Surrogate safety measures and traffic conflict observations.

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How to analyse accident causation?

A handbook with focus on vulnerable road users

InDeV

IN-DEPTH UNDERSTANDING OF ACCIDENT CAUSATION FOR VULNERABLE ROAD USERS

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 635895

How to analyse accident causation?

A handbook with focus on vulnerable road users

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Preface: the InDeV-project

Road safety has greatly improved in recent decades as the number of road fatalities has steadily decreased (European Commission, 2018a). However, this trend is not the same among all road users. Vulnerable road users (VRU), such as motorcycle and moped riders, cyclists and pedestrians, remain especially at risk due to their notable increase in the share of road deaths and serious injuries (European Commission, 2018b, 2018c). VRUs are generally unprotected and vulnerable in traffic, so increasing concern about their road safety exists.

The European Commission (2018b) recognises the urgency of VRUs' safety and devotes special attention to formulating several actions to increase VRU safety in its policy orientation on road safety for 2021–2030. This vision proposes the Safe System approach as a common framework to further reduce the number of deaths and serious injuries. This approach acknowledges that people make mistakes that lead to collisions but holds that these mistakes should not be punishable by death or serious injury.

In-depth Understanding of Accident Causation for Vulnerable Road Users (InDeV) is a European research project in the field of road safety, co-funded within the Framework HORIZON2020 by the European Commission. Covering 2014–2018, the InDeV project was established to meet the Commission's need to enhance the road safety of VRUs by developing an integrated methodology to understand the causes of accidents involving VRUs and a framework of good practice for a comprehensive assessment of the socio-economic costs related to road accidents involving VRUs. However, the estimation of the relative contribution of different causal risk factors leading to VRU injuries and their consequences lies out of the scope of the InDeV-project and this handbook. InDeV has developed a toolbox (this handbook) to help practitioners diagnose road safety problems by gaining more insights into the mistakes by road users that lead to collisions. As our aim is to deliver a main reference manual for road safety professionals, researchers and practitioners, the authors encourage every reader to circulate the handbook as widely as possible. Applying the principles described in this book will contribute to the further improvement of road safety and a better, in-depth understanding of the causal factors contributing to VRU accidents. These enhanced insights will allow us to better understand the mistakes road users make, which is crucial to select targeted countermeasures to reduce the number of deaths and serious injuries.

The InDeV project was carried out by a consortium of nine partners and coordinated by Lund University (Sweden). It included European organisations with skills and experience in the area of road safety analysis and evaluation, gathering expertise from throughout Europe. More information on the InDeV project can be found on the website www.bast.de/indev-project.

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Executive summary

This handbook is a product of the Horizon2020 InDeV project, commissioned by the European Commission. The main objective of the InDeV project was to contribute to the improvement of vulnerable road user (VRU) safety in Europe by developing an integrated methodology to understand the causes of accidents involving VRUs and a framework of good practice for a comprehensive assessment of the socio-economic costs related to road accidents involving VRUs. However, the estimation of the relative contribution of different causal risk factors leading to VRU injuries and their consequences lies out of the scope of the InDeV-project and this handbook.

The purpose of this handbook is to compile current knowledge on road safety diagnostic techniques to identify accident causation factors into a detailed, practical overview of these varied techniques. The main target audience of this handbook is road safety practitioners, professionals and researchers involved in diagnosing road safety in Europe and abroad. The authors, therefore, concentrate on the application of state-of-the-art but accessible techniques that make optimal use of existing data and data that are relatively easy and cheap to collect. Each chapter describes a different road safety technique that can be applied for in-depth analysis of the causes of accidents involving VRUs (and other road users), such as accident data analysis, surrogate safety indicators, self-reported accidents and naturalistic behavioural data. The handbook also focuses on delivering better calculations of the socio-economic costs of VRU accidents. These chapters are written in a stand-alone manner. If readers' main interest lies in a certain road safety technique, they may skip the other chapters and immediately start reading the chapter on their technique of choice. Furthermore, each technique is illustrated by examples, use cases and best practices. Clear indications of the strengths and limitations of the different techniques are given, and suggestions are offered to overcome the techniques' limitations by supplementing them with other techniques and data sources.

This handbook assists in linking accident causal factors to VRU accident risk, so it contributes to further improving road safety and developing a better, in-depth understanding of the causal factors contributing to VRU accidents. These enhanced insights allow us to better understand the mistakes by road users that are essential to develop and select targeted countermeasures to reduce the number of fatalities and serious injuries. This handbook thus also indirectly contributes to the European Commission's road safety objective to further reduce fatalities and serious injuries by 2030.

The InDeV research project specifically focused on improving the road safety of VRUs as they experience elevated accident and injury risk even though road safety in Europe has greatly improved in recent decades. This handbook, therefore, mainly focuses on how different road safety techniques can be used to identify the accident causal factors for VRUs. Nevertheless, these techniques can also be applied to assess the safety of other road users. Based on the study objectives, the following techniques can be used to assess the road safety of VRUs.

Accident data statistics and analysis techniques are presented in **chapter 2**. The traditional approach of accident data analysis is the most commonly used technique to assess the road safety situation of VRUs and other road users. For instance, accident data analyses are very useful to assess and monitor the road safety situation in areas of interest, identify the time trends of accident occurrence and resulting injury severity and compare the safety situation among countries, regions and cities. However, this chapter also discusses the important disadvantages of accident data, which influence the reliability of the technique (e.g. underreporting, random variation, misreporting and data harmonisation). This chapter starts by discussing the theoretical background of accident data statistics and analysis by addressing topics such as road accident data in European Union countries, road safety analyses based on accident data, identification of hazardous locations and accident prediction modelling. Furthermore, an overview covers several national and international accident databases the practitioner can use to obtain accident data. Next, road safety assessment objectives for accident data analysis are presented. The chapter concludes by presenting different tools to conduct accident data analysis, such as general road safety reports, black spot management, network safety analysis, collision diagram analysis and the empirical Bayes method.

The focus of **chapter 3** is applying self-reporting of accidents and near-accidents to capture a coherent view of the actual road safety situation of VRUs. This technique collects information directly from VRUs themselves. Self-reporting is especially useful for gaining knowledge on near-accidents, which are usually not registered, and less severe accidents (e.g. with slight injuries or only property damage), commonly under-reported in official statistics. However, combining police-reported accident data with hospital data remains the recommended approach to mitigate the underreporting of accidents with serious and fatal injuries. An introduction to self-reporting is provided, followed by a discussion on the main advantages and disadvantages of the technique. Subsequently, criteria for selecting self-reporting as a road safety technique to assess VRU safety are presented. Next is an overview of the data collection methods that can be used to collect self-reported data on accidents and near-accidents, such as paper and online questionnaires, telephone interviews and face-to-face interviews. The preferred data collection method depends on the study objectives. The remainder of this chapter focuses on practical considerations before, during and after the collection of self-reported data.

Chapter 4 primarily focuses on observing traffic conflicts (also known as near-accidents) as a site-based road safety analysis technique. Traffic conflicts are a type of surrogate safety measure. The term *surrogate* indicates that non-accident-based indicators are used to assess VRU safety instead of the more traditional approach focusing on accidents (see chapter 2). The theory underpinning surrogate safety measures is briefly described, followed by a discussion on the characteristics of the traffic conflict technique. Next, guidelines for conducting traffic conflict observations using trained human observers or video cameras are presented. Chapter 4 concludes with examples of the use of the traffic conflict technique in road safety studies focusing on VRUs.

Chapter 5 presents behavioural observation studies. These on-site studies assess the frequency of and identify particular characteristics of road user behaviour in normal interactions and near-accidents. Behavioural observation studies focus on observing VRUs' behaviour characteristics, so the results can be used as a basis to identify which target groups and risk-increasing behaviours require attention to reduce road fatalities and serious injuries. Chapter 5 starts by presenting the advantages and disadvantages of behavioural observation studies, followed by a discussion on the criteria for selecting this technique to gain insights into VRU safety. These criteria are illustrated through practical examples targeted at VRUs. Next, possible methods to collect behavioural observation data are presented. The two most common methods to collect behavioural observation data are discussed: on-site trained human observers and video cameras (or a combination). This discussion is followed by a step-by-step guide to setting up behavioural observation studies. The chapter concludes with a short presentation of other road safety techniques that can be combined with behavioural observation studies to obtain a comprehensive picture of the road safety situation at particular locations.

Chapter 6 discusses naturalistic cycling and walking studies as a technique to continuously collect data on VRU behaviour. In these studies, data are collected through instrumented vehicles and portable measuring devices. These studies collect data continuously, so they enable evaluating not only the last movements and constellations leading up to accidents but also the underlying factors that may have led to road users ending up in safety-critical situations. An introduction to naturalistic cycling and walking studies is provided, followed by a discussion on the technique's main advantages and disadvantages. Criteria for selecting and methods for conducting naturalistic cycling and walking studies are presented and illustrated with use cases focusing on VRUs. The remainder of this chapter focuses on practical considerations before and during naturalistic cycling and walking studies.

Road safety audits (RSA) and road safety inspections (RSI) are presented in **chapter 7** as techniques to perform site-based observations of road infrastructure. Both RSI and RSA are aimed at reducing road accidents by analysing road infrastructure elements that could influence accident risk. These techniques study accident patterns on new and existing roads and evaluate the self-explaining and forgiving character of roads by assessing the crash-friendliness of road infrastructure elements. Both techniques assist in reducing fatal and serious injuries among road users as self-explaining and forgiving roads concepts are well known to assist in reducing injury severity. The chapter starts with an explanation of the differences between RSA and RSI, followed by a discussion on European Directive 2008/96/EC on road infrastructure safety management, which sets the legal basis for RSI in the EU. In addition, this chapter outlines the basic concepts and actors involved in RSA and RSI and presents a step-by-step guide to apply road safety audits and inspections. Chapter 7 concludes with an overview of useful checklists and templates typically used in conducting road safety audits and inspections. Finally, examples of RSI targeted at VRU safety are provided.

Chapter 8 provides an introduction to estimating the socio-economic costs of VRU accidents. This chapter explains the cost components of VRU injuries to society and provides insights into use cases of these cost estimates. To conclude, this chapter offers suggestions for further reading on the estimated socio-economic costs of VRU accidents.

Chapter 9 draws on this entire handbook. The chapter starts with an integrated overview of the road safety techniques discussed and provides recommendations for combining several techniques to overcome their separate limitations. It is concluded that definite advantage lies in combining road safety techniques to enrich the complementary results from multiple techniques and to verify study results. Furthermore, it is discussed that the most important benefit of combining techniques to study road safety of VRUs lies in the possibility to study road user behaviour from a system perspective. It, therefore, can be recommended that countries pursuing a system-based road safety vision adopt an integrated approach based on a combination of techniques to observe road user behaviour in interactions, near-accidents and accidents. Besides road user behavioural factors, vehicle, road and emergency medical system factors are also critical to a Safe System Approach. Even though, the latter factors are not the focus of this handbook, it can be suggested that the proposed integrated approach to study road user behaviour is a first and important step to further reduce the number of road fatalities and serious injuries and to formulate policy priorities in order to eventually establish an inherently safe road traffic system.

PART 1

Introduction

CHAPTER 1

Introduction

1.1 About this handbook

In Europe, road safety is considered to have largely improved over the past few decades, since the number of road fatalities has been steadily decreasing during that time (European Commission, 2018b). However, the benefits of various efforts intended to enhance road safety are not equally distributed among all types of road users. During the past few years, the number of accidents resulting in fatalities and serious injuries involving vulnerable road users (VRUs), such as riders of motorcycles and mopeds, cyclists and pedestrians, have actually increased in some European countries (European Commission, 2018d, 2018c). The urgency associated with better guaranteeing the protection of VRUs is therefore addressed in the European policy orientations on road safety 2021–2030 (European Commission, 2018c).

This vision stresses the need to further reduce the number of road fatalities and serious injuries. The situation is especially pressing for VRUs, since the European Commission estimates that they account for the majority of the 135,000 people who are seriously injured in road accidents every year (European Commission, 2018a). Consequently, the 'Safe System' approach has been proposed as a common framework for achieving the ambitious goals of both reducing the number of road fatalities to as close to zero as possible by 2050 and halving the number of serious injuries between 2020 and 2030 (European Commission, 2018c). This approach acknowledges the inevitability that people will make mistakes that lead to collisions, although it prescribes that such mistakes should not be punishable by death or serious injury. More specifically, the road system should be adjusted to reflect the fallibility of road users, while actors at different levels of the road traffic system should share responsibility for guaranteeing road safety (Salmon, Lenné, Stanton, Jenkins, & Walker, 2010). For instance, infrastructure and vehicles should be designed in such a way that the likelihood of human error is taken into account and the impact forces are minimalised when collisions do occur so that road users are able to avoid serious injuries or death when using the road system (Wundersitz, Baldock, & Raftery, 2014).

Furthermore, since active travel is currently being encouraged for health, environmental, congestion and other reasons, the safety of traveling by foot and bicycle in particular must be urgently addressed (Gerike & Parkin, 2016). It is therefore vitally important to create a road traffic system that guarantees the safety for (vulnerable) road users. However, due to under-reporting issues, legislation and policymakers, road infrastructure designers and the designers of vehicle safety systems are all currently lacking detailed information about the accident involvement of VRUs, the causal factors associated with accidents involving VRUs and the interactions that take place between VRUs and other road users within the environment of the road traffic system (Methorst, Eenink, Cardoso, Machata, & Malasek, 2016). This detailed information is necessary in terms of diagnosing the nature and quantifying the magnitude of the problem in order to select and apply the most effective remedial measure(s) for the road safety issue in question.

As stated by Martin H. Fischer (1944), "diagnosis is not the end, but the beginning of practice" (McDonald, 2004, p.35). Consequently, in order to adopt not only effective, but also targeted and efficient countermeasures, it is necessary to gain detailed insights into the mistakes that road users make in the run up to collisions. The present handbook addresses this need by providing a detailed and practical overview of the various road safety diagnostic techniques available for studying road users' behaviour during interactions, near-misses and accidents. It describes various road safety methods that can be applied for an in-depth analysis of accident causation in relation to VRUs (and other road users), such as accident data analysis, surrogate safety indicators, self-reported accidents and naturalistic behavioural data. More specifically, the techniques discussed in this handbook serve to identify the mistakes, behaviours and other factors that play a role in the occurrence of accidents, as well as the resulting consequences in terms of fatalities and serious injuries. As diagnosing the mistakes road users make is the first step on the journey towards road safety improvement, it can be stated that this handbook indirectly contributes to the European Commission's road safety objective of reducing fatalities and serious injuries by compiling current knowledge regarding road safety diagnostic techniques aimed at identifying accident causal factors.

The main target audience of this handbook comprises road safety practitioners, professionals and researchers involved in the diagnosis of road safety in Europe and abroad. Therefore, the authors concentrate on the application of state-of-the-art yet accessible techniques that make optimal use of existing data and/or data that are relatively easy and cheap to collect. Furthermore, each road safety diagnostic technique is illustrated by examples, use cases or best practices. A clear indication of the strengths and limitations of the different techniques is provided, and suggestions are offered with regard to overcoming the limitations of the techniques by supplementing them with other techniques and data sources.

To summarise, this handbook only focuses on road safety diagnostic techniques applied to identify VRU accident causation factors. Therefore, the estimation of the relative contribution of different causal risk factors leading to VRU injuries and their consequences lies out of the scope of this handbook. Furthermore, it does not propose countermeasures intended to address the road safety issues that are diagnosed with the discussed techniques. If the reader is interested in this topic, s/he is referred to the wide range of materials that offer recommendations, guidelines and measures aimed at increasing road safety, such as The Handbook of Road Safety measures (Elvik, Høye, Vaa, & Sørensen, 2009), The PIARC Road Safety Manual (PIARC, 2015) and the SafetyCube Decision Support System (DSS) (SafetyCube, 2018).

