. Roundabouts on urban roads can be classified into four broad categories: as follows

1. Mini roundabouts
2. Urban compact roundabouts
3. Urban single lane roundabouts
4. Urban double lane roundabouts

Table 18.7 compares the fundamental elements of these four categories

- Safety is the most important principle in roundabout design. Roundabouts limit vehicular speeds by virtue of their design and are hence effective even in peak or late hours when traffic signals are not followed.
- To ensure safety is not achieved at the cost of efficiency, principles of modern roundabout must be followed. They are:
- Entering vehicles give way to exiting vehicles by design
- This is achieved by ensuring that the speed of entering vehicles is reduced by design
- Vehicles exit at a relatively higher speed.
- Limiting vehicular speeds inside roundabouts.
- This is achieved by providing an adequate turning radius for vehicles. Low turning radii ensure reduced speeds in the roundabout. Appropriate turning radius can be achieved with the aid of the central island diameter, the circulatory roadway width, the entry turning radius and the entry width.

- *Integrating a safe crossing infrastructure for pedestrians and cyclists.*
- Roundabouts permit near continuous vehicular movement due to which special attention must be paid to the requirements of pedestrians, cyclists, and other NMV users at all arms of the junction.

18.5 URBAN ROAD SAFETY AUDIT

A road safety audit (RSA) is required because it is a means of accident prevention rather than accident reduction (DFID 2003). It is a formal safety performance examination of an existing road or a future road or an intersection, by an independent audit team (Rodrigues and Bzerra 2005).

A RSA can be conducted at any stage of a project, starting with the project planning stage through the Final design stage. It can even be conducted on roads that have already been completed and have started operating. That is, it can be conducted at different stages of the road infrastructure life cycle (ADB 2003; Austroads 2002; FHWA 2007; NZTA 2010; Rodriguies and Bezerra 2005; DFID 2003; SURREY 1996). The audit aim is to minimize the risk and severity of road crashes; minimize the need for remedial works after construction; and reduce the life costs of the project (Austroads 2002).

Internationally, development of road safety audits has resulted in a number of guidelines. These guidelines are supported by audit checklists and audit procedures which are being implemented and tested in different countries. The Institute of Urban Transport has issued guidelines (IUT 2013b) for conducting urban road safety audits with detailed checklists. These can be used to ensure the safety of all road users. Annex 1 shows a standard checklist for an arterial road. Similar checklists are available for other categories of roads.

18.6 CONCLUSION

Since the users of low cost modes – pedestrians, bicyclists and public transport are captive users, their presence on the network is inevitable. If the infrastructure design ignores their needs, and traffic laws restrict their movements, often these users are forced to defy laws and continue to use the road infrastructure, exposing themselves to a high risk. Motorised vehicles are forced to operate in sub-optimal conditions despite huge investments in car oriented infrastructure.

Safe urban roads require prioritizing the safety requirements of pedestrians, bicyclists, and public transport users over motorized traffic. It is clear that returns on limited resources, which are space and finances in most cities, can be maximised by allocating highest priority to the needs of pedestrians, bicyclists and public transport users, in that order. This requires not only redesigning roads but also legitimising services needed by these road users which are provided by hawkers and including their requirements in formal designs. The most important principle for ensuring urban safety to all road users is speed control by design-speed humps, roundabouts, and other traffic calming measures to ensure appropriate speeds for different categories of roads.

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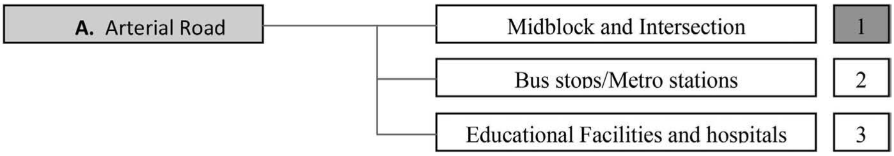
APPENDIX - I

Checklist A - 1



Important issues for Arterial roads:

- Audit is to be conducted in all approaches of the junction in both directions
- Service road is required
- Signage for pedestrians and cyclists for arterial roads are required
- Bicycle track and pedestrian pathway for arterial roads are required
- Arterial Road speed limit is 50 km/h

Audit area:

Intersection: All approaches (for 4 way junction 4 approaches, etc.)

Midblock: one road to be audited (Both sides)

Checklist A-1

URSA at Arterial roads for midblock and intersections

Location name (Description) ………………………………………………… Date ………………..

Names of auditors

1.

2.

3.

4.

5.

Location Map Name and description of area: ………………………

<Map Display>

<Description >

CHECKLIST A – 1.1 – SPEED

Note: Checklist should be filled up after Speed has been measured for different modes.

Vehicle	Truck Multi-Axle	Truck	Bus	LCV	Car/Jeep	Auto Rickshaw	Scooter /Motor cycle	Cycle	Hand Driven Rickshaw/	Pedestrian
0 – 10 min										
10-20 min										
20-30 min										
30 – 40 min										
40-50 min										
50-60 min										
Hourly Volume										
Average Speed (km/hr)										

Indicators			**Quality**			**Total**	**Remark**
Speed measures for roads		**Present/Yes (1 pt)**	**Good**	**Fair**	**Poor**		
		Absent/No (0 pt)	**(1 pt)**	**(0.5 pt)**	**(0.2 pt)**		
Existing Speed Variation (Total km/hr)	Truck Multi-Axle		< 50 km/h	>50 km/h	> 80 km/h		
	Truck		< 50 km/h	>50 km/h	> 80 km/h		
	Bus		< 50 km/h	> 50 km/h	> 80 km/h		
	LCV		< 50 km/h	>50 km/h	> 90 km/h		
	Car/Jeep		< 50 km/h	>50 km/h	> 90 km/h		
	Auto Rickshaw		< 50 km/h	>50 km/h	> 90 km/h		
	Scooter/Motor cycle		< 50 km/h	>50 km/h	> 90 km/h		
Overall						**07.0**	

Score for Speed = Average total score for Speed *100

CHECKLIST A – 1.2 - FOOTPATH AND PEDESTRIAN ACCESSIBILITY

Indicators		**Quality**			**Total**	**Remark**
Footpath	**Present/ Yes (1 pt)**	**Good**	**Fair**	**Poor**		
	Absent/ No (0 pt)	**(1 pt)**	**(0.5 pt)**	**(0.2 pt)**		
Pavement type		Concrete/ Interlocking block/ Paver blocks/ Tar/ Asphalt	Tiles	Unpaved/ non medaled surface		
How wide are the footpaths?		Arterial and Sub arterial roads: 1.8 to 5.0m (including curbs)	Arterial roads: 1.5 - 1.8m	Badly congested (< 1.5m)		
Height of footpath (standard size is 150 mm)		Arterial Roads: Maximum < 100mm (4")	Arterial Roads: 100mm (4") – 300mm (12")	Very user unfriendly (>300mm)		
Cleanliness and maintenance of footpath		Well maintained footpaths	Need better maintenance and cleanliness	Foot paths are not maintained		
Provision of amenities for pedestrians for path way (lighting, Hawkers exclusive zone, cover from sun and rain, etc.)		Pedestrians provided some good amenities and feel safe	Limited number of provisions for pedestrians and slightly uncomfortable at late nights	No amenities and Unsafe		
Provision of Disability friendly Infrastructure (tactile flooring, audible signals, railing)		Infrastructure for disabled is present	Some infrastructure is available	Mostly absent		
Barrier free footpaths (obstructions such as trees, parking vehicles, hawkers and vendors etc. should be absent)		There are no obstructions	Pedestrians has to slow down sometimes	Pedestrian has to slow down most of the time		

Availability of Crossings (frequency of crossings)		Avg. spacing between controlled crossings is 250 m	Avg. spacing between controlled crossings is between 250 m – 500 m	Avg. Distance of controlled crossings is >500 m		
Type of Crossing		Level/ at grade crossing	Foot over bridges with elevators or half subways which are well lit.	Foot over bridges without elevators or completely covered subways without proper lighting		
Difficulty in crossing / Time taken for crossing		10-20sec	20-30 sec	>30 sec		
Overall					**10.0**	

Score for Footpath and Pedestrian accessibility =

Average total score for Footpath and Pedestrian accessibility *100

CHECKLIST A – 1.3 – CYCLIST ACCESSIBILITY

Footpath accessibility	**Explanation**	**Yes**	**No**
		(1 pt)	**(0 pt)**
Continuity of cyclist path			
Car not parking on footpath?			
Are cycle lanes or segregated cycle tracks required?			
Have the needs of cyclists been considered especially at junctions and roundabouts?			
Overall		4	

Score for Cyclist Accessibility = Average total score for Cyclist Accessibility *100

CHECKLIST A – 1.4 –LIGHTING

Indicators		Quality			Total	Remark
Footpath	**Present/Yes (1 pt)**	**Good**	**Fair**	**Poor**		
	Absent/No (0 pt)	**(1 pt)**	**(0.5 pt)**	**(0.2 pt)**		
Light after dark (Visibility to walk after dark)		Light poles at every 20 m and lighting intensity of 40 lux along the road and 50 lux at crossing	Light poles at every 20 m with lighting intensity of 20- 40 lux Or Light poles at every 40 m with lighting intensity of 40 lux.	Average distance between Light poles distance is >40 m Or Intensity of light less than 20 lux.		
Provision of lighting for pedestrians for crossing		To see Motorized vehicles and feel safety	slightly uncomfortable at late nights	Unsafe		
Overall					**02.0**	

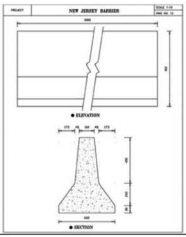
Score for Lighting = Average total score for Lighting *100

CHECKLIST A – 1.5 –SIGNAGE

Signage	Explanation	Yes	No
		(1 pt)	**(0 pt)**
Signing for Pedestrian	In arterial roads signage for pedestrian and cyclists are important		
Signing for bicyclists			
Signing for Cars and 2W and Trucks			
Does the signing make clear the intended use facilities?			
Speed limit signage			
Overall		**05.0**	

Score for Signage= Average total score for Signage *100

CHECKLIST A – 1.6 – MOTORIZED VEHCILES SAFETY

For Motorized vehicles	**Explanation**	**If applicable 1** **If not applicable 0**	**Yes** **(1 pt)**	**No** **(0 pt)**
Speed limits sign is provided	Example: 			
Are safety measures provided for construction at road sides?				
Is the median design safe?	Usually more than 150 mm median is hazardous for motorized vehicles. Higher median should be designed like new jersey barriers.  			
Kerb design safe?	150 mm, is the standard			
Is kern free of vertical hazards?	Any tree or pole (sign pole should be at least 1 meter away from carriage way			
Is approach of flyover safe?	Approach of the flyover should have proper chevron marking			
Overall			06.0	

CHECKLIST A – 1.7 –INTERSECTIONS OR MIDBLOCKS

Intersection Sketch

Junctions – Geometric design issues	Explanation	Yes	No
		(1 pt)	(0 pt)
Have safety fences been provided where appropriate?			
Are parking or stopping zones for buses, taxis and public utilities vehicles situated within the junction area?			
Is the junction signing adequate and easily understood?			
Are signs appropriately located and of the appropriate size for approach speeds?			
Overall		4.0	

Score for Intersection = Average total score for Intersection *100

SCORE A -1

Access Mode Type	Score	Weight
Speed		
Footpath and Pedestrian accessibility		
Cyclist accessibility		
lighting		
signage		
Motorized vehicles safety		
intersections or Midblock		
Total		

CHAPTER 19

Urban Safety and Traffic Calming

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CONTENTS

ABSTRACT

Safety action needs a lot of basic understanding of what safety is and how it can be treated. The problem is that everybody is a road user for more than 60 minutes per day, thus implying that everybody quickly becomes "an expert". One of the consequences of this – presented in this chapter – is that there is a clear tendency for speed to become one of the most important qualities of traffic today. Roads – even city streets – are built in a way allowing very high speeds. Another element is the car, which today most often can do speeds (well) over 200 km/h. Speed management has not been a very succesful area. Compliance rates are around 50%. A scenario is checked with absolute speeds below 30 km/h. The result indicates strong positive effects on safety, interaction, noise, retail etc. However, this can not be achieved unless systematic traffic calming is introduced, specifically with humps and similar “vertical” measures and roundabouts. It is also necessary to introduce effective “vehicle calming”. The ISA-systems of today are producing small changes, and need to be complemented with authority-driven systems that will force drivers to pay more respect to speed limits. The effects of traditional traffic calming and “vehicle calming” have a very great potential in making cities more attractive and useful in an inclusive way to all citizens.

Key Words: Traffic calming; speed; pedestrians; bicyclists

19.1 INTRODUCTION

In the introduction a number of aggravating circumstances will be presented and qualified. These are e.g. lack of knowledge and lack of understanding of safety related matters. In view of the fact that everybody is a road user 60–70 minutes a day, everybody also feels like an expert on traffic, including traffic safety. The result has been great difficulty in introducing expert knowledge in developing urban safety. Non-professionals including politicians, interest groups, residents, etc., claim that they know the area as well as professionals. My interpretation is that this is the main reason why we have a strange situation regarding the **speed issue.**

The result of this, on a macro level, can e.g. be seen in the following questionnaire results. 2000 Swedes were asked to rank the three most important behaviours from a safety point of view.

As can be seen, speed is ranked only number five among males, three among females. By far the highest ranked is alcohol. I have looked at the relation between speed and alcohol. In an Australian study there is a comparison between relative risks at different alcohol levels with risks of exceeding the speed limit in built up areas in Australia, a speed limit of 60 km/h. I now make the assumption that the risk relations presented are more or less the same as they are in Sweden. The table below shows that the actual risk difference between alcohol and speed “abuse” seems to be quite different from what is stated by (Swedish) citizens in the questionnaire study. This is obviously also followed up by the official view on these abuses. In the same table I have examined the Swedish laws and rules regarding speeding and alcohol respectively. Sanctions against drinking and driving are much stricter than speeding abuse if you compare sanctions at the same relative risk level:

1/ Drinking and driving; alcohol level: 0.21 g/100 ml.
Relative risk (Australian study): 30.4.
Sanctions in Sweden when drinking and driving.
Above 0, 10 g/100 ml: Drunken driving renders maximum 2 years imprisonment. Withdrawal of the license: up to two years

2/ Speeding; 20 km/h above speed limit.
Relative risk (Australian study): 31.8.
Sanctions in Sweden when going +20 km/h: 31.8.
Fine; maximum 2800SEK (corresponding to 2 days salary).
(http://www.mhf.se/sv-SE/rattfylleri/info-om-rattfylleri/lag-och-straff/).

The official view on drinking and driving is much more strict than it is for speeding, which corresponds well with the view of people in general. The problem is that this difference does not

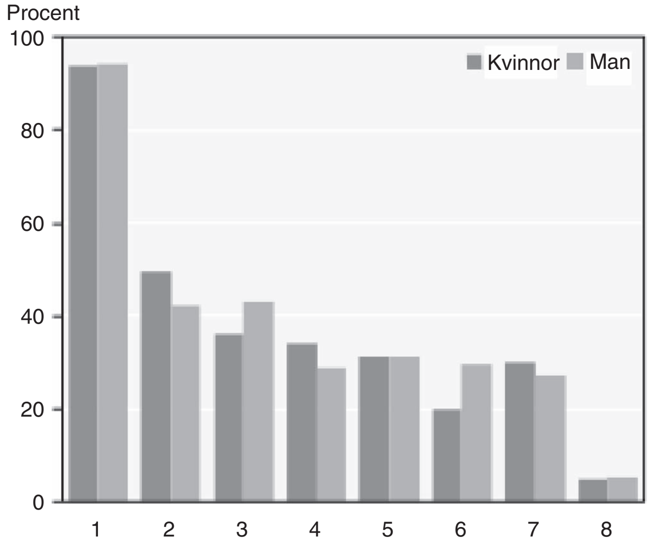

Figure 19.1 "What three behaviours do you consider to be the most important from a traffic safety point of view?" Share of respondents for the respective alternatives, 2013.

1. Not drinking and driving.
2. Use safety belt.
3. Not drive against red light.
4. Keep speed limits.
5. Keep distance to vehicle ahead.
6. Do not talk on the mobile while driving.
7. Not driving when tired.
8. Use bicycle helmet.

Derived from Trafikverket (2013a).

at all correspond to the risks involved. There is a considerably higher acceptance of speeding than drinking and driving. This is also reflected in the efforts made by the Government in Sweden to prevent people from drinking and driving and speeding respectively. In Sweden – one of the leading safety countries – for example, the share of drivers complying with the speed limit is (in 2012) between 45 and 50%, at the same time as the target share is far from reached (dotted line), see Figure 19.2.

If one compares with alcohol, figure 19.3 the share of drinking and driving is less than 0.3 percent, which is more positive than for speeding.

The consequences of this "biased view" on the importance of speed have been crucial for the traffic system. I will look at this problem from the most fundamental system definition; the Environment (in my case the infrastructure in terms of streets and roads), the Machine (in my case the automobile) and the Man (in my case the driver). This system view has been used for decades in order to assess the system in terms of the "guilt" of the road user. I have looked at this system on a meta level.

19.1.1 Infrastructure

Regarding **the infrastructure** the motorisation started soon after the second world war. The increase in car numbers quickly led to a demand for more space for streets. Improvements

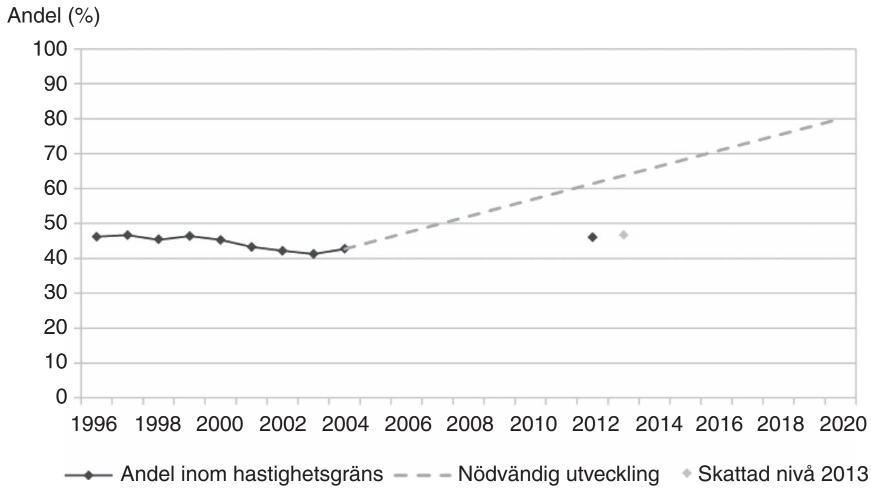

Figure 19.2 Share complying with the speed limits (from: Trafikverket 2013b).

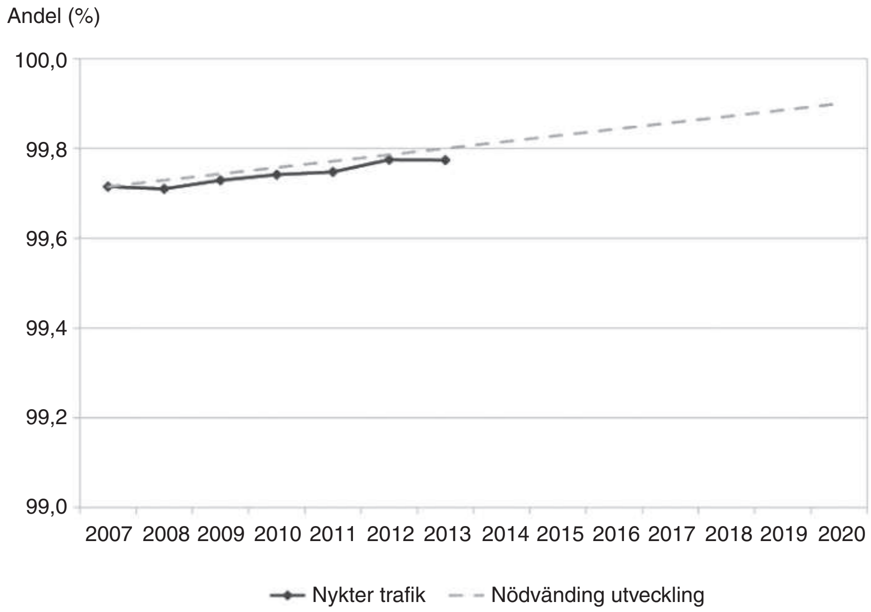

Figure 19.3 Share complying with the drinking and driving laws (from: Trafikverket 2013c).

had to be made which was equal to using as much space as possible to increase the number of lanes. Bicycling and walking became “out of fashion,” so therefore in the Swedish city of Malmö footpaths and bicycle lanes were removed for the benefit of car lanes (Figure 19.4). From a safety point of view there was little possibility of improving the infrastructure. The main element that was introduced was the non-signalised zebra crossing, which is quite indicative; meta results on the safety effect shows that when looking at all streets, the number of injury accidents to pedestrians has increased by 44% (−6%–+121%) (Høye et al 2012).

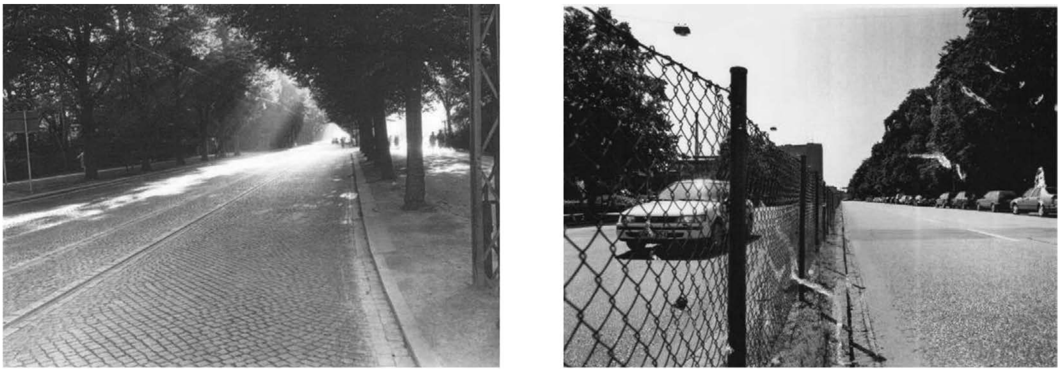

Figure 19.4 Regementsgatan in Malmö, in the 1950s and 1990s.

Figure 19.5 “High speed” streets built in Sweden in the 1960s and 70s. Speed limit 50 km/h.

The image of the 1990 street is self explainatory; it is about mobility and efficiency at high speeds. Almost any speed is possible on the 1990-street, even though it is located in the middle of the city, and with a speed limit of 50 km/h. This is how even rather minor streets were built from the 1960s and onwards. Figure 19.5 gives some more Swedish examples.

When general speed limits were introduced in the 1950s, the default speed for built up areas was set at 50 km/h. I have never been able to find out why this limit was arrived at; somehow it is a compromise between different interests. Obviously safety was not given high priority and vulnerable road users were to “blame” if they were involved in accidents.

19.1.2 The car

The second system element, **the car,** has been acting together with the infrastructure to push the system into higher and higher expectations regarding speed as a positive factor for higher mobility and efficiency of the system. In the beginning of the seventies the oil crisis led to an introduction of general speed limits. All countries – except Germany – introduced speed limits on all roads, with maximum speed limits varying between 100 and 130 km/h (ETSC 2010). In spite of this limitation, the top speed of cars has increased gradually ever since. Today most vehicles can do speeds above 200 km/h (in Sweden, in 2007 the median speed of all cars produced by SAAB, Volvo, BMW and Audi was 230 km/h! (Spolander 2007)). The discrepancy between maximum speed limit and maximum performance has thus increased a lot since the beginning of the seventies, without any strong action to keep the discrepancy down.

Figure 19.6 Car advertisements (https://www.google.no/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=bilreklam+Audi&spell=1).

The car industry is spending large amounts on advertising. In Sweden 2 billion SEK (>200 million Euros) was spent on car advertisements during one year (Spolander 2007). The message was focussed on performance, speed, and acceleration. One example: in 2005 Volkswagen presented a new Golf in the following way: "Nothing for cowards. The new Golf R32 has a 3.2 liter engine V6 engine with 250 horse power and 4MoTIoN four wheel drive. It makes 0–100 km/h in 6.2 seconds" (translated into English from Spolander 2005). "Joy of driving" is playing an important role in convincing people to buy their cars. Societal efforts to "compete" with these messages, focussing on interaction, active safety, etc., is bound to lose.

The development of the car is very quick. We are getting acquainted with very spectacular functions. There are different kinds of collision warnings, there is automatic braking, lane change warning, etc. Safety is more in focus, however, there is still a lack of focus on the interaction between different kinds of road users. The driver does not have to play an active role in adapting speed to the prevailing conditions. This very crucial function, from a safety point of view, is taken care of by the system. More assistance is produced by a new invention: the "Magic Body Control" presented by Mercedes-Benz. With the help of a stereo camera and the suspension system, bumps can be compensated for. "*Therefore MAGIC BODY CONTROL allows a unique synthesis of comfort and agility even on bad roads*". (http://techcenter.mercedes-benz.com/en/magic_body_control/detail.html). There is no documentation about its effects, on speed.

19.1.3 The man

The third system element; **the man,** is facing a an extremely quick development. In a bit more than 100 years, which represents a tiny fraction of man's life on earth, we are suddenly facing the Motorised Man.