1.2 Background

1.2.1 THE SCOPE OF THE ROAD SAFETY PROBLEM ASSOCIATED WITH VRUS

Road safety is typically measured and analysed in terms of an undesirable side effect of mobility, namely road accidents and casualties. During the past few decades, countries worldwide have made significant advances in relation to reducing the incidence of accidents as well as their impact on society. However, road traffic injuries remain a leading cause of preventable death in countries all over the world (World Health Organization, 2015), and they also have a tremendous negative impact on our society in terms of physical, emotional, material and economic costs. For instance, more than 25,300 Europeans lost their lives in road accidents in 2017, while more than 135,000 people were seriously injured, accounting for a 1% loss in the European GDP (European Commission, 2018c).

A closer look at the European road safety situation of VRUs reveals that they accounted for almost half of all road fatalities; some 21% of all people killed on the roads were pedestrians, while 25% were riding two-wheelers (14% were motorcyclists, 8% were cyclists and 3% were powered two-wheelers (PTW)) (European Commission, 2018a). Furthermore, the overall number of road traffic fatalities decreased by 20% from 2010–2016, whereas the number of pedestrian and cyclist fatalities decreased by a much lower rate of 15% and 2%, respectively, during the same period (European Commission, 2018a).

Fatal accidents involving cyclists and pedestrians occur more frequently in urban areas and at intersections, whereas fatal PTW-accidents predominantly occur on rural roads (Aarts et al., 2016). Elderly people and children are the dominant age groups involved in fatal pedestrian accidents (European Commission, 2017c), while youngsters and the elderly are mostly involved in fatal bicycle accidents (European Commission, 2017a). Additionally, fatal PTW-accidents predominantly involve young adults in central European countries, as well as older riders (European Commission, 2017b).

These figures show that the most vulnerable age groups, such as children, youngsters and the elderly, are particularly likely to be involved in fatal VRU accidents, which has led to increasing concern about VRU road safety. These facts emphasise that VRU safety continues to be a growing area of concern and, further, that additional efforts and insights regarding VRU accident causal factors are necessary in order to secure future road safety benefits for these currently inadequately protected road users.

1.2.2 HOW TO DIAGNOSE ROAD SAFETY

The traditional approach to road safety diagnosis

During the past few decades, the necessity of road safety diagnosis and evaluation has increased significantly due to the enormous socio-economic losses caused by road accidents and the associated consequences. This need has been further heightened by recent recognition that the implementation of road safety management systems and policies needs to be evidence-based in order to guarantee that road safety investments contribute to achieving beneficial road safety outcomes (Papadimitriou & Yannis, 2013). Additionally, Schulze and Koßmann (2010) also mention that the greater the degree to which road safety policies are evidence-based, the more efficient they will be in terms of reducing fatalities and the severity of road accidents.

As a result, road safety professionals continuously aim to reduce the number of accidents by gaining better insights into the factors that contribute to accident occurrence and severity (Lord & Mannering, 2010). Traditionally, most road safety studies have relied on accident data to identify which locations, target groups or risk-increasing behaviours require attention; to detect positive and negative road safety developments, to evaluate road safety measures and to infer causal factors from accident patterns (Chin & Quek, 1997; Muhlrad, 1993; Oppe, 1993; Svensson & Hydén, 2006). This traditional approach has established accident data as the main data source for road safety diagnosis, thereby rendering accidents and their consequences as well-accepted road safety indicators. Although accident data provide interesting and useful road safety information, they are characterised by various disadvantages.

First, accidents are exceptional when compared to other events involving traffic. Therefore, accident data are characterised by the random variation inherent in small numbers (Hauer, 1997). Additionally, it takes quite some time to collect sufficient accident data to produce reliable estimates of traffic safety. For longer periods, it is difficult to associate the change in number of accidents with a specific factor, since other factors might also change during the same period (Chin & Quek, 1997; Laureshyn, 2010; OECD, 1998). Consequently, it is insufficient to only rely on accident data for everyday road safety purposes. Second, not all accidents are reported, while the level of reporting is unevenly distributed depending on the accident severity and type of road users involved (Laureshyn, 2010; OECD, 1998; Svensson, 1998). For instance, VRUs in particular are heavily under-represented in police accident statistics when compared to accident information found in hospital records (Alsop & Langley, 2001; Amoros, Martin, & Laumon, 2006; Elvik, Høye, Vaa, & Sørensen, 2009).Third, accidents are the consequence of a dynamic process in which a certain combination of factors related to the road user, the vehicle and the environment leads to a collision. However, accident data are not capable of capturing either the interaction between these factors or the behavioural and situational aspects that precede the accident and thus play a role in accident occurrence (Laureshyn, 2010; OECD, 1998). Due to this, the accident development process remains unclear, since the information contained in accident databases only describes the outcome of each registered accident. Without knowing and understanding the accident development process, it is difficult to identify the causal factors and propose effective measures for reducing accident occurrence (Laureshyn, 2010). Finally, a road safety analysis based on accident data represents a reactive approach, since a large number of accidents have to take place before a particular road safety problem is identified and remedied using appropriate safety countermeasures (Archer, 2005; Lord & Persaud, 2004). This also raises ethical concerns regarding the use of accident data, since one has to wait for accidents to occur, and thus for people to suffer, before the road safety situation can be evaluated (Chin & Quek, 1997; Laureshyn, 2010). In that respect, indicators that provide faster feedback about the road safety situation are preferable (Chin & Quek, 1997).

From this point of view, there exists a distinct need as well as enormous potential for swifter, more informative and more resource-efficient road safety techniques that are able to provide a more comprehensive analysis of the road safety situation (Archer, 2005).

Diagnosing road safety by means of non-accident events

In the road safety literature, the terms *non-accident-based data* and *surrogate safety measures* (SSM) are used to refer to indirect road safety indicators. The term *surrogate* denotes that these measures or indicators do not rely on accident data (Tarko et al., 2009). The motivation behind the use of non-accident-based data for road safety purposes is that the interactions between road users can be described as a continuum of safety-related events in which the frequency of the events is inversely related to the severity of the events (Svensson, 1998; Svensson & Hydén, 2006). If there is an adequate understanding of the relationships between these safety-related events, as well as of how these events are related to differences in road safety, it is possible to diagnose road safety by studying non-accident events as a supplement or alternative to accident data.

This continuum of safety-related events, which describes the relationship between the severity and frequency of road user interactions, is usually illustrated by a pyramid (Hydén, 1987). This *safety pyramid* describes the relationships between normal events in traffic, traffic conflicts and accidents, as shown in Figure 1-1. The top of the pyramid represents the most severe and most exceptional events in traffic, that is, *accidents*. Accidents can be further divided into fatal, injury and property-damage-only accidents, and the accident frequency increases with decreasing accident severity (Hydén, 1987; Svensson, 1998). *Traffic conflicts* or *near-accidents* are traffic events that are characterised by very small margins in both time and space that almost end in accidents. During these events, the collision is avoided because (at least one of) the involved road users detect(s) each other and are able to avoid the imminent risk of colliding by successfully taking evasive action (Svensson, 1998). Similar to accidents, traffic conflicts can also be classified as either serious, slight or potential conflicts according to their severity. The base of the 'safety pyramid' is formed by the majority of the events that characterise the normal traffic process, that is, the *undisturbed passages* (Laureshyn, 2010).

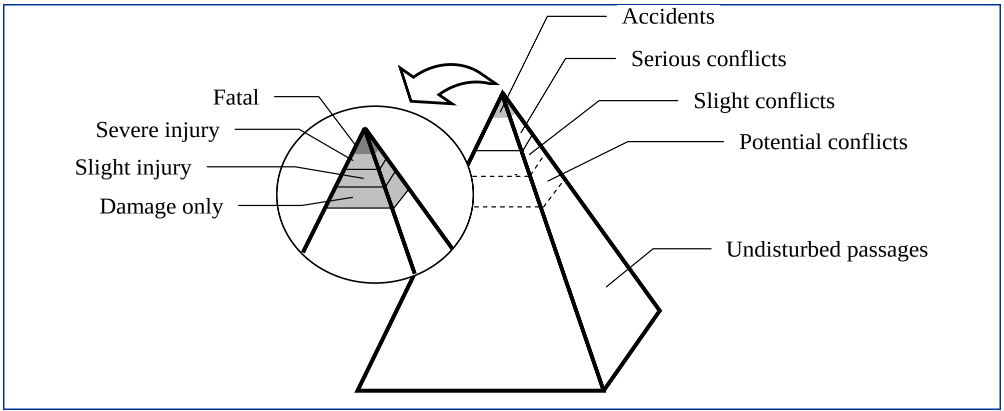

Figure 1-1: The 'safety-pyramid' - the interaction between road users as a continuum of events (adopted from Laureshyn (2010), based on Hydén (1987))

From a theoretical point of view, every encounter between two or more road users may eventually result in an accident. Each accident is the result of a number of factors that have all contributed to the event. If some of the contributing factors had not been present, or if the contributing factors coincided with other circumstances, the accident might have been avoided (Laureshyn, Svensson, & Hydén, 2010). As a consequence, it can be considered an unlucky coincidence that all these factors happened to occur at the same time and result in an accident. Furthermore, this *accident potential* implies that every interaction/event illustrated by the *safety pyramid* could result in a collision when new factors arise or the circumstances differ. For example, imagine a signalised intersection where a pedestrian is waiting for the green signal to appear in order to cross. This interaction can be regarded as an undisturbed passage if the pedestrian safely waits to cross until the vehicles are confronted with a red signal and the crossing signal for VRUs turns green. However, if the pedestrian is in a hurry and decides to cross when the red signal is showing, this situation could end in a near-accident or accident depending on whether or not the approaching vehicles can brake in time to avoid a collision.

The 'safety pyramid' also illustrates that the traditional approach to road safety diagnosis and evaluation based on accidents only encompasses an insignificant fraction of all the traffic events that take place, since there is a total disregard of the much more frequent traffic events that describe safe or unsafe interactions between road users. This could result in important insights into road safety being overlooked. When compared to accident data, the main advantage of non-accident-based data is that they provide more context-appropriate information regarding the accident development process as well as the contributory factors that played a role in both accident occurrence and severity.

This large variety of interactions within the road traffic system, as well as the multi-causal and complex nature of the road safety problem, also require a variety of road safety diagnostic techniques that can be applied in order to gain a more in-depth picture of the road safety situation of VRUs and other road users. Therefore, this handbook not only discusses accident data and analysis as the main techniques for the road safety diagnosis of VRUs, but also focuses on diagnostic techniques based on surrogate safety indicators such as self-report instruments, road user behavioural data and near-accident data.

1.3 Guide for readers and structure of the handbook

This handbook was designed to offer road safety professionals easy access to information regarding road safety diagnostic methods as well as how they can be applied in order to identify a certain road safety problem. It is divided into three main parts.

Part I consists of this introductory chapter. It explains the purpose of this handbook and provides background information about the safety problems of VRUs and the different available road safety diagnostic methods.

Part II is more practical and consists of eight chapters, seven of which are devoted to one specific road safety diagnostic technique:

- Chapter 2: Accident data and analysis techniques
- Chapter 3: Self-reporting of accidents and near-accidents
- Chapter 4: Surrogate safety measures and traffic conflict observations
- Chapter 5: Behavioural observation studies
- Chapter 6: Naturalistic cycling and walking studies
- Chapter 7: Site observations of traffic infrastructure
- Chapter 8: Estimating the socio-economic costs of injuries to vulnerable road users

Each chapter starts with an introduction (explaining what can be learned from the chapter), followed by a description of the considered diagnostic technique. A clear indication of the strengths and limitations of the different techniques is provided, and suggestions are offered for overcoming the limitations of the techniques by supplementing them with other techniques and data sources. For each technique, the relevant chapter also explains when and how it should be performed. Throughout the handbook, additional information is included in text boxes, such as best practices, use cases or practical examples. At the end of each chapter, the conclusions are presented, the key points are detailed and the recommended reading is suggested. The final chapter in this part of the handbook provides an integrated overview of the discussed road safety techniques and describes possibilities for combining these techniques for road safety research purposes.

The chapters in this handbook are written in a stand-alone manner, so that users can start with any chapter. The safety continuum of traffic events or *safety pyramid* introduced by Hydén (1987) is used to guide the reader throughout the handbook and the different techniques it describes. The scope of each chapter is schematically represented in Figure 1-2, and it is indicated graphically by smaller *safety pyramids* at the beginning of each chapter.

Part III provides a glossary of the words, symbols and abbreviations that are used throughout the handbook.

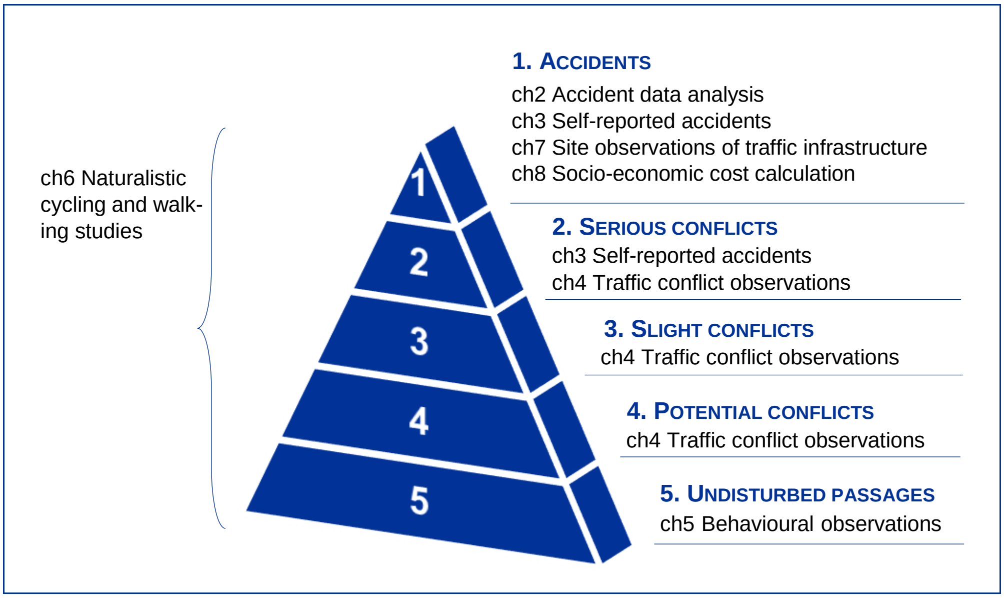

Figure 1-2: Overview of the link between the chapters in this handbook and Hydén's (1987) safety pyramid

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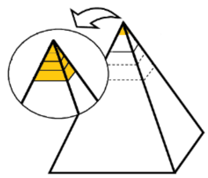
PART 2

Safety diagnosis tools

CHAPTER 2



Road accident statistics and available analysis techniques

This chapter demonstrates how traffic accident data can be used to assess and monitor the road safety situation in an area of interest. The basics of statistical theory used in analysing accident data are first introduced (readers who are not interested in statistics and mathematical formulae can skip the sections 2.1.3 to 2.1.5 in this chapter).

General accident reports are prepared to identify the time trends of accident occurrence and the severity of resulting injuries, and to compare the safety situation among countries, regions or cities. Benchmarking between countries can help to monitor progress towards the set targets for traffic safety improvement and to assess the relative importance of problems. Accidents are rare and random events, and their occurrence in a particular location must be interpreted with caution. This chapter shows how to correctly identify dangerous locations using black spot analysis and network safety analysis. Although the techniques presented concern all road users, the focus is on vulnerable road users (VRUs), especially pedestrians and cyclists.

2.1 Theoretical background

2.1.1 ROAD ACCIDENT DATA IN EU COUNTRIES

According to the definition adopted in the European Union (Community Road Accident Database, CARE), road traffic accidents are collisions on public roads involving at least one moving vehicle, as a result of which at least one person is killed or injured. The condition of injury or death in the definition exists to distinguish accidents from collisions, also known as property-damage-only accidents (see Figure 1-1). Thus, the term “road accident” is reserved only for accidents in which injury occurs[1]. In most countries, non-injury accidents or collisions are not registered by the police. The above accident definition includes also single-vehicle-injury accidents (such as falls from a bicycle) but excludes pedestrian falls (no vehicle present). It is sometimes argued that the definition of a road accident should be changed to include pedestrian falls.

Epidemiological studies regard road accidents in the same way as diseases and investigate the distributions and frequencies of their occurrence. Epidemiological studies are based on information from national or regional accident databases. In most countries, road accident data are collected and maintained by the police, and in some countries also by hospitals or by governmental organizations (ETSC, 2006). The Swedish system STRADA (Swedish Traffic Accident Data Acquisition) is an example of a database that contains information about accidents from both the police and hospitals.

CARE was created by the European Commission in 1993 with the aim of identifying road safety problems and improving road safety in the European road network. It is based on police accident records from EU countries. In addition to CARE, there are several international accident databases, for example IRTAD (International Road Traffic and Accident Database) and IRF (International Road Federation) World Road Statistics.

Safety analyses based on international records are subject to a number of problems. One such important problem is incompatibility between definitions used in various countries, for example, the levels of injury severity (slight or serious). This issue was thoroughly discussed in an ETSC report (2006). In fact, only fatal injuries can be reliably compared between countries. Most countries use the definition adopted by the Vienna Convention: “a road fatality is any person killed immediately or dying within 30 days as a result of a road traffic accident”.

As an example, Table 2-1 shows the distribution of VRU accidents and victims by road user type and injury severity in

[1] It should be noted that the term ”crash” used in the USA includes both injury accidents and property-damage-only crashes. For the sake of consistency the authors use the term ‘accident’ in this chapter to both denote injury and property-damage-only accidents as they do not differentiate between the terms in relation to the context.

Poland in 2015. The number of accidents in which pedestrians were killed or injured was the largest, followed by cyclists, motorcyclists and moped riders. The numbers of victims are always greater than the numbers of accidents, as accidents often have more than one victim.

Table 2-1: VRU accidents and victims by injury severity in Poland in 2015 (Polish Police Crash Database: SEWIK)

Type of road users	Number of accidents	Number of victims			
		Killed	Seriously injured	Slightly injured	Total victims
Pedestrians	8581	915	3015	5025	8955
Cyclists	4368	300	1341	2787	4428
Moped riders	1603	65	584	1072	1721
Motorcyclists	1995	208	867	1084	2159

2.1.2 ANALYSES OF ROAD SAFETY BASED ON ACCIDENT DATA

Analyses of road safety based on accident data statistics can be performed using accident frequencies or accident rates. Frequencies are the numbers of accidents (or numbers of accident victims) in a given area recorded during a given time period. Accident rates are numbers of accidents divided by some measure of exposure:

Accident Rate = Accidents/Exposure

Exposure represents the extent to which road users are exposed to the risk of becoming victims of a road accident. An elementary but valid measure of exposure is the number of meetings between two road users, either resulting in accident or not. By ”meeting” is meant ”arrival at a conflict zone at the same time or within a very short time interval” (Elvik, 2013). However, in the case of pedestrians, this is rather difficult to define. In all cases, exposure data are hard to collect, so instead some proxy measures are used, ranging from relatively simple ones such as population to more complex ones such as the number of vehicle-kilometres travelled in the area in question. Different exposure measures result in different accident rates, as shown in Table 2-2.

Table 2-2: Accident rates based on different exposure measures

Exposure measure	Unit	Accident rate	Applications
Population	person	accidents/million population/year	Country, city, area
Vehicle fleet	veh	accidents/million vehicles/year	Country, city, area
Road length	km	accidents/kilometres of road/year	Road segment, road network
Travel	veh-kms	accidents/million vehicle-kilometres travelled/year	Road segment, road network
Traffic	veh	accidents/million vehicles entering/year	Intersection
Traffic product	veh*person	accidents/million vehicle*person crossing	Intersection, pedestrian crossing

In all the rates given in Table 2-2, the numbers of victims per type of injury can be used instead of the numbers of accidents. Specifically, numbers of fatalities are often used in international comparisons, for reasons explained earlier, and the resulting rates are called fatality rates. Accident rates can be calculated for specific types of accidents, such as pedestrian, cyclist or motorcyclist accidents. However, for assessing the safety of VRUs, exposure measures such as road length or number of vehicle-kilometres travelled are not suitable, as they do not reflect the number of VRUs exposed to motorised traffic. For general assessment (country, region, city comparison), population-based accident rates can always be used. For pedestrians, it is best to use person-kilometres walked (together with vehicle-kilometres travelled), but such data are generally not available. For assessing VRU safety at specific sites, traffic product seems to be an appropriate proxy of exposure, as the number of potential conflicts is dependent on the magnitude of both crossing traffic streams: motor vehicles and pedestrians or cyclists.

2.1.3 PROBABILITY DISTRIBUTION OF ACCIDENT COUNTS

Road accidents are random events, and the distribution of their counts at a specific location per unit time (e.g. per year) can be represented by the Poisson probability distribution. The probability of observing n accidents during one year $P(A = n)$ is given by the following formula:

$$P(A = n) = \frac{\lambda^n e^{\lambda}}{n!}$$

where:
λ = average number of accidents per year,
n = non-negative integer number (0, 1, 2 …),
A = actual accident count in a year.

A characteristic property of the Poisson distribution is that its variance, Var(A), is equal to the mean, λ. Therefore, standard deviation (s) is equal to the square root of the mean, $s = \lambda^{0.5}$. This property makes it possible to quickly assess the confidence in estimates based on accident statistics. The expected value of accident frequency based on a series of Y years of observations is calculated as an arithmetic mean:

$$E(A) = \frac{\sum A}{Y} = \lambda$$

where:
Y = number of years of observation.

Standard error of this mean, given by the general statistics formula as: $s/\sqrt{Y}$, in case of the Poisson distribution reduces to:

$$s_E = \frac{s}{\sqrt{Y}} = \sqrt{\lambda/Y}$$

For example, let us assume that during a 3-year period 270 accidents were recorded at site 1 and 18 at site 2. This gives the mean counts per year $\lambda_1 = 90$ and $\lambda_2 = 6$. The standard errors of the mean are: $s_{E1} = (90/3)^{0.5} = 5.48$ and $s_{E2} = (6/3)^{0.5} = 1.41$. We can then say that the expected numbers of accidents in one year will be: $E(A_1) = 90 \pm 5.48$ at site 1 and $E(A_2) = 6 \pm 1.41$ at site 2. In the first case, this margin of error represents 6.1% of the mean and in the second case 23.5%.

The fact that the relative margin of error increases as the average accident frequency declines has important implications. First, as the general road safety situation improves, there are fewer accidents but also less precision in terms of the expected number of accidents. This problem is especially evident in countries that are leaders in road safety. Second, the precision of accident estimates decreases when the number of accidents is divided by type or severity, i.e. if we consider only fatal accidents or pedestrian accidents, rather than all accidents.

When analysing accident count statistics from several sites, the count variability is often greater than required by the Poisson distribution, that is, the variance of accident counts is greater than the mean. This phenomenon is known as "overdispersion". In such cases, it is better to model accident numbers with a negative binomial distribution. This distribution is more general than Poisson and has two parameters. The variance is related to the mean in the following way:

$$\boldsymbol{Var(A) = Mean(A) + \varphi\, Mean(A)^2}$$

where:
Mean(A) = average number of accidents per site,
$\boldsymbol{\varphi}$ = overdispersion parameter[2].

The value of parameter φ relates to data dispersion in the following way. When φ is small, variance is close to the mean, so the distribution is close to Poisson. As φ gets increasingly larger, the data become more and more dispersed. The value of φ can be estimated from the above equation using accident data from a reporting period of at least three years.

2.1.4 IDENTIFICATION OF HAZARDOUS LOCATIONS

The process of identifying hazardous locations involves identification and analysis of black spots, as well as safety analysis of road networks. The difference between these two tasks can be explained as follows:

- Black spot analysis is defined as a method of identifying high-risk accident locations (intersections or very short road sections, such as dangerous curves), i.e. locations with a high concentration of accidents. Black spot analysis is usually part of

[2] The definition used here follows that of Elvik (2011). In some textbooks a related but different parameter: k = 1/φ is used and is also called "overdispersion parameter".

a black spot management programme.

- Road network safety analysis is defined as a method of ranking road sections with high accident concentration. It is a means of identifying, analysing and ranking sections of the road network where a large number of accidents have occurred in proportion to the traffic flow and road length. Road network safety analysis is usually the first step in a Road Network Safety Management process.

As already mentioned, road accidents are relatively rare, random events and as such their frequency is subject to random fluctuations in time. If hazardous locations are identified based on short-term (typically three-year) accident counts, their selection can be biased by the so called “regression-to-the-mean” effect. As shown in Figure 2-1, accident frequency at a particular site is high during period 2, owing to random variation. If this site is identified as a black spot, the accident frequency will go down during period 3 even if no safety treatment is implemented, owing to the natural regression to the long-term mean. Thus, if black spots are selected for safety improvement based on high accident counts alone, the effects of the treatment will be overestimated, as a natural random decrease in the number of accidents will be wrongly attributed to the treatment.

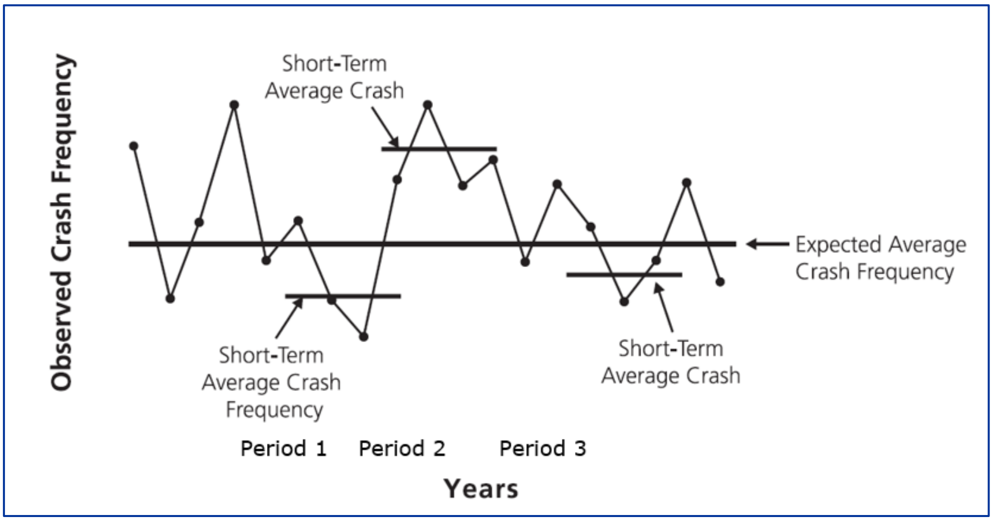


Figure 2-1: Variation in short term average accident frequency at a particular site (AASHTO, 2010)

2.1.5 ACCIDENT PREDICTION MODELLING

Accident prediction models relate the number of accidents to a measure of exposure (traffic volume or vehicle-kilometres of travel) and several variables describing characteristics of the road site (geometry, traffic control). To ensure that the predicted accident numbers are non-negative, a multiplicative model form is used. The general model form can be written as follows:

$$A_{pre} = \text{constant} \times f(\text{exposure}) \times AMF_1 \times AMF_2 \times \ldots$$

where:
A_{pre} = predicted number of accidents per year at the site,
***f*(exposure)** = a function of traffic volume or vehicle-kilometres,
AMF_i = accident modification factor i which reflects local site characteristic (*i*).

This accident prediction model is sometimes called the "safety performance function". Development of a good accident prediction model is difficult. A review of the methodological problems involved is presented in Elvik (2007). The general form of an accident prediction model for a road segment is:

$$A_{pre} = \alpha Q^{\beta} e^{\sum \gamma_i x_i}$$

where:
Q = traffic volume (AADT) at the site,
x_i = set of risk factors associated with the site,
α, β, γ_i = model parameters.

For road section models, model variables (i.e. the number of accidents) are normalised and expressed per unit of road length (km). This normalisation applies also to the overdispersion parameter φ.

For intersections, another form of the model can be more appropriate:

$$A_{pre} = \alpha Q_1^{\beta_1} Q_2^{\beta_2} e^{\sum \gamma_i x_i}$$

where:

Q_1 = first traffic volume (e.g. major road) entering the intersection,

Q_2 = second traffic volume (e.g. minor road or pedestrian) at the intersection,

x_i = set of risk factors associated with the site,

α, β_1, β_2, γ_i = model parameters.

Both models can be calibrated using multiple linear regression after taking logarithms from both sides of the equation. Figure 2-2 presents an example of such an intersection model, taken from the US Highway Safety Manual (HSM; AASHTO, 2010). The model represents accident frequency (accidents plus property-damage-only collisions) for a typical urban four-leg signalised intersection in the United States as a function of major and minor road traffic volume at the site (AADT). To account for local conditions, accident modification factors (called crash modification factors in the HSM) are used.

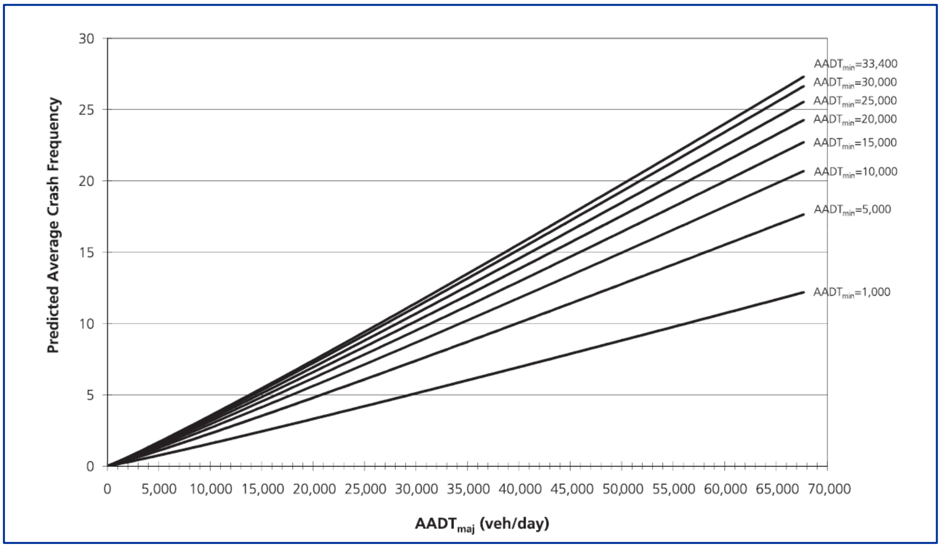


Figure 2-2: Accident prediction model (per year) for a four-leg signalised intersection (AASHTO, 2010)

2.2 Sources of accident data

2.2.1 NATIONAL ACCIDENT DATABASES

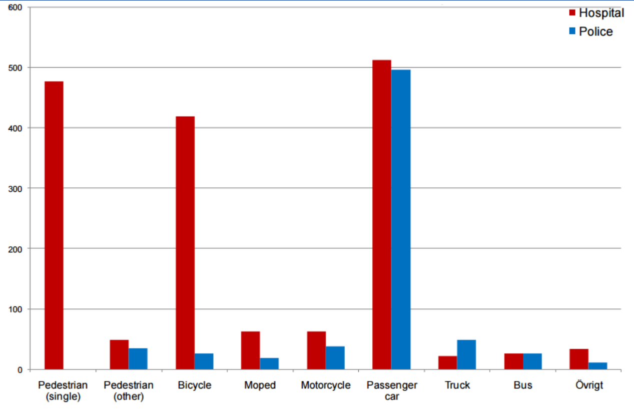
In most countries, road accident data are collected and maintained by the police, and in some countries also by hospitals (Denmark, the Netherlands, Greece, Sweden, Spain, Slovenia) or by governmental organisations (the Netherlands, Belgium, Portugal, Hungary) (ETSC, 2006). The Swedish STRADA (Swedish Traffic Accident Data Acquisition) system, based on Geographic Information Systems (GIS), contains information about accidents from both the police and hospitals. A useful link for finding the sources of information in this respect is: https://ec.europa.eu/transport/road_safety/specialist/erso/important-links_en

A data linkage project using data from various sources, such as emergency hospital and ambulance services, fire services, forensic services, mortality records and information from insurance companies has been developed in the Netherlands (IRTAD, 2011). Another good example of a national database is FARS (Fatality Analysis Reporting System), created for the USA. It is a disaggregated database providing detailed information on traffic accidents with open access to raw data files.