The man is suddenly sitting in an "armchair", listening to nice music, talking on the phone, having route guidance, at the same time as we are protected by ABS, AICC, ASR, CAS, DSC, DSR, ESC, EDS, ESF, ESP, HBA, TSC, TPM, night vision, emergencybraking, magic body control, safety belts, air bags, alcolock, belt reminder, ISA, whiplash protection, stereo, mobile, dvd, Navigation System – and – Games. The consequences of this is of course difficult to predict. Everything is new, almost at the same time, so how can we ever say what is "good" and what is "bad" for our development? It will of course depend on what the end result ought to look like. In a way it is clear that drivers manage the system to such a large degree, in view of the potential

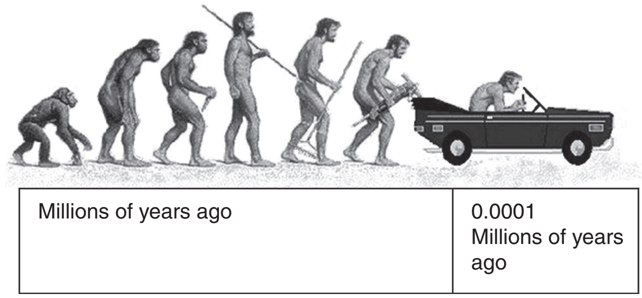

Figure 19.7

weaknesses that characterize the driver: inexperienced, Premature, Reacts to the wrong signals, Does not manage the complexity, Asocial, Aggressive, Ridden by habits, Demonstrating power, Develops strong habits, obeys rules only when the police are present, Easy to manipulate, and – finally – Courageous.

19.1.4 Conclusions

Even though safety, in terms of killed and seriously injured road users, has declined more or less continously since the beginning of the seventies, there are still a lot of opportunities to improve the system. Speed management has failed to a very large degree. Compliance is low and the number of injuries and fatalities could be reduced considerably. For instance, the Swedish Transport Administration presents the following facts regarding speed and compliance: If everybody was complying with the speed limits 100 to 150 lives would be saved every year ! (Trafikverket 2015). Other studies find similar effects. In Norway a 21% reduction is simulated (Høye et al 2012) in Belgium 35, 50 and 52%, depending on road type (ETSC 2008). ETSC highlights the problem:

> *The OECD estimates that at any one moment 50% of drivers exceed legal speed limits. This is why changing speed behaviour is different from other areas: it requires a majority of drivers to adopt a different way of driving, whereas compliance with BAC limits (Blood Alcohol Content) and seat belt legislation requires only a minority of drivers to change. The extent of the behavioural change needed illustrates the urgency and indicates that regulatory action is the most sensible approach to tackle speed (ETSC 2008).*

Even though actual changes of behaviour are very slow there is a steady growing interest for life in the cities. With a lot of focus on speed. The idea of implementing 30 km/h or 40 km/h as the default speed in residential areas has become quite common, with lots of stated goals and ambitions. Ontario, Canada (http://www.680news.com/2015/01/29/province-reportedly-considering-lowering-default-speed-limits-to-below-50-kmh/), Paris (30 km/h), Milan, and Edinburgh are just a few examples. Spain's new general road law contains the boldest plan of any European country, with 30 km/h limits on most city streets across the country, though implementation has been delayed for several months. And in Switzerland 38% of the population lives in 30 km/h zones. (http://etsc.eu/30-kmh-limits-gaining-rapid-acceptance-across-europe/). There is also an initiative on a European scale where 30 km/h as a default speed for all the roads in cities is promoted (European Citizen's Initiative "30 kmh – making streets liveable!" (http://en.30kmh.eu/).

In Sweden the authorities have introduced 40 km/h instead of 50. Quite a few cities have followed. The street in the city of Malmö showed in Figure 19.8 has a new speed limit of 40 km/h.

Malmö: Before, speed limit: 50 km/h

Malmö: After, speed limit: 40 km/h. New section

Malmö: After, speed limit: 40 km/h. Same new section

Figure 19.8 Regementsgatan in Malmö, new speed limit and restructuring.

In addition, part of the street adjacent to the section shown in Figure 19.8, has been rebuilt by minimizing the width, introducing bus humps, and planting more trees.

The interest is there, but still not the capability of solving the problem. To be sucessful authorities need to transmit a much more comprehensive understanding of the system of Man-Machine-Environment. All three main parts of the system need to be involved, and authorities must act in a more decisive way, **not** accepting driver preferences. Here Traffic Calming plays a central role.

19.2 TRAFFIC CALMING

There exist quite a few definitions. One of the broadest one is as follows:

> ***Traffic calming refers to a combination of network planning and engineering measures to enhance road safety as well as other aspects of liveability for the citizens.***
>
> *Van Schagen (ed.; 2003)*

This definition deals both with engineering and planning, and seems to cover the whole range of qualities, from road safety to liveability. This last part is covering a lot of different aspects: interplay between road users, security, the feeling of safety, emissions, noise, climate effects, etc. This definition is very relevant today, from the perspective of an ever-growing interest for the "Good City", a city which is based on liveability aspects.

I have defined a liveability-related issue which I call well-being, where I have included the following aspects in an urban traffic-related context: safety, security, comfort, convenience, accessibility, attraction, efficency (also VRU), equality between road users, equal preconditions, mistakes must not lead to injuries/fatalities, and receptiveness.

All issues relate to all "users of the city", but in view of a clear imbalance today, it must be clear that the status of vulnerable road users has to be considerably enhanced, partly "at the expense" of car occupants.

19.2.1 The role of speed in urban transport – overview

In view of all the aspects related to traffic calming, and in view of the fact that speed (calming) is a basic element, a first step is to find – as much as possible – the relation between vehicle speeds and different quality aspects related to traffic calming. A low speed scenario is presented:

- Speeds: maximum 30 km/h (alternatively 20 km/h)
- Presence of children, elderly, particularly vulnerable road users decide the level

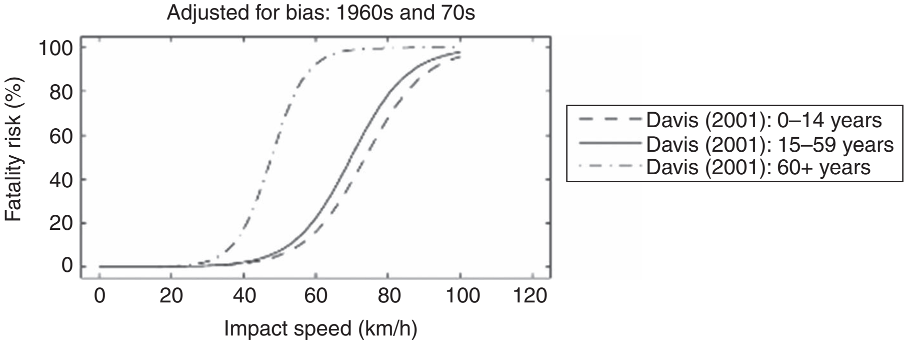

Figure 19.9 Relation between collision speed and fatality risk for pedestrians (extract from Rosén et al 2009).

- **Maximum** speeds – no one is exceeding
- As many as possible of the imaginable effects of low speeds in cities
- Assessment based on experiences from mainly industrialized countries

19.2.1.1 Travel speed and safety

No other safety aspect has ever been studied to such a great extent as speed. The most well established relation is the so-called power model (Nilsson 2004; Elvik et al 2004). It shows that fatalities are related approximately to speed to the power of four. This means for instance, that a 10% reduction in speed results on an average in a 35% reduction of fatalities.

The Swedish Transport Administration presents the following figures for Sweden on their web page (translated from Swedish): A lowering of speed by 10% decreases fatal accidents by 40%. Every reduction of speed by 1 km/h saves 25 lives per year!! (Trafikverket 2015).

Even though the fourth power has now been revised for built up areas (Elvik 2009), and that power is dependent on the initial speed (Elvik 2013), the relation is still very strong. One reason for this strong relationship is the fact that lower speeds have an influence on **both** the risk of a crash **and** the risk of severe injuries once in a crash. Lower speeds offer more time for reaction, resulting in a better chance of avoiding an accident, or at least for lowering the collision speed.

19.2.1.2 Collision speed and severity of crashes

This relation has been very difficult to study, because collision speed has been difficult to obtain. Most studies indicate that collision speeds of 50 to 60 km/h increase the risk of a pedestrian of being killed by a factor ranging from a couple of times up to at least twenty times compared with 30 km/h. The study by Davis in Rosén et al (2011), Figure 19.9, indicates that the older you are the higher the risk is, and for pedestrians aged 60+ the probability of being killed is approx. 60% at a collision speed of 50 km/h, while it is only a few percent at 30 km/h. So, a tentative conclusion is that speeds should be “well below” 50 km/h between pedestrians (and bicyclists) and motorized vehicles. This was also acknowledged when the Swedish Road Administration (now Swedish Transport Administration) in 1997 presented the so-called Vision Zero (Trafikverket 2014).

Effects described above are direct effects of a lower speed on safety. There are also indirect effects. For instance, lower vehicle speeds will improve the relative attractiveness of the environment (Wegman and Aarts (ed.) 2006 in Nielsen 2007). The result will be the increased use of public transport and walking and cycling. More pedestrians and cyclists will lead to fewer crashes for these groups (Hydén, C. ed. 2008).

Another indirect effect is that lower speeds result in car drivers making detours to use roads that allow higher speeds without the humps and other similar measures that produce discomfort. The net safety result of this is difficult to predict. To ensure a positive outcome, a holistic view of the traffic system must be applied, with safety measures in line with the need from a strategic point of view for the whole system.

19.2.1.3 Speed and subjective safety

Subjective safety deals with people's fear of being involved in traffic accidents. The topic is complicated as people's feelings represent a mix of a lot of different aspects, one of which is the feeling of being at risk. Information regarding the importance of lower speeds in relation to subjective safety is scarce. There is one example from Sweden where the speed limit on an arterial was lowered from 50 km/h to 30 km/h for some months. Actual speeds were lowered almost as much, 16 km/h from around 48 km/h to around 32 km/h. All members of a focus group felt that speed had been reduced and that the feeling was that there was less aggresiveness and stress. It was easier to interact with car drivers and it was easier to cross the street and it also felt safer. A majority in the interviews wanted a permanent speed decrease (Wahl 2006). In another study – where interviews were made on streets with 30 km/h and 50 km/h – speeds came out as very important: *In 30 km/h-areas, the situation is also significantly better than in 50 km/h-areas: In 30 km/h-areas the persons asked do not attribute so much importance to those interaction types where car drivers do not slow down in good time, where they do not stop at pedestrian crossings, where they try to be first, and where they are ruthless* (Risser 2004).

These examples are too anecdotal to allow any kind of modeling, but there seems to be a fairly clear relationship with speed.

19.2.1.4 Interaction/communication

The relation between speed and interaction presents some interesting points. Figure 19.10 shows the relation between the give way behavior among car drivers and bicyclists. At speeds above 55 km/h almost no driver stops, while at speeds below 30 km/h a great majority of car drivers are giving way to the bicyclists even though they do not have to; in Sweden where this study is done, the rule says the opposite, namely that bicyclists should give way to cars. The result indicates clearly that yielding behavior is as strongly speed related as injury accidents. One reason may be that at low speeds it is easy tier and more relevant for the driver to slow down. This study is just one example of many – in industrialized countries – where the same kind of trend is documented, in connection with either pedestrians or bicyclists.

19.2.1.5 Mobility for vulnerable road users

The fact that car drivers are yielding more for pedestrians and cyclists at lower speeds indicates an improved mobility for these groups. It is difficult, however, to make any quantification as long as no further specifications are done regarding the type of street, car volumes, etc.

19.2.1.6 Mobility for motorized traffic

Lower speeds will result in more time consumption, both regarding personal transportation and goods transportation by car in cities. Regarding the former, the point to be made first is that lowering speeds/higher travel time with car – to make it less attractive – is one of the main ideas behind traffic calming. Secondly the time loss is not necessarily very large; there may even be a time gain! In Stockholm there was a study made where the question was what the effect would be of introducing a 30 km/h speed limit where the speed limit was 50 km/h.

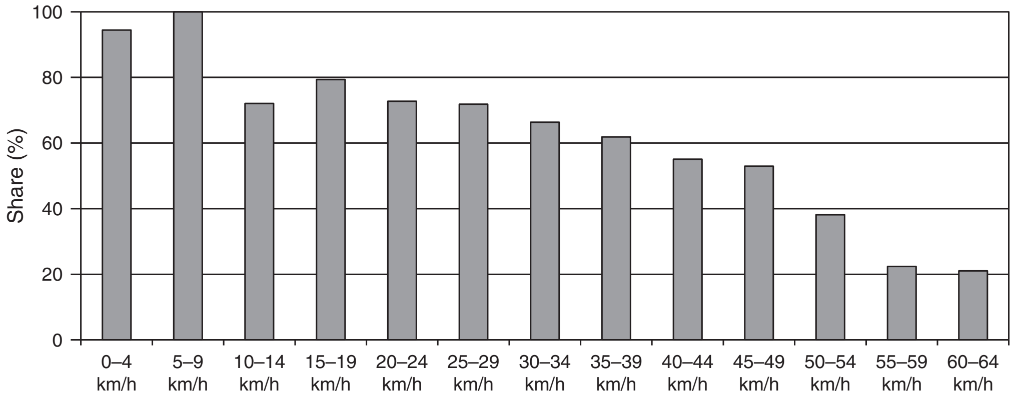

Figure 19.10 Share of car drivers who give way to bicyclists in relation to the car speed just prior to the interaction.

Driving was made at the prevailing speed limit of 50 km/h and then "simulated" driving at 30 km/h (as if the speed limit was 30). In short the conclusion was that driving with the basic (prevailing) speed limit of 50 km/h compared with driving with a fictive speed limit of 30 km/h, did not make any significant difference in travel time; sometimes it even took less time at 30 km/h. According to the author, the main reason for the small effects was that things like zebra crossings and signalisations had a much larger effect on travel times (Hartzell 2004, in Spolander 2007). Another important reason is that the average travel speed by car in most cities is not actually more than 25–35 km/h, even though the speed limit is 50 km/h.

Regarding goods transportation in cities it is difficult to predict the importance of speeds. There are many other important factors when it comes to the efficiency of goods transport in cities, like logistics, accessibility, etc. In line with what is said about private cars and travel speed, it is likely that low speeds in the city will have a significant impact on goods transportation as well. Regarding bus transport there is a problem as long as buses use the same streets as other motorized traffic. New solutions are demanded, like speed reducing measures that only affect cars, so-called bus cushions, or special bus lanes, etc. The latter is getting a lot of attention today in terms of so-called Bus Rapid Transit (BRT)-systems, with separate lanes devoted to buses.

19.2.1.7 Noise

Even though there are many factors influencing the noise level, it is obvious that speed is one of them.

The figure indicates a possible reduction of noise from 77 dBA at 50 km/h – all cars with "uneven speed" – to 63 dBA at 20 km/h all cars with "even speed". This reduction of 14 dBA is – if achieved – very significant, taking into consideration that a difference of 8–10 dBA is perceived as a doubling/halving of the noise level. It is noteworthy that the noise level is gradually going down all the way to 20 km/h.

19.2.1.8 Emissions

Emissions in traffic, in a city, is extremely complicated to predict. There are many factors that are of importance. On the technology side it is motor and fuel technology, catalytic cleaning,

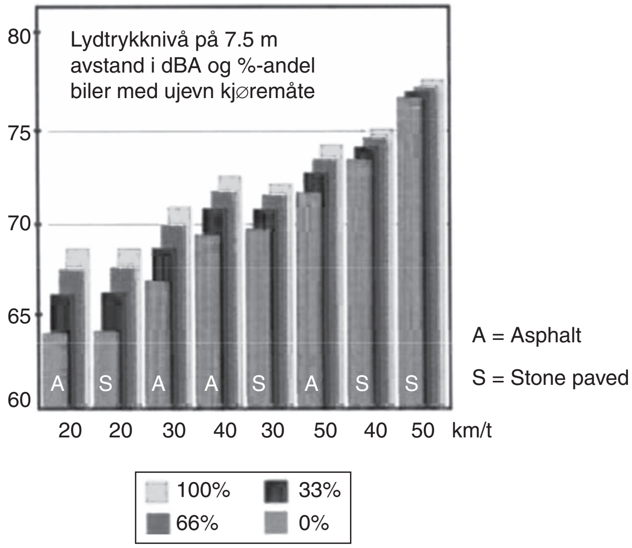

Figure 19.11 Noise level, dBA at 7.5 m from the vehicles, as a function of the proportion of vehicles with a rough driving style and type of road surface (Vegdirektoratet 1992/Umweltbundesamt 1990) (From: Nielsen et al 2007).

etc. Regarding speed and emissions the conclusion is that: "*It is important to use measures of speed reduction that encourage smooth driving at low speed, and discourages driving with large variations in speed. At speeds below 50 km/h the style of driving is more important than the average speed*" (Svensson and Hedström 2003 in Nielsen 2007). This can be demonstrated by studies where different types of traffic calming measures were used. In the first, **bumps** were used, which lowered speeds to only 10–15% of the maximum speed. In this case emissions – HC, NOx, CO, PM10, CO_2, and fuel consumption increased considerably (Jazcilevich et al 2015). The other study is based on four different driving pattern studies that yielded both experimental and observational data in street networks with and without traffic calming measures. These calming measures were different from the former case. The **humps** only reduced speeds to around 50–60% (distance between humps is less than 150 meter) (Towliat 2001). The conclusion regarding speed was: Speed reducing measures and speed limits in urban areas did not indicate a generally increasing negative environmental impact. 30 km/h in residential areas had a positive effect on the total environmental (Smidfelt 2003).

In this context it is important to note that cars of today are not optimized for driving at low speeds. There is every reason to believe that technological solutions are right around the corner, and optimizations regarding environmental factors such as noise, CO_2, NOx and other gas emissions at low speeds may present very significant reductions.

19.2.1.9 Retail

Most retailers, at least in town centres, appreciate the fact that the number of people walking past their shop and not the number of people driving past their shop is the key to getting people inside to spend money. In a summary report, Nielsen (1997) concluded that "In contrast to what is often claimed, positive effects from car traffic reductions and environmental improvements can be gained for economic activities such as retail businesses, restaurants and other typical urban personal services. This has been seen in a large number of cities and empirical studies, as reviewed by the author".

This is a good focus for Traffic Calming; before and after studies in a number of towns revealed that traffic calming schemes had a positive effect on retailing (Hummel et al 2002). The question remains, however, as to how "much" traffic calming.

19.2.1.10 The role of speed in transport – general conclusions

Even though a lot of empirical evidence is lacking it is still demonstrated that low speeds have important implications for most of the qualities – both for the individual and for the society as a whole. Safety, interaction andnoise are very basic qualities in cities. Some of the other aspectsthough less conclusive, show clear tendencies that low **and** smooth speeds have great potential. The problems of drawing more firm conclusions are simply because we have no "test bed". There are no cities that so far have produced comprehensive planning (including town planning, traffic planning, design etc. in one package) of traffic in towns, with priority for environmentally friendly modes of transport. There is a great – "hidden" (i.e. not tried) potential – regarding the positive effects of (considerably) lower speeds in cities. Referring to all the results/indications above, it looks as if conditions are improving gradually. The main exceptions are time consumption for motorized traffic and emissions. There do not seem to be any absolute values for the "optimal speed". It may even be below 30 km/h. It would be of great interest – and of utmost importance – to try to find out more about the empirical relations between different quality aspects and speed.

There is no doubt that cities are suffering from a lot of traffic and high speeds. Politicians often claim that they want to support a development where environmentally friendly modes of transport are given higher priority. Speed is a major restricting factor, and I think we are lacking a historical perspective. We must ask ourselves what has led us to the present state of things. I do not think there is any scientific background for the present conclusion regarding appropriate speeds in our cities. There is only some kind of laissez-fair strategy. Car use exploded in many countries after the Second World War. Authorities were not prepared and applied a very pragmatic view. No drawbacks were identified to the increasing car use. So, it was quite clear that the main goal was to accommodate the fast growing car traffic. Speed was one of the most obvious laissez-fair strategies. A speed limit of 50 km/h was introduced in many countries. The scientific backing of 50 – and not 60 or 40 or 30 or 20 km/h – did not exist – as far as I have been able to determine. More generally, authorities seemed never to question what was going on. So the result was that "... The vehicle itself has become a much more powerful entity. In addition, the top speed (normally about 200 km/h or over) and acceleration capabilities have been improved to levels far beyond what is legally accepted or actually required in almost all countries" (Almqvist 2006). It has never been clarified which role this has played in how traffic in towns was looked upon and, specifically in my case, what role the automobile played in creating the traffic system we have today and what implications it has for safety and the climate.

The results presented above are primarily based on experience from environments where motorization has developed for many decades. There is no reason to believe, however, that preconditions and conditions in less motorized, and/or newly motorized countries, are more favourable from a safety point of view.

19.2.2 Traffic calming and the infrastructure

The "only" remaining question is **how** to reach low and smooth speeds (below 30 km/h) with a minimum of accelerations and decelerations, and to validate the reduced risks of such measures. This is where Traffic Calming has to enter the scene. Experience so far has shown that soft measures are not sufficient. When the speed limit was reduced in a trial in Sweden by 10 km/h, from 40 to 30 km/h, the actual (mean) speeds were only reduced by a bit more than 2 km/h (Hydén, et al 2008). There are lots of examples showing the same tendency (Høye et al 2012). Drivers interpret the change as if they are asked to slow down to the new speed limit, not that

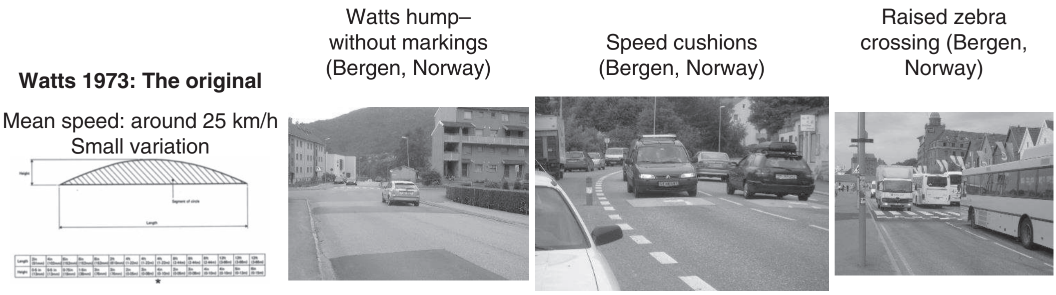

Figure 19.12 Humps.

they have to. This is the basic reason behind the call for physical measures that in one way or the other “force” drivers to slow down. That is the basic principle behind traffic calming measures.

19.2.2.1 Humps and other “vertical” measures

There is an excellent review of the safety and other effects of all sorts of measures (Høye et al 2012). This includes effects on speeds. The main conclusion is that there are a few measures that have proven to be more efficient than others. Number one is a different form of raised surface, either traditional round-top or flat-top humps with different designs. Most efficient in this respect is the traditional **hump;** a device which has a rounded top, of different length, spanning the whole width of the road (except for the so-called bus cushion which is narrower in order to let buses pass without inconvenience), see figure 19.12. Traditionally humps have been around 3.5 meters long and 10 centimeters high, producing mean speeds of 25 km/h, with a very small variation between vehicles. It is called “Watts hump”. This design can be changed in endless ways; length or height can be modified, see Figure 19.12. One centimeter less in height can increase the speed by 2–3 km/h.

Nowadays there is a lot of variation in hump design, resulting in varying mean speeds. In principle the hump can be designed for any target speed. I will, however, stick to this traditional hump as it fulfills the need of achieving speeds below 30 km/h.

The safety effect is very significant. In a Meta analysis it was shown that traditional humps reduce injury accidents by 41% (−57;−34). These results were based on quite a few studies where the mean speed on average was reduced from 47.7 to 36.3 km/t on those roads where humps were installed (Høye et al 2012), a reduction by 24%. According to Elvik (2013) such a reduction of mean speeds would render a very large reduction in fatal accidents.

An interesting observation is that injury accidents were reduced by 7% (−14;0) on roads without humps, but with humps on adjacent roads (Høye et al 2012). This is a very promising result indicating that drivers do not try to compensate for the humps, rather the opposite. It may be important to try to validate this kind of positive result, especially in view of the skepticism regarding humps in general and their effects on safety specifically.

The effects of this kind of “forced” speed reduction are in line with earlier results on the effects that were presented in the section on low speeds. Two examples; the first one is about the safety effect of humps. In a Meta analysis made by Høye et al (2012) they conclude that humps on residential streets reduce injuries by 40%, and mean speed by 24%. If the power model is applied the speed should have been reduced by 31% in order to reach the same reduction in injuries. **Thus**, the humps seem to produce a **stronger** safety effect than other kinds of speed reductions. The second example is on the give-way behavior by car drivers at locations where the speed is “forced down” with the help of humps in the after situation. Earlier in the chapter it was shown that drivers let bicyclists pass before them depending on the approach speed by the car driver. If the speed was around 50 km/h only about 40% of the drivers let bicyclists pass

TABLE 19.1 Speeds at sites with comparative humps in Jaipur, India and Lund, Sweden.

	Length (m)	Height (m)	Mean speed (km/h)	85-percentile speed (km/h)
Collectorate, Jaipur	3.8	0.10	21	24
Lalkothi, Jaipur	3.8	0.11	18	23
Average, 6 humps, Lund	3.6	0.10	18	21

before them, while at speeds of 30 km/h the share was raised to 65%. This is compared with results from a study of the give-way behavior at nine intersections where humps were installed (Towliat 2001). Median speeds went from around 50 km/h on average at the nine sites in the before situation (without humps) to a bit less than 25 km/h in the after situation (with humps). The corresponding give-way figures – pedestrians and cyclists combined – were 11% and 63% respectively. Thus there is a strong speed effect, similar to the one where approach speeds were "spontaneously" chosen by the drivers. The fact that only 11% of the drivers gave way in the before situation is primarily due to the fact that there was no law (either in the before situation or the after situation) that made yielding at zebra crossings obligatory. So the conclusion is that humps seems to work at least as well as any other speed reducing measures, probably better.

In addition, there are clear indications that it works also on a large scale. In the city of Gothenburg in Sweden effective speed-reducing measures have been introduced in an almost complete way on all streets except for on the largest arterials. The results are very encouraging; traffic calming is largely the cause of a large reduction in the numbers of deaths and serious injuries to pedestrians and bicyclists (Thulin and Nilsson 2004) resulting in a socio-economic benefit of approximately 40 times the direct costs. The safety benefits are supported by the fact that if traditional ("Watts") humps are located at a distance of at most 85–100 meters, speeds will be lower than 35–40 km/h all along the street (Høye et al 2012) which will result in almost no severe or fatal accidents.