Swedish Traffic Accident Data Acquisition (STRADA)

The Swedish national information system STRADA contains data on road accidents and injuries, based on information from reports provided by the police and medical reports provided by the hospitals. STRADA was implemented in cooperation with the Swedish Police, the Federation of Swedish County Councils, the National Board of Health and Welfare, the Swedish Association of Local Authorities, the Swedish Institute for Transport and Communications Analysis (SIKA) and Statistics Sweden (SCB). The Swedish Transport Agency is the authority responsible for STRADA.

Registration in STRADA is mandatory for the police and for hospitals. Nationwide reporting to STRADA by the police has been carried out continuously since 2003. In 2012, 19 of 21 counties had all hospitals registered in the system (in total, 68 hospitals were registered in STRADA in 2012). The data entered by the police and hospitals into STRADA are then matched, which results in more detailed information on traffic accidents. In 2013, about 30% of all injured persons registered by the hospitals were also registered in police databases. In hospital databases, injuries are coded using the Abbreviated Injury Scale (AIS), Maximum Abbreviated Injury Scale (MAIS), Injury Severity Score (ISS), International Classification of Diseases (ICD 10) and Reaction Level Scale (RLS). Information from STRADA is used by national, regional and local authorities and by road safety researchers.



Number of injured persons in the County of Värmland reported from the police and from hospitals, and type of road user (2011) (Swedish Transport Agency, 2012)

2.2.2 INTERNATIONAL ACCIDENT DATABASES

There are several international accident databases:

- **CARE** (Community Road Accident Database for Europe);
- **IRTAD** (International Road Traffic and Accident Database) – see below;
- **Eurostat database** – contains statistical data on persons killed in road accidents aggregated by countries; the data is provided by EU member states;
- **UNECE** (Economic Commission for Europe) **Statistical Database** - contains information on persons killed or injured in road traffic accidents aggregated by country, category of user, accident type, age group and time of accident;
- The **WHO** (World Health Organization) **Mortality Database** – is a source of information on traffic fatalities aggregated by country, year, sex and age. The data are provided by member states from their civil registration systems since 1979 and safety reports are published. However, the reports present only an overall view of road fatalities. Access to the database is open and possible via the WHO website. A special application can be used to perform the analysis or the raw data files can be downloaded directly from the website.

A comparison of databases and their accessibility is presented in Table 2-3.

Table 2-3: Comparison of international databases

Database	CARE	IRTAD	Eurostat database	UNECE statistical database	The WHO mortality database
Coverage	EU countries	32 OECD countries	EU countries	56 UNECE countries	182 countries
Access	limited	open	open	open	open
Type of data	disaggregated	aggregated	aggregated	aggregated	aggregated
Information on VRU accidents	yes	yes	no	yes	no
Exposure data	none	vehicle kilometres	none	population vehicle fleet	population

CARE is a disaggregated database, which contains information on individual accidents provided by countries in Common Accident Dataset (CADaS) format. Permission from the EC is required to access the database: https://ec.europa.eu/transport/road_safety/specialist/statistics_en

The following classes of information are collected in the CARE database (IDABC, 2004):

- Person class (road user type: pedestrian, driver, passenger);
- Gender;
- Age group;
- Vehicle group;
- Area type;
- Road class;
- Junctions;
- Accident type;
- Lighting conditions;
- Weather conditions;
- Time of accident.

The disaggregation of data enables more detailed and broader safety analysis. However, the lack of exposure data, some differences in injury severity definitions and gaps in the accident information provided by countries limit benchmarking studies.

The Common Accident Dataset (CADaS)

CADaS was developed to provide a common framework for road accident data collection in Europe. The minimum data elements selected for CADaS were based on extensive research on data sources and systems available in 25 European countries, as well as stakeholders' needs and priorities for accident data analysis at the national level (Yannis et al., 2008). The data elements of CADaS were finalised after more than four years of consultations with road safety data experts and are currently being applied in the European CARE database. The resulting common dataset was reviewed by experts and practitioners in several countries and revised for relevance and feasibility. The purpose of implementing this common dataset was to help countries to improve and standardise their own road accident databases.

CADaS glossary contains detailed information on variables which should be provided to the CARE database. http://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/statistics/cadas_glossary.pdf

The International Road Traffic and Accident Database (IRTAD) collects and aggregates international data on road accidents from 32 OECD countries. The IRTAD includes safety and traffic data, aggregated by country and year from 1970 to the present. All data are provided in a common format, based on the definitions developed and agreed by the IRTAD Group. Most of the IRTAD data can be found in IRTAD's Road Safety Annual Reports. Online access to the full IRTAD database is available for subscribers via the OECD statistics portal. The IRTAD database contains the following categories of information, including exposure data:

Accident data: fatalities, injury accidents, hospitalized victims, injuries by:

- road type (motorways, urban roads, rural roads);
- road user (pedestrians, cyclists, car occupants, powered two-wheelers (PTWs), other);
- age;
- gender;
- seat position in the car.

Exposure data:

- vehicle-kilometres;
- modal split;
- vehicle fleet, by type of vehicles;
- population;
- driving licence holders.

Other safety data:

- seatbelt-wearing rates;
- helmet-wearing rates.

Although the IRTAD database is aggregated and enables the analysis of trends in VRU accidents by type of road user, gender and age, it is impossible to perform accident causation analyses on the basis of these data.

European Commission Road Safety Statistics

In order to support road safety research in Europe, the web-based Road Safety Knowledge System has been developed within the DaCoTA research project (Yannis et al., 2016). The system contains not only accident data but also exposure, safety performance and socioeconomic indicators, as well as information on road user attitudes and traffic laws and regulations. These data are used in road safety analysis to produce Basic Fact Sheets and annual statistical reports. Since 2012, the data are available on the EC Mobility and Transport webpage (European Commission, 2017) and are currently being further developed by the DaCoTA research group.

2.2.3 PROBLEM OF DATA HARMONISATION

International databases such as CARE are created with the goal of harmonising accident information between countries to make international comparisons more meaningful. However, in most EU countries there is a lack of detailed information about the collision type (manoeuvres), and there are also different subcategories of junction type. National accident data collection systems across the EU use the CADaS format on a voluntary basis. There are a lot of differences between the national databases, and some values and variables may not be compatible with the CADaS format. Data transformations are very often difficult, which explains why many entries in the CARE database are currently classified as “not available” or “other”.

The definition criteria used to classify injury severity vary from country to country and only fatalities can be included in benchmarking studies.

The CARE definitions of injury severity

Injury road accident – incident on a public road involving at least one moving vehicle and at least one casualty (person injured or killed)

Fatally injured – death within 30 days of the road accident, confirmed suicide and natural death are not included

Injured – road user seriously or slightly injured (but not killed within 30 days) in the road accident

Seriously injured – injured (although not killed) in the road accident and hospitalized at least 24 hours

Slightly injured – injured (although not killed) in the road accident and hospitalized less than 24 hours or not hospitalized

Not injured – person participating in the accident although not injured

At present, there is an attempt to harmonize the definitions of traffic accident injury severity by using one of the medical injury scales:

- Abbreviated Injury Scale (AIS);
- Maximum Abbreviated Injury Scale (MAIS);
- Injury Severity Score (ISS);
- New Injury Severity Score (NISS).

As a result of the work of experts and public consultations (IRTAD 2011), the European Commission recommended using the MAIS3+ scale to determine the number of serious injuries (European Commision, 2013). As from 2015, Member States started to report data on serious injuries based on this scale. This was a milestone in the work addressing the problem of serious road traffic accidents as injuries classified as MAIS 3+ cause most long term damage and consequences.

Definitions of injury severity according to medical injury scales

Abbreviated Injury Scale (AIS) is a medical scale describing the severity of injury for each of nine regions of the body as: 1 Minor, 2 Moderate, 3 Serious, 4 Severe, 5 Critical, 6 Unsurvivable. The body regions are: 1 Head, 2 Face, 3 Neck, 4 Thorax, 5 Abdomen, 6 Spine, 7 Upper Extremity, 8 Lower Extremity, 9 External and other.

Maximum Abbreviated Injury Scale (MAIS) is the maximum of the AIS scores for all regions of the body.

"MAIS 3+" - MAIS with the score 3 or more is now used for the definition of serious injuries. The European Commission adopted MAIS 3+ as a common scale score among EU countries for serious road traffic injuries instead of non-medical definitions based on the length of hospital stay or need for hospital treatment.

Some researchers advocate using **the disability-adjusted life years (DALYs)** to rate injury severity. DALY expresses the number of life years lost due to ill-health, disability or early death. It conveys additional information about the influence of an accident on the future life of the person involved in the accident.

2.2.4 PROBLEM OF UNDERREPORTING

Misreporting and underreporting largely occur because, in most EU countries, the national road traffic injury databases are based on police reports only (European Commission, 2013). However, the police are not called to every traffic accident and cannot be expected to perform a medical diagnosis; their assessment of injuries is only a rough on-the-spot estimation. This initial assessment by the police is not always checked against subsequent medical reports about injury severity. Many studies (e.g. Alsop & Langley, 2001; Amoros et al., 2006) confirmed that underreporting varied with injury severity and road user type. Cyclist victims have the lowest probability of being police-reported (especially when involved in single-user accidents), followed by pedestrians and motorcyclists.

Thus, it can be concluded that police records are generally biased against VRU victims. Because of the incompleteness of police databases, the records collected by the police are being combined with hospital records in some countries (e.g. the STRADA system in Sweden). This approach is the most appropriate way to capture the underreporting of serious and slight injuries.

2.3 When to conduct accident data analysis?

The needs for accident data analysis vary depending on the geographical scale (country, region, city, local area, specific site) and time period considered (long-term, short-term). In general, the following possible objectives of safety assessment are:

- overview of the road safety situation in the area, diagnosis and identification of the most serious problems;
- benchmarking or comparing the safety situation among countries or cities;
- monitoring how the road safety situation changes in time;
- identification of hazardous locations as part of black spot management or network safety management;
- before-and-after evaluation when implementing some safety treatment;
- detailed site analysis of hazardous locations earmarked for treatment.

Table 2-4 presents the analytical tools suitable for different types of studies and different assessment objectives. Detailed descriptions of the tools and examples will be provided in the next section.

Table 2-4: Tools suitable for different safety assessment objectives

Objective of assessment	Tools				
	General traffic safety reports	Black spot analysis	Network safety analysis	Accident prediction modelling	Collision diagram analysis
Overview of safety situation	V				
Monitoring of trends	V		V		
Identification of critical locations		V	V	V	
Before-and-after evaluation	V			V	V
Detailed site analysis	V	V			V

2.4 How to conduct accident data analysis?

2.4.1 GENERAL TRAFFIC SAFETY REPORTS

General traffic safety reports are routinely prepared by road authorities or the police in most countries and regions at regular time intervals, typically every year. They provide an overview of the road safety situation in the area under consideration, using descriptive statistics. The reports also identify time trends and specific problems, such as the situation of VRUs. These studies are based on police accident records and therefore the results are biased, owing to the well-known problems with police data as described above. However, general traffic safety reports provide an overview of the road safety situation and should form the basis of any safety assessment.

Steps in preparing a general traffic safety report
1. Define the area of interest, time period (years) and types of accidents to be examined. 2. List the variables needed for analysis (e.g. injury severity, road user type, accident location, road type, vehicle type, victim's age and gender, etc.). 3. Obtain disaggregate accident data as specified above (if available) or request tabulations below from database administrator. 4. Perform cross-tabulations (e.g. injury severity by location) and frequency distributions (e.g. victims by age and gender). 5. Produce diagrams and charts. 6. Draw conclusions (assess time trends, identify problem areas).

The European Road Safety Observatory publishes yearly reports (European Commission, 2015) that present general traffic safety facts in EU countries concerning various road transport modes and user groups. Three of these reports focus on VRU user groups: pedestrians, cyclists and motorcycle/moped (PTW) riders. The reports are based on analysis of the CARE database and are very good examples of general traffic safety reports.

Accident frequencies and accident rates can be presented in various forms as tables, graphs and maps. These can show time trends, distributions of accidents by type, severity, circumstances and victim characteristics. Such tabulations and graphs can point to the problems and safety-critical issues. While the exact causes of accidents cannot be determined, the contributing factors can often be deduced.

As an example, Figure 2-3 shows the trends in VRU fatalities in 28 EU countries since the year 2000. While pedestrians comprise most VRU fatalities, they also show the biggest decrease in the number of accident victims. The number of motorcyclists killed in EU peaked in 2007, steadily decreasing since then. In percentage terms, the biggest improvement in 13 years is for moped riders. For cyclists, a steady decrease in the number of fatalities was observed between 2000 and 2010, but since then there has been practically no decrease.

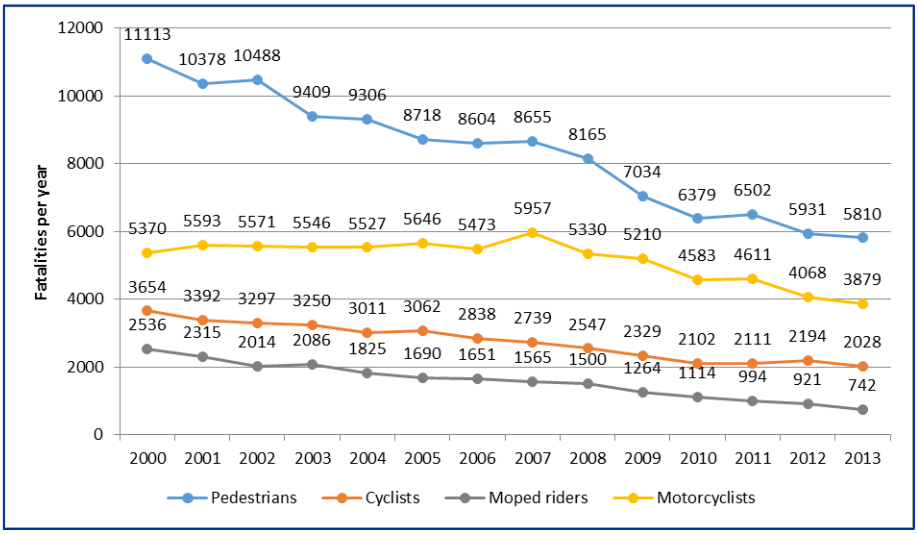


Figure 2-3: Trends in VRU fatalities in 28 EU countries (based on IRTAD database, years 2000-2013)

Figure 2-4 presents the distribution of road fatalities in 28 EU countries according to road user type (2009–2013). VRUs constitute 46% of all fatalities, pedestrians having the largest share, followed by motorcyclists, pedal cyclists and moped riders.

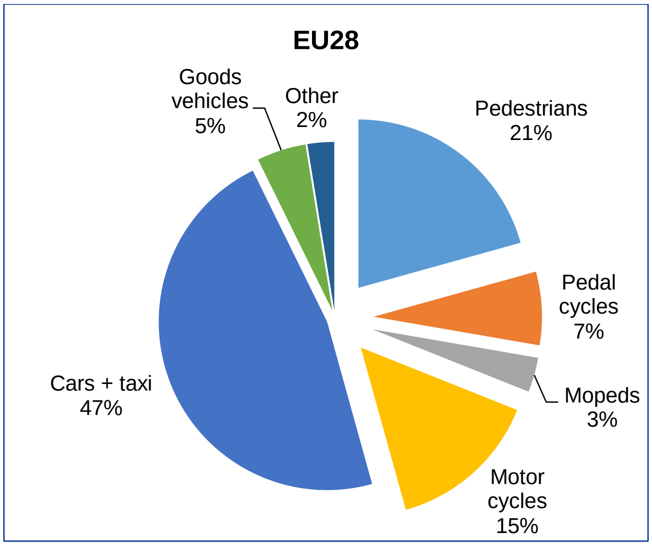


Figure 2-4: Distribution of road fatalities in EU according to road user type (based on CARE database, years 2009-2013)

Figure 2-5 shows the comparison of VRU fatality rates in selected EU countries according to road user type (2009–2013). The rates range from one to 10 persons killed per million population per year. Among the countries compared, the lowest fatality rates are in Sweden, the Netherlands (except for cyclists) and Denmark (except for pedestrians). Spain, Germany and Belgium have the highest fatality rates for pedestrians, motorcyclists and cyclists. Moped riders have the lowest fatality rates.

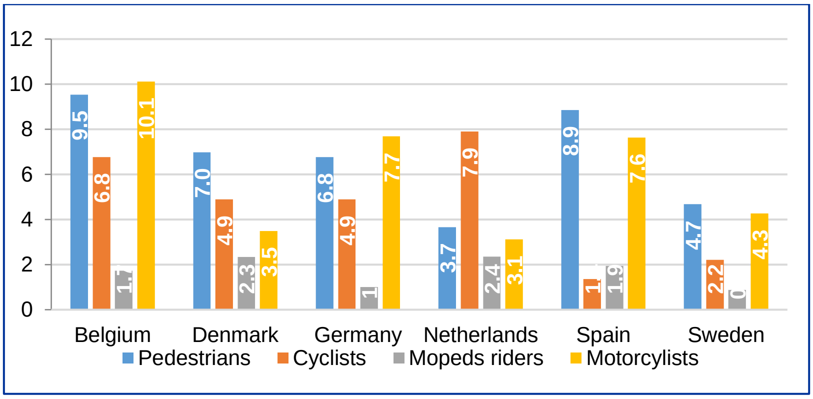


Figure 2-5: VRU fatality rates (fatalities/1 million population/year) in selected EU countries (based on CARE database, years 2009-2013)

Figure 2-6 shows the distribution of VRU fatalities in 28 EU countries by victim's age and road user type (2009–2015). As may be clearly seen, the elderly (65+ years) form a disproportionally high share of fatalities among both pedestrians and cyclists. Another striking figure is the high share of older teenagers (15–17 years) among the fatally injured moped riders.

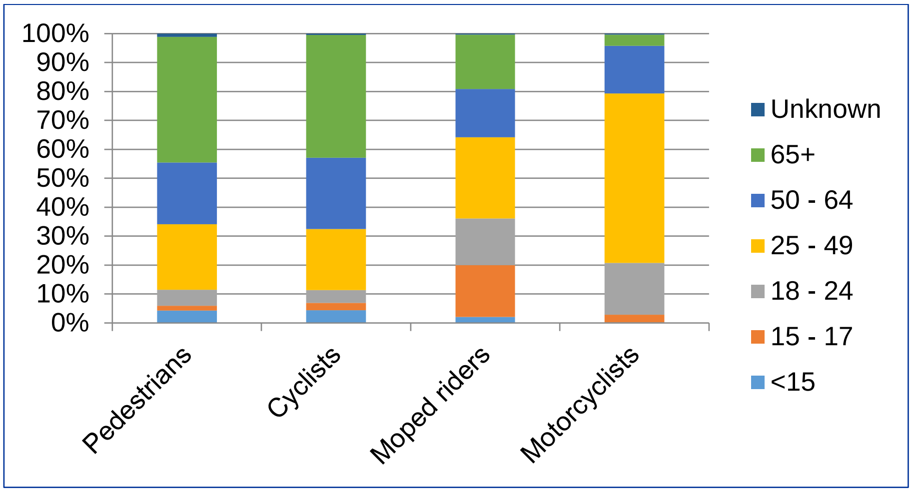


Figure 2-6: Distributions of VRU fatalities by age in EU28 countries (based on CARE database, years 2009 – 2015)

2.4.2 BLACK SPOT MANAGEMENT

Black spot analysis (or, more generally, black spot management, BSM) has a long tradition in traffic safety studies performed by road administration authorities. In most cases, the identification of black spot locations (also known as accident hotspot locations, high-risk locations) is the first and arguably most important step of the safety management process (Qu & Meng, 2014). This type of analysis usually involves the identification, analysis and treatment of black spots (including before-and-after studies). However, both the current approaches and the quality of BSM differ from country to country. Definitions of black spots used in some European countries were presented in the Ripcord report (Elvik & Sørensen, 2007), "Best Practice Guidelines on Black Spot Management and Safety Analysis of Road Networks".

Accident black spots are usually defined as road locations with a (relatively) high accident potential or locations with a higher expected number of accidents than other similar locations (intersections or short road sections, less than 0.5 km long). Elvik (2007) described a state-of-the-art approach to road accident black spot management and proposed a theoretical definition of a black spot: "A road accident black spot is any location that has a higher expected number of accidents than other similar locations as a result of a local risk factor".

The main conclusions of the Ripcord study (Elvik, 2007) are the following:

- Black spots should be identified in terms of the expected (not recorded) number of accidents and by reference to a clearly defined population of similar sites (whose members can in principle be enumerated).
- To estimate the expected number of accidents, multivariate accident prediction models should be developed (combining the recorded number of accidents with the model estimated for the site produces the best estimate).
- The evaluation of the effects of black spot treatment should employ the empirical Bayes before-and-after design.

Steps in identification of hazardous locations (black spots or segments)
1. Define the set of sites (intersections or road segments) to be examined. 2. Obtain historical data on accidents of interest (e.g. accidents with VRUs) for these sites. Analyse accident count distribution. 3. Calculate the predicted number of accidents for each site using an appropriate accident prediction model (Safety Performance Function – see e.g. Highway Safety Manual, AASHTO 2010) for similar sites. 4. Estimate the expected number of accidents for each site applying the Empirical Bayes Method (see section 2.4.4), making use of both the observed and predicted accident numbers. 5. Identify the hazardous sites as those with the highest expected numbers of accidents.

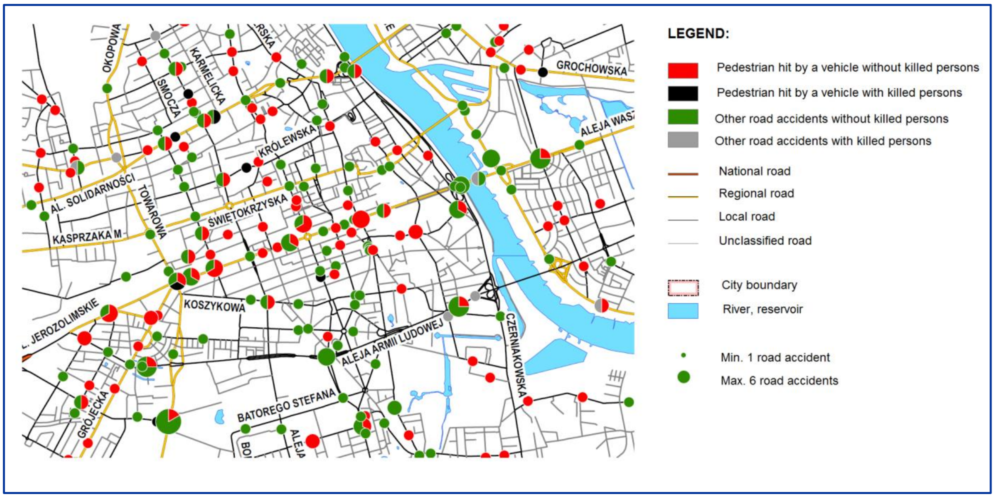


Figure 2-7: Accident map for year 2015, Warsaw (adopted from www.zdm.waw.pl)

2.4.3 ROAD NETWORK SAFETY ANALYSIS

In order to identify the safety deficits in a road network, it is necessary to perform section-specific accident analyses – also termed network safety management (NSM). The EU prescribes NSM as part of a comprehensive system of road infrastructure safety management (European Parliament and European Council, 2008). These analyses form the basis for road safety improvements at all levels. However, the standards of road network safety analyses in particular EU countries differ considerably. Another problem is that an important part of the analyses does not take VRUs into account.

In a review of international publications about NSM, Sørensen (2007) counted more than 20 different terms used to rate road segments, for example: hazardous road sections, dangerous roads or problem roads, accident-prone locations, and roads with safety potential. The most common and frequently used term for road sections identified in NSM was hazardous road section. Similarly to a black spot, a hazardous road section can be defined as any section at which the site-specific expected number of accidents is higher than for similar sections, owing to local and section-based risk factors present at the site. In addition, this definition should include not only the number of accidents but also their severity.

Elvik (2008) compared five techniques of road network safety analysis, including using recorded numbers of accidents and accident rates (per million vehicle-kilometres) during a specific period. He concluded that hazardous road locations are most reliably identified by applying the empirical Bayes technique.

EuroRAP/iRAP is a validated network safety management tool, which rates the safety of roads for different road user types including VRUs. The EuroRAP methodology provides a structure for measuring and managing road safety risk. The EuroRAP programme (Elvik & Sørensen, 2007; EuroRAP, 2018) has developed four standardised protocols for showing the safety level of a road, expressed in common terms that everyone can understand. These protocols are risk mapping, performance tracking, star rating and safer road investment plans (EuroRAP, 2018; iRAP, 2018).

The risk mapping protocol is based on real accident and traffic flow data and therefore can be considered a variation of network safety analysis. Colour-coded maps show the safety performance of each road in terms of accident density, i.e. the rate at which road users are being killed or seriously injured. The exposure measures used include: km of road length, km travelled, costs per road km and per km travelled, and the potential savings per road km and per km travelled. Risk is depicted in colour-coded bands from high (black), through medium-high (red), medium (orange), low-medium (yellow) to low (green). The performance tracking protocol is related to the risk mapping protocol as it uses the data compiled for consecutive risk maps to assess how risk on individual road sections or the road network as a whole evolves over time (EuroRAP, 2018; iRAP, 2018). Performance tracking can be used as a means to measure whether or not investments in safer roads had the desired effect. In that respect, governments and funding agencies can use this protocol as an objective measure to assess the effectiveness of infrastructural measures and investments (EuroRAP, 2018; iRAP, 2018).

The third protocol, star rating, uses road inspection data to provide a clear and objective measure of the safety level of roads for all types of road users (vehicle occupants, motorcyclists, pedestrians and cyclists) (EuroRAP, 2018; iRAP, 2018). The safety level is expressed by means of a colour code ranging from one to five stars, in which five-star roads (green) are the safest and one-star roads (black) are the least safe. An advantage is that these star ratings can be conducted without using detailed accident data. Instead, more than 50 different road features, known to influence accident occurrence and injury risk, are collected during on-site inspections. These features are for example related to intersection design, road markings, roadside hazards, footpaths and bicycle lanes (EuroRAP, 2018; iRAP, 2018). The last protocol, safer road investment plans, identifies how fatal and severe injuries can be improved in a cost effective way (EuroRAP, 2018; iRAP, 2018). These plans consider proven and affordable road improvements ranging from low-cost road markings and pedestrian refuges to higher-cost intersection upgrades (EuroRAP, 2018; iRAP, 2018).

The EuroRAP/iRAP methodology is widely recommended by international organisations to all countries and is already used in the best performing EU countries. Specifically for VRUs, Cycle RAP and School Star Rating for Schools have also been made available within the EuroRAP/iRAP programme.

More information about the iRAP/EuroRAP protocols

For further reading on this subject, we refer to some interesting references such as:

- Overview of the four iRAP protocols: https://www.irap.org/how-we-can-help/
- Overview of the four EuroRAP protocols: https://www.eurorap.org/protocols/
- Overview of iRAP/EuroRAP casestudies: https://www.vaccinesforroads.org/case-studies-of-success/

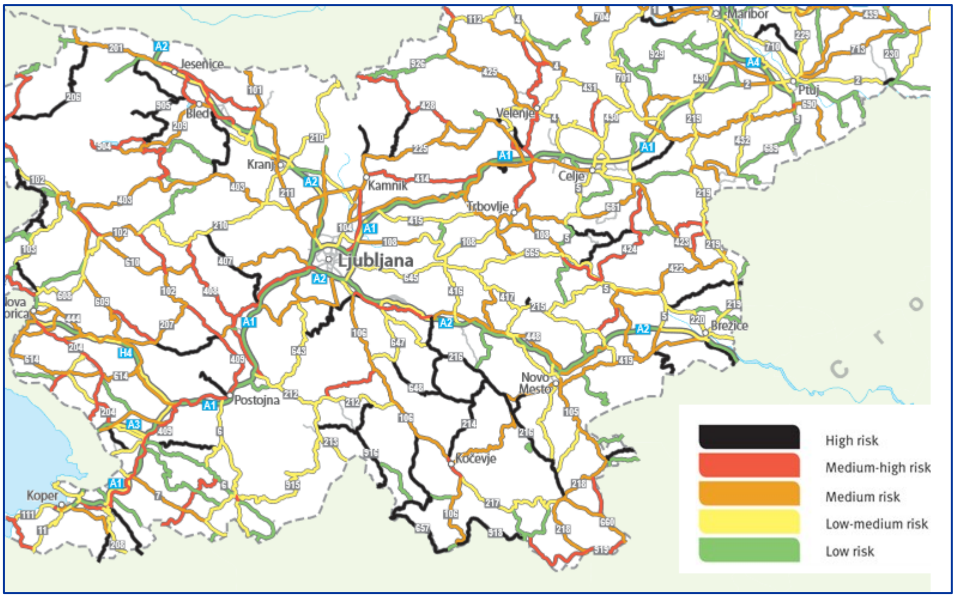


Figure 2-8: Network Map: EuroRAP risk map for Slovenia (adopted from www.eurorap.org)

2.4.4 EMPIRICAL BAYES METHOD

The Empirical Bayes (EB) method has been found to represent the current state-of-the-art approach to both black spot identification and network safety management. The method was developed by Erza Hauer (1997) and has been widely used in the USA and implemented in the US Highway Safety Manual (AASHTO, 2010). Key elements of the method are the following:

- The EB method combines the accident count at a specific site in the most recent years with an estimate of the expected annual number of accidents, based on the accident history of similar sites.
- Black spots should be identified in terms of the expected number of accidents, not the observed number of accidents.
- To estimate the expected number of accidents, accident prediction models based on independent variables should be developed.

Application of the Empirical Bayes method involves calculation of the expected number of accidents for a single site by combining the observed number of accidents with the number estimated, using the accident prediction model. In the case of road segments, both the predicted and observed accident numbers are normalised for unit road length (i.e. expressed as accidents per kilometre). The result is a linear combination of the two numbers: the observed and the predicted number of accidents. The two numbers are multiplied by respective weights: w and (1-w) as follows:

$$E(A) = wA_{pre} + (1 - w)A_{obs}$$

where:
E(*A*) = estimated expected number of accidents per year,
A_{pre} = number of accidents per year predicted by the accident model for similar sites,
A_{obs} = number of accidents per year observed at the site,
w = statistical weight.

The statistical weight w is calculated as follows:

$$w = \frac{1}{1 + Y\varphi A_{pre}}$$

where:
Y = number of years for which accident observations are made,
φ = overdispersion parameter associated with the accident prediction model (see section 2.1.3).