It is important to note that it is the low speeds that primarily produce the positive results. This means that in principle any measure that produces low speeds will work as effectively from a safety point of view. Measures capable of producing these low speeds are primarily measures with a "vertical effect", like humps, speed cushions, and raised crossings. In India and Kenya it has been observed that the use of rumble strips has a very strong speed reducing effect on an average speed of around 5 km/h (Hydén 2015). Even if the safety effect is extremey positive – locally – it should be noted that the environmental effects are quite bad. Speeds around 30 km/h have a safety effect that is good enough, and in addition are much more environmentally friendly.

Regarding humps, there is a rather unique opportunity to draw some conclusions regarding the use of this kind of measure in countries with a low degree of motorization. In a pedestrian safety project in Jaipur in India (Hydén and Svensson 2009) some very important conclusions regarding hump design and effects in a less motorised country could be drawn. In table 19.1 speeds at some humps in Jaipur were compared with some humps of the same design in the Swedish town of Lund.

It is striking to see that even though the car fleet is rather different, and the city size too is different, the mean speeds are almost exactly the same in Jaipur and Lund. This is a very strong indication that humps are universal in their function. So the tentative conclusion is that there is no reason to believe that humps would not work as effectively from a s afety point of view in less motorized countries.

In the same study in Jaipur (Hydén and Svensson 2009) it was also demonstrated that different designs (length and height) were used which produced different mean speeds in the range of 15 to 30 km/h, when crossing the humps. This is interesting, particularly because there were humps that produced speeds that were in line with the "Watts" hump but needed much

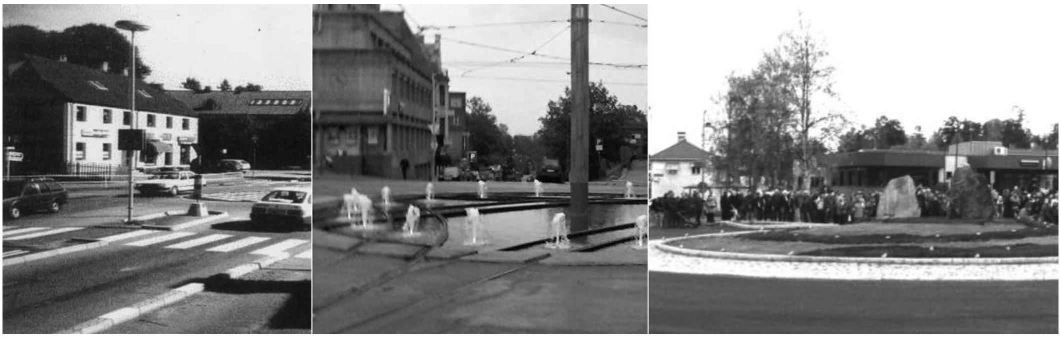

Figure 19.13 Small roundabout.

less asphalt – or other material – for the same effect. This means that when there is a scarcity of material, many more humps can be produced at the same cost. Interestingly it was also observed that motorcycles only drove slightly faster than cars. So from this point of view motorcycles had the same safety potential as cars. This was also supported by conflict studies that did not indicate that motorcycles were disproportionally involved in conflicts compared with cars (Hydén and Svensson 2009).

19.2.2.2 Small roundabouts

So far the focus has been on measures that are most efficient in producing low speeds, namely measures that produce vertical accelerations. There is one very big exception though, and that is the small roundabout. A Meta analysis based on quite a lot of studies showed that the introduction of a roundabout reduces fatalities by more than 50% at four leg intersections. It is even considerably safer than traffic signals. In addition, roundabouts produce smoother interaction resulting in less noise and emissions (Høye et al 2012).

In a study 21 small roundabouts were built on a provisional basis in a Swedish city. The roundabouts were installed in a two week time and were then operationg for half a year. The results of empirical studies showed that – with the right design – it was possible to reduce entering speed to around 30 km/h, and injuries by 40%, and to increase yielding by car drivers. It was even possible to reduce time consumption even for car users, by replacing a traffic signal by a roundabout. It was also possible to show that roundabouts at consecutive intersections along a road kept speeds low. Besides, a majority of all road users were in favour of the measures, especially in the longer run (Hydén and Várhelyi 1999). One of the advantages with small roundabouts is that there is not a need for a lot of space, see Figure 19.13. This means that roundabouts could be built in principle in all intersections. Today there are more than 3000 in Sweden alone, which have enhanced the environment in many cities, and even become well-known pieces of art, Figure 19.13.

One lane roundabouts work fine till around 25,000 incoming vehicles per day (Hydén and Várhelyi 1999). This opens up for using roundabouts in a large majority of all intersections, except in the largest arterials. Roundabouts can work as an efficient traffic calming device all over the city. And it does not have to be costly, as the example to the left in Figure 19.13 shows.

19.2.3 Conclusions regarding traffic calming and infrastructure

The main conclusion regarding the presented traffic calming measures is that they are quite capable of reducing speeds to 30 km/h and even lower. So the first part of the criteria, low speed, is fulfilled. However, regarding the second part, smooth speeds with a minimum of accelerations and decelerations, things are more critical. Speeds will go up between each pair of humps. The longer the distance between the humps the higher the speeds between will be them.

Today traffic calming is only applied in a very pragmatic, non-systematic way. For instance in Sweden – on top of the "traffic safety list" – there are some schools that have a speed limit of 30 km/h and humps, while the majority of schools have not. Priorities for improved safety and environmentally friendly means of transport are often well phrased political goals. The way to reach these goals is, however, extremely slow in most cases. We still have to live with indirect messages from the authorities which more or less clearly indicate that the norm of driving with higher speeds is ok. At the same time it can be observed – again in my country – that speeds in cities are slowly going down, primarily because of the new speed limits and because there are now more and more humps and more small roundabouts. So in spite of the slow progress, there is a clear tendency towards lower speeds.

There is one strong force that I have not brought up, and that is the pleasantness and attractiveness of streets/areas. As an engineer I have focused on the engineering means of lowering speeds. However, attractiveness is a prerequisite in order to receive public support and to attract pedestrians and bicyclists and travellers on public transport demonstrated by Van Schagen (2003).

19.2.4 Traffic calming and the vehicle

"Vehicle calming" has never been linked to traditional traffic calming. The speed of the automobile has been developed in isolation from the development of city life, it seems. That is, of course, strange in at least one way, as the vehicle is the system element with the greatest theoretical potential for controlling speed. An obligatory dynamic Speed Limiter – based on prevailing speed limits – can prevent all speeding from day one! Besides that, such a system would not only reduce speeds to any low level, but could also reduce any "excessive" accelerations and decelerations.

There is a lot of research being done on the vehicle. Most is done under the umbrella term ISA – Intelligent Speed Adaptation. Carsten (2011) explains: "ISA generally works by identifying the current speed limit from an enhanced digital road map, although alternative systems using in-vehicle cameras to recognise speed signs are also feasible. The information on speed limit can be used to warn the driver when he or she is exceeding the limit (advisory ISA) and can also be linked to the vehicle drivetrain to provide an overridable system (voluntary ISA) or a non-overridable system (mandatory ISA). Both voluntary and mandatory ISA can be installed as retrofits but they are far cheaper and probably better in operational terms when installed as original equipment. Advisory ISA can be a feature in normal satellite navigation software whether in a specific satnav device or in an application on a smartphone".

The vast majority of research projects deal with advisory or voluntary ISA. One of the few exceptions is a project with a mandatory ISA, also called Speed Limiter, done in Sweden (Almqvist and Nygård 1997). Twenty cars were equipped and running for two months. The speed limit was 50 km/h which could not be overridden by the drivers. The harmonization of speeds – below the limit – over a stretch of road is clearly demonstrated in Figure 19.14.

Even if the example is just from one of the few existing ones it clearly shows that a "definite" maximum speed is possible smoothing the distribution strongly, and keeping the speeds at or below the speed limit. Speed difference between cars is almost disappearing and there are almost no dips along the road stretch any more. The project was of course too small to allow any safety estimates to be done. However, there were tendencies to an improved behavior (less driving against red, keeping longer distances, and lower speeds on stretches). At the same time it increased speeds at approaches and turns at intersections. Drivers' opinion was that driving was smoother, and that there was more attentiveness paid to pedestrians and cyclists. It was negative, in the sense that it was impossible to make accelerations above the speed limit.

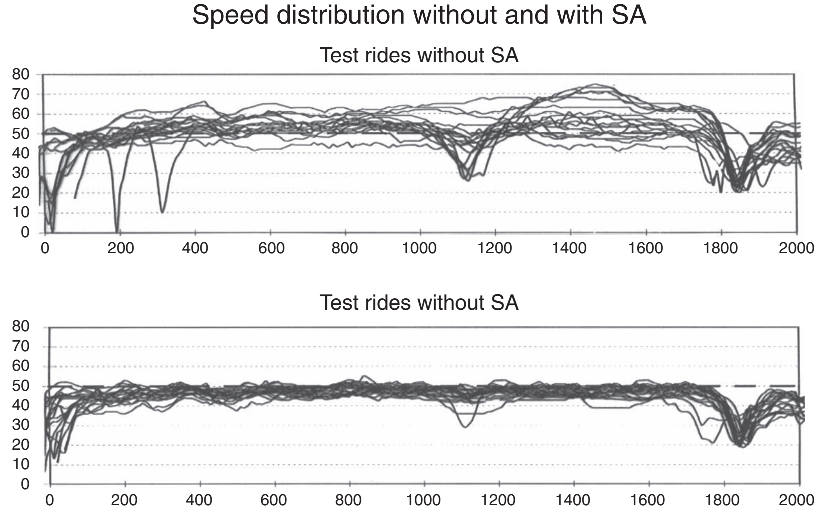

Figure 19.14 Speed distribution with and without Speed Limiter (SA in the figure).

The estimated safety effect of different ISA-systems has been simulated in a study in the UK. Based on models from the literature of the relationships between speed and crash risk, the results showed that Advisory ISA would result in a −2.7% reduction of injury accidents, Voluntary (Overridable) ISA would reduce injury accidents by 12.0%, while a Mandatory (Non-Overridable) ISA would result in a reduction by 28.9%, 50% reduction of fatal crashes (Lai et al 2012). Volunatarity is thus a very important factor. Another one is whether the scenario is market driven (users choose to have ISA because they want it) or authority driven (in which adoption of ISA, particularly 'stronger' forms of ISA, is initially encouraged and eventually required). The prediction shows that the Authority Driven scenario is predicted to save 30% of fatal accidents and 25% of serious accidents, while the Market Driven scenario would save 13% of fatal accidents and 8% of serious crashes in a period of 60 years (Lai et al 2012).

19.2.5 Conclusions regarding vehicle measures

The different ISA-trials have had positive results regarding many aspects, like speed and accident reduction; they have also shown improvements regarding environmental conditions (emissions), and cost-effectiveness (Lai et al 2012). There is also a reasonable level of acceptance by users, even though users might feel somewhat disadvantaged by having ISA, because they can see other drivers travelling faster than they are.

The problem is that any result so far achieved is far from optimizing the use of ISA. The main reason is that these systems have been advisory or voluntary. Compliance is quite low and different projects have found that drivers who need ISA most are using it the least (Várhelyi et al 2002). So even though speeds have been reduced, they are far from being reduced to the speed limit. The conclusion therefore is that this kind of device is just like any other follow-up of the compliance with the speed limits. So I am afraid that these approaches will not lead us to the "Slow speed city", as long as there are no serious attempts to start focusing on systems that might have significant effects on safety. The problem is that the car industry does not show any great interest, which is quite understandable since the customers do not ask for it. A much greater problem is that authorities do not seem to move at all. In an assessment of the situation in the UK Oliver Carsten concludes: "In other words, it is the Department's intention to do absolutely nothing to promote ISA as a tool for encouraging compliance with speed limits. It is also the Department's intention to ignore any encouraging results from a project which received a large amount of public funding, even though those results are fully in accord with DfT's stated policies" (Carsten 2011).

The situation on the experimental front supports the idea of low interest. In spite of quite promising results from the first trial with a Speed Limiter in the real world, described above, there have not been any new trials with a Speed Limiter ever since the beginning of the seventies, not even in a research context. The question is, of course, whether it ever will be possible to overcome this political and industrial unwillingness to change.

19.3 GENERAL CONCLUSIONS

There is clearly a great potential in creating low speeds in cities with a minimum of accelerations and decelerations. In principle, all quality aspects linked to low speeds have great potential in improving the life of the individual and society. There is a lack of comprehensive town planning that is holistic in the sense that it considers all different quality aspects, for all different groups simultaneously and based on matters of equality and fairness. It is such a demanding, and complex task that two groups of decision makers would come to different conclusions for the same case because they would prioritize differently. It would be very interesting to see the result of a more comprehensive follow-up of my small scale, tentative, study on a "maximum 30 km/h" scenario. It may open the eyes for many people who take the present system for granted, and may start a more sophisticated discussion about city life and car speeds than what we normally see in our daily lives.

Humps and similar measures have come to stay, and they are spreading globally. There is almost no inhabited place on earth where you not will find some kind of humps today. And once installed they will never be removed. If authorities do not respond to a public demand, people install the humps themselves. In the vast majority of cases where humps and similar measures are used there is very little follow-up. If there is any, it is primarily about the drawbacks for drivers; increased drive time, damaged the car, danger (because drivers look at the hump and not on the surroundings), etc. You rarely see any positive reactions from residents or vulnerable road users. They are very weak interest groups compared to the car users. There is a need for scientific backing, to find a more novel, more comprehensive view of traffic calming. City planners need this support; they do not have the financial muscle to do research and they need to focus on action. So the responsibility for research belongs to the central authorities. Research that tries to gradually find empirical evidence for how different elements in a "holistic speed reducing strategy" works is needed. Researchers should engage engineers who are "the masters" of the infrastructure (and vehicle engineers for the vehicle). Together – and together with lots of other disciplines – they should develop implementation strategies to gradually improve knowledge and enlarge the comprehensiveness of the strategy, thereby gradually overcoming hesitations from decision makers, experts, and researchers generally. There might be quite strong synergy effects, by self instruction by drivers that an efficient and comfortable strategy might be to utilise assistance from the car in order to comply with the demands raised by the infrastructure (e.g. a hump). I am surprised that there seems to be so little proactive action by traffic engineers. I thought that they would be happy to have vehicle measures supporting **or** replacing the need for humps. Basically the idea of forcing drivers to slow down with the help of "a kick in the ass" (i.e. humps) is quite a primitive one I think . . .

Finally regarding the universality of my conclusions I just want to repeat that I think all the conclusions are valid everywhere around the globe. Traffic problems develop in the same way everywhere, so even though the scale is different the same kind of problems evolve and will evolve if not present today. We **all** have a lot to learn from each other, and for instance in countries with a low degree of motorization today, this will change rapidly. In the safety area we have always claimed that it is important that countries less motorized than others should learn not to make the same mistakes as their predecessors. Theoretical knowledge (which is what primarily has been transferred) is too abstract for most receivers. Proper experiments, tests and field trials can be used both to learn about effects and to demonstrate for others what is tried and evaluated. This can be made parallel in countries with different backgrounds. The study in Jaipur, India clearly showed that comparisons with Swedish conditions were quite relevant. So, let us leave the ad-hoc status of research on the city of tomorrow, and let us try and convince decision makers everywhere that we are dealing with the survival of the city. That should be motivation enough.

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CHAPTER 20

Public Transport and Safety

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CONTENTS

ABSTRACT

All cities are faced with serious problems of inadequate mobility and access, vehicular pollution and road traffic crashes, and crime on their streets. Improvements in public transport and promotion of non-motorised modes of transport can help substantially in alleviating some of these problems. However, the introduction of better technologies alone is not likely to shift adequate numbers of people from cars and motorcycles to public transport. Much of the effort associated with public transport trips is performed to simply reach the system and the final destination. If public transport use has to be promoted in cities, much more attention has to be given to the improvement in safety levels of bus commuters and the non-motorised transport segment of the road users. Unless people actually perceive that they are not inconvenienced or exposed to greater risks as bicyclists, pedestrians, and bus commuters, it will be difficult to reduce private vehicle use. In this chapter the processes needed to improve the safety of public transport users and are discussed.

Key Words: Public transport; safety; commuters; bus system

20.1 INTRODUCTION

Most of the megacities in the world are already located in less motorised countries (LMC) and many more cities in these countries will grow to populations of ten million or more in the next few decades (UN Habitat 2011). All these cities are faced with serious problems of inadequate mobility and access, vehicular pollution and road traffic crashes, and crime on their streets. The increasing use of cars and motorised two-wheelers (MTW) adds to these problems, and this trend does not seem to be abating anywhere. Many recent reports suggest that improvements in public transport (PT) and promotion of non-motorised modes of transport can help substantially in alleviating some of these problems (Mohan et al 1996; Wu Yong and Li Xiaojiang 1999; OECD 2000; Commission of the European Communities 2001). In recent years, bus rapid transit systems (BRT) with dedicated busways have been shown to be economically feasible and capable of transporting large numbers of people efficiently in more than 200 cities around the world (Hidalgo 2013; Hans Örn 1998; World Bank 2000). A report prepared for the World Business Council for Sustainable Development (2001) states that "Compared to its investment in urban roads and railways, the private sector expresses little interest in busways, yet they are among the most cost-effective means of improving urban mobility. The great benefit of dedicated busways is their ability to move large numbers of passengers — typically up to 25,000 passengers per hour per direction — at relatively low cost, typically $1 to $3 million per kilometer, 50 to 100 times cheaper than subways."

However, introduction of better technologies alone in PT is not likely to shift adequate numbers of people from using cars and motorcycles. Some of the standard countermeasures suggested to promote PT include the following:

(a) Promote mixed land use.
(b) Move toward a greater diversity in modal splits with more importance to non-motorised modes.
(c) Lower commuting distances as well as shorter access to PT.
(d) Increase costs of personal modes of motorised travel and raise fuel prices and introduce road fuel taxation.
(e) Increase frequency of buses.
(f) Bus stops should be within easy walking distance of homes and work places.
(g) Buses should be made more accessible and comfortable for children, women, the elderly, and the disabled.
(h) Make public transit affordable for the lowest quintile income.
(i) Improve the quality of pedestrian and bicycle environments.
(k) Access to the bus must be made safe for all bus users.

Of all the measures listed above, (a) to (d) already exist in some form in Delhi and many LMC cities. Delhi has a very mixed land use pattern, a large proportion (∼39%) of all trips are walking or bicycle trips (Operations Research Group 1994; RITES 2008); of the motorised trips more than 50% are by PT or shared para-transit modes; compared to cities in highly motorised countries (HMC), trips per capita per day in LMCs are lower and more than 40% of trips are less than 5 km in length; and costs of motorised travel are high compared to average incomes. In spite of these structural advantages, PT systems in Delhi and other LMC cities are not adequate, both in terms of the quantity and quality of services.

Introduction of BRT with modern low floor-buses is likely to take care of the measures (e) to (g) listed above. However, what these cities do not have are safe and convenient walkways and bicycle lanes, and streets that ensure the safety of all commuters from accidents and crime.

Deaths and injuries due to road traffic crashes are also a serious problem in LMCs (Peden et al 2004; WHO 2013). According to one estimate the losses due to accidents in LMCs may be comparable to those due to pollution (Vasconcellos 1999). These problems become difficult to deal with because there are situations in which there are conflicts between safety strategies and those which aim to reduce pollution (OECD 1997). For example, large and heavy vehicles can be safer but they consume more energy and pollute more; congestion reduces probability of serious injury due to crashes but increases pollution; increase in bicycling rates can decrease pollution but may increase crashes if appropriate facilities are not provided. However, unless access to PT systems is made much safer it will be difficult to ensure success of the BRT systems. In this chapter we outline some of the issues and policy options connected with PT and safety.

20.2 PUBLIC TRANSPORT AND SAFETY

The safety record of bus transit operations has been reasonably good in most cities of the world as compared to other modes of transport, yet people prefer to use their cars if they can afford it and when it is convenient to do so. The main problem of safety is not as a passenger inside the bus but as a pedestrian or bicyclist on the access trips. A study of risk of accidents by different travel modes in Copenhagen (Jorgensen 1996) concluded, “There is no reason for a traveller to choose bus instead of car for the point of view of his own safety,” and that “From a social point of view there would be a safety benefit through a change of car driving into bus driving”. These conclusions were based on the fact that the risk of death per trip for a bus user was very high on access trips (see Figure 20.1).

The high risk of injuries and fatalities in urban areas to pedestrians, bicyclists and commuters in access trips have been documented from all over the world. The greatest risk to schoolchildren

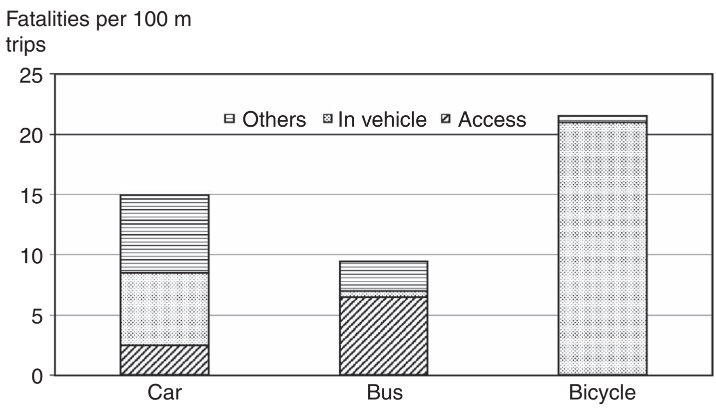

Figure 20.1 Fatality rates for different trip types in central Copenhagen (adapted from Jorgensen 1996).

from bus related injuries was found to be as pedestrians after alighting from a bus in New South Wales, Australia (Cass et al 1997); in Mexico City 57% of deaths from traffic crashes involve pedestrians (Hijar et al 2001); injury to pedestrians was the most frequent cause of multiple trauma (54%) among children 0–16 years in a large Spanish urban area (Sala et al 2000); in California a motor vehicle versus pedestrian accident study reported that these accidents are common in a large urban trauma system and the high mortality rate among the elderly indicated the need for more aggressive and effective prevention efforts (Peng and Bongard 1999); a study from Canada showed that children's exposure to traffic (number of streets crossed) and injury rates were positively correlated (Macpherson et al 1998); in Kumasi, Ghana, the most common mechanisms of injury (40.0%) to children were pedestrian 'knockdowns' (Abantanga and Mock 1998); a study of older people's lives in the inner city in Sydney, Australia, showed that the environmental hazards, such as pedestrian and traffic management, affect the whole population and require interventions at government level (Russell et al 1998); a study from Seattle shows that 66% of the fatal injuries occurred on city or residential streets, and 29% occurred on major thoroughfares, and a single urban highway accounted for 12% of pedestrian fatalities and represented a particularly hazardous traffic environment (Harruff et al 1998).

Quite obviously, people's fears regarding safety on the roads when using PT are not unjustified. A large proportion of the decrease in road traffic injuries and deaths in HMCs is the result of the availability of cars, which provide much greater safety to the occupants in crashes, and the result of a very significant reduction of the presence of pedestrians and bicylists on HMC streets and highways. Recent estimates from the UK suggest that the number of trips per person on foot fell by 20% between 1985/86 and 1997/99 (House of Commons UK 2001). Such trends suggest that reduction in pedestrian, bicycle and MTW fatalities in HMCs could be largely because of the reduction in exposure of these road users and less because the road environment has been made "safer" for them. In LMCs the exposure rates for pedestrians and bicyclists are much higher, and with the introduction of BRT, it would become essential that road and vehicle designs ensure safety on access trips, otherwise the system may operate at sub-optimal capacities.

20.3 PUBLIC TRANSPORT AND TRAFFIC CHARACTERISTICS OF INDIAN CITIES

PT accounts for a major share of total trips made in any city in India (Mohan 2013, WSA 2008). While the exact shares of PT vary from one city to another, there is no doubt regarding the importance it plays in terms of the number of passengers carried (Figure 20.2). In India, availability of PT has a large number of economic and social implications. PT as compared to private modes of transport is cheaper and is the only mode of transport that is economically feasible for a significant portion of the population.

In most LMCs including India, the experience has been that government agencies are unable to provide adequate formal PT systems; in such cases 'informal PT' systems emerge to cater to the demand. In fact, even where PT is adequate, informal transport systems cater to the mobility needs unmet/partially met by the formal PT systems; in such cases, informal systems provide last mile connectivity, compliment the formal systems and provide more options to commuters, which may be more flexible and cheaper (ORG 1994; WSA 2008). These informal modes of PT are also termed para transit systems.

20.3.1 Importance of public transport accessibility

Public transit is a key component of any sustainable transportation system of a city. It improves systemic mobility and can serve to mitigate economic and environmental burdens that increased auto ownership can impose on the traveling population. While provision of public transit and

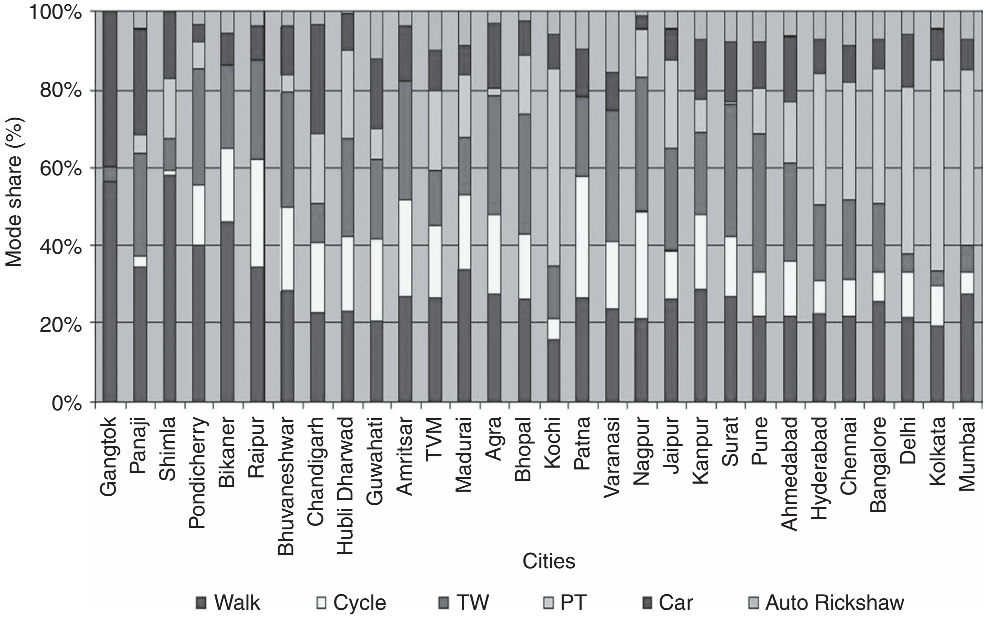

Figure 20.2 Figure 1 1 Modal shares in Indian Cities.
Source: Wilbur Smith Associates, 2008.

infrastructure is important, this alone will not help in increasing the attractiveness of PT. It is also necessary that the system provided is accessible for its users, so that its full potential is realized. The system must be accessible and available to the community and its activity centers, and connected with the rest of the transportation system.