The value of w varies between 0 and 1.0. The weight controls the relative importance of model predictions versus the recorded number of accidents. If many years of observations are used (high Y number), w will be smaller and thus more emphasis will be given to A_{obs}. If data used to calibrate the accident prediction model show little dispersion (low φ value), w will be larger, as in this situation we have more confidence in the model.

The EB method approach makes it possible to provide unbiased estimates of the number of accidents expected in the long term at a particular site, such as an intersection or a road segment. It eliminates the bias in the observed number of accidents due to random fluctuations, which is known as the regression-to-the mean effect.

Example of EB method application

Consider a three-leg rural intersection where 10 accidents were recorded in the last three years. The following model was calibrated for a group of similar intersections to predict the number of accidents per year:

$$A_{pre} = 6.54\times10^{-5}\times Q_1^{0.82}\times Q_2^{0.51}\times AMF$$

For our intersection, Q_1 (major road AADT) is 4000 veh/day, Q_2 (minor road AADT) is 500 veh/day and AMF to account for local differences from nominal conditions is 1.27. The value of overdispersion parameter φ for this type of intersection is given as 0.313.

1) Predicted number of accidents per year:

$$A_{pre} = 6.54\times10^{-5}\times4000^{0.82}\times500^{0.51}\times1.27 = 1.78$$

In the three years for which accidents are recorded we would expect: 3×1.78 = 5.34 accidents.

2) The statistical weight w is calculated as:

$$w = \frac{1}{1 + 3 \times 0.313 \times 1.78} = 0.375$$

3) Estimated expected number of accidents:

$$E(A) = 0.375A_{pre} + (1 - 0.375)A_{obs}$$

$E(A) = 0.375 \times 5.34 + 0.625 \times 10 = 8.25$ accidents in 3 years or 2.75 accidents per year. The standard deviation of the estimate is: $s_e = (0.625\times2.75)^{0.5} = 1.31$. Thus, the expected accident frequency at this intersection is: 2.75 ± 1.31 per year.
We note that the estimate is between the observed number for this site (3.33) and the average for similar sites (1.78). The EB estimator pulls the accident frequency towards the predicted mean and therefore corrects the regression-to-the-mean bias.

2.4.5 COLLISION DIAGRAM ANALYSIS

Collision diagrams provide a visual representation of accident data at a given location (intersection, road segment) to illustrate how each accident happened. They use symbols to denote different accident types, their locations and manoeuvres of vehicles involved. These allow traffic safety engineers to determine the main accident causes, identify specific accident factors and pick locations to install new safety measures. It is possible then to go from the network level analysis to viewing the actual accident reports for individual accidents.

Collision diagram analysis is often used for further detailed investigation of hazardous locations identified as part of the black spot management process. It usually involves the following stages:

1. Preparation of a collision diagram which should show the road geometry, the location of all accidents, their types and severity, as well as movements of vehicles involved (see Figure 2-9 for an example).

2. Preparation of a “condition diagram”, showing the traffic layout plan, including location of traffic signs and markings, pedestrian crossings, traffic signals, bus stops and parking spaces.
3. Site visit to check local conditions such as visibility, location of obstructions and fixed objects, pavement condition (e.g. skid resistance).
4. Preparation of a traffic safety improvement plan including the proposed remedial actions.

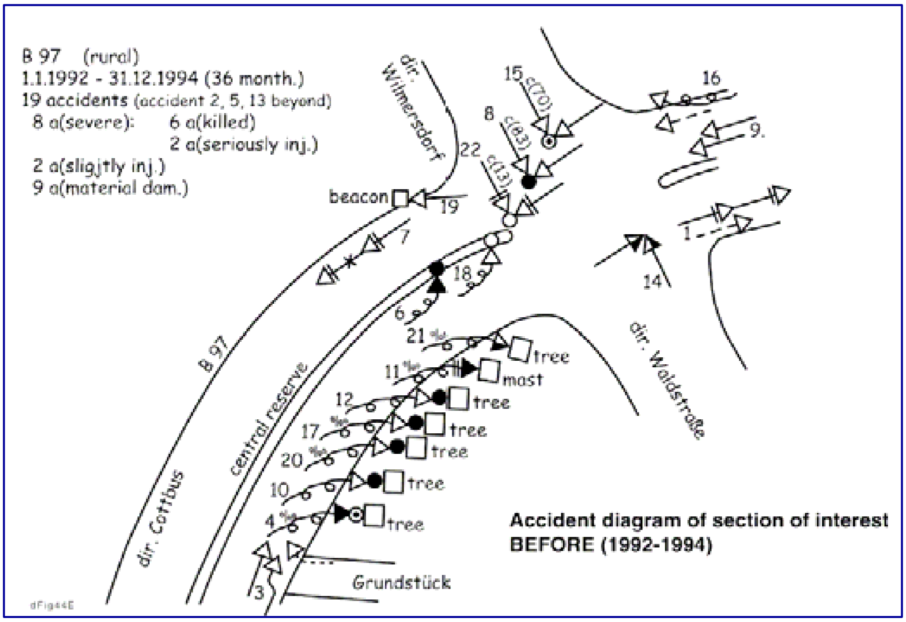


Figure 2-9: Example of a collision diagram – Germany (PIARC, 2015)

2.4.6 IN-DEPTH ACCIDENT CAUSATION STUDIES

In-depth accident causation studies are aimed at collecting data and identifying, usually by means of on-scene visits, the contributing factors that have played a role in the process leading towards a specific accident and to store the collected data in an accident causation database for post-hoc accident causation analysis. The approach originally stems from air crash investigations where the systematic in-depth investigation and analysis of plane crashes was already widely adopted.

In an on-road in-depth accident causation investigation, typically a multi-disciplinary team of investigators carries out an ‘on-scene’ or ‘nearly on-scene’ visit immediately (or shortly) after the accident to collect data, i.e. to conduct vehicle and road inspections as well as interviews with crash participants. Additionally, the use of advanced accident simulation models can help to understand the dynamics, process and stages of the accident leading to a certain accident outcome.

Already in the 1990s, the vehicle manufacturing sector set up in-depth accident investigations under the umbrella of European funded projects, including for example the European Accident Causation Study (EACS), the Motorcycle Accident In-depth Study (MAIDS), and the European Truck Accident Causation (ETAC) Study. However, given the variety of methods and difference in approaches between different countries and different transport modes, the EU FP6 SafetyNet project came up with a set of best-practice recommendations for in-depth accident causation studies and a suggested methodology (SNACS), as well as the development of a structure for an accident causation database (See Thomas et al., 2009).

Although in-depth accident causation studies can be a very effective way to gain a deeper understanding in the potentially contributing factors of road accidents, they have sometimes been criticized for their cost efficiency, which in several European Member States has led to difficulties in their systematic adoption.

More information about in-depth accident causation studies

For further reading on this subject, we refer to some interesting references such as:

- the UK RAIDS on the spot pedestrian study (https://www.gov.uk/government/publications/road-accident-investigation-road-accident-in-depth-studies/road-accident-in-depth-studies-raids);
- the German In-Depth Accident Study (GIDAS) (https://www.bast.de/BASt_2017/EN/Automotive_Engineering/Subjetcs/gidas.html);
- the DaCoTA on-line manual for in-depth road accident investigators (http://www.dacota-project.eu/deliverables.html).

2.5 Interpretation of results

Road traffic accidents are random events and therefore their counts should be analysed with proper statistical tools and always interpreted with caution. Any estimates and predictions based on accident counts are subject to a statistical error, and the relative magnitude of this error increases as the accident counts get smaller. It is a paradox that, as the road transport system becomes safer and the accident numbers decrease, predictions and conclusions become less and less precise, as they are based on fewer accident observations. The same problem occurs if a more dedicated analysis is attempted, such as looking at a particular accident subcategory (e.g. fatal cyclist accidents at signalised intersections). This would mean looking at accidents fewer in numbers, which inevitably yields less precise results.

Results of road accident data analysis should be interpreted according to the study objectives, as listed in Table 2-4. These objectives can be grouped into two broad categories:

- Assessment and monitoring of road safety situation.
- Identification of hazardous locations and their detailed analysis.

In the first category, accident statistics for whole countries, regions or cities are used. Absolute numbers of accidents and their victims are important because they show the magnitude of the problem and indicate where most accidents occur. For the purpose of benchmarking and comparing countries or regions, accident rates are more appropriate than absolute numbers. Fatality rates calculated as the average number of fatalities per million population give an indication of the extent to which road accidents constitute a public health problem. Fatality rates expressed per million kilometres travelled can show the level of safety of different transport modes and the degree of personal safety of the different road users.

In the second category – identification and analysis of hazardous locations – the problem of random accident count variations becomes more apparent. Therefore, it is essential to use the statistical tools recommended in this chapter, namely the Empirical Bayes method, before coming to conclusions on the safety level of individual sites.

Accident statistics alone are not sufficient to assess the safety performance of a road transport system, as they do not tell us anything about the road safety policy or safety measures and treatments introduced. For that purpose, various safety performance indicators were introduced (Hakkert & Gitelman, 2007), such as: proportion of fatal accidents resulting from alcohol use, percentage of vehicles exceeding the speed limit, seat belt wearing rates, vehicle fleet crashworthiness and availability of emergency medical services. Road safety performance indicators are useful tools for policy making, as they allow information to be gathered on the effectiveness of safety interventions in specific areas.

2.6 Conclusions and key points

In every country, statistics on road accidents and injuries of their victims represent essential information for traffic safety specialists to assess the safety situation. General accident reports help to identify the time trends of accident occurrence and to compare the safety situation among countries, regions and cities. Benchmarking between countries can help monitor progress towards the targets for traffic safety improvement and to assess the relative importance of problems. Although the exact causes of accidents cannot be determined, by analysing spatial distributions of accidents and their characteristics, the factors contributing to road accidents can often be deduced.

Whereas absolute numbers of accidents and fatalities indicate the magnitude of the safety problem, accident rates are more appropriate for benchmarking and reflecting the degree of safety of the different road users. Accident rates are obtained by dividing numbers of accidents by a measure of exposure, e.g. population or vehicle-kilometres of travel. The exposure measures used should be appropriate for VRUs and include pedestrian and bicycle volumes, in addition to motorised traffic volumes.

Accident data are available from several national and international databases, such as the European CARE database. In using and interpreting these data, one should be aware of the different definitions of injury severity and accident attributes used in different countries. Efforts aimed at harmonising injury severity definitions are under way, but so far only accident fatality numbers are comparable between countries.

Identification of dangerous locations is performed using black spot analysis and/or network safety analysis. Both are important and useful for VRU safety assessment – black spots identify dangerous intersections and road crossings and network analysis identifies dangerous road links. In both cases, it is recommended to use a proper statistical method, namely the Empirical Bayes method, for identifying hazardous locations. This method makes use of both accident counts observed at a site and results from an accident prediction model for similar sites. Thus, the regression-to-the-mean bias associated with random variation of accident counts is corrected.

When drawing conclusions from accident data analysis, it should be borne in mind that road accidents are random events and therefore analysis results should always be interpreted with caution. Any estimates and predictions based on accident counts are subject to statistical error. Furthermore, accident statistics alone are not sufficient to assess the safety performance of a road transport system, as they do not reveal anything about the road safety policy or safety measures and treatments introduced. Several additional safety performance indicators are needed to get a full understanding of road safety trends.

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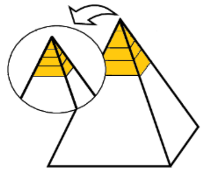


CHAPTER 3

Self-reporting of accidents and near-accidents

The focus of this chapter is the use of self-reporting for increasing knowledge about traffic safety and creating a coherent view of the actual traffic safety challenges facing the country/region/city in question. Self-reporting can be used to collect information about a larger share of all accidents than those included in the official statistics. Furthermore, self-reporting can be used for collecting detailed information directly from the road users on their involvement in less severe events, such as traffic conflicts. The method can also be used for reporting on normal behaviour.

The self-reporting of accidents is particularly useful for gaining knowledge about traffic conflicts, which are usually not registered, and about less severe accidents, such as those resulting in only minor injuries or property damage only; in both circumstances, there is a large degree of underreporting in the official statistics. However, combining police-reported accident data with hospital data remains the recommended approach for coping with the underreporting of accidents resulting in serious and fatal injuries.

Furthermore, injury severity can be included in the accident data collection process via self-reporting, although a certain amount of underreporting of severe injuries and fatalities does, of course, remain. Likewise, the information gained from self-reporting about injury severity can form a basis for socioeconomic calculations, but the same limitation exists in terms of underreporting. For both perspectives, a careful use of comparison groups can compensate for this weakness in the data type.

In this chapter, the use of self-reporting for collecting information on traffic accidents and conflicts will be described. Guidance is provided about when self-reporting is beneficial, how to collect data and how to interpret the results.

What will this chapter tell me?

- What is self-reporting?
- How can self-reporting be used to assess traffic safety?
- Why conduct studies using self-reporting?
- How can a study involving self-reporting be carried out?
- Which data are collected, and how can they be analysed?

3.1 Introduction to self-reporting

Self-reporting is a method for the collection of detailed, first-hand information about accidents and traffic conflicts from the road users involved. The aim of self-reporting is to let the road users report their accidents or near-accidents themselves. This data source can be used as a supplement to the official accident statistics, from the police or hospital records, and can potentially be used to focus on specific road user groups (e.g., cyclists or the elderly), specific topics or specific areas.

In this method of data collection, information about accidents and/or near- accidents is collected using questionnaires or by interviewing road users in order to get detailed information. For instance, information similar to that which is usually registered by the police can be collected, such as the location and time of the accident, the road and weather conditions, the people involved, a description of the accident, and the potential influencing factors at the time of the accident (e.g., fatigue, alcohol intake or phone use).

Self-reporting can either be conducted using one survey in which the respondent is asked to recall all their accidents and near-accidents for a certain period of time (e.g., within the past year) or by following the respondents for a certain period of time (e.g., the year ahead) and asking them to report accidents via multiple questionnaires that are distributed regularly (e.g., monthly or bi-monthly).

What is self-reporting?

Self-reporting is a method for the collection of detailed information about traffic accidents and conflicts directly from the road user, including when and where the incident happened, a description of the incident, who was involved and the circumstances of the incident.

The self-reporting of accidents and near-accidents also makes it possible to include information that is not part of official police reports but could be of relevance to the occurrence of the event. The collection of self-reported accidents and near-accidents is particularly interesting because it makes it possible to collect a larger share of accidents and, thus, overcome issues with underreporting and biased data. For instance, less severe accidents are often underreported compared to more severe or fatal accidents. In this way, self-reported accidents and near- accidents can contribute to better and more complete insights into the current state of traffic safety. This will enhance the ability to target all road users and accident types in all aspects of traffic safety work.

3.1.1 ADVANTAGES AND DISADVANTAGES

The self-reporting of accidents and near-accidents is a means by which to collect more data regarding traffic safety than is possible with official accident reporting alone. This makes it more likely that there will be enough data for analyses at specific locations. As opposed to the official statistics, it is also possible to collect information about near-accidents, and less severe accidents will have a higher chance of being registered. This means that this method can be used to compensate for underreporting in the official statistics and, thus, to obtain information on accidents that would otherwise remain unknown. However, accidents in which the most severe injuries and fatalities occur will often be missing in the self-reported events, as the road user is often not capable of reporting the accident for a long time, if ever. Therefore, it is beneficial to use self-reporting as a supplement to official accident data.

Self-reporting has the advantage that the information is obtained directly, without any intermediary procedures, and that the self-reports provide an opportunity to obtain information on aspects that are normally not covered in official statistics, such as the road users' well-being before the accident occurred or what the road user considered plausible accident factors. However, gaining information from the direct source can also be seen as a disadvantage of using self-reporting, as self-reports contain only the information the road user remembers, knows and decides to report. In addition, considerations for privacy and ethical issues might be an obstacle for the collection of some important parameters to link self-reports with data from other sources and to get a full overview of the accident or near-accident. Last, self-reports only contain one side of the story, which might not fully represent what actually happened.