A significant number of current PT users are captive users, who use PT not out of choice but due to a lack of other options. With rising income levels in the country, it will be an important challenge for all cities to maintain the current shares of PT. To increase the use of PT services by choice, it is necessary to ensure that the use of PT is attractive. Accessibility to PT will be key to improving its attractiveness. Unless the effort required on using the system is within reasonable limits, there will be a considerable fall both in user satisfaction and the use of PT facilities over time. Hence, steps have to be taken by the concerned authorities to not only provide PT facilities but also to improve its accessibility to the public.

Much of the effort associated with PT trips is performed to simply reach the system and the final destination. Access and egress stages (together with wait and transfer times) are the weakest part of a multimodal PT chain and their contribution to the total travel disutility is often substantial. An increase in access and egress (time and/or distance) is associated with a decrease in the use of PT. Should the access and egress trip components be more acceptable, users may use the PT system in increasing numbers. Arguably, if the proportion of trip time spent on the access and egress stages is considerable, PT trips will be considered a less suitable choice because these stages involve much physical effort.

It is also to be noted that depending on the type of PT system being discussed and the city for which it is planned, the feeder services will be different. For example: A demand estimation model of PT in Delhi, 2011 showed that there are 9 modes for access to PT (Figure 20.3). The mode choices were different for the metro system and the bus system (Figure 20.4). While the access mode to the bus system was confined to two choices, the mode choices for the metro were as many as 5 (Advani 2011).

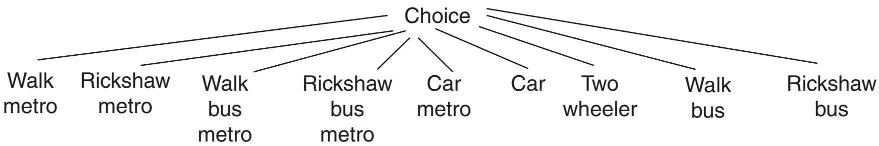

Figure 20.3 Public transport feeder mode choice.
Source: Advani 2011.

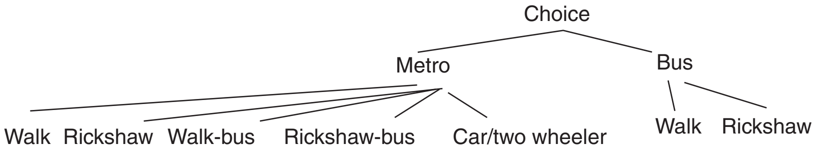

Figure 20.4 Feeder mode choice for different public transport systems.
Source: Advani 2011.

It is necessary to understand different access modes and plan for each and every one of them as well as other potential access modes to ensure accessibility to PT. This also helps in identifying which access modes need to be provided in Indian cities. Five types of modes have been identified – pedestrian, cyclists, IPT users, bus users and private motor vehicle users.

To meet the different requirements of each mode, separate checklists have been recommended in the tool kit prepared by IUT, 2013, for assessing the quality of public transport accessibility.

20.3.2 Social accessibility

20.3.2.1 Safety and security

The use of PT is also dependent on the safety and security of using the system. Safety aspects include the risks that the commuters are subject to in and around a particular station. Risk to commuters could be captured using accident data but since accident data is not always available for Indian cities, it is better to use a proxy for the same. Speeds of motorised traffic around a station are a good indicator of the risk that commuters face.

Security is, on the other hand, a perception-related issue. Areas or locations that have fewer activities or fewer people, or poor lighting, are perceived to be unsafe. If the PT stop or its vicinity is perceived as insecure either because of lack of street vendors or lighting, this will then make certain segments of the society, like women and senior citizens, not use the system at certain times of day. Provision of infrastructural elements like lighting is necessary to ensure that the PT system is accessible to everyone.

20.3.2.2 Disabled friendly

"India has a disabled population of approximately 70 million or 7% of its population. An additional 20–30% of the population is rendered less than able or temporarily impaired by environmental barriers. These include people with temporary health problems, the aged and the persons with reduced mobility (pregnant women, elderly persons, children, persons carrying luggage and those with temporary ailments, etc.). Lack of access to public infrastructure and facilities is one of the greatest impediments to education and employment of persons with disabilities and the aged" (Agarwal 2012). It is hence necessary to build PT systems which provide accessibility to the permanently and temporarily disabled.

20.4 QUALITY OF PEDESTRIAN AND BICYCLE ENVIRONMENT

In light of the discussion above, an exclusive focus on bus and fuel technologies may not be a sustainable option for cleaner air in cities like Delhi. In all LMC cities non-motorised modes constitute a high proportion of all traffic. Unless these modes are given importance and roads specifically designed for their needs, they make the movement of motorised modes less efficient. In addition to bicycles, non-motorised carts and *rickshas* are used for delivery of goods like furniture, refrigerators, washing machines etc. Semi-skilled workers, carpenters, masons, plumbers, postmen, and courier services use bicycles or walk. Therefore, the demand for bicycles and other non-motorized modes exists in large numbers at present and is likely to exist in the future also.

Better facilities for pedestrians, and segregated bicycle lanes, would also result in enhanced efficiency of the PT buses that can be given the curbside lane or central two lanes as per the site demand. Physically segregated lanes also improve safety of the vulnerable road users by reducing the conflicts between motorised and non-motorised modes. This would ease traffic flow and hence reduce pollution. Data clearly indicate that if PT use has to be promoted in mega-cities in LMCs much more attention has to be given to the improvement in the safety levels of bus commuters and the non-motorised transport segment of the road users. This is particularly important because promotion of PT use can also result in an increase in the number of pedestrians and bicycle users on city streets. This is because every PT trip involves two access trips that are mostly walking or bicycle trips. Unless people actually perceive that they are not inconvenienced or exposed to greater risks as bicyclists, pedestrians, and bus commuters, it will be difficult to reduce private vehicle use.

Mohan and Tiwari (2000) also show that in LMCs buses and trucks are involved in a much greater proportion of crashes than in HMCs, but relevant safety standards for these vehicles are lacking. In particular, a strong case can be made for the evolution of pedestrian friendly fronts for buses and trucks, but such issues are not given any priority at present.

20.5 PUBLIC TRANSPORT, MOTORISED TWO WHEELER AND POLLUTION TAX

To solve problems of safety and vehicular pollution in an integrated manner we need to work from first principles. Quite obviously, the most long lasting solution would be if people travelled less. This depends mostly on how your city is organised. Mixed land use helps. Homes, businesses, hospitals, schools, entertainment areas, all need to be intermixed in localities. This is happening more by default than by policy in our cities.

Even the existence of poor neighbourhoods cheek by jowl with rich ones may be reducing motorised trips and increasing employment. When you shift low-income people to the periphery of a city you have to provide bus transport to the formally employed. But the others become unemployed and may take to crime.

It is easy to list the above principles but not so easy to make and implement effective policy. All policies, like drugs, have side effects. Before prescribing a drug you have to be certain that the side effects are not worse than the disease! For example, our simple calculations show that all the effects of reducing pollution from buses would be *nullified* if only 10–15 percent of bus users shift to using two-wheelers or cars (Sanghi et al 2001). This may also result in an increase in road traffic crashes and injuries. Greater use of MTW would also increase injuries due to accidents. Therefore, before we make new laws that might increase the cost of buses, we have to make arrangements for cross-subsidy of PT. This follows from the polluter and user pay principle.

Since car users pollute the most, use the most road space and injure more people per person transported, they must pay for their comfort that harms others. MTW users come next, and bus users a low third. A pollution and road tax paid by private vehicle users could help pay for better buses so that we could avoid a migration from buses to two-wheelers and cars. It is quite clear that safety and cleaner air will come at a price, and only if we have well thought out long term policies. The future committees which deal with these issues would be well advised to consider all the complex issues, consider the side effects and perform cost effectiveness studies before issuing edicts. If we don't do this, the air will not be cleaner and a lot of people will be angry.

The Institute of Urban Transport (2013) has developed a PT accessibility tool kit. The tool kit has following checklists to carry out a detailed audit.

- Check List 1: Accessibility to Pedestrians
- Check List 2: Accessibility to Cyclists
- Check List 3: Accessibility to IPT Users
- Check List 4: Accessibility to MV Users
- Check List 5: Accessibility to Bus Users
- Check List 6: Driver Behavior
- Check List 7: Pedestrian Behaviour
- Check List 8: Traffic volume

The parameters in the checklists are dependent on the type of PT being evaluated and the type of road on which the study is conducted. Keeping these differences in mind, separate sets of checklists have been provided depending on the PT system and road type.

20.6 DEVELOPMENT OF A BUS COMMUTER SAFETY POLICY

The safety of bus commuters can only be ensured if a scientific policy is put in place and implemented by a proactive system. A recent report on the subject commissioned by the U.S. Department of Transportation (1999) lists the following conditions for such a system:

- Address all departments within the transit system (safety, operations, maintenance, etc.).
- Include both patrons and employees in the plan development.
- Address all of the safety issues associated with the transit system.
- Provide for and maintain top management and board of directors approval in the form of a signed policy and the allocation of adequate resources.
- Ensure that the safety director/officer has direct access to top management.
- Designate one individual as the responsible safety authority for the system.
- Clearly identify the roles and responsibilities of the safety director/officer and the safety department.
- Clearly identify the safety roles and responsibilities of all other transit system departments.
- Establish a proactive safety program with the process and procedures necessary to identify and resolve hazards prior to their resulting in accidents.
- Include a mechanism for ensuring that all employees are accountable for safety. This must include a disciplinary process.
- Provide a mechanism for cooperation (including the resolution of differences) between the individual transit system departments and external agencies that support the transit system.
- Include the establishment and review of data bases to assist in the continuous monitoring of the system safety program to ensure that it is providing the results expected.
- Prepare a fully documented system safety program plan.

Such a system must include the following elements (Federal Transit Administration, 2001).

20.6.1 Safety process-centric elements

- Safety Data Acquisition/Analysis
- Accident/Incident Reporting & Investigation
- Hazard Identification/Resolution Process
- Emergency Response Planning, Coordination and Training
- Internal Safety Audit Process

20.6.2 Human-centric elements

- Driver Selection (Basic safety element)
- Driver Training (Basic safety element)
- Drug & Alcohol Programs(Basic safety element)
- Employee Safety Program
- Fitness for Duty (additional requirements beyond the drug and alcohol requirements)
- Rules/Procedures Review
- Contractor Safety Coordination

20.6.3 Infrastructure & equipment-centric elements

- Vehicle Maintenance (Basic safety element)
- Facilities Inspections
- Maintenance Audits/Inspections
- Hazardous Materials Program
- Alternative Fuels and Safety
- System Modification Review/Approval Process
- Interdepartmental/Interagency Coordination
- Configuration Management
- Procurement
- Security
- Operating Environment and Passenger Facility Management
- Dedicated Busway or Roadway Inspection and Maintenance

In addition, special attention has to be paid to the safety of women (METRAC 2000) and children (see for example a report prepared by the National Association of State Directors of Pupil Transportation Services 1998). Such policies should ensure that women and children are free from violence and the threat or fear of violence in buses, at bus stops, and on their access trips.

Kharola et al (2010) analysed fatal crashes involving buses in Bengaluru. The study came up with major policy recommendations for different aspects of bus systems, as presented below.

20.6.3.1 Adequate right of way for all modes of transport

Separation of buses from non-motorised road users and the provision of safe pedestrian and bicycling facilities on arterial urban roads can go a long way in not only reducing the number of crashes but also improving access to the public transport system. Improvement in pedestrian facilities is not capital intensive and is well within the reach of the municipal bodies and the State Governments. In a large number of cases, mere clearing the pavements of parked vehicles could lead to substantial improvements. In the long run, improved road infrastructure with adequate illumination at night can contribute to a substantial reduction in crashes. The effectiveness of such designs has been demonstrated on the BRT corridors in Bogota (Echeverry 2004), and Delhi (DIMTS 2009) where road traffic fatalities have been reduced by more than 90%.

20.6.3.2 Installing automatic doors

Kharola et al (2010) showed that 92% of the bus passengers involved in fatal crashes sustained fatal injuries due to a fall while entering or leaving the bus. Similar results have been reported from a study of DTC operation in Delhi (Mohan 1985). The large number of passenger deaths while boarding and alighting indicates the need for having automatically closing doors and much lower floors in buses.

At present, the traffic situation demands that mechanically operated doors be mandated in city buses. In all high income countries and others like China, no city buses can ply unless they are equipped with mechanically operated doors. Already, several bus transport companies like the Delhi Transport Corporation (DTC), BMTC etc. are using buses equipped with pneumatically operated doors. Therefore, the time has now come to mandate by law (through the Motor Vehicle Rules) that no city bus shall be permitted to operate unless it has mechanically operated doors. With this one intervention, fatalities in bus crashes can be brought down by 20% and injuries decreased by a greater number.

20.6.3.3 Changing the design of the bus body

There are a large number of cases where the victim is run over by the bus (Kharola et al 2010). Such crashes could be prevented through better design of buses. At present, most of the buses in Indian cities are fabricated on chassis which are more suited for trucks. As a result, the bus floor is about 1.0 m above the ground. Such large ground clearances are helpful in negotiating uneven road conditions. Consequently the side panel of the bus body is also kept at a clearance of about 70–80 cm from ground. This leaves a very big opening under the bus and an inadvertent victim in a crash has a high probability of getting into this opening and getting run over by a wheel. Therefore, there is a strong case for making it compulsory for all buses in cities to have their body fabricated in a manner such that the side panels of the bus body are low enough to prevent a person accidentally or during a crash getting under the bus. This has been made possible by the proposed Automotive Industry Standards Code of Practice for Bus Body Design and Approval (AIS-052) which requires that Automotive Vehicles – Lateral Protection (Side Guards) – Technical Requirements be followed for side under run guards of buses (BIS (1999). Automotive Vehicles – Lateral Protection (Side Guards) – Technical Requirements, IS 14682. New Delhi: Bureau of Indian Standards). This standard mandates that the maximum clearance be limited to 550 mm above road level (Figure 20.5).

In a large number of crashes injuries and fatalities are caused to VRUs (Vulnerable Road Users) in frontal impacts. Research has been done in India and Europe showing that fatalities in such impacts can be reduced significantly by designing safer bus fronts (APROSYS 2004; Chawla et al 2000; Kajzer et al 1992). It would be appropriate if the recommendations of these reports to set standards for protection of VRUs in impact with buses were put in place as early as possible.

20.6.3.4 Better personnel policies

It has been adequately shown by the analysis that the risk factor of a driver varies according to his age. This should be an important input in designing the personnel policies of public transport utilities. New drivers should not be placed on ‘difficult routes’ in the initial four to five years of their careers.

20.6.3.5 Selective but effective enforcement of regulations

One of the major reasons for crashes is speeding and non-compliance regarding traffic safety regulations. Police officers must be given training in safer traffic management techniques and

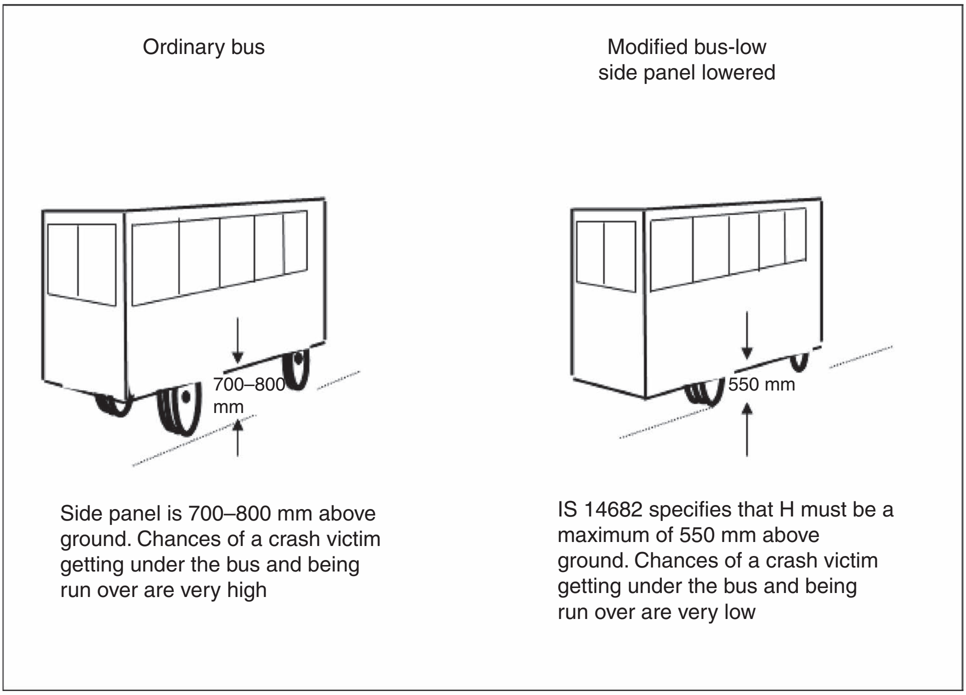

Figure 20.5 Modified bus body showing safe clearance from the ground.

must be given budgetary support for the placement of adequate number of policemen on all roads.

20.6.3.6 Overall concerns for PT safety

What modes of travel people use in cities is decided by a balancing of economic compulsions, comfort, and safety. Studies of travel behaviour around the world suggest that people don't necessarily minimise the time spent on trips (Goodwin and Van Dender 2013). Most seem to have a personal travel time budget preference and utilise it fully except when circumstances don't permit them to do so. If provided faster modes of travel they live further away from work! Public transit is used mainly by those who don't have a vehicle for personal use or when personal vehicle use is very inconvenient (irritating driving conditions, very long distance travel), time wasting, impossible (no parking at destination), or very unsafe. At the very least, public transport should not take more time than car travel. This means that buses on main arterial routes cannot be mixed with car traffic because that will always make them slower than cars.

Safety on access trips also emerges as a very important issue, especially for women and children. Unless the walking trip is safe from accidents, harassment, and crime, people avoid using public transport. Therefore, safety emerges as a precondition for promoting public transport and active travel (Appleyard 2013; Behrens and Jobanputra 2013; Cardia 2013; Cohen et al 2013; Roberts 2013; Villaveces 2013). Except for the BRT in Delhi, no other urban rail project or bus transport authority in any city in India has made a special effort to ensure provision of safe walking and bicycling facilities in the vicinity of every station. Unless there are wide sidewalks with a treeline, dedicated bicycle facilities, and safe road crossing facilities on the surface of every arterial road, we are unlikely to attract more transit users easily.

In addition to traffic safety, safety from crime and harassment is a major concern for parents, children, and women. Forty seven years ago, in her book *The Death and Life of Great American Cities*, author Jane Jacobs suggested that crime could be reduced by having "eyes on the street." This book is quite possibly the most influential American book on urban planning to this day. By "eyes on the street" Jacobs meant shops on ground floors abutting the side walk, abundance of kiosks and cafes, and a vibrant walking atmosphere. She was quite clear that safety could not be achieve by policing alone. We are again fortunate to have these "eyes" on all our streets (except in very rich neighbourhoods) in the form of hawkers and vendors. Without them, our streets would not provide the relatively crime free atmosphere we have. These vendors then become essential as a part of our transportation planning process. It is not very difficult to plan for them as every road needs a treeline which occupies a corridor of 1–1.5 m of space on the pedestrian path. Vendors only need 1–1.5 m and they can occupy spaces between trees without bothering pedestrian traffic.

20.6.3.7 Bus technology and modern developments

Now bus technology has come into its own. The modern bus, supported by computer optimising and global positioning technology, web and mobile based public information systems, smart card ticketing, low floors, and quiet low polluting engines has become the public transport choice of the century. Such technologies or choices were not available just ten years ago. Bus schedules, routing and operational details can be hugely flexible, ideal for a fast changing modern city. The only thing that has to be ensured is that they do not get in the way of other road users. This is being done in many cities around the world by operating buses in segregated bus ways wherever possible, and mixing them with other traffic on sections where it is impossible to do otherwise. The cost is very moderate, almost one twentieth of that for a grade separated system. The secret of success is in the details – making sure commuters don't have to climb stairs or take escalators, ensuring a safe access trip, a high frequency of buses, and providing information so that trips can be planned on short notice.

20.7 CONCLUSIONS

Buses and non-motorised modes of transport will remain the backbone of mobility in LMC mega-cities. To control accidents and pollution in an integrated manner, both bus use and non-motorised forms of transport have to be given importance without increasing pollution or the rate of road accidents. This would be possible only if the following conditions were met:

20.7.1 Public transport

- Design and development of modern Bus Rapid Transit systems should be given priority in megacities of Asia.
- The increase in fares because of more expensive buses is likely to shift bus passengers to cars and MTWs and thus increase total pollution and accidents. The benefits of better technologies will be defeated if bus passengers shift to personal modes of travel due to fare increases. Therefore, the government must put in place a comprehensive policy of financing of PT, including cross subsidies. This could be done by invoking the "polluter pay principle". Owners of cars and MTWs must be made to pay a pollution tax, which could be used for financing more efficient bus transport.
- The problem of shift to MTWs and cars from PT has to be addressed irrespective of the fuel used by buses. Therefore, PT has to be made more convenient, safe and efficient. The safety and efficiency of bus transport, and its attractiveness for users could be increased substantially if modern low-floor buses were inducted in the fleet.

20.7.2 Facilities for non-motorised transport and safety

- Every round trip by PT involves four non-motorised trips and at least two street crossings. Therefore, greater use of PT cannot be ensured unless use of roads is made much safer for pedestrians and bicyclists.
- All arterial roads must have segregated lanes for non-motorised transport and safer pedestrian facilities.
- Urban and road design characteristics must ensure the safety of pedestrians and bicyclists by wider use of traffic calming techniques, keeping peak vehicle speeds below 50 km/h on arterial roads and 30 km/h on residential streets and shopping areas, and by providing convenient street crossing facilities for pedestrians.

The above recommendations have to be considered in an overall context where safety and environmental research efforts are not conducted in complete isolation. We have to move toward adoption and implementation of schemes that remain at a human scale and improve all aspects of human health. The authors of a report on the integration of strategies for safety and environment published by the OECD (1997) suggest the following guidelines for policy makers:

- Ask leading questions about safety and environmental goals at the conceptual stage of the project and look beyond the immediate boundaries of the scheme.
- The safety and environmental consequences of changes in transport and land use should be made more explicit in technical and public assessments.
- There should be simultaneous consideration of safety and environmental issues by involving all concerned agencies.

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CHAPTER 21

Road Safety Management from the National to the Local Level

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CONTENTS

ABSTRACT

The management pattern of having separate ministries or departments based on the sector of intervention is patently unsuitable to manage inter-sectorial policies. These require combined decisions in several sectors at the planning, design and implementation levels. Being a multi-faceted problem, the issue of road safety requires a multi-disciplinary approach. This can be addressed only by having a specific *transversal* organization, by-passing the hierarchical channels, to facilitate development and implementation of road safety policies. The organization of road safety management should establish, not only inter-sectoral links, but also channels for consultation and dialogue with the citizens. This chapter reviews the road safety management processes and components of road safety policies. Further, the actors involved are identified and the requirements for organization are discussed. The findings presented herein are from empirical work and observations carried out in low- and middle-income countries in Africa and Asia as well as in OECD countries.

Key Words: Road safety; Safety management; Traffic safety policy

21.1 INTRODUCTION: THE NEED FOR ROAD SAFETY MANAGEMENT

Democratic governments are responsible for the health and security of their citizens, for whom these are basic human rights. Road safety – or rather *unsafety*, measured through the frequency and severity of road crashes and their consequences – is a major health problem, one which is still growing in the world although it has gradually been controlled, at least temporarily, in most OECD countries. Moreover, safety on public roads or in the public space is part of the broader security from violence and trauma. These are two reasons that governments, whether national, regional or local, have to tackle the issue of ensuring the best possible level of road safety. To ensure this best level, planning is required, which means that governments need to develop and implement short-, medium- and long-term road safety *policies.*

As shown by years of multi-disciplinary clinical research, road crashes are multi-factorial events. They result from processes in which elements or characteristics of all the components of the road transport system interact: crash factors are thus related to the road infrastructure and its environment, vehicles and traffic, and road users, whether vehicle drivers and passengers, pedestrians or bicycle riders. Reducing or even eradicating injury-producing crashes therefore involves both an in-depth understanding of crash processes and directing interventions at all relevant crash factors. Road safety policies are thus multi-sectoral and complex.

Most or all governments are organized according to a hierarchical pattern based on sectors of intervention: separate ministries or departments deal with infrastructure, traffic, urban planning, education, enforcement, health, research, etc. This pattern is patently unsuitable to manage inter-sectorial policies as this requires combined decisions in several sectors at the planning, design and implementation levels. Hence the need for a specific *transversal* organization, by-passing the hierarchical channels, to facilitate development and implementation of road safety policies.

Road safety management is thus performed by a large number of actors with different disciplinary and sectoral backgrounds, who get involved in transversal work structures to which they are not accustomed. Moreover, citizens are themselves safety actors as their way of life, choice of transport modes and behaviour affect the traffic situation and road crash occurrence. Therefore, the organization of road safety management needs to establish, not only inter-sectoral links, but also channels for consultation and dialogue with the citizens.

In the following chapter, road safety management processes, components of road safety policies, the actors involved, and the requirements for organization are reviewed. The findings are from empirical work and observations carried out in low- and middle-income countries in Africa and Asia as well as in OECD countries and from the European research project DaCoTA (2010–2013, Thomas et al 2013).