Furthermore, self-reporting makes it possible to tailor the data collection for a specific research question or road user group and to use it as a background for the implementation of traffic safety measures. Because a larger share of all accidents are included—and there is the potential to include near-accidents for a larger data source—trends in the accident statistics will be revealed more quickly and an evaluation of specific traffic safety measures can be conducted earlier.

Why should I collect self-reported data?	
ADVANTAGES	**DISADVANTAGES**
First-hand information from the involved road user;	Accident information only obtained from one party in the accident
Lower degree of underreporting than in the official statistics;	Potential lack of ability or willingness to answer truthfully in reports
Possible to get information regarding near-accidents;	Lack of expert information – such as exact speed, road geometry
Possible to tailor the data collection for a specific research question or road user group	Privacy and ethical issues might hinder collection of some parameters
Possible to include aspects that are normally not covered in official statistics (police and/or hospital)	Fatal accidents and accidents with severe injuries will not be registered
Trends in accident statistics will be revealed at an earlier stage	
Evaluation of traffic safety measures can be conducted earlier	

3.2 When to collect self-reported accident data

Self-reported traffic accidents can, in general, provide extra knowledge and an increased amount of data in all situations where official accident statistics are used. This means that, often, analyses can be made even though the number of accidents in the official statistics is low. Hence, the method can be used for the following:

- Monitoring trends in accidents and injuries;
- Following up on traffic safety goals;
- Estimating the underreporting rate in official statistics;
- Evaluating traffic safety measures;
- Analysing accident causal factors and injury factors;
- Identifying hazardous road locations;
- Analysing accidents occurring at specific locations.

Trends in accidents and injuries over a period of time can often be difficult to find due to a low number of accidents, which makes it difficult to know whether changes in the numbers are random or founded on developments that can affect traffic safety (e.g., safer vehicles being produced). By referring to a larger data source via self-reported accidents and incidents, trends can be identified faster and with greater certainty. This also makes it possible to follow up on specific traffic safety goals for a faster assessment of whether they have been met. Similarly, self-reported accidents or near-accidents can be used to evaluate specific traffic safety measures, such as the effect that the establishment of a bicycle path on a road has on the number of car–bicycle collisions or the effect that the use of visible cycling clothing has on the number of multi-party accidents involving cyclists.

The self-reporting of accidents can be used to estimate the degree of underreporting in the official statistics from police or hospital records in order to provide better knowledge about the actual number of accidents occurring. Based on this information, it is also possible to adjust for any differences in the degree of reporting between various accident types and road user groups and, accordingly, to better prioritise how to use the available resources for traffic safety improvements.

Questionnaires for the self-reporting of accidents and near-accidents can contain questions related to factors that are normally not fully covered in the official statistics. For instance, questions regarding the behaviour and personal circumstances (e.g., the presence of stress, fatigue or inattentiveness caused by doing other activities) leading up to the accident may give insight into accident causal factors.

With the increased amount of data that is obtained via self-reporting, and particularly in cases where there is a large group of respondents in the same area, it is likely that more accidents will be registered at specific locations. This means that the identification of hazardous road locations becomes easier and that accident analyses of specific locations can be conducted.

Estimating the degree of underreporting in police records: an example

An Australian study (Boufous et al., 2010) among a cohort of young drivers (aged 17–24) used the self-reporting of on-road accidents to assess the accuracy of self-reports made by young drivers and to estimate the amount of underreporting in this age group.

Participants were recruited from a pool of newly licensed drivers in New South Wales, Australia, who were originally recruited for the Drive Project. Two years after their participation, a sample of 5,000 participants was asked to fill in an online questionnaire in which they were asked to recall and describe any traffic accidents they were involved in during the past year. In total, 2,991 out of the 20,822 DRIVE participants responded to the self-reporting questionnaire.

The results showed that the participants reported five times as many accidents via self-reporting compared to what was recorded in the police database. Furthermore, self-reporting had a high accuracy when compared to police-recorded accidents. Of the police-reported accidents, 85.1% were also self-reported by the respondents.

Evaluation of the effect of permanently running lights on bicycles: an example

A Danish study (Madsen et al., 2013) used the self-reporting of accidents to assess the safety effects of mounting permanently running lights on bicycles. In the study, a randomised controlled trial (RCT) was conducted using 3,845 bicyclists; permanently running lights were mounted at 1,845 bicycles, and the remaining participants constituted the control group. The participants were volunteers who learned about the study through the media.

Online questionnaires were distributed every second month over a period of one year, yielding a total of six questionnaires per participant. In each questionnaire, respondents were asked to recall any traffic accidents they had been involved in as cyclist during the past two months. For each accident reported in the questionnaire, detailed information was collected, such as where it happened, what happened and who was involved.

The results showed an accident rate that was 19% lower for cyclists with permanently running lights mounted on their bicycles compared to cyclists without permanently running lights.

Evaluation of the effect of cycling with a yellow bicycle jacket: an example

In a Danish study (Lahrmann et al., 2018) of the safety effect of cyclists wearing a highly visible yellow jacket when cycling, an RCT was conducted.

Volunteers (who were over the age of 18 and used their bicycle more than three times a week) were found using press releases in national media, by contacting interest groups related to traffic safety and with help from practitioners working with local authorities. The volunteers were also prompted to tell their friends about the project. Almost 12,000 signed up for the study, of whom 6,793 were included in the study. The participants were randomly divided into a treatment group, who received the bicycle jacket and had to wear it throughout the study, and a control group, who had to use their normal garments when cycling.

An online questionnaire was distributed once a month for one year, yielding twelve questionnaires per respondent in total. In the questionnaire, the respondents were asked to register information (e.g., location, who was involved and what happened) regarding their cycling accidents from the past month.

The results showed that the use of the highly visible jacket while cycling reduced the involvement in multi-party accidents by 38% compared to the control group.

Analysis of accident causal factors and injury factors: an example

In a study of elderly Dutch cyclists (de Hair et al., 2015), 879 elderly cyclists (aged 65+) completed a questionnaire with the purpose of gaining better insight into single-cyclist accidents involving elderly cyclists. Furthermore, in-depth interviews and focus group sessions were carried out.

In the questionnaire, which the respondents received either on paper or via a link to a web-based version of the questionnaire, based on their preference, the respondents were asked about their demographic information (age, gender, province and living environment), bicycle use, physical and cognitive impairments and critical cycling situations, among other things.

The results showed that slippery roads, getting on/off the bike and colliding with the curb and with limited visibility poles and other obstacles were among the most frequently reported causes for single-cyclist accidents among the elderly cyclists.

3.3 Methods for collecting self-reported traffic accidents and incidents

Self-reported accidents and incidents can be collected using various methods depending on the study objectives. Overall, there are four different methods to use for the collection of data: paper questionnaires, online questionnaires, telephone interviews and face-to-face interviews. The most commonly used method for collecting self-reports on traffic accidents is questionnaires, whether paper based, online or via a combination of the two, because the cost is low and the method is suitable for studies containing a large number of respondents. Interviews are less common and often have a higher cost per respondent, which makes them most suitable for studies involving fewer respondents. Table 3-1 provides an overview of the cost, time consumption, suitable target group and suitable sample size for each of the four methods.

Table 3-1: Overview of methods to collect self-reports of accidents

Method	Cost / respondent	Time consumption / respondent	Suitable target groups	Suitable sample size
Paper questionnaire	Medium (postage)	Medium	All except children	Large
Online questionnaire	Low	Low	All except children, but less suitable than paper for the elderly	Large
Telephone interview	High	Medium	All except children	Medium
Face-to-face interview	High	High	All	Small

3.3.1 PAPER QUESTIONNAIRE

A paper questionnaire is a basic data collection method that has been used for many years and in many fields. A questionnaire is constructed, printed and distributed to the target group. Paper questionnaires have the advantage of only needing a pen for answering the questionnaire.

A paper questionnaire can be conducted once or numerous times. Some costs will, occur every time, regardless of the number of respondents, such as printing costs and postage. Furthermore, data must be digitalised prior to data analysis. After data digitalisation, the analysis costs are identical to the costs of other data collection approaches.

Paper questionnaires are particularly useful for collecting data from road users who do not have access to a computer. Some users, however, might be reluctant to answer paper questionnaires because it requires handwriting and posting the questionnaire afterwards.

Paper questionnaires for self-reporting of accidents and near-accidents: an example

A Finnish study (Korpinen & Paakkonen, 2012) studied the impact of mobile phone use on traffic accidents and close-call situations, with a focus on mobile phone use as a potential accident causal factor.

A paper questionnaire was sent to a random sample of 15,000 Finns aged 18–65. In the questionnaire, participants were asked to recall any accidents in which they had been involved during the past year. A total of 6,121 respondents filled out the questionnaire.

The results showed that 2.8% of the respondents had been involved in an accident where mobile phone use had played a role in the escalation of a situation to an accident.

3.3.2 ONLINE QUESTIONNAIRE

Online questionnaires are similar to paper questionnaires but provide the opportunity to tailor the questionnaire based on the answers provided by the respondent. For instance, it is possible only to ask about the use of bicycle helmets if respondents have answered that they have used a bicycle. Similarly, one can include interactive maps to increase the ease with which respondents can log the location of an incident. Online questionnaires can be fitted to a variety of platforms and made as either web-based questionnaires or app-based questionnaires for tablet/smartphones.

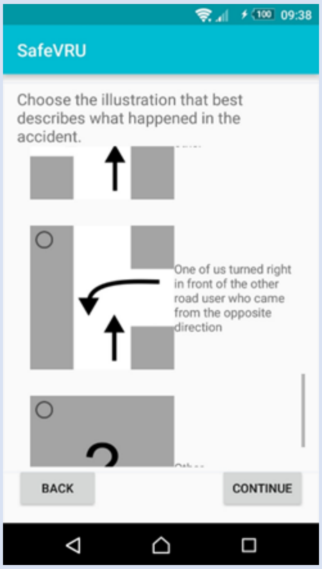
Online questionnaires are particularly useful for large studies, as this type of survey can be answered by a large number of respondents with a marginal additional cost per respondent. Furthermore, it is easy to repeat the distribution of the questionnaire multiple times to follow the respondents for a longer period of time. However, some groups might be reluctant to answer an online questionnaire due to lack of access to computer/tablet/smartphone or to the internet.

App and web based questionnaires for self-reporting of accidents and near-accidents: an example

Within the InDeV project (Madsen et al., 2018), a study was carried out to collect information about accidents and near-accidents from vulnerable road users (VRUs) in Belgium, Denmark, Spain and Sweden.

Participations were recruited through social media, by contacting interest groups related to VRUs and via practitioners working with local authorities. In the study, participants were asked to register their accidents and near-accidents as a pedestrian, cyclist or moped rider each month, during a period of nine months, via an Android app (SafeVRU, see example below) or an online questionnaire. In the app, they could register incidents in real time. A personal link to the online questionnaire was sent to each participant every month.

Each month, the participants reported whether they had been involved in an accident or near-accident. If confirming, they registered detailed information about the incident, such as its location, the type of road it occurred on, weather and road conditions, who was involved and what happened. In total, approximately 2,500 participants registered accidents and near-accidents via the app and the online questionnaire.



SaveVRU Screenshot

3.3.3 TELEPHONE INTERVIEW

A telephone interview is conducted using an interview guide with questions for the respondents to answer. The questions can either be presented as closed questions with fixed options for responses (e.g., yes/no questions) or open questions to allow for more elaborate answers (e.g., a description of the accident/incident). A telephone interview can be conducted an unlimited number of times. However, additional costs for telemarketing personnel will be added every time the survey is conducted. Typically, a respondent will only be contacted once or twice in a study.

An advantage of conducting telephone interviews is the option to clarify misunderstandings with the respondent. However, telephone interviews may imply a risk of lacking anonymity, as the interviewer knows the identity of the respondent. This can influence the responses, as there may be some things that the respondent does not want to admit to the interviewer because they may have consequences for the individual if revealed, such as conducting specific behaviour that is not permitted (e.g., drink driving).

Telephone interviews for self-reported accidents: an example

A Canadian study (Fuller et al., 2013) of the safety impact of implementing a public bicycle share programme in Montréal used the self-reporting of collisions and near- accidents.

Respondents were recruited from households with a landline telephone connection in areas that had introduced the public bicycle share program. Telephone interviews were made in three rounds, with approximately 1,000 respondents in each round. During the interview, they were asked about their cycling accidents and near-accidents in which they had collided with a motorised vehicle.

The results showed that users of the public bicycle share programme did not have a higher risk of a collision than did cyclists using their own bicycle.

3.3.4 FACE-TO-FACE INTERVIEW

Face-to-face interviews can be conducted either in groups or among individuals. Similar to telephone interviews, they are based on an interview guide, often with very open questions that leave room for discussion and elaborate answers. Face-to-face interviews are often used when children are the main target group and are useful for questions in which interactive features are useful (e.g., discussions based on map data or a demonstration of equipment used) or where it is beneficial to visit the particular site where the accident or incident happened.

Another type of face-to-face interview consists of few closed questions. This interview can be advantageous if you need information about a very limited geographical area. Road users in the area of interest can be stopped and asked a few questions before continuing their journeys.

Face-to-face interviews can be conducted once or a very limited number of times to the same target group. While the interview guide can be used an unlimited number of times, there are additional costs to personnel and travel expenses every time interviews are conducted. As with telephone interviews, the lack of anonymity and the circumstance of sitting in front of an interviewer may result in situations where respondents are likely to modify their answers to some questions, which they would not have done had they responded to an online questionnaire with no contact between the respondent and the interviewer.

Face-to-face interviews for self-reported accidents – example

In a study among Australian cyclists (De Rome et al., 2014), participants were recruited using hospital records and contacted by mail in order to arrange interviews with those who agreed to participate.

Interviews were conducted either by telephone or face to face at the hospital. During the interviews, participants were asked to provide information about their accident and injuries in order to study injury outcomes in different cycling environments.

The results showed that most participants crashed in traffic (39.1%) and on shared paths (36.1%), while fewer crashed on footpaths (16.8%) and in cycle lanes (7.9%). More than 50% of the injuries were minor, approximately 33% were moderate and just over 5% were severe.

3.4 How to collect self-reported accidents

Certain practical considerations should be kept in mind when planning a study involving the collection of self-reported accidents or incidents. These are related to the planning phase (before data are collected), the collection phase (during the data collection) and the processing of responses (after data are collected):

- What is the purpose of the study?
- Which road users are relevant for the study?
- What type of information should be registered?
- Which method should be used for self-reporting?
- How to deal with ethical and/or privacy issues?
- How to recruit participants?
- How to establish a hotline during data collection?
- How to clean the self-reported data?

3.4.1 WHAT IS THE PURPOSE OF THE STUDY?

First, the purpose of the study should be defined; what is the purpose of collecting self-reported accidents and/or near-accidents? Self-reported information can, for instance, be used to provide a larger sample than that which is possible when using official accident statistics (police and/or hospital data), to collect information about single accidents among cyclists and pedestrians and to collect information about less severe multi-party accidents and near-accidents. They can also be used to estimate the degree of underreporting in the official accident statistics. Depending on the purpose of the study, specific criteria should be set for the study design, including who are relevant as participants in the study.

3.4.2 WHICH ROAD USERS ARE RELEVANT FOR THE STUDY?

The target group must to be valid for the purpose of your study. If, for instance, you want to evaluate the implementation of a traffic safety measure targeting pedestrians, your target group will be made up of pedestrians. In contrast, if you want to collect general accident data over a long period for an entire municipality or city, the target group must represent all road users. Generally, there are two types of sampling techniques for selecting respondents for self-reporting studies: random and volunteer. For both types, specific criteria can be included (e.g., specific age groups, only road users who cycle at least three times per week or only people admitted to the hospital after road accidents within a certain period of time).