21.2 ROAD SAFETY POLICY-MAKING

Based on management research (Dunn 1981), developing road safety policies can be described as a cycle in which:

- *Agenda setting* is identifying road safety as a major (social, economic, health) problem in the country or region; if the facts don't talk by themselves, advocacy and communication policies are needed, based on objective data . . . and often personal involvement of particularly motivated citizens or professionals.

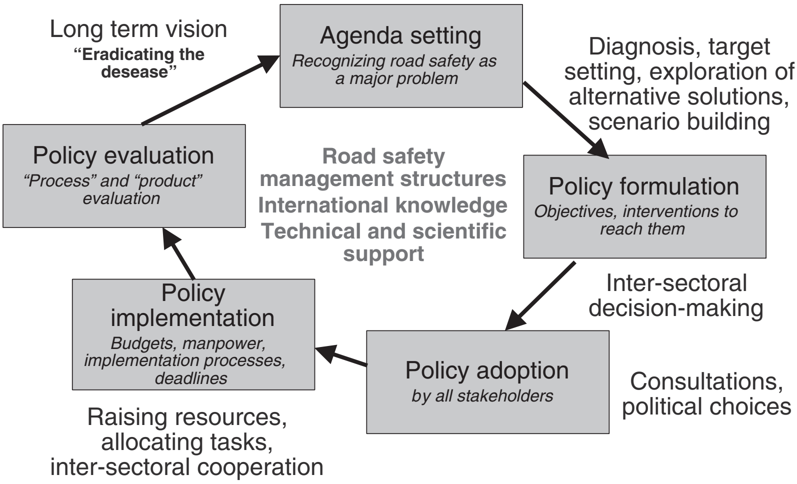

Figure 21.1 Policy-making cycle (based on DaCoTA, Muhlrad et al 2011).

- *Policy formulation* is the selection of objectives to reduce the problem, and of appropriate strategies and interventions to reach these objectives; in good practice, all known alternatives should be considered and their potential effects compared, which requires up-to-date knowledge of the problems at hand and possible solutions as well as technical and science-based studies.
- *Policy adoption* is the appropriation by the stakeholders involved of all elements of the policy; this step involves agreement at the higher levels of decision making, and also consultations to ensure that citizens, as major stakeholders, accept and support the policy; possible obstacles to policy implementation (social, financial, legal, managerial, etc.) need to be tackled at this stage.
- *Policy implementation* is putting into use all the interventions planned in the policy; budgets have to be found and the necessary manpower mobilized; deadlines must ensure that interventions are implemented in time for objectives to be met.
- *Policy evaluation* includes two types of activities: monitoring implementation to check that it is working according to plan and is likely to reach the objectives while there is still time for improvement and control of undesired side effects ("process evaluation"); checking after implementation that objectives are met and quantifying the effect and act of the global policy and of specific interventions ("product evaluation"). Evaluation also requires objective science-based studies (Muhlrad et al 2011).

Evaluation leads to a new assessment of the road safety situation and stimulates further action, provided a long term view has been adopted (gradually "eradicating the disease" represented by fatalities and serious injuries from road crashes).

Figure 21.1 shows the policy-making cycle and indicates some of the activities and requirements involved.

21.3 COMPONENTS OF ROAD SAFETY POLICIES

The components of road safety policies are the outcome of policy formulation and policy adoption which will govern implementation. "Good practice" as defined by experts, researched in European projects and adopted by WHO and the World Bank, implies that the following components are

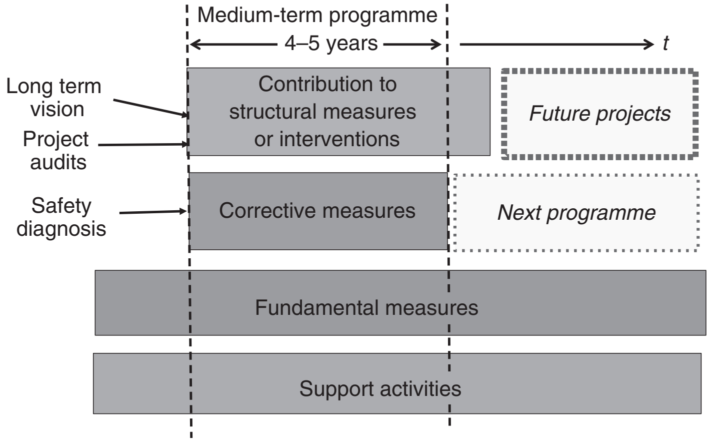

Figure 21.2 Components of a medium-term road safety programme.

produced and adopted (Bliss and Breen 2009; Muhlrad et al 2011; Muhlrad 2005, 2009; OECD 1984, 2002, 2008):

1. A *long term vision* which should ensure that the road safety effort is sustained in order to obtain a continuing reduction of fatalities and serious injuries generated by road crashes (keeping road safety on the political agenda, even after successful action programmes and regardless of the political changes in governments). It is often useful to get the Vision voted in Parliament so that it becomes law.
2. A medium term *strategy* which creates the framework in which successive road safety intervention programmes will be designed and implemented. The strategy is needed for capacity building and may include some policy orientations, principles for involving all relevant stakeholders (managers of the road transport system and road users), a process for building up a technical and scientific support system, financial resources, a road safety management structure and evaluation capabilities.
3. Short-to-medium term (four to five years) *quantitative targets* of road crash injury reduction which will be used to calibrate the road safety effort, justify allocation of the necessary resources, and act as a reference to assess the implementation process and evaluate the effects of interventions. The target may be global or allocated to complementary objectives. Targets have to be realistic but nevertheless ambitious to trigger substantial action.
4. A *road safety programme* coordinating all interventions planned to meet the target(s) over a period of four to five years. The programme usually includes several types of multi-sectoral interventions or “packages of measures” as well as support activities and capacity building (Fig. 21.2):

   – *corrective measures* or interventions are aimed at eliminating some crash and injury factors in the transport system so that particular types of road crashes which occurred in the past do not repeat in the future or, at least, occur less frequently. Such measures include, for instance reducing speeds, re-designing dangerous locations, developing assistance to road victims, etc. Corrective measures are based on a thorough diagnosis of characteristics, patterns and causation processes of road crash injuries and their effects directly contribute to meeting the quantitative target set for the programme.
   – *Fundamental measures* or interventions are meant to make the road transport system function smoothly and should thus support and enhance all other safety measures. Fundamental interventions include, for instance, road safety education from childhood to driver licensing (and beyond), updating the Highway Code to take into account the safety of all road users, enacting regulations on the working conditions of professional

drivers, etc. Such interventions involve step-by-step development, and the current steps need to mobilize some of the resources of the safety programme although it will take much longer for their effects on road crash occurrences to be felt. It is to be noted that a programme that would be based only on such measures as education or safety campaigns cannot be expected to reach any ambitious medium-term targets.

– *structural measures* or interventions are aimed at developing or renovating the road transport system so that it is made as safe as possible and will remain so (fewer corrective measures should thus be needed in the future). Structural interventions include, for instance, safety requirements for urban transport plans, systematic rehabilitation of key sections of the road infrastructure according to safety criteria, incentives to switch from private modes (cars, motorcycles) to safer public transport modes, etc. Structural interventions respond to a long term vision and imply that road safety is taken into account as a major objective in broader-scoped plans. Although implementation of such plans call for resources and timespan separate from those of the safety programme, some human resources and study capabilities have to be devoted to these activities and accounted for.
– Some *support activities* have to be funded in the programme as they are absolutely necessary to plan, design and implement interventions although they do not directly contribute to reducing the road crash problem. They include data gathering and treatment, building up study and research capacities, training key decision-making or implementation actors, etc.

5. A *funding mechanism* ensuring multi-annual financing of the action programme and support activities. In most countries, funding through the national Treasury is annual, so some special planning will be required. In countries where the national or regional budgets do not allow for hardware interventions such as road infrastructure rehabilitation or correction, funding can often be found from broader-scoped projects, but only interventions limited in time and implemented once for all (such as blackspot treatment, for example) can be financed that way; a specific mechanism to collect and allocate funding on a sustainable basis will have to be set up in order to implement fundamental measures, support activities and any intervention to be repeated in time (Muhlrad 2005).
6. *Setting up implementation conditions* to ensure that human, technical and financial resources are available when needed, a training plan is ready to enable implementation personnel to perform their respective tasks, and the time schedule is clear so that the effects of corrective interventions can meet the targets in time.

21.4 A REPRESENTATION OF ROAD SAFETY MANAGEMENT

In order to analyze the current situation of road safety management in a country, region, city, etc. and to build up capacities, it is necessary to get an overview of a road safety management system as it should exist for the policy-making cycle. The system must allow for pre-conditions to develop (Methorst et al 2010) and for the necessary *management processes* to take place (Muhlrad et al 2011).

Pre-conditions have been identified as political will, which leads to putting road safety on the political agenda, and a safety culture shared by the citizens, which leads to a favourable climate towards somewhat constraining road safety interventions. *Awareness raising* directed at politicians and decision-makers and at the road users is a necessary process to reach the pre-conditions.

Policy formulation consists in selecting and coordinating packages of measures addressing all components of the transport system (infrastructure, transport and traffic systems, vehicles, road user characteristics and behaviour); it is thus a multi-sectoral technical task which should not

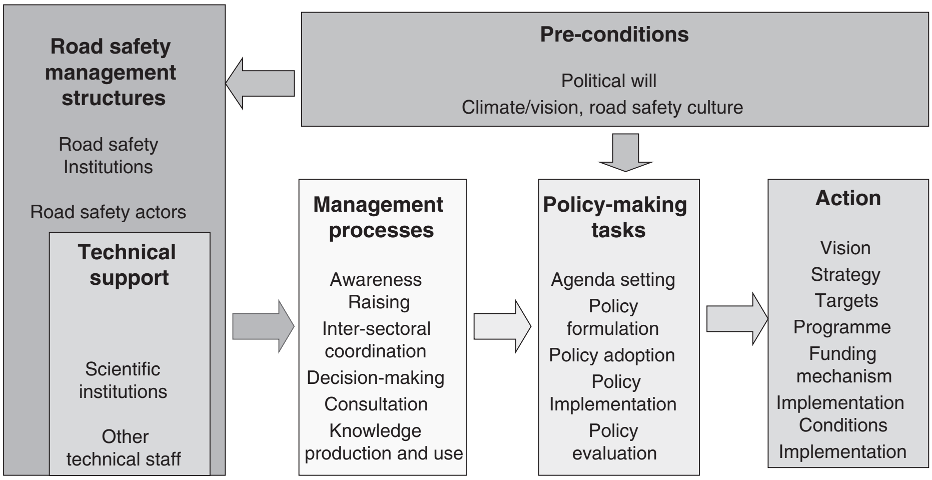

Figure 21.3 A representation of road safety management systems (from DaCoTA, 2011).

involve politicians. To formulate road safety policies, some form of *inter-sectoral decision-making coordination* is required between actors at the technical or operational level.

To ensure that policy-formulation is science-based, a *multi-disciplinary technical and scientific support* is needed to gather relevant data and the necessary knowledge from all available sources, and to study the underlying choices. Similarly, the scientific support will contribute to policy evaluation as sound methodologies and objective studies are required to produce valid and useful evaluation results. Evaluation results and experience from policy formulation, adoption and implementation are a source of new knowledge which the scientific support may later disseminate: thus, a process of *knowledge use and production* is interwoven with the decision-making processes.

Policy adoption involves mostly politicians who make the final choices; however, politicians rely on the technical and operational actors who produced, and have to defend, the policy scenarios, and are somewhat limited by potential political, legal, financial, social or technical obstacles (feasibility of interventions, competition of road safety and other policies, political opposition, professional organizations and lobbies, goodwill and participation of the road users, operational costs). As road safety policy is multi-sectoral, some form of *inter-sectoral decision-making coordination* is needed, this time at the political (government, Parliament) level. In order to neutralize potential obstacles before they paralyse political decision-making, *consultation processes* need to take place, setting up communication channels between decision-makers and the lobbies and representatives of civil society.

Road safety management structures need to be set up to facilitate all the management processes (awareness raising, inter-sectoral coordination, consultation, decision-making, knowledge production and use). The World Bank also advocates the designation of a *lead road safety agency* at least to start the policy-making cycle (Bliss and Bree 2009). European research however indicates that the concept of a lead agency tends to become irrelevant once the inter-sectoral structures have been created and truly represent road safety at the country level (Papadimitriou et al 2012).

Figure 21.3 summarizes this representation of road safety management systems.

21.5 GEOGRAPHICAL LEVELS OF ROAD SAFETY MANAGEMENT

In most countries, road safety management has to start at the national (or federal) level, first because it is a democratic responsibility, and second because some road safety measures can only be taken at that level (at least legislation and part of road infrastructure improvement). Moreover, large-scale transport, urban, health or education projects with a bearing on road safety, are usually directly negotiated between national (federal) governments and international financial institutions. Finally, national government may provide strong incentives to involve other actors in the policy-making process.

However, the national level is not sufficient. From the political viewpoint, regional or local elected bodies also have a responsibility for the safety of their citizens. From the operational viewpoint, some data (on road crashes and injuries, on traffic, etc.) may be more easily available at the local level than at a higher aggregated one; characteristics of road safety problems may differ between different areas or regions according to geographical conditions (terrain, weather), levels of economic development, ways of life of the population, and past activities of the local authorities to improve safety; local actors and citizens are more directly affected by the consequences of road crashes and may thus be more easily mobilized to work on improving the situation; finally, local sponsors may contribute to finding the necessary funds.

Any road safety effort carried out in a country contributes to reducing the global burden of road crashes. Thus, national targeted road safety policies need to encompass all interventions carried at the national, regional or local levels. Some form of *geographical decision-making coordination* is thus needed in addition to the technical and political inter-sectoral coordination processes already introduced.

Geographical coordination may work in two ways (Muhlrad and Wittink 2005):

– *top-down*: policies are formulated and adopted at the national (federal) level and involve regional and local authorities and stakeholders, either through incentives, or through directives, or by allocating sub-targets of crash injury reduction to regional or local authorities and territories. The national budget allocated to road safety should logically contribute to funding interventions at all levels as they are centrally decided.
– *bottom-up*: road safety programmes formulated and adopted at the regional and local levels are summed up at the national level and complemented with country-wide measures to constitute the national policy; scientific, technical and operational support may be provided by national institutions to local stakeholders as their interventions contribute to the national effort.

The choice between top-down and bottom-up approaches depends on countries' political and social organizations. The two approaches are not exclusive and can be combined (Figure 21.4).

At another level, countries are also often part of broader political or economic organizations such as the European Union, UEMOA in Western Africa, OECD, etc. These organizations can also play a part in enhancing national road safety policies by lobbying for road safety, providing a typical management framework, global regional targets of road crash reduction, incentives though benchmarking, and technical support (international data, gathering of international knowledge, methodologies, training tools, research, etc.) (Muhlrad and Adolehoumé 2000; see also the website of the European Road Safety Observatory, http://ec.europa.eu/transport/wcm/road_safety/erso/index-2.html). Quantitative targets, comparing country performances through road safety indicators, providing syntheses of knowledge on key road safety topics, and funding research projects have proved to be efficient tools in boosting national road safety efforts, particularly in Europe over the last decade.

21.6 THE ACTORS (OR STAKEHOLDERS) INVOLVED

To develop a road safety management system, an overview of all stakeholders involved is essential. Road safety actors or stakeholders may be described according to their social role (public or private), their activity sector, their level of intervention (decision, design, operations, research),

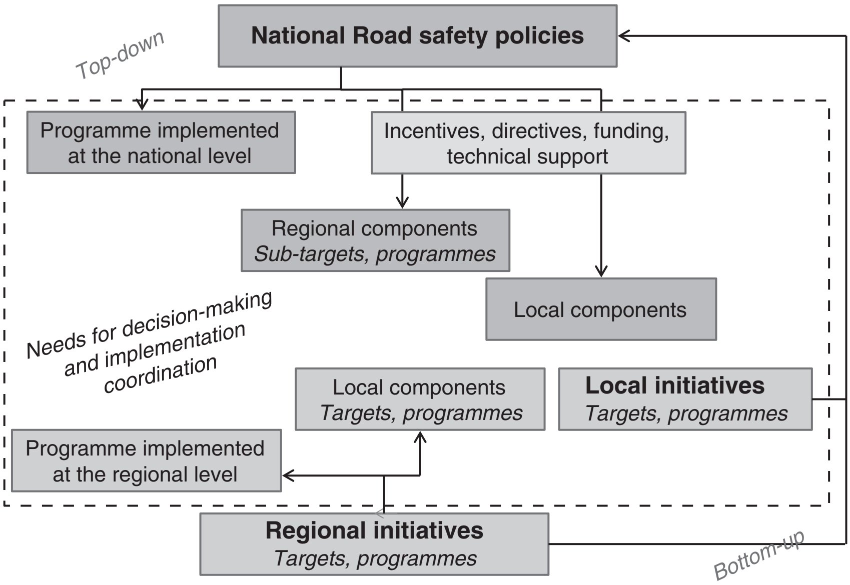

Figure 21.4 Road safety management, from national to local level.

and their geographical level of action. A true picture of stakeholders is thus multi-dimensional (Muhlrad 2006, 2009). Only a simplified description can be given here.

21.6.1 Public actors

Public actors are either politicians (Heads of State and of regional and local authorities, elected representatives, government ministers) involved in policy-adoption, or practitioners and researchers involved in policy formulation, implementation and evaluation. Most public actors, at all geographical levels, operate within the government hierarchy in which one can identify:

- the pilot-sectors for road safety, which participate in the design and structuring of the road and transport system and make it work: road infrastructure, urban planning, transport management, vehicle and traffic regulations, safety laws, enforcement and justice, civil protection;
- the sectors that contribute to road safety by raising awareness, developing a safety culture, providing knowledge or otherwise providing smoother functioning of the existing road and transport system: public education, road-user information, public health, emergency rescue systems, research, professional education and training.

The organization of these sectors into ministries, departments, or services may vary from country to country. Some sectors, such as health or education, are sometimes decentralized at the regional level with no operational presence at the national level. Academic and scientific organizations that may provide scientific support are usually not directly part of governments. The key public actors or stakeholders are thus to be identified in each country prior to setting up inter-sectoral decision-making and operational coordinations.

21.6.2 Private actors

Non-governmental actors, at the national, regional, and local levels, may participate in the road safety effort, either because they represent components of the transport system submitted and reacting to road safety interventions (associations of road users, of urban residents, unions of transport operators, of professional drivers, of teachers, etc.), or because of the economic or humanitarian interests they may have in road safety improvement (insurance companies, vehicle manufacturers, medical associations, human rights associations, associations of families of road crash victims, religious institutions etc.). At the local level, local firms employing a large number of people or generating heavy traffic may often be induced to join in (industries, commercial centres, etc.).

Active participation of non-governmental organizations and other private actors may work through direct involvement in policy formulation, implementation and evaluation, and/or through sponsoring specific interventions. Some of the private stakeholders will actually lobby against proposed road safety interventions when they think they hurt their particular interest.

Inter-sectoral decision-making coordination at the operational level may include the key private stakeholders and thus facilitate dialogue between private and public actors at all relevant stages of the policy-making cycle. When this is not found feasible, consultation processes should be set up, so that expressions of interest or opposition can be worked upon as early as possible.

21.7 DEVELOPING THE ROAD SAFETY MANAGEMENT SYSTEM

Developing a road safety management structure that by-passes the usual hierarchical organization of public policies is not an easy feat because it introduces changes in the public actors' working practice and conditions, in financing processes, and in decision-making patterns. The legal framework may also have to be adapted. Capacity building in road safety management is thus a step-by-step process. Any step has to be absolutely necessary, so a preliminary diagnosis of the current institutional situation identifying the obvious obstacles to effective road safety policy-making is needed before defining any changes.

21.7.1 Institutional diagnosis (or "institutional analysis")

Performing an institutional diagnosis involves identifying the key persons whose position and background enables them to have access to factual information on road safety management and interviewing them to get the information. The diagnosis usually starts at the national (federal) level, and has to include investigations of institutional relationships with the regional and local levels if any. Similar diagnoses may be carried out at the regional or local level, according to country characteristics and the particular purpose of capacity building (for example, when developing road safety policies in a large city).

The institutional diagnosis is guided by our representation of road safety management systems (Fig. 21.3) and includes:

- identification of all the stakeholders (persons and/or structures) involved, their level of intervention (decision-making, policy development, implementation, research and studies), and the part they play or may play in road safety policy-making;
- identification of the existing structures representing road safety at the national level and providing inter-sectoral coordination and consultation capabilities; identification of the links with similar structures at other geographical levels;
- identification of the the technical support or institutions that may play that role and of research resources;
- review of the basic support tools for road safety such as they are (data bases, periodical statistics, traffic counts, access to international knowledge, etc.).
- identification of funding procedures for different kinds of road safety interventions (corrective, fundamental) and for technical and scientific support;

- review of current and recent road safety policies (strategy, targets, programme, interventions) and identification of the possible design, decision-making or implementation problems encountered;
- review of evaluation processes and of knowledge production;
- assessment of the needs for training and providing methodological support to current active stakeholders.

Extensive interview guidelines have been designed (Adolehoume et al 2003; Bliss and Breen 2009; Muhlrad 2005, 2009). The European DaCoTA project also defined a questionnaire which can be filled in by key stakeholders (Muhlrad et al 2011); however, it has been found that such a questionnaire is easy only for practitioners well acquainted with road safety management systems, so that guidance may prove necessary to fill it in; moreover, complementary interviews are always needed to clarify some points of the organization. Direct interviews cannot be avoided!

Findings of the institutional diagnosis (feasibility of management processes, redundancy of some tasks or functions, etc.) determine the needs for building or improving road safety management structures and making them sustainable, and for enhancing road safety management capacities.

21.7.2 Building up road safety management structures

In the first cycles of policy-making, when no specific road safety structure yet exists, the first process to consider is *agenda setting.* Making road safety an issue for politicians and high-level decision-makers is essential for resources to be found to perform the other processes. The highest possible level is the President (or otherwise Head of State); at least the Prime Minister (or otherwise Head of government) should be involved. It is thus logical to set up a high level inter-sectoral decision-making structure under the President or Prime Minister (for example, an Inter-Ministerial Road Safety Committee, IMRSC) whose role will be to impulse, orientate and formally adopt a long-term vision, a strategy, global interventions programmes and resource allocation.

Actors at the inter-ministerial level cannot be expected to get into the technical details of policy-formulation. The next step is thus to provide an enabling structure at a less political and more professional level of decision-making where studies can be undertaken or commissioned and technical or science-based choices can be made. A lead agency well suited to inter-sectoral dialogue can be designated; ministries of Transport are most often selected for the task, ministries of Health have sometimes played that role. The lead agency is logically the head of the inter-sectoral decision-making structure to be set up at this operational level, which we can refer to, for practical purposes, as the Inter-sectoral Road Safety Board (IRSB). In some cases, it has been found that, once properly set up, the IRSB itself could collectively play the part of lead agency.

IRSB usually needs to have a legal existence to be able to commission studies, allocate resources to policy-formulation and, later, allocate resources to implementation. It is to be remembered that IRSB has to work from knowledge and objective facts and must therefore develop a collective expertise. Moreover, it must be a stable institution provided with sustainable resources. Thus, when creating the structure, a number of requirements, based on empirical experience, have to be taken into account (Muhlrad 2005, 2009); in particular:

- IRSB should include high level-representatives of all the sectors involved in road safety policies, for taking operational decisions and seeing them implemented in their respective administrations;
- IRSB members should be personally appointed, and delegated from their administrations, for a given period of time (at least that of a road safety programme) so as to ensure continuity in decision-making and make it possible for a learning process to take place;

– membership in the IRSB involves allocation of working time which must be recognized in individual work conditions and future professional careers;
– IRSB must be able to rely on a sustainable budget covering every day running costs, funding of studies (diagnosis, evaluation, policy formulation), basic tools (data bases, access to knowledge), communication on IRSB activities and results, road safety training of key actors;
– IRSB must be able to commission the necessary studies for policy-making and to use the working force in the sectors represented as needed;
– IRSB must also be empowered to direct adequate resources towards implementation of the road safety policy, once it has been formally adopted.

Appropriate communication channels need to be established between IRSB and IMRSC: The broad lines of the policy adopted at high political level feeds detailed policy formulation under the umbrella of IRSB; conversely, the targets and programme scenarios developed feed political decision-making and have to be argued and defended. A small-size Road Safety Secretariat is usually found useful to provide communication channels, monitor the policy-making process, and organize meetings of IMRSC and between IMRSC and IRSB as appropriate. The most effective organization of the Secretariat has to be found according to country conditions; it is logically placed within the lead agency, when there is one.

At the same time as the IRSB is created, a technical/scientific support structure should be built up to perform the studies necessary to policy formulation and evaluation, provide organized access to relevant international knowledge, and disseminate the knowledge produced at home through experience and evaluation. Multi-disciplinary human resources can generally be found in universities or other educational institutions (professors, researchers), from the administrative sectors (engineers, computer scientists, etc.), sometimes from local or international consultants. Without extracting them from their respective institutions, it is advisable to organize these technicians and scientists into a formal transversal structure (let's call it Road Safety Study Team, RSST) to ensure sustainable inter-disciplinary work, availability, and access to appropriate tools and equipment. Tasks and funding processes have to be defined to ensure that the team gets appropriate road safety information and training and does not dissolve between two successive cycles of policy-making. To facilitate funding processes, it may be practical to formalize the RSST as a consultancy firm.

With its scientific support, IRSB should become a strong enough institution to be acknowledged as representing road safety policies and collective knowledge in negotiations of larger-scale projects, so as to be able to introduce road safety structural measures and interventions and obtain some medium-term resource allocation. An effective inter-sectoral structure working out science-based choices should wield more power than a simple technical ministry formally designated as a lead agency which seldom gets access to discussions with international financial organizations (Adolehoume et al 2003).

Once a road safety programme has been adopted, interventions have to be implemented by all the sectors involved in road safety. As some interventions include complementary measures of different nature (for instance, law, communication and enforcement, or infrastructure, communication and enforcement, or education and communication, etc.), inter-sectoral communication is also necessary at this level. Based on past experience in some industrialized countries (in particular New Zealand), the World Bank and OECD have recommended that a third-level inter-sectoral structure should be in place (Bliss and Breen 2009, OECD 2008). However, this has often seemed to add too much complexity to the system. If it meets the practical requirements stated before, IRSB should be able to allocate tasks, impulse implementation in the sectors involved,and monitor their progress.

Similar road safety structures, obviously smaller in size as the scope of local interventions is limited, may be created at the regional and/or local levels. Institutional links or communication channels should be set up between the national and other geographical levels to provide the types

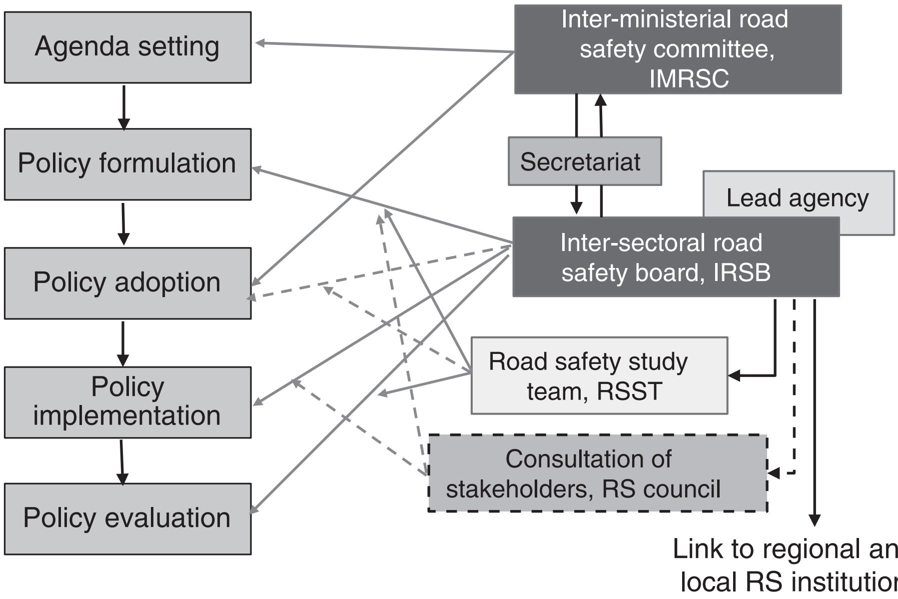

Figure 21.5 Building up road safety management structures.

of exchanges (targets, directives, incentives, funding, monitoring, etc.) determined by top-down or bottom-up approaches.

In policy formulation and implementation, c*onsultation of non-governmental stakeholders* is a particularly useful management process when the civil society is highly pro-active through NGO's and/or some powerful lobbies operate against some key road safety interventions. Some countries have established specific advisory structures gathering public and private stakeholders where discussions and negotiations can take place to improve acceptability of key interventions or propose alternate solutions. Consulting professional organizations (of transport owners, drivers, of teachers, of health personnel, etc.), which are easily identified and often have a good knowledge of the safety or operational problems to solve, can however be performed under the umbrella of the IRSB, even if the specific advisory structure has not been created.

It is to be noted that IRSB is a decision-making institution, integrated in the administrative chain of decision-making. No advisory structure set up as a non-governmental institution (often called the "National Road Safety Council" in some countries) can perform multi-sectoral policy formulation and be sure that the product of their work will even be considered for adoption, far less for implementation: this kind of set-up is only fit to consult or mobilize stakeholders. However, in order to provide the inter-sectoral institution with independent funding, some countries choose to set it up as a Road Safety Agency, outside the administrative system but governed by a board representing all the sectors involved. This may work if the political will is strong enough and the Agency develops unique expertise, but there is a risk of marginalization (leaving the Agency to deal with the interventions that do not fit well into the routine of regular ministries or departments, such as road safety campaigns (Muhlrad, Adolehoume et al 2000)).

21.8 CAPACITY BUILDING

Capacity building includes at least three areas: enhancing the skills and knowledge of road safety stakeholders, developing support tools and equipment, and setting up funding procedures for all stages of road safety management. Capacity building supports all processes in policy formulation, implementation and evaluation and should therefore be a task performed under IRSB.

21.8.1 Training

New structures can work only if the people manning them fully understand their tasks and have the knowledge and abilities to undertake them. Key actors in the road safety management system may be recruited from totally different areas of activity. Moreover, the turnover is often high. It is therefore important to periodically investigate training needs (road safety basic knowledge, management processes and methodologies) among the stakeholders, to identify priorities and to design a training plan accordingly. Once set up, the scientific support structure, RSST, may be called in to organize training sessions and programmes.

Similarly, RSST may work out information or training programmes for private stakeholders and the citizens, based on a variety of media, and so contribute to disseminating a broader road safety culture.

21.8.2 Developing basic tools and equipment

The first support tools to develop are of course data bases of road crashes and injuries, but each measure or intervention requires specific methodological tools and equipment. To identify the needs, operational definitions of the interventions adopted have to be worked out by the appropriate implementation specialists. An investment plan can then be drawn up, including short- and long-term needs for funding.

21.8.3 Funding

The need for a funding mechanism has already been underlined. Policy-making tasks and processes, programmes, support tools, research and studies, training, all require financing. However, there are two kinds of funding needs (Muhlrad 2005):

- Some activities or interventions occur only once and over a limited period of time: for example, corrective infrastructure measures, setting up a data base, developing a teaching programme and material, etc. These activities require only short-time funding.
- other activities of interventions are developed over a long period of time, must be sustained, or must be periodically repeated; for example, up-grading the road safety infrastructure, maintaining a database, routine road traffic education based on a programme initially developed, performing road safety studies, etc. Such activities require *sustainable* funding.

There are many sources for one-time only, short-term funding. Large-scale transport, infrastructure, urban, education, health projects negotiated with international financial organizations often include a percentage budget to allocate to road safety, and part of it can be harnessed to implementing suitable elements of a national programme or strategy.

Sustainable funding may be obtained from the government budget if political will and road safety culture are very strong. Most often, other sources of funding have to be found. Referring to environmental policies, the principle according to which "polluters should be payers" can also apply to road safety: the motorized road users without whom no injury crashes would occur should contribute to financing road safety. Thus, logical sources of funds may, for instance, be taxes on petroleum products, on driver licenses, on vehicle registration, or a percentage part on profits from road tolls or vehicle inspection. Harnessing these kinds of funds to road safety management can be done through a specific Road Safety Fund, endowed with a governing board representing all sectors involved. Procedures to allocate funds to all the relevant road safety management and implementation tasks have then to be defined. Where the inter-sectoral road safety institution has been created as an independent Agency, funds can be directly fed to the Agency's budget.

Some countries have developed a Road Maintenance Fund on the same lines as the Road Safety Fund suggested above. Such a road fund is likely to drain most of the resources that could have been devoted to road safety, but its statutes may be revised to encompass funding of at least some road safety tasks and interventions.

21.9 CONCLUSION

Road safety management is complex . . . but it can be done! Creating institutions where necessary, step by step and according to countries' government and administrative specificities, learning from experience and periodical institutional analyses, generating skills and expertise, leads to substantial progress in road safety delivery. Conversely, the author knows of no country where a safe system approach and effective multi-annual road safety programmes have been implemented without any road safety institutions to by-pass the hierarchical government structure.

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CHAPTER 22

Road Safety Law and Policy

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CONTENTS

ABSTRACT

More than one-and-a-quarter-million people have been killed in road accidents in India over the last decade. Road safety in India needs a coordinated, crisis-level response. But the response of the central government and the state governments is incremental at best. This chapter examines the problem of road safety in India from a law and policy perspective. We look at the legislative and policy response to the road safety crisis, examine the existing and proposed traffic safety policies and enabling legislation, summarize the attempts to update legislation and how such attempts have not made much progress, and end by looking at the attempts by the High Courts and the Supreme Court of India to fill the road safety gap left by the apparent abdication of responsibility by the legislature and executive.

Key Words: Road safety law and policy; litigation to enhance road safety; legislative and policy response for road safety

22.1 INTRODUCTION: ROAD SAFETY IN INDIA – THE PROBLEM AND ITS CONTEXT

In 2011, nearly 150,000 people were killed in India, and more than 500,000 were injured in motor vehicle accidents (MoRTH 2011).

The numbers of people killed in road accidents in India have increased at about eight per cent annually over the last ten years. Cyclists and pedestrians account for about half of all road fatalities. Two-wheeler riders account for another quarter of the fatalities.

There are many reasons for this "silent tsunami on Indian roads." Researchers have identified the following primary causes:

- Poorly designed and maintained roads and footpaths
- Little to no provision for safe accessibility to non-motorized traffic and pedestrians
- Unsafe vehicles
- Mix of high-speed motorized traffic and vulnerable road users
- Drunk driving
- Rudimentary accident investigation
- Unresponsive road-related systems

TABLE 22.1 Road accidents and fatalities in India.

Number of Accidents and Number of Persons Involved: 2002 to 2011					
	Number of Accidents		Number of Persons		
Year	Total	Fatal (%)	Killed	Injured	Accident Severity*
2002	4,07,497	73,650 (18.1)	84,674	4,08,711	20.8
2003	4,06,726	73,589 (18.1)	85,998	4,35,122	21.1
2004	4,29,910	79,357 (18.5)	92,618	4,64,521	21.5
2005	4,39,255	83,491 (19.0)	94,968	4,65,282	21.6
2006	4,60,920	93,917 (20.4)	1,05,749	4,96,481	22.9
2007	4,79,216	1,01,161 (21.1)	1,14,444	5,13,340	23.9
2008	4,84,704	1,06,591 (22.0)	1,19,860	5,23,193	24.7
2009	4,86,384	1,10,993 (22.8)	1,25,660	5,15,458	25.8
2010	4,99,628	1,19,558 (23.9)	1,34,513	5,27,512	26.9
2011	4,97,686	1,21,618 (24.4)	1,42,485	5,11,394	28.6

*Accident Severity: No. of Persons Killed per 100 Accidents.

Source: National Crime Records Bureau, Delhi. Table presentation format from MoRTH presentation to UNESCAP.

22.1.1 The myth of driver error

Note that "driver error" is not on the list of primary causes above. Unless one labels the very act of driving a motor vehicle an error, claiming that driver error is the leading cause of road accidents is an easy way out for policy makers and concerned state agencies, since this deflects the responsibility from their own failure to address the real causes identified above.[1]

Projecting driver error as a major cause of road accidents also lets automotive manufacturers off the hook for poor design. As Professor Carol MacLennan pointed out nearly 30 years ago, "for 40 years, automotive manufacturers had successfully promoted the view that they were responsible agents, while drivers were irresponsible and unskilled (MacLennan 1988)."

Safety research from around the world suggests that road and street design influences driver and pedestrian behaviour very significantly. In other words, what gets labelled as driver error or carelessness on the part of pedestrians is often the result of behaviors induced by road design. For instance, designing and building a high-speed expressway induces high-speed driving – irrespective of the posted speed limit. Building a highway through populated rural and peri-urban areas with no provisions for pedestrians to cross safely will result in pedestrian fatalities, as is the case all over India. Building straight, wide boulevards in urban areas will result in high speed crashes and pedestrian fatalities. Building hard curbs on highway and expressway medians will result in tyres rubbing against the median at high-speed with the result being tyre bursts and flip-over crashes – a clear case of design error rather than "driver error" or "poor maintenance," as is listed in crash reports so often.

22.1.2 Road safety needs a multi-dimensional approach

As noted by the Sundar Committee (2007), road safety is a multidimensional issue which "incorporates the development and management of road infrastructure, provision of safer vehicles, legislation and law enforcement, mobility planning, provision of health and hospital services, child safety, urban land use planning, etc., . . . [and] is a shared, multi-sectoral, responsibility of the government and a range of civil society stakeholders. The success of road safety strategies in all countries depends upon a broad base of support and common action from all stakeholders."

Road safety in India needs a coordinated, crisis-level response. But the response of the Centre and the States is incremental at best. Interviews with officials, analyses of statements by politicians and various stakeholders during the debates leading up to the drafting of MVA 2012, and news media reports around the road safety issue suggest that strong measures to promote road safety are not opposed by anyone in principle (Agrawal et al 2013). But there is no political will to bring in change, since road safety is not seen as an electoral issue. As such, political parties in India do not take road safety seriously, and road safety has not moved from the sidelines as a political and policy concern for any major political party. Political parties have no history of championing road safety at a national or state level, although individual leaders have expressed an interest in road safety at various times.

Despite bringing forward initiatives at a high level to integrate road safety in the urban planning and development process, through the Ministry of Urban Development (MoUD), and to look at road safety as a public health concern through the Ministry of Health and Family Welfare (MHFW), governments at the national and state levels do not make much of an effort to make effective changes in policy or modify/update legislation to enhance road safety. Of course, there is a flurry of activity when there are high profile fatalities, most recently the rush to draft and present the Road Transport and Safety Bill 2014, which resulted from the outcry following

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[1] The Ministry of Road Transport and Highways, MoRTH, claims that 75% of accidents are due to driver error. Save Life Foundation, perhaps the most prominent and influential NGO focused on road safety in India, claims without any evidence that "bad road user behavior" is a leading cause of "India's exceptionally high number of [road] crashes."

the deaths of two high-profile politicians in quick succession early in 2014,[2] but no structural changes in policy are implemented, or even proposed.

A second major part of the problem is that responsibility for road safety in India is diffused. There is no single agency to deal with the wide range of issues related to road safety. Instead, there are a plethora of organisations dealing with various aspects related to transportation such as creation of infrastructure, urban planning, traffic law enforcement, highway development, public health, and insurance, among others. There is no effective mechanism for coordinating the activities of different agencies and organizations.

A third major contributor to the problem is that agencies lack skilled professionals dedicated to road safety. Professor Dinesh Mohan points out in a recent article that a reason "why it has been impossible to set evidence-based road and vehicle safety standards in India is that the Government does not have domain experts with technical knowledge of issues at hand along with information about international developments (Mohan 2015)." Policy makers in government do not identify research issues keeping in view the conditions in India, and research is also not being funded adequately at either the central or state level. Although expert committees are appointed by Parliament from time to time, they are often staffed and controlled by administrators with no domain-specific expertise. There is no effort to create permanent expertise in the form of research groups who can support the working committees. "In the absence of permanent expertise, the authorities will continue to function based on the 'intuitions and common sense' of the non-specialist committee members. This has proven detrimental to improving safety in the country in the last 60 years" (Tiwari 2014).

22.2 LEGISLATIVE AND POLICY (NON) RESPONSE

The existing law and policy debate on road safety in India is centered on three things:

- Fixing liability – based on "rash or negligent" acts, an ingredient in all of the relevant sections of the Indian Penal Code (IPC)
- Enhancing penalties
- Creating additional offences

There is no move towards changing vehicle or infrastructure design to enhance transport safety, leave alone pedestrian safety. The existing statutory and policy regime also does not provide a mechanism to incorporate research results into a coherent safety policy framework.

22.2.1 Creating a lead road safety agency

On January 13, 2005, with a view to identifying the policies and interventions that are necessary for promoting road safety, the Cabinet Committee on Infrastructure (CoI), chaired by the Prime Minister, directed the Ministry of Road Transport and Highways (MoRTH) to present a note to the Empowered Committee of Secretaries under the chairmanship of the Cabinet Secretary for the creation of a *Directorate of Road Safety and Traffic Management* and the amendment of traffic laws as required. As part of this effort, in late 2005, MoRTH constituted an Expert Committee under the Chairmanship of Mr. S. Sundar, Distinguished Fellow, The Energy and Resources Institute (TERI), and former Secretary of the then Ministry of Surface Transport,

[2]Gopinath Munde, a senior leader of the Bharatiya Janata Party (BJP), and newly appointed Union Minister of Rural Development, died in a road accident in New Delhi on June 3, 2014. Shobha Nagi Reddy, a senior YSR Congress leader, died in a road accident in Andhra Pradesh on April 24, 2014.

Government of India. This *Committee on Road Safety and Traffic Management*, hereinafter the "Sundar Committee 2005," was given two responsibilities:

1. Study what new laws or amendments to existing laws would be required
2. Recommend a structure for the proposed Directorate of Road Safety and Traffic Management and advise on its role and functions

After extensive consultations, the *Sundar Committee 2005* submitted its report to MoRTH in February 2007, which then held consultations with various stakeholders and State Governments and placed the report before the CoI in its meeting held on December 5, 2007. The Empowered Committee of Secretaries approved the recommendations contained in the report on April 20, 2009.

Some of the key observations in the Sundar Committee's report are that:

- Existing institutions are not equipped to deal with increasing traffic on the roads
- Key ministries and public sector agencies play a peripheral role in improving road safety
- Road safety is not a priority in the development agenda of the state and central governments
- The existing National Road Safety Council does not have adequate statutory backing, budgetary resources or the mandate to be effective
- India must adopt the advancements made globally in road safety techniques and technology

The Sundar Committee also appended a draft of a law to its report, calling it the *National Road Safety and Traffic Management Act*. The stated purpose of this act is to:

> [P]rovide for the establishment of National and State level Road Safety and Traffic Management Boards for the purpose of orderly development, regulation, promotion and optimization of modern and effective road safety and traffic management systems and practices including improved safety standards in road design, construction, operation and maintenance, and production and maintenance of mechanically propelled vehicles and matters connected therewith or incidental thereto.

Following the acceptance of the Sundar Committee report by the Empowered Committee of Secretaries, the MoRTH prepared and submitted the *National Road Safety and Traffic Management Board Bill, 2010* (NRSTM Bill). The government introduced the Bill in the Lok Sabha on May 4, 2010. This bill had some crucial changes from that recommended by the Sundar Committee. Two of the most critical were that the Bill restricted the scope of the proposed law to just the national level by removing the words "and State," and further restricted the scope of the bill to just the national highways – less than 2% of India's roads.

The NRSTM Bill was referred to the Standing Committee on Transport, Tourism & Culture, which heard the views of MoRTH and some experts as well as some stakeholders. The Standing Committee recommended that there was no need for the bill, in its report presented to the Rajya Sabha and the Lok Sabha on July 21, 2010. The primary objections of the Standing Committee to the NRSTM Bill were that there was no need for Road Safety Boards as the Motor Vehicles Act already provides for Road Safety Councils at both the Central and State levels, and that independent Road Safety Boards will duplicate the efforts of existing bodies, whereas the need, in the Standing Committee's view, was for "strengthening the existing mechanism and making it effective, rather than creating another one."

The Standing Committee's objections to the creation of Traffic Safety Boards are invalid, as summarized in the table 22.2 below.

22.3 TRAFFIC SAFETY POLICIES AND ENABLING LEGISLATION

> More people die of road accidents than by most diseases, so much so [that] the Indian highways are among the top killers of the country. ... Indian Transport is acquiring

TABLE 22.2 Existing Road Safety Councils versus Traffic Safety Boards proposed by the Sundar Committee in 2007.

Existing Road Safety Councils	**Proposed Traffic Safety Boards**
Purely advisory bodies with no statutory authority	Statutory authority to set standards
Not staffed by experts	Staffed by domain experts with technical knowledge of issues at hand along with information about international developments
Not independent as they are headed by the Ministers, and as such, are part of the Government	Independent
Mandate that is confined to motor vehicles only and they do not cover the various aspects of road safety	Will address all issues relating to road safety – data, roads, vehicles, emergency care, enforcement, education, research, etc.

> a menacing reputation which makes travel a tryst with Death. It looks as if traffic regulations are virtually dead and police checking mostly absent. By these processes of lawlessness, public roads are now lurking death traps. The State must rise to the gravity of the situation and provide road safety measures through active police presence beyond frozen indifference, . . ., and rigorous vehicle invigilation, lest human life should hardly have a chance for highway use. (Ratan Singh vs State of Punjab, 1979 SCC (4) 719)

Not much has changed since the Supreme Court of India made the above observation nearly 40 years ago. India still has no specific road safety legislation, at either the national or the state level. The Motor Vehicles Act of 1988 (MVA) is the principal legislation by which road transport, and by extension, road safety, is regulated in India. Even when the MVA does regulate road safety, it does so by imposing nominal monetary fines, or by deferring the punishment to the criminal justice system.

The Central Motor Vehicle Rules (CMVR), 1989, the enabling rules for MVA 1988, define specific offences and punishments, with nominal monetary fines for offences which do not involve personal or property injury such as violation of traffic rules or violation of motor vehicle registration and maintenance requirements. The following provisions of the Indian Penal Code (IPC) cover situations when motor vehicles are involved in an incident resulting in bodily harm:

- Section 279 – *Rash driving or riding on a public way*
- Section 304A – *Causing death by negligence*
- Section 336 – *Act endangering life or personal safety of others*
- Section 337 – *Causing hurt by act endangering life or personal safety of others*
- Section 338 – *Causing grievous hurt by act endangering life or personal safety of others*

All but one of these, Section 279, are general criminal statutes.

22.3.1 Primary legislation – Motor Vehicles Act of 1988

The Motor Vehicles Act of 1988 came into force on July 1, 1989, replacing the Motor Vehicles Act, 1939, which was no longer considered relevant to contemporary requirements. MVA 1988 consolidated and rationalised various laws regulating road transport. In order to keep the law relevant to changing technology and transport patterns, MVA 1988 has been thrice amended – in 1994, 2000, and 2001. These amendments did not make any substantive changes to MVA 1988.

22.3.2 Legislative domain of control

The Constitution of India divides the legislative domain into three parts: the State list, the Union list and the Concurrent list. As the names suggest, the first two are lists of subjects in which the state and the central governments hold exclusive powers. The third is a list of subjects on which the state and the central government hold joint power. Transport, and by extension road safety, is a state subject in India. Although one would expect that all associated aspects of transport, such as infrastructure and vehicles which use this infrastructure, would be considered state subjects, this is not the case. For instance, "mechanically propelled vehicles" are on the concurrent list. Ports, shipping, inland waterways, are all on the concurrent list. Air transport is on the union list. This results in a situation where the Central government has little to no direct control over state transport laws and policies, or over their implementation, except for setting the motor vehicles rules through the Central Motor Vehicles Rules (CMVR), 1989, and road standards through the Indian Roads Congress (IRC).[3]

22.3.3 Legislative process

Any new legislative act has to be proposed as a bill, either by the government or by a member of the opposition, in both houses of Parliament. Each house votes on the bill and if it gets a simple majority of votes, it is sent to the President of India, the nominal head of the government. Once the President signs the bill, it is notified in the *Gazette of India*, and becomes law. In the case of a government-sponsored bill, the Union Cabinet, headed by the Prime Minister, first votes on the bill and after reaching a consensus, the concerned minister proposes the bill in Parliament by formally tabling it in both houses.

22.3.3.1 Parliamentary committees

Given the extent and diversity of parliamentary work, a good deal of its business is transacted by what are called the Parliamentary Committees. These are of two types: Ad hoc Committees and Standing Committees. Ad hoc Committees are appointed for a specific purpose and they cease to exist when they finish the task assigned to them and submit their report. The principal Ad hoc Committees are the Select and Joint Committees on Bills. Apart from the Ad hoc Committees, each House of Parliament has several Standing Committees. The *Department-Related Parliamentary Standing Committee on Transport, Tourism and Culture* is the standing committee responsible for all motor vehicle, road and transport safety issues.

The *Committee on Road Safety and Traffic Management*, usually referred to as the Sundar Committee, was an ad-hoc committee constituted in November 2005 with the express purpose of exploring options regarding Road Safety and to make recommendations about changes to the Motor Vehicle Act. Similarly, ad-hoc expert committees are also created so as to both give focused attention to the issue at hand, and to create legitimacy in the Parliament for specific legislative goals.

22.3.4 Attempts to update legislation

22.3.4.1 Motor Vehicles (Amendment) Bill 2007

Nearly 20 years after MVA 1988 came into effect, the Motor Vehicles (Amendment) Bill, 2007, was introduced in Parliament, seeking to make major amendments to MVA 1988. The Motor Vehicles (Amendment) Bill, 2007 (hereinafter, "MVA Bill 2007") is a private member bill, proposed by Dr. Raman Senthil, a medical doctor, and at that time a Lok Sabha MP for PMK, a regional party active in Tamil Nadu. The MVA Bill 2007 was introduced in the Rajya Sabha on May 15, 2007.

[3]It is worth noting here that the Standards promulgated by the IRC do not have any statutory authority, and so are not mandatory for either the National or State Highways, or for any other road.

MVA Bill 2007 was in partial response to the rising chorus of voices to update MVA 1988 to make road safety a priority. As Mr. M. S. Upadhye, a former Additional Commissioner of Police (Traffic) for Delhi and Head of Security, Delhi Metro Rail Corporation, points out in an interview: "A Road Traffic Act is the need of the hour. The present system does not look at who is at fault but ... assumes that the victim [in a road accident] is innocent," and that the "Act was more oriented towards motor vehicles, and did not cover the entire range of road users in India ... [T]he present fine of Rs. 100, applicable for most road offences, is hardly a deterrent and needs to be increased."

Amendments relevant to road safety as proposed by MVA Bill 2007 may be classified into five broad categories: (i) enhancement of penalties wherever considered necessary, for violation of the provisions of the MVA 1988 with a view to ensure road safety and discipline, (ii) provide for civil penalty in addition to the existing criminal liability, (iii) devolving greater powers to state governments to regulate road transport, (iv) streamlining provisions dealing with the payment of compensation to road accident victims, and (v) prescribing a time bound process for disposal of appeals.

The MVA Bill 2007 was forwarded to the Department–Related Parliamentary Standing Committee on Transport, Tourism & Culture. The Standing Committee tabled its report on 28 April 2008. An Expert Committee was constituted in September 2008 by MoRTH, again under the Chairmanship of S. Sundar. The terms of reference of the Expert Committee were to "[r]eview the provisions of the Act [MVA 1988] in a comprehensive manner and to make appropriate recommendations for amendments in the Act," and "[s]tudy the contemporary Act of the leading Asian countries like China, Japan, etc., and make suggestions to adopt best practices as could be suitable for the country." The Sundar Committee submitted its report in January 2011.

22.3.4.2 Motor Vehicles (Amendment) Bill 2012

The government prepared a modified version of the MVA Bill 2007 in late 2011. This modified version was called the Motor Vehicles (Amendment) Bill 2012. It was approved by the Union Cabinet on March 1, 2012, and presented to Parliament on May 8, 2012 by the then highways minister, Mr. C.P. Joshi.

The MVA Bill 2012 was passed by the Rajya Sabha on May 9, 2012. The Bill languished in the Lok Sabha for two years and lapsed when the Fifteenth Lok Sabha was dissolved for the 2014 elections.

22.3.4.3 Road Transport and Safety Bill 2014

Presented by the Modi government in early September 2014, the draft Road Transport and Safety Bill 2014 (Draft RTSB) is the first piece of legislation in India which has road safety as its focus. This proposed legislation is deeply flawed on many grounds. Three of the most problematic issues are briefly discussed next from a policy perspective.

22.3.4.4 Flawed policy approach

The Draft RTSB reflects, in many ways, the deeply flawed policy approach towards road safety in India. Although the Bill resulted from an explicit declaration by the new NDA government within the first week of its tenure that road safety was one of its highest policy priorities, and appears to be comprehensive in that it includes provisions for different aspects of transport and safety – strengthening institutional mechanisms, ensuring safety of vulnerable road users, addressing the issue of infrastructure design, and inter-modal connectivity – it will not actually do any of this.

First, the Draft RTSB is poorly written – a hodge-podge of legislation copied from different countries. In Professor Mohan's words: "[A] hasty cut and paste job . . . done by many people, some of whom may not be privy to the complexities of the subject (Mohan 2014)."

Second, the Draft RTSB continues to see road safety as a "driver behavior" issue, and proposes dramatic increases in penalties without any thought given to the likely impact, strict licensing procedures, and driver training. As discussed in Section 1.1 above, this notion deflects attention from the real causes of unsafe roads. Take the issue of increased penalties, as Professor Tiwari notes:

> The notion of enhanced penalties as a deterrent is based on the premise that drivers are basically careless and do not care about traffic laws. Hence, the increased penalties and fines supposedly deter them from breaking laws. On the other hand, there is every possibility that drivers who actually break laws will not stop to pay fines and law enforcers may not report cases. Drivers may find it easier to "settle" the case for much smaller amount (Tiwari 2014).

Third, the Draft RTSB does not address the critical problem of the lack of skilled professionals dedicated to road safety in the public agencies and standard-making bodies. Instead, the Draft RTSB includes the setting up of three new authorities: Motor Vehicle Regulation & Road Safety Authority of India (MVR), National Road Transport and Multi-Modal Co-ordination Authority (NRT), and a Highway Traffic Regulation and Protection Force (HTRPF). Unfortunately, too many responsibilities and duties have been mixed up for the MVR and NRT. The MVR is responsible for setting safety standards and managing the driving license and vehicle registrations system in the country. Professor Mohan points out that:

> As a matter of principle, a standards-making authority (MVR) with responsibility for research and data analysis should not be in the business of testing and policing since it is likely to get corrupted and come under undesirable pressures for conformity. The NRT is given the responsibility for managing public and goods transport in [the] country, including monitoring of BRT and urban transport issues in a very centralized manner. The authorities are expected to work by appointing temporary committees for each topic. This will not work at all since our current experience suggests that working by committees results in half-baked recommendations (Mohan 2014).

A professional agency such as the MVR or the NRT "must have its own cadre of professional employees working under similar contracts as agencies like the Council of Scientific and Industrial Research. This is essential, as standard-making bodies must make recommendations, enact policies or support legislation ensuring that the measures are proven effective and backed by sound research."

22.3.5 Roadblocks to policy and rule framing

While building political consensus to pass the various pieces of legislation identified and discussed in the preceding sections, it is also extremely important to work towards the actual framing of rules and policy related to the implementation of road safety. This latter falls in the domain of administration. A number of government departments and agencies at the central level are currently involved in road safety related governance. But the power to frame road safety policy and rules is located formally in the state governments. The enforcement agencies, as well as the departments and agencies that have an interest in promoting road safety are also part of the individual state administrations and there is very little coordination between the different states. In the present configuration, states have very little interest, motivation, or organizational infrastructure to promote road safety across state lines. Actors with the highest levels of

TABLE 22.3 Stakeholder Mapping – Policy and Rule Making.

Stakeholder	**Power**	**Interest**
Ministry of Road Transport and Highways	High	Moderate
Ministry of Urban Development (MoUD)	High	Moderate
State Traffic police	Moderate Traffic police have very little power in making rules and framing policy. They are an agency that is primarily involved in enforcement. However, from time to time, the police commissioners do invoke special powers to impose certain conditions of behavior at certain places and at certain times.	Moderate Decreased accident rates, and traffic rule violations can improve the image of the traffic police as they are seen as primarily responsible for safety of the citizens.
Ministry of Health and Family Welfare (MHFW)	Moderate	Moderate
Civil Society Organizations	Low	High

interest in formulating and promoting measures to improve road safety on a nationwide scale, the MoRTH, the Ministry of Urban Development (MoUD), the Ministry of Health and Family Welfare (MHFW), and civil society organizations, do not have the statutory authority to make or shape policy and rules at the state level. For instance, although MoRTH did establish a Road Safety Cell in 2011, there has been no concerted movement to establish the Road Safety and Traffic Management Boards at the national and state levels as recommended by the Sundar Committee in 2007. Table 22.3 provides an overview of the stakeholder mapping for policy and rule making.

22.4 ROAD SAFETY AND THE COURTS

22.4.1 Road safety in rulings by the Supreme Court of India

Road safety as a stand-alone litigable matter generally does not make its way to the Supreme Court of India. The Court has rarely issued a ruling on road safety per se, but has sometimes made observations about issues relating to road safety in very strong language, expressing its dismay about the government's apparent lack of focus on road safety. Unfortunately, in almost all such cases, this expression of dismay occurs in dicta along with rulings on appeals from criminal convictions in lower courts for various offences related to road accidents or violations of the Motor Vehicles Act and related rules.

22.4.1.1 Rulings which say nothing about safety

The State Of Uttar Pradesh vs Bansraj (And Connected Appeal), 1959 AIR 79, 1959 SCR Supl. (1) 153. The Court ruled that drivers of motor vehicles are equally liable as the owner of the vehicle for use contrary to the conditions of the vehicle permit *State Of Haryana vs Darshana Devi & Ors*, 1979 AIR 855, 1979 SCR (3) 184. Ruling ordering faster and free access to courts, and adequate compensation for poor and indigent victims of road accidents.

22.4.1.2 Rulings which say something about safety

Ratan Singh vs State Of Punjab, 1979 SCC (4) 719. The case came to the Court on appeal by a truck driver who had been convicted of the criminal offence of causing death by rash and negligent driving. While denying the appeal and affirming the driver's sentence, more than half of the Court's short judgment (less than a thousand words) was an expression of distress on the state of road safety in India. Among other observations, the Court said the following:

> More people die of road accidents than by most diseases, so much so the Indian highways are among the top killers of the country. What with frequent complaints of the State's misfeasance in the maintenance of roads in good trim, ***the absence of public interest litigation to call state transport to order, and the lack of citizens' tort consciousness***, and what with the neglect in legislating into law no-fault liability and the induction on the roads of heavy duty vehicles beyond the capabilities of the highways system, Indian Transport is acquiring a menacing reputation which makes travel a tryst with Death. It looks as if traffic regulations are virtually dead and police checking mostly absent. By these processes of lawlessness, public roads are now lurking death traps. ***The State must rise to the gravity of the situation*** and provide road safety measures through active police presence beyond frozen indifference, through mobilisation of popular organisations in the field of road safety, frightening publicity for gruesome accidents, and promotion of strict driving licensing and rigorous vehicle invigilation, lest human life should hardly have a chance for highway use. (Emphasis added.)

22.4.1.3 Important indirect ruling on road safety

Chairman, R.S.R.T.C. & Anr. vs Santosh & Ors., Judgment dated 10 May 2013, Special Leave Petition (C) No. 3265 of 2012 (2013). The Court ruled on what constitutes a Motor Vehicle such that it falls within the purview of the MVA and so can be regulated. This ruling outlawed all *Jugaad* vehicles everywhere in India, but enforcement to date is negligible. Even within the NCR, farm vehicles such as tractors are routinely used as transport vehicles, hauling trailers filled with goods and people on public roads, including high-speed highways.

22.4.1.4 Rulings which directly address road safety

M.C. Mehta vs U.O.I. (1997) 8 SCC 770 and M.C. Mehta vs U.O.I. (1998) 1 SCC 676 (Writ Petition (Civil) 13029 of 1985). Also called the MC Mehta road safety case, this case resulted in landmark rulings to enhance road safety in a series of connected judgments in 1997–98. The case was initiated by a PIL field by M.C. Mehta in 1985, asking for:

> Proper management and control of the traffic in the National Capital Region (NCR) and the National Capital Territory (NCT), Delhi to ensure the maximum possible safeguards which are necessary for public safety

The Court found that the existing law had adequate provisions, "which, ***if properly enforced***, would take care of the immediate problem and to a great extent eliminate the reasons which are the cause of the road accidents in NCR and NCT, Delhi." (Emphasis added.) The Court also noted that it was the inaction of the Executive which had resulted in the road safety "menace" continuing to grow. The Supreme Court established a new principle in Indian jurisprudence by equating the right to be safe on the roads with the right to life. The Court noted that public safety on the roads is "within the ambit of Article 21 of the Constitution [,]" and so implicates the right to life. The Court explicitly overrode objections filed by transporters, claiming that the ruling would negatively impact their livelihoods, by ruling that the right to be safe on the roads takes precedence over the Article 19 (1) (g) right "to practise any profession, or to carry on any occupation, trade or business."

Common Cause (A Regd. Society) vs. Union of India & Ors. This ruling resulted from a writ petition filed in 2003 by Common Cause, asking the court to order the government to establish Road Safety Committees, improve medical facilities, including "having readily available ambulances," improve road safety education, improve infrastructure, and make enforcement effective through enactment of a Road Traffic Safety Act.

The Court dismissed the petition in April 2008. The ruling itself was short, but the 2-judge bench went on at length about why courts should stick to *applying* the law and not get into *making* law or *making* policy. The Court noted that "the Motor Vehicles Act is a comprehensive enactment on the subject ... [and] that the relief sought for in this Writ Petition is adequately taken care of by the Motor Vehicles Act itself and ***if there are lacuna or defect [in the Act], it is [up to] the legislature to correct it by amending the Act and not the Court***" (Emphasis added).

S. Rajaseekaran vs. Union of India & Ors. (2014) 6 SCC 36. This case arose from a PIL asking the Supreme Court to order the government to effectively implement and enforce the MVA to reduce the number of Fatal Traffic Accidents in India. In an unusual move, noting that since 98% of India's road network lies within the jurisdiction of the states, the Court impleaded all the States as party respondents. In its judgment dated April 22, 2014, the Court directed "the Government of each State to effectively implement and enforce all the provisions of the [Motor Vehicles] Act in respect of which the States have the authority and obligation to so act under the Constitution in addition to the tasks specifically alluded to in the ... present order." Some key elements of this ruling cover safety devices such as seatbelts and helmets. The Court ruled that "there should be no exemption for wearing helmets (such as the exemptions in favour of women in some States)," and that "seatbelts should be compulsory for driver and front-seat passenger. On national highways, seatbelts should be compulsory for back-seat passengers, too."

The Court said that it will continuously monitor implementation of its order to make the states accountable for any inaction or lapse. It directed the state [and local] governments to ensure the "strict enforcement of traffic violations, since every traffic violation is a potential RTA [road traffic accident]," and that governments must "maintain a minimum number of traffic policemen – as per the road conditions and population – in a region [and] must ensure that such personnel are not diverted for any other reason (such as facilitators, traffic marshalls and guards for political rallies or to provide security for visiting dignitaries)."

22.4.2 Road safety in rulings by the High Courts

Similar to the Supreme Court, road safety as a stand-alone litigable matter generally does not make its way to the High Courts. A majority of High Court rulings addressing road safety issues have been on specific aspects of road safety. Additionally, these rulings are usually limited to a specific metropolitan region. The High Courts appear much less reluctant to step into the policy vacuum.

22.4.2.1 The Blue Line Bus case – Delhi High Court (W. P. (CRL.) 878/2007 and Misc. appeals)

Alarmed by the high number of fatalities being caused by the so-called Blue Line buses in Delhi – 61 fatalities in the first 6 months of 2007 – a Division Bench of the High Court took *suomoto* notice of the havoc being created on the roads of Delhi.[4] Treating the issue of "the persistent threat to life by the Blue Line buses, light commercial vehicles like the vehicles being used by the Call Centres, RTVs and other heavy commercial vehicles like trucks" as being in the Public Interest, the Court issued notice to the NCT of Delhi as well as Ministry of Transport, Government of India and directed the NCT of Delhi to file an affidavit on enforcement of existing

[4] *Court On Its Own Motion vs. State of NCT Of Delhi & Ors.*, W. P. (CRL.) 878/2007 & Misc. appls (collectively referred to in the popular media as the "*Blue Line Case*").

road rules and permitting regulations for commercial vehicles, particularly the Blue Line buses. The Court also asked the government to show "[w]hat action had been taken to ... [enforce] the directions given by the Hon'ble Supreme Court in M.C. Mehta vs. Union of India (1997) 8 SCC 770 and M.C. Mehta vs. Union of India (1998) 1 SCC 676?"

The High Court issued notice to the NCT of Delhi as well as Ministry of Transport, Government of India and directed the NCT of Delhi to file an affidavit on enforcement of existing road rules and permitting regulations for commercial vehicles, particularly the Blue Line buses. The High Court also asked the government of Delhi to show what actions it had taken to enforce the directions given by the Supreme Court in its M.C. Mehta [Road safety case] rulings almost 10 years ago.

Over the next four years, the High Court accepted multiple submissions from the government as well as from various stakeholders and issued multiple writs. In early 2011, the High Court consolidated several issues and delivered a lengthy judgment ordering that:

- All Blue Line buses must be removed from the streets of the NCR (National Capital Region) and NCT of Delhi
- The proposed cluster scheme for public transport buses was valid
- The government must make adequate public transport available within a limited time frame
- Owners and operators of the Blue Line buses claimed that a ban on operations of all Blue Line buses violated their right "*to practice any profession, or to carry on any occupation, trade or business,"* as provided per Article 19 (1) (g) of the Constitution of India
- The *right to life* guaranteed under Article 21 *took precedence* over the rights guaranteed by Article 19 (1) (g) [Relying on the Supreme Court's rulings in the M.C. Mehta road safety case as controlling precedent.]
- "The right under Article 19 (1) (g) would be subject to restrictions, particularly those which protect the right to life and the liberty of citizens to move freely within their city. Article 21 is all pervading in balancing of fundamental rights. The scheme for phasing out of Blue line buses is indeed a scheme directly within the ambit and would enjoy the protection of Article 21 of the Constitution of India."
- "It is settled law that the right to life is the paramount right. It is above all over rights as may be available to a citizen. Correspondingly, it is the paramount duty of the State to protect the life of its citizens, especially from wanton killing by reckless driving of Blue Line buses on the roads of Delhi."
- ***"The fundamental right to life takes precedence over all statutory rights. The right to livelihood of the blue line bus operators, numbering a few hundred, would have to be subservient to the larger public interest of safety to other road users."*** [Emphasis added.]

22.4.2.2 The Roadside Advertisement Hoarding case – Madras High Court

A PIL was filed in 2011 by Coimbatore Consumer Cause (CCC) against advertisements posted on central medians. In its petition, CCC had noted that "[a]ccording to the Ministry of Road Transport and Highways, the Union Government's extant policy[,] and instructions and the Indian Road Congress guidelines, no advertisement was permitted on the highways except signs of public interest." The petitioners had also told the Court that the Union Government had repeatedly sent letters to the Chief Ministers/Chief Secretaries of all the state governments and to its own officials for removal of existing advertisements on all the national highways since such advertisements were a distraction that caused accidents.

CCC had originally filed a PIL before the Supreme Court against the State and Central Governments, but the Supreme Court dismissed the PIL stating that the matter was a state subject and the petitioners should move the Madras High Court. CCC then filed its PIL before the Madras High Court against the District Collector, Highways Secretary and Chief Secretary of Tamil Nadu Government, the National Highway Authority of India, and the Ministry of Road Transport & Highways, Government of India.

The Madras High Court ruled in the petitioner's favor and ordered removal of advertisement hoardings from all central medians within its jurisdiction.

22.4.2.3 *Implementation of Traffic Rules and Regulations – Bombay High Court (PIL No. 18 of 2010)*

In a series of 18 rulings starting in February 2010, the Bombay High Court has taken an active, ongoing role in trying to improve road safety in Bombay. The case was initiated by a PIL filed by the Bombay Bar Association seeking implementation of traffic rules and regulations.[5] The immediate impetus for the PIL was a letter written by Ms. Armin Wandrewala, a member of the Bombay Bar Association, who had written to the Court after a run-in with a traffic police following an errant motorist. In one of the earliest rulings on the case, the Court had directed the joint commissioner of police (traffic) to set up sub-committees headed by the zonal deputy commissioner of the police to select and recommend repairs/modifications/upgrades at pedestrian crossings at more than 500 roadway junctions. In its ruling of June 23, 2011, the Court directed that more sub-committees be appointed at the police station level for "expeditious redressal of 'micro grievances' of pedestrians as well as motorists in the city."

At a later stage, the Court further directed the state government to permit "utilisation of funds collected for traffic violation for the purpose of the traffic department including generation and service of notice upon traffic violators and any other measures which may be necessary for more efficient and effective enforcement of the traffic rules."

In another interim ruling on March 13, 2013, the High Court directed that road signs and road markings must be improved, with priority given to "zebra crossing, stop line, arrow, yellow box, and no parking boxes."

The Court is actively monitoring compliance with its various orders.

22.4.3 So are courts any use in enhancing road safety?

Historically, almost all road safety-related litigation in the Indian courts is in the form of Public Interest Litigation (PIL). PILs can be a double-edged sword, particularly in the Supreme Court of India if the justices see the PIL as asking them to "give directions of a legislative or executive nature" since the contemporary Court generally does not consider such matters a legitimate judicial function. This concern is particularly well illustrated in the Court's ruling on the Common Cause PIL (*see* Section 4.14). This PIL was not only unsuccessful in that the Court saw the petitioners as attempting to use PILs as a policy tool and so denied the petition, but Justice Markandey Katju, the junior justice on the 2-judge bench which heard the case, also took the opportunity to express his strong displeasure with what he saw as an abuse of the PIL process. Justice Katju's ruling effectively negated the Court's earlier judgment in the MC Mehta road safety case (*see* Section 4.14) – a judgment which had had a narrower scope and which had led to changes in government policy resulting in increased road safety, at least in the National Capital Territory (NCT) of Delhi. This ruling effectively also undermines various high court judgments on road safety which relied on M.C. Mehta, including the Delhi High Court's judgments in the Blue Line bus cases. Although the Common Cause ruling is by a 2-judge bench, and so can theoretically be overruled by a larger bench, the Supreme Court has not done so to date. And it appears very likely that it will not do so lightly.

[5] *Bombay Bar Association & Anr. vs. The State of Maharashtra & Ors.*, Public Interest Litigation No. 18 of 2010, In the High Court of Judicature at Bombay, Ordinary Original Civil Jurisdiction.

It is also important to remember that since road safety is a state subject in India, and each state designs road safety policies that it considers best for its conditions, a PIL in the Supreme Court is likely to have unintended consequences if the petitioner asks the court to give directions to the government on broad road safety policies, and obtains a favorable ruling, which ruling would then apply throughout India.

A final point to keep in mind is that a PIL is not private litigation in that the petitioner is given standing in the larger public interest, and not for a personal grievance, and as such, the petitioner cannot withdraw the case if the proceedings turn unfavorable. Additionally, a PIL of necessity looks for sweeping changes, or if not sweeping, then at least on a broad canvas. This makes PILs a risky tool, particularly in the Supreme Court in that a broad negative ruling from the Supreme Court will cut off access to possible litigation strategies which may be developed to enhance road safety by incremental changes.

None of this is to say that a PIL-based strategy does not still have value as a tool in India for enhancing road safety. It does. As the cases summarized in Section 4 illustrate, a PIL has a fair likelihood of success in a state High Court, but only if the petitioners focus on aspects of road safety for which the laws are already on the books – helmet laws, drinking and driving, seat belt use, and speed limits –, but a state is not doing what it is supposed to do, that is, enforce the law.

22.5 CONCLUSION

Road safety policies and enabling legislation in India need a radical rethink. The existing law and policy debate in the mainstream has not moved away from treating all road accidents as 'rash or negligent' acts such that sections of the criminal code become applicable. This is a road to nowhere as far as road safety is concerned. For the situation to improve, the focus of road safety legislation and policies needs to move away from fixing liability, enhancing penalties, and creating additional offences. India needs to move towards changing vehicle and infrastructure design to enhance transport safety, particularly for the vulnerable road users such as pedestrians and non-motorized transport users who overwhelmingly pay the price for unsafe roads.

The higher judiciary in India has made many attempts over the last 50-plus years to bridge the road safety chasm left by the legislature and the executive, but without a strong, parallel legislative response, judicial efforts are a band-aid at best. The courts are, understandably, also reluctant to step onto legislative and executive turf. Litigation to enhance road safety still has value as a tool. Courts are willing to evaluate the constitutionality of existing laws and policy, but will likely not respond favourably if a litigant asks for directions to the government on road safety policies, or for amendments in the law, or for directions to the government regarding desired legislation. On the other hand, if the litigation is narrowly tailored to address specific aspects of road safety, and the petitioners make a convincing argument that unsafe roads have a negative impact on a fundamental constitutional right, and so any 'intrusion' on the functions of the legislature and the executive is justified, then the courts are much more likely to consider the issue favorably

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Pre-Hospital Care of the Injured

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CONTENTS

ABSTRACT

Worldwide, injuries have become a major cause of morbidity and mortality. Early care of the injured can help reduce the disability from injuries. Emergency trauma care has become a major specialty in most major hospitals. However, there is wide gap in the access and availability of care for the injured until he reaches a hospital. Pre-hospital care of the injured has evolved significantly over the years and has almost become synonymous with advances in Ambulance based transportation of the injured. Several technical interventions are done from the site of the injury until the patient reaches a definitive care facility. Many of these have been adopted as consensus based interventions and not really based on evidence based medicine. Research in this area has been challenging because of the multiplicity of agencies involved, the urgent nature of the problem with the randomization of multiple tasks done in the pre-hospital setting, and changes from traditional protocols are difficult, not only for research but also for ethical reasons. However, looking at the issues that are controversial there is a need to do serious research on outcome studies in this area. By and large, it seems in urban areas where access to care is easier and possible in less than an hour, we do not need to do too much other than safely transporting the patient to a definitive care facility. This chapter looks at some of the components of pre-hospital care, and discusses some of the key areas of controversy.

Key Words: Ambulance, Pre-hospital care; ATLS; BLS; AIS; ISS; CPR

23.1 INTRODUCTION

Injury is best prevented; however, not all injuries can be prevented. As in any disease, care of the injured must begin soon after injury, but since most injuries happen in the world, away from where this care can be given, there is a need to take the care to the injured or take the injured to the caregiver. Over the last fifty or sixty years, this process of taking care to the injured and getting the injured to a care giving facility has evolved. While it should be a continuum of care from injury to recovery, for administrative and logistical purposes this is divided temporally into what is done before the patient reaches the hospital and what is done after the patient reaches the hospital. Pre-hospital care of the injured has developed on its own and also in tandem with developments in hospital care of the injured. Many of the interventions were done empirically while some were based on understanding of the physiology of the injured. The processes and the science of emergency care of the injured are still evolving. Recent wars in the Middle East and other conflict areas have brought us a new set of understanding on the injured patient. This review looks at the some of the established systems and current understanding and controversies in the emergency care of the injured.

23.1.1 Injury severity

The outcome of injury depends on the extent of the injury. The extent of injury is dependent on the amount of energy transferred to the tissues. The more acute the transfer of energy, the more severe the injury and the poorer the outcome. While there are ways of assessing the energy transferred to the patient by investigating the place where the injury happened and the mechanism of injury, (which is a separate science by itself) these are beyond the domains of this article. Neither the health care worker nor the emergency care provider in the pre-hospital or hospital setting is competent to do this. However, it is important to know as much as possible to prognosticate the outcome of the injury. Abbreviated Injury Scoring (AIS) was one of the earliest scoring systems that attempted an anatomical scoring of injuries to different anatomical parts of the body. The AIS© is an anatomically based, consensus derived, global severity scoring system that classifies an individual injury by body region, according to its relative severity on a 5 point scale. The current version is AIS© 2005 Update 2008 (Gennarelli and Wodzin 2008). Injury Severity Scoring (ISS) and the New Injury Severity Score (NISS) attempted to look at the impact of injury to multiple regions of the body on the outcome (Baker and O'Neill 1976; Osler, Baker, and Long 1997). Both these are important to compare outcomes of injuries in different communities and regions. But data collection and record keeping has been an issue in many settings around the world, because often there are a multiplicity of agencies involved (Fire, Police, Health Care Technicians, Paramedics and also many times, bystanders), a multiplicity of tasks involved, and the emergency nature of all that is done. The lack of empirical data on the benefit of many pre-hospital care interventions is a serious problem (Sasser 2006). The World Health Organisation in Geneva proposed a collaboration to identify core strategies, equipment, supplies, and organizational structures needed to create an effective and adaptable pre-hospital care system for injured person worldwide (Mock et al 2005).

To improve the predictability of outcomes after injury, several physiological parameters have been included like the pulse, blood pressure, respiratory rate and others. However, these are time dependent variables and are difficult to gather in a field setting. The Trauma and Injury Severity Score (TRISS) uses a weighted combination of patient age, ISS, and Revised Trauma Score (RTS) where RTS is calculated from the Systolic Blood Pressure (SBP), Respiratory Rate (RR) and the Glasgow Coma Scale (Schluter 2010). Similarly other scales have tried to include co-morbidities that may influence outcomes in the Acute Physiology and Chronic Health Evaluation (APACHE II).

23.1.2 Injury outcome

Trauma patients have tissue damage from acute exposure to energy. The outcome depends on the severity and the part of the body that is injured. Over 50% of deaths in the early period results from traumatic brain injury. The next most common cause of death is bleeding. Trunkey described the classic trimodal pattern of death from trauma where 50% of the deaths occur within the first hour, 30% of the deaths occur within 1 hour to 1 week, while 20% of deaths occur later (Trunkey 1983). Recent studies on this trimodal pattern from mature trauma systems seem to challenge this pattern. In a study in New Zealand, Pang et al (2008) found there was a skew towards early deaths. The trimodal distribution of trauma deaths was not demonstrated in this group of patients. Other workers also found the absence of a typical trimodal pattern (de Knegt, Meylaerts, and Leenen 2008; Demetriades et al 2005). But for the sake of convenience most trauma systems follow this in planning.

Pre-hospital care evolved as a specialty to care for the injured from the time of injury until he reaches a hospital. Time is critical to all the activities in trauma care. This is because the consequences of energy transfer take time to evolve. Bleeding itself, when uncontrolled, leads to a series of physiological changes that eventually leads to multi-organ failure, tissue hypoxia and eventually death. The conventional ABC of resuscitation priorities, the establishment of a clear Airway for breathing, enabling of Breathing, and maintenance of Circulation by controlling bleeding and management of the physiology of circulation. Over the years several interventions have been recommended and practiced to improve the outcome of trauma. Ambulances have become the key carriers of technology and intervention to the roadside patient, even as the patient is transported to a hospital. Protocols have been developed to ensure uniform care patterns and to ensure quality. These include Advanced Trauma Life Support (ATLS), Pre-hospital Trauma Life Support (PHTLS), Advanced Life Support (ALS), and Basic Life Support (BLS). Many of these protocols are consensus based. Increasingly, components of these protocols are being challenged as audits and reviews on what works and what does not are done.

23.1.3 ABC of resuscitation

23.1.3.1 Airway

Oxygenation of the blood in the lungs can be done only if fresh air is circulated through the lungs. For air to reach the lungs the passage from the nose/mouth to the throat and then to the larynx and wind pipe must be clear. In a trauma patient these may be blocked by blood from head injury or facio-maxillary injury, or by a foreign body like a broken tooth or vomitus or at times even by falling back of the tongue. This must be cleared for the air to be breathed in. Clearing of airways is done ‘by sweeping’ fingers across the mouth to remove foreign bodies. This standard basic life support manoeuvre is practiced by emergency medical technicians. In addition, lifting of the chin helps lift the tongue away from blocking the air passage. According to the ATLS protocol, if the patient is not breathing after clearing the airway then insertion of an endotracheal tube may be required. However, endotracheal tube insertion is a technically demanding psychomotor skill that needs training, regular practice, and in many centers around the world the procedure cannot be done without licensing. This is because the intubation may result in the tube being placed in the food pipe rather than the wind pipe (Gerich et al 1998; Pointer 1988; Dickinson 1999). Even in those patients that had correct placement of tubes the survival was low. Design modifications have been done to reduce this risk. Combitube is a specially designed tube that avoids this problem and can be inserted more safely.

A patient seriously injured enough to need endotracheal intubation may end up having hypoxic brain damage within minutes. To get expertise to the patient within a short time is extremely difficult. A more practical solution, to be realistic, is to provide simple chin extension and clearing of airway as training for drivers and bystanders who are likely to be on the road most of the time.

23.1.3.2 Breathing

If after clearing of airway the patient does not breathe, then he will need external support for breathing. In the hospital setting this is done with the help of a ventilator while in the field setting, until recently, the recommendation was to do mouth-to-mouth expired air ventilation. In view of the need to do close lip approximation with the patients' mouth there were a lot of inhibitions in this at the field level. This is further compounded by the risk of infections. Bag valve ventilation is a good alternative; however, this also requires that the technology reach the patient in a short span of time. Recent evidence shows that compressions of the chest, done for cardiac resuscitation produces sufficient negative pressure to allow respiration, provided a clear airway is maintained. This understanding has come only recently (Travers 2010).

23.1.3.3 Circulation

If the patient has no pulse and no heart beat, then cardio-pulmonary resuscitation (CPR) needs to be initiated. Successful resuscitation following cardiac arrest requires an integrated set of coordinated actions. This includes:

- Immediate recognition of cardiac arrest and a call for help which includes the activation of the emergency response system of the area.
- Early CPR with an emphasis on chest compressions
- Rapid defibrillation
- Effective advanced life support
- Integrated post–cardiac arrest care (Travers 2010)

While these are recommendations of the American Heart Association, all this is possible only if a trained person with the required equipment has reached the patient. In the short span of time between a critical injury and cardiac arrest, this may be virtually impossible. While this may be possible in a situation of an angina or an MI patient (Myocardial infarction), in a trauma patient who is exsanguinated with a cardiac arrest the probability of survival is low. In trauma patients the probability of revival after a pre-hospital cardiac arrest is practically nil, unlike in cardiac disease patients. Usually the injury has caused so much of haemorrhage that the oxygen carrying capacity of blood is significantly deranged and the myocardium is unlikely to respond to defibrillation. In one series the overall mortality was 95% (Willis et al 2006). In a series of 130 cases of trauma patients who needed CPR there were no survivors (Rosemurgy 1993). CPR is also a skill that needs an intensive training and re-training.

23.1.4 Control of bleeding

All trauma patients bleed. Some bleed externally with bright red blood, causing alarm in the people around, and panic in the patient. Bleeding may also be internal, with truncal (abdomen and chest) and pelvic injury patients losing huge volumes of blood internally without the patient showing any external blood. In such a situation, patient assessment may be difficult unless the nature of the crash causing the injury is assessed. In high-energy trauma one can anticipate such bleeding and monitor the patient accordingly. At initial monitoring, the patient's blood pressure and pulse may show only mild increase while he may go into shock with no recordable pulse very quickly. So it is important to keep track of the physiological parameters before shifting the patient/transferring the patient.

Traditional understanding of the physiology of bleeding was based on animal experiments where the loss of an increasing volume of blood led to the increased probability of complications liked renal shutdown or shock and cardiac arrest. Replacement of the blood volume led to improvement in survival and reduced complications. This was the basis for IV line placement and IV fluid infusion to patients of trauma. The ATLS 1998 manual recommended the placement of two large bore intravenous lines (IV), and crystalloid solutions may be given. In retrospect, the animal experiment models that were used to arrive at this IV fluid intervention recommendation were flawed models. This was because the experiments did not truly mimic a trauma situation where the closed loop of blood circulation was converted to an open loop and patient continued to lose even when he was being transfused with IV fluids. This could cause masking of the true physiology and/or cause increased loss of blood from artificial maintenance of blood pressure. An alternative model where bleeding was allowed to continue even as the IV fluid was being infused clearly showed higher morbidity and mortality (Kowalenoko 1992; Owens 1995; Okumura 1995).

In normal human physiology whenever the closed loop circulatory system becomes an open loop, the injury patient has compensatory mechanisms that are initiated depending on the volume of blood that was lost. Small volumes cause only a slight increase in heart rate, but as the volume of blood loss increases, the heart rate increases, blood pressure stops, dropping until a point is reached when blood pressure becomes un-recordable. Sensors in the blood circulatory system and the brain convey this message to initiate compensatory mechanisms like redistribution of fluids from outside the circulatory system initiated to restore blood volume, however, as this is been done, the clotting mechanism is initiated and completed the to seal the leaks in blood vessels. The lowered blood pressure ensures that clots that are formed are not washed away by high pressure ahead of blood flow. By infusing intravenous fluids in the pre-hospital setting without controling the bleeding, the normal physiological compensatory mechanisms may be delayed. This may lead to increasing haemorrhage and complications.

Clinical studies (Krausz et al 1992; Bickell 1994) showed better results with delayed resuscitation. Kaweski (1990) also reported no significant difference in resuscitating shock patients with injury severity scores over 25. Krausz et al (1992) found that intravenous access placement failed in 27 per cent of cases, and an average of 10–12 minutes were lost in placement of intravenous cannula. Placement of an intravenous cannula is particularly difficult in a shock patient as all the veins collapse in shock. In children it is difficult even when they are not in shock because the normal calibre of their veins is small.

Cotton et al (2009) in a review, found no level 1 evidence for the volume of fluid to be infused in a trauma patient. There was only level II evidence for keeping the vein open, and with a recommendation that rapid infusion system should not be used. In a review of the 8th edition of the ATLS protocol found in haemorrhagic shock management there is no role of hypertonic saline; persistent infusion of large volumes of fluids in an attempt to achieve a normal BP is not a substitute for control of bleeding (Kortbeek 2008). Balancing the goal of normal organ perfusion with the risk of re-bleeding by accepting a lower than normal BP has been called "Controlled resuscitation" or "Balanced Resuscitation". The 9th edition of the ATLS protocol emphasizes balanced fluid resuscitation instead of aggressive resuscitation (ATLS Subcommittee 2013).

The ideal time to initiate re-resuscitation, the ideal rate for a given patient, the ideal volume for a given injury are all grey areas where no clear understanding is available. Though there are recommendations which are more in the form of consensus statements, as in the ATLS document. In urban settings where pre-hospital times are less than 30–40 minutes, mortality following trauma is not influenced by the pre-hospital administration of intra-venous fluid, but it is related to the severity of underlying injuries. In summary, the overall evidence on the use of intravenous fluids seem to suggest that these may not be useful in the pre-hospital setting where transportation times are less than an hour.

Control of bleeding and prevention of haemorrhagic shock is one of the key goals in a bleeding trauma patient. For a patient who is bleeding externally, direct pressure with gauze, or elevation of the limb are very simple measures that can be taught and practiced by any bystander.

Tourniquets, which were once popular, became unpopular because of gangrene and ischemic loss of limb due to improper use. The pendulum is again swinging in favour of tourniquets because of experience from conflict areas in Iraq and Afghanistan where bleeding from blast injuries to the limb could be reduced by “supervised” use of surgical tourniquets (Beekley, Starnes, and Sebesta 2007).

Internal bleeding is difficult to assess and in a patient with suspected internal bleeding the goal should be to take the patient as soon as possible to a definitive care facility for definitive treatment.

23.1.4.1 Blood transfusion

Replacing blood for blood is ideal; however, it is not possible in the field setting. The risks of blood transfusion have also helped formulate better guidelines for blood transfusion; currently it is neither desirable nor necessary to provide for blood in ambulances. O negative blood has been made available in some special situations in VIP ambulances but it is not recommended on a routine basis. Many countries have protocols on documenting the blood group of drivers on their driver’s licenses and ID cards; while knowing your blood group is useful as a potential donor, it provides you no advantage as a victim of trauma.

23.1.4.2 Pneumatic Anti-Shock Garments (PASG)

PASGs were a military invention in the 1970s. They were like pneumatic trousers that exsanguinated limb blood to re-circulate it to the heart and lung. However, the pneumatic inflation and pressure, especially on injured limbs, caused several complications. Because they work like tourniquets they cannot be used for long periods. They may also increase blood loss, especially in uncontrolled truncal bleeds. They are therefore not recommended and should not be used, but they are still being sold for use in ambulances in low-income countries (Dickinson and Roberts 1999).

23.1.4.3 Triage

The classification of patients according to medical needs and the matching of these patients to available care resources is called triage. The purpose of triage is to ensure that a given patient gets transported to a definitive care facility where skills and technology for managing his injury are available. This avoids unnecessary delay in treatment, and the proper utilization of facilities. In trauma situations where one or two patients are involved, this may not seem so critical. This becomes very important in disaster situations where facilities in hospitals of different levels may be overwhelmed by patients. The ideal triage criteria in any given situation is difficult. In urban situations where ambulances are not available, an informal kind of intuitive triage occurs when a crowd of bystanders decides where to take the patient.

23.1.5 Transportation of the injured patient

Ambulances have become synonymous with patient transport vehicles. Different kinds of ambulances have been designed for transporting patients. Some even have subspecialty designations like Neonatal transport ambulances, ALS ambulances, and BLS ambulances. In high income countries over 90 per cent of patients are transported by ambulances. Whereas, in low-income countries like India and Africa, most patients are transported outside ambulances in taxies, private cars, and police vehicles.

Even in high income countries some of the patients are transported by non-EMS vehicles (Demetriades et al 1996). Interestingly, patients with severe trauma who were transported by private means in this setting were found to have better survival than those transported via the EMS system. Persons without access to a telephone also often use private transport to transfer trauma patients to a trauma centre. Of the 4 per cent of patients transported in private vehicles 50 per cent did not have access to telephone. Among the others, fear of delay and under estimation of the severity of trauma were the other causes (Hammond 1993). In Philadelphia 61 per cent of Police Chiefs indicated that police officers would occasionally (Sinclair and Baker 1991) 'scoop and run' with a critically ill child rather than wait for the emergency medical services to arrive. In a study done in Delhi it was found that ambulances transported only 4 per cent of patients. Of the injured, 51 per cent were transported to the hospital by taxies. Despite the absence of an ambulance, about 53 per cent of these patients were transported within 30 minutes of the injury (Maheshwari 1989). This is comparable with urban ambulance transfer times in high income countries. In a comparative study of trauma mortality patterns, Mock (1998) reported no patients were transported in ambulances to a teaching hospital in Ghana, while over 90 per cent were transported by ambulances in Mexico and Seattle.

23.1.6 Equipment in an ambulance

The ambulance itself may be a simple vehicle with a stretcher or it could be fitted with the most sophisticated equipment for monitoring and providing advanced cardiac life support. Other equipment like suction machines and immobilization devices for limb or spinal immobilization boards, cervical immobilization collars, IV cannullas, oxygen cylinders, bag valve ventilators also form part of ambulance equipment. With improvements in technology defibrillators, mechanical ventilators, and mechanical CPR machines are all getting added on. However, there is no data to suggest that use of this equipment alters the outcome of trauma. One set of equipment which is essential and often found missing in ambulances is a set of tools to extricate patients trapped in crashed vehicles.

23.1.7 Speed of ambulances

Transportation of the trauma patient within this first hour of high mortality was highlighted by the widely used term 'Golden Hour'. However, Lerner and Moscati (2001) reported that the Golden Hour concept was not based on data or evidence. Dr Cowley used the term as part of a presidential address to the American College of Surgeons (Lerner and Moscati 2001; Berger 2010). The platinum half hour concept is an extrapolation of this to further highlight the importance of reducing time to definitive treatment.

Transportation time for the injured during World War I was estimated to be 12–18 hours while mortality was estimated to be 8 per cent; during World War II it was 6–12 hours and the estimated mortality was 4.5 per cent; during the Korean war it was 2–4 hours, and 2.5 per cent, and during the Vietnam war it was one and a half hours and mortality was estimated to be 2 per cent. However, during this period not just travel times but the entire medical system changed from asepsis; antibiotics, and anesthesia, and overall, surgery became much safer.

Though it is important for the injured patient to reach a definitive care facility at the earliest in urban situations with short transportation times, excessive speeding cannot improve transportation times. Speeding may in fact contribute to risk of injury to patients, other motorists, and pedestrian on the road. The incidence of fatal ambulance crashes during emergency use is reportedly higher than during non-emergency use. These are particularly higher for lights and siren travel (Saunders and Heye 1994; Pirrallo and Swor 1994). Kahn and colleagues found that most crashes occurred at intersections and rear compartment occupants were more likely to be injured than those in the front (Kahn, Pirrallo, and Kuhn 2001). Hunt and colleagues have shown that ambulances with flashing lights and sirens do not significantly reduce patient transportation time. The study used ambulances with lights and sirens, and a control ambulance without; it revealed the mean time saved to be 43.5 seconds in 50 trips (Hunt et al 1995). In another study the mean time saved was 2.9 min in urban areas and 8.9 min in rural areas (Petzall et al 2011). The use of sirens also significantly disturbs the patients being carried. The noise of sirens and traffic also disturb the recording of blood pressures of patients in moving ambulances (Prasad et al 1994). A study found though the rate of ambulance injuries was greater in the urban environment, the severity of the injuries was worse in the rural environments, where crashes occurred at higher posted speeds. In the rural setting non restrained passengers were more likely to be injured (Weiss et al 2001).

23.1.8 Air ambulances

Air ambulances have been promoted to reduce transportation times and hence reduce mortality. Air ambulances are costly, and their health benefits are small (Snooks et al 1996). The study found that there was no improvement in response times and the time on scene was longer for helicopter-attended patients. Logistic regression analysis in helicopter transported trauma patients has shown that transportation by helicopter does not affect the estimated odds of survival (Brathwaite 1998).

Another study showed that a large majority of trauma patients transported by both helicopter and ground ambulance had low injury severity measures. Outcomes were not uniformly better among patients transported by helicopter. Patients transported by helicopter had 18 per cent mortality as compared to 13 per cent for ground transported patients in urban areas (Schiller et al 1988).

Air transport is also fraught with risks of crashes and fatalities. Fatalities after helicopter EMS crashes are especially associated with post crash fire (Baker et al 2006). Some counties have seen a ‘distressing number of air ambulance crashes’ (Zigmond 2008). Helicopter services may have a role in remote inaccessible areas in the sea, desert or mountains. However, routine use of air ambulances in an urban setting is not cost effective.

23.1.9 Ambulance personnel

The number and training of ambulance personnel varies from place to place. Some have only drivers trained in emergency care while others have emergency care paramedics. In some parts of the world there are physician-manned ambulances. Trained medics and paramedics are posted in the emergency medical service ambulance to ensure that the trauma patients receive optimal care from the site of the accident. Physician-manned on scene care was found to cause a significant increase in scene time and total pre-hospital time. These delays are associated with an increase in the risk for death in patients with severe injuries (Sampalis 1994). Physicians on the scene tend to try to provide more care in the field than well trained paramedics, therefore, the time to definitive care of the haemorrhage may be delayed (McSwain 1995).

With the information available it seems that in an urban setting all that is required is a comfortable vehicle with sufficient space to carry the injured safely to a hospital. Analgesics for trauma patients and cardiac drugs for non-trauma patients are the most commonly used medications. Fentanyl was used in 75.4 per cent of patients with fractures during transportation to the hospital (DeVellis et al 1998). Drugs were administered in 8.5 per cent of urban emergency patients and 7 per cent of rural emergency patients either at the crash site or during transportation (Moss, Kolaric, and Watts 1993). So far, there is no reported evidence that pre-hospital medications are either beneficial or cannot be delayed until the arrival at the emergency room. Tranexamic acid was found to be useful to reduce the amount of blood loss in patients with trauma (Vu et al 2013).

23.1.10 Care of wounds

Antiseptics and antibiotics are not necessary for the care of wounds. All that is required is to keep the wound clean. Healing is a natural process, which cannot be hastened by any medicine, and ointments can only delay healing. In case of small wounds, if the wound is dirty, then the best treatment is to wash the wound with clean water. This is the only first aid that may be required for small wounds and abrasions. Splints for the fractured/dislocated limbs can be used to help reduce pain and prevent further injury to the patient. This is an important first aid measure, and must be attempted at the scene to make the patient more comfortable. All kinds of materials can be improvised to work as splints and if nothing is available, the opposite uninjured limb of the patient can function as an effective splint. Air splints are available which encircle the limbs and compress tissues. These can cause serious damage if applied too tightly. Softer easily available materials like cushions, pillows or even rolled up magazines and newspaper may be equally effective without causing further damage.

23.1.11 Care of the spine

Recognizing a spinal injury is not easy, even for trained medical personnel. However, a high index of suspicion can prevent paralysis and further damage in a spinal cord injured patient. Spinal cord injury must be suspected if the patient has a head injury, is unconscious or has altered sensorium, has paralysis of the limbs or is complaining of pain in the neck or back. There is, however, significant variation in clinically clearing cervical spine practice among emergency duty physicians (Cone, Wydro, and Mininger 1999). If spinal cord injury is suspected then the best first aid is to treat the patient as a 'log of wood'. All movements of bending, extending or rotation are to be avoided. Four or five persons can together transfer a patient as a 'log of wood'.

A semi-rigid collar for the neck or even a simple rigid board can be used for shifting the patient. Repeated transfer of the patient is to be avoided in all patients suspected of having a spinal cord injury. In a systematic review of literature to look at cervical spine immobilization it was found there is a lack of high-level evidence on the effect of pre hospital cervical spine immobilization on patient outcomes (Oteir et al 2015).

23.2 ATLS vs BLS

In the mid 1970s, cardiac patients were found to do much better with the availability of ATLS care. It was assumed, therefore, that all patients would do better with more being accomplished in the field (McSwain 1995). This assumption neglected a basic premise of patient care: the most important factor in patient survival is the time from the onset of the emergency to the provision of definitive care. There has been a lot of controversy about the value of ATLS for injured patients (Trunkey 1984). ATLS involves a greater use of technology, psychomotor skills and medication for pre-hospital care. BLS on the other hand focuses on basic airway support, control of bleeding, immobilization of the spine and the provision of supplemental oxygen when required. In a sample of 360 severely injured patients Sampalis (1993) found that the outcome of trauma is not affected by ATLS on the scene. Cayten, Murphy, and Stahl (1993) also found no benefit from the use of ATLS for trauma patients with pre-hospital times less than 35 minutes. This was also reported by Adams (1996) and Sampalis (1994). Jurisdictions throughout the US and some other parts of the world have invested substantial time and resources into creating and sustaining a pre-hospital advanced life support (ALS) system without knowing whether the efficacy of ALS-level care had been validated scientifically. The strongest support for ALS level care was in the area of responses to victims of cardiac arrest. Provision of ALS on scene was associated with a higher incidence of mortality, whereas definitive care in level 1 or 2 compatible hospitals was associated with lower mortality (Sampalis 1994, Bissell 1998). In a major study of ALS vs BLS in the field setting did not seem to change the outcome. Regardless, these interventions did not appear to benefit our rapidly transported, urban penetrating trauma patients (Seamon et al 2013).

23.2.1 'Scoop-and-run' versus 'stay-and-stabilize'

There are proponents for and against each of these approaches. 'Scoop-and-run' involves extrication of the patient, maintenance of a clear airway, protection of spine and control of haemorrhage whenever possible. 'Stay-and-stabilize' on the other hand, involves placement of intravenous lines, infusion of intravenous fluids, application of immobilizers, and endotracheal intubation whenever required. There are many controversies related to trauma patient care during the pre-hospital period nowadays. A balance between 'scoop and run' and 'stay and stabilize' is probably the best approach for trauma patients. The approach chosen should be made according to the mechanism of injury (blunt versus penetrating trauma), distance to the trauma centre (urban versus rural) and the available resources (Beuran et al 2012).

23.2.2 Backup at the hospital

Not all hospitals have the same level of expertise for managing trauma patients. Unnecessary shifting from one hospital to another hospital can be avoided if proper triaging is done in the beginning. The quality of a trauma system can be assessed by the rate of preventable deaths. One question that can help is if the patient had sustained the accident in front of the hospital in a normal working day, might death have been prevented? The main failures in a review of trauma deaths were found to be errors and delays during the first phases of in-hospital assessment and care. An improvement in pre-hospital care will be almost useless if the quality of definitive in-hospital management is not addressed (Stochetti 1994). It is important to have trauma teams and trauma systems in hospitals to improve the outcome of trauma. These have to be inclusive systems built into general or multispecialty hospitals. Standalone trauma centres are not recommended.

23.2.3 Future

While today's emergency and trauma care system offers significantly more medical capability than was available in years past, it continues to suffer from severe fragmentation, an absence of coordination, and a lack of accountability (Committee on the future of Emergency care in the U.S. health system 2007). We are in a situation where something as basic as the starting of an intravenous fluid in a traumatized patient is being labelled as controversial. Factual meta-analysis needs to be done to separate what really works from what is perhaps useful. The future may find that even some of our very basic parameters of measurement of end points of resuscitation may have changed completely. One of the dilemmas of pre-hospital care has been 'are we doing too little for a damage which seems too much?' Our emotional response seems correctly to be to do whatever is possible to save as many lives as possible. There is a need, however, to avoid deification of technology and to homogenize responses to a problem which is essentially heterogeneous. To make scientific conclusions we must have well-controlled prospective randomized studies. There is a strong general feeling that randomizing pre hospital care is unethical (Gold 1987). Since component-based research doesn't fit well into the uncontrolled, multi-tasking environment of EMS, we need to begin to develop models specifically for systems research (Spaite et al 1995). However, there are natural control populations in place in the world where a total contrast of no pre-hospital care exists, along with places where high-tech pre-hospital care is practiced. Advantage could be taken of such situations; normalize them for different injuries to have a controlled study. Until such carefully designed studies are carried out, we will continue to grope for answers and components of pre-hospital care will remain controversial.

As of today a review of literature and the physiological processes involved suggests that in urban areas with transportation times of less than one hour and no delay in extrication, scoop-and run seems to be the best policy.

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TRANSPORT PLANNING & TRAFFIC SAFETY

MAKING CITIES, ROADS, & VEHICLES SAFER

GEETAM TIWARI • DINESH MOHAN

In recognition of the importance of road safety as a major health issue, the World Health Organization has declared 2011-2021 the Decade of Safety Action. Several countries in Europe, North America, and Asia have been successful in reducing fatalities and injuries due to road traffic crashes. However, many low-income countries continue to experience high rates of traffic fatalities and injuries.

Transport Planning and Traffic Safety: Making Cities, Roads, and Vehicles Safer offers a source book for road safety training courses as well as an introductory textbook for graduate-level courses on road safety taught in engineering institutes. It brings together the international experiences and lessons learned from countries which have been successful in reducing traffic crashes and their applicability in low-income countries. The content is based on lectures delivered during an international course on transportation planning and traffic safety, sponsored annually by the Transportation Research and Injury Prevention Programme (TRIPP) at the Indian Institute of Technology, Delhi.

The book is interdisciplinary and aimed at professionals—traffic and road engineers, vehicle designers, law enforcers, and transport planners. The authors examine trends in performance of OECD countries and highlight the public health and systems approach of traffic safety with the vulnerable road user in focus. Topics include land use (transportation planning, mobility, and safety), safety education and legislation, accident analysis, road safety research, human tolerance to injury, vehicle design, safety in construction zones, safety in urban areas, traffic calming, public transportation, safety laws and policies, and pre-hospital care of the injured.

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