Sampling of respondents

Random: The sample of potential respondents is chosen randomly, typically using information from an administrative register. The potential respondents are then contacted directly.

Volunteers: Respondents are recruited via traditional and social media and/or specific organisations (e.g., companies or interest organisations). In this way, a lot of road users can hear about the study and have the opportunity to participate. The ones who choose voluntarily to participate in the study will be contacted. When using volunteers, it is of great importance how information about the study is spread. Contacting interest organisations, such as automotive organisations, has the potential to result in a biased group of respondents, whose behaviour may differ considerably from the behaviour of the general population.

Which type of sample should I use?		
TYPE	**ADVANTAGES**	**DISADVANTAGES**
Random	Results are easily compared with official statistics and can be extrapolated to the population in general.	Typically involves costs to the bureau administrating the register. Response rate can be quite low.
Volunteers	Higher response rate than with random samples.	Biased sample, since some groups never volunteer for studies, particularly not if they violate the traffic rules.

3.4.3 WHAT TYPE OF INFORMATION SHOULD BE REGISTERED?

The objective of the data collection is important in order to decide what kind of information should be collected via self-reporting. In Table 3-2, an overview of mandatory and optional information is given in relation to the purpose of the study. However, no comprehensive list can be given because the content of the self-report should be customised to the purpose of each individual study.

Table 3-2: Mandatory and optional information in self-reports based on the objective of the study

Purpose of the self-reporting study	Basic accident information	Demographic information on road user	Detailed accident information	Location	Detailed information on road user
Monitoring	x	(x)	(x)	(x)	(x)
Follow-up on safety goals	x	(x)	(x)	(x)	(x)
Estimating the underreporting rate	x	(x)	(x)	(x)	(x)
Evaluating measures	x			(x)	
Analysing factors	x	x	(x)		(x)
Identifying hazardous road locations	x			x	
Analysing specific locations	x		(x)	x	
x = mandatory, (x) = optional, blank = not necessary					

Basic accident information

The basic information that is always needed, regardless of a study's purpose, is the time of the accident or near-accident. This information can vary depending on the desired level of detail but usually consists of the year, month, day, hour and sometimes even minute of the events (sometimes divided into intervals of 5, 10 and 15 minutes). Furthermore, information on the type of accident (single- or multi-party), road user type, the counterpart's means of transport, injuries, type of infrastructure and other similar features can be included.

Demographic information on road users

The basic information collected about road users can include gender, age and area of residence. If data are to be compared to official accident statistics, a personal identifier is also needed. A personal identifier could come from the Civil Registration System (CRS). However, using a personal identifier from the CRS often calls for approval, according to the National Data Protection Act.

Detailed accident information

This category covers a wide list of questions. The main idea is to get as detailed information as necessary without bothering the road user with unnecessary questions.

For example, for obtaining more knowledge about accidents, information that contributes to a detailed description of what happened in the accident may be of relevance, including the manoeuvres of the involved road users, speed estimations (e.g., lower than speed limit, according to speed limit or higher than speed limit), the weather conditions, whether light poles were turned on/off and the state of the road.

However, if the objective is to gain knowledge of the cost of accidents, the questions should focus on the consequences caused by the accident. This could be information about absence from work, hospitalisation, estimates of material damage and the length of time traffic was blocked.

Location

Location, in this context, refers to fairly precise data about where the accident occurred. Preferably, this data is given in the form of GNSS (GPS) coordinates (obtained, for example, by mapping the accident or near-accident on an interactive map in the questionnaire). Alternatively, the location can be provided as an address that can then be used to map the event on the road network.

Detailed information on road users and vehicles

If the study's purpose is to conduct an analysis of potential accident causal factors or injury factors, information is needed regarding explanatory factors, such as whether the road users were distracted, whether smartphones were in use at the time of the incident, the number of hours road users slept the night before or the number of years road users had held a driving license. Moreover, the state of the vehicle could be of interest, such as its age, its model, the presence of passive and active safety equipment and the use of personal safety equipment (e.g., a seatbelt or helmet).

Control and classification questions

Because the information being collected relates to accidents and near-accidents, control questions should be included to ensure the validity of the information gathered. For instance, discrepancies can occur within answers to multiple about the same issue, indicating imprecise or falsified information that should be corrected, if possible, or removed before processing the data.

Furthermore, the self-reporting system should include questions to facilitate the classification of the events into groups (e.g., non-accidents, near-accidents or accidents). For instance, accidents can be defined as events resulting in injury or property damage. Questions can then be included regarding whether there was any physical contact between road users or between a road user and infrastructure. This could be supplemented by questions about whether anyone was injured during the accident. If not, it may have been a near-accident instead of an accident. Based on the classification, events of no interest to the study can be discarded.

3.4.4 WHICH METHOD SHOULD BE USED FOR SELF-REPORTING?

Depending on the information being collected and the number of respondents desired, some methods may be more appropriate than others. For instance, face-to-face and telephone interviews are suitable for small studies with few participants from which detailed information regarding the incident is collected. For large studies and studies that require knowing the location of the accident or near-accident, online questionnaires may be used. For some groups of respondents, paper questionnaires may be sent instead.

How to assess the degree of underreporting?

To assess the degree of underreporting, a survey of self-reporting on a representative sample of the population can be carried out.

In the survey, the respondents are asked to report all their accidents for a certain period of time (e.g., one year), preferably by the use of multiple questionnaires throughout the survey to reduce the recall time between the time of the distribution of the questionnaire and the time of the accident. For instance, a questionnaire can be sent out each month, or the option of immediate registration can be provided, followed by monthly reminders to register all accidents.

Furthermore, demographic information (e.g., gender, age, car ownership, residence and transport habits) should be collected to ensure that the results from the sample can be scaled up to account for the general population.

Finally, to be able to assess the degree of underreporting, the results from the sample should be scaled up so that each cluster from the sample (e.g., divided into groups based on age and gender) is weighted according to the distribution of the population. The results should then be compared to the official statistics.

If available, a link between the respondents' self-reported accidents and their accidents as recorded by the police or hospitals can be used to compare the number of self-reported and officially registered accidents directly for the respondents of the study. For instance, one can use information from the CRS or a similar identifier available in the official records.

3.4.5 HOW TO DEAL WITH ETHICAL AND/OR PRIVACY ISSUES?

Personal information may be collected via the questions in self-reporting studies. Therefore, it must be considered whether ethical approval (i.e., from the ethical board) and approvals according to the General Data Protection Regulation (GDPR) (consult the legal department to clarify) should be granted before the study can start.

In some countries, it is time-consuming to get ethical approval, so it might be worthwhile to consider skipping questions or road user groups that necessitate ethical approval (e.g., including children in the study). Similarly, if approval regarding the National Data Protection Act is needed, you must choose between seeking this approval and adjusting your survey so that approval is not necessary. Whether or not it is advisable to seek the approval depends on how time-consuming and costly it is to get the approval weighted against how essential the private data are for the study.

Participants should be notified about what personal information is collected and how this information is stored and treated.

3.4.6 HOW TO RECRUIT PARTICIPANTS?

Based on the target group and the type of sample needed for the study, participants can be recruited directly via personal contact (e.g., telephone, letters sent to their address or emails) or indirectly via the distribution of information regarding the need for participants for the study on traditional and social media or through newsletters and messages to network contacts, specific companies or organisations, and interest organisations.

How to recruit participants?	
TYPE	**HOW TO REACH**
Random	Sample from a national statistical bureau or local citizen register. Each person in the sample is contacted directly, either via telephone or letters (paper or electronic).
Volunteers	Recruit through traditional and social media or via large organisations or public institutions.

The following strategies can be used to prompt respondents to participate:

- Rely on people's desire to help the greater good. When contacting people, it is important to inform potential respondents why their participation is important and how their information might help others.
- Offer a prize to be drawn from among those who participate in the survey. The prize should be appealing but not so big that it will affect respondents' answers.
- Offer a gift to all who participate. This could be somehow related to the study subject. For instance, if the study only concerns bicyclists, every respondent might receive bicycle gloves, other types of bicycle equipment or a gift certificate for a bicycle shop. However, the gift should not influence the outcome of the study (e.g., if the purpose is to study the trend in the number of cycling accidents, bicycle lights given to the participants may influence the safety level).

3.4.7 ESTABLISHMENT OF HOTLINE DURING DATA COLLECTION

Depending on the data collection method used, it is recommended to establish a hotline for support with answering the questionnaires. For instance, respondents may experience problems with answering the online questionnaire, have troubles using the smartphone app for self-reporting, have questions about the study or want to quit the study. The majority of these problems can be solved by a hotline function.

3.4.8 CLEANING SELF-REPORTED DATA

Self-reported data should be processed before the data are used. This process includes cleaning the data in order to ensure its correctness, removing outliers (e.g., respondents who have reported far more accidents than the average due to a misunderstanding or a desire to disrupt the study) and removing information that is not part of the study (e.g., non-accidents).

In general, it is important to keep track of the cleaning process. One way to do this is to keep track of the number of removed events at each step of the cleaning process, such as the number of non-accidents, the number of events that are outside the scope of the study and the number of unfinished responses that cannot be included (Figure 3-1).

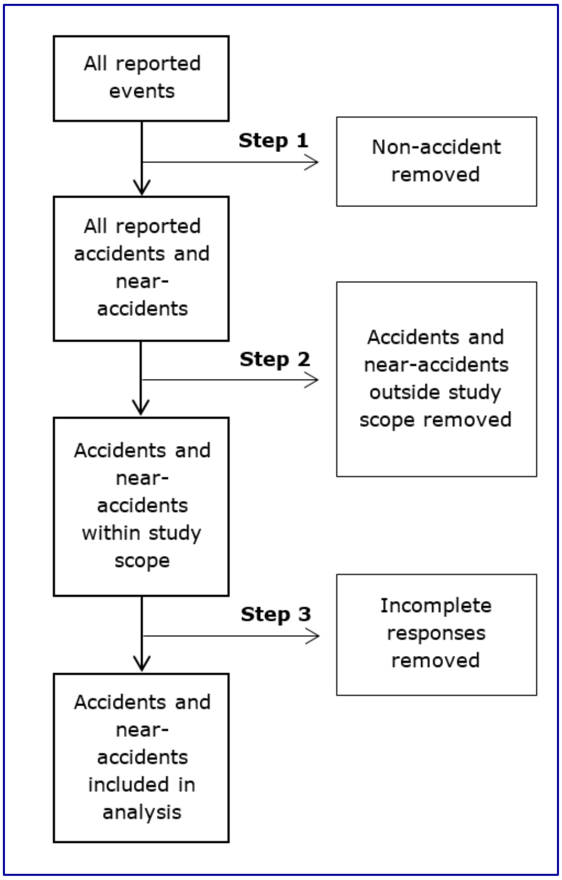


Figure 3-1: Example of track changes for the data cleaning process in a study of accidents and near-accidents

3.5 Interpretation of results based on self-reported accidents

Interpreting self-reported accidents and near-accidents does not differ substantially from interpreting other types of accident data, and as such, they can be used for descriptive statistics and/or be analysed using statistical tools. Similar to data about accidents from official records, survey data should be interpreted with caution. Particularly, because the road users register the information themselves, one should keep in mind that some responses may not be correct, either on purpose or due to ignorance. Most road users want to 'fit in', which can make respondents reluctant to answer social unacceptable answers—such as reporting that they were drunk driving. However, if the respondent is sure of her/his anonymity, this reluctance usually decreases, improving the reliability of the responses.

When interpreting the data, it is important to keep in mind how the respondents are selected and contacted. Specifically, if the results are to be generalised to include the entire population, it is important to have a large sample of road users who have been randomly selected. In short, remember that the larger the sample, the more generalisable the results and that the more random the sample is, the more generalisable the results. If the sample is not representative of the population, is may hinder generalisation. However, via the stratification of data, corrections can be made to adjust for a skewed distribution of the study population compared to the general population.

3.6 Conclusions and key points

Collecting self-reported traffic accidents and near-accidents can provide knowledge that is valuable when considering road safety work. This self-reported data can be used to supplement official accident data in many situations, such as for monitoring trends, evaluating traffic safety measures, analysing accident causal factors and estimating the underreporting rate in the official accident records, depending on the information registered by the road user. The advantage of using self-reporting is that it offers a broader picture of safety levels in traffic. However, this broader picture is usually collected from only one road user's perspective.

Different methods can be used for collecting self-reports, including paper or online questionnaires, telephone interviews and face-to-face interviews. Some issues should, however, be considered before collecting self-reported information regarding accidents and/or near-accidents via these methods:

- What is the purpose of the study?
- Which road users are relevant for the study?
- What type of information should be registered?
- Which method should be used for self-reporting?
- How to deal with ethical and/or privacy issues.
- How to recruit participants.
- How to establish a hotline during data collection.
- How to clean self-reported data.

When interpreting results, it is important to be aware that data are collected via the road users themselves. In this regard, it is important to know how the sample of respondents is recruited and who they are (e.g., in terms of gender, age, location and transport patterns) in order to be able to generalise results to the population as a whole. Furthermore, one should be aware of the risk that respondents might be reluctant to admit if they have conducted socially unacceptable actions that resulted in an accident, such as reporting oneself as a drink driver.

3.7 Recommended reading

Overview of conducted studies of self-reported traffic accidents:

Andersen, C., Kamaluddin, N., Varhelyi, A., Madsen, T., & Meltofte, K. (2017). Review of current study methods for VRU safety. Appendix 7 – Systematic literature review: Self-reported accidents (Deliverable 2.1 – part 5 of 5). Horizon 2020 EC Project, InDeV. Lund, Sweden: Lund University.

General information on survey design:

Dillman, D. A., Christian, L. M., & Smyth, J. D. (2014). Internet, phone, mail, and mixed-mode surveys - the tailored design method (4th ed.). Hoboken, New Jersey, USA: John Wiley & Sons, Incorporated

References Chapter 3

Boufous, S., Ivers, R., Senserrick, T., Stevenson, M., Norton, R., & Williamson, A. (2010). Accuracy of self-report of on-road crashes and traffic offences in a cohort of young drivers: The DRIVE study. Injury Prevention 16(4), 275–277. doi: 10.1136/ip.2009.024877

De Rome, L., Boufous, S., Georgeson, T., Senserrick, T., Richardson, D. & Ivers, R. (2014). Bicycle crashes in different riding environments in the Australian Capital Territory. Traffic Injury Prevention 15(1), 81–88. doi:10.1080/15389588.2013.781591

Dillman, D. A., Christian, L. M., & Smyth, J. D. (2014). Internet, phone, mail, and mixed-mode surveys - the tailored design method (4th ed.). Hoboken, New Jersey, USA:John Wiley & Sons, Incorporated.

Fuller, D., Gauvin, L., Morency, P., Kestens, Y., & Drouin, L. (2013). The impact of implementing a public bicycle share program on the likelihood of collisions and near misses in Montreal, Canada. Preventative Medicine 57(6), 920–924. doi.org/10.1016/j.ypmed.2013.05.028

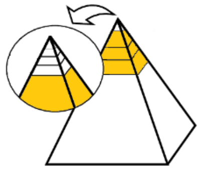
de Hair, S., Engbers, C., Dubbelman, R., Zeegers, T., & Liers, H. (2015). A better understanding of single cycle accidents of elderly cyclists. Paper presented at the 6th Internationale Konferenz Expertensymposium Accident Research, Hannover Medical School, 20-21 June (pp.298–308). Hannover, Germany.

Korpinen, L. & Paakkonen, R. (2012). Accidents and close call situations connected to the use of mobile phones. Accident Analysis & Prevention 45, 75–82. doi.org/10.1016/j.aap.2011.11.016

Lahrmann, H., Madsen, T. K. O., Olesen, A. V., Madsen, J. C. O., & Hels, T. (2018). The effect of a yellow bicycle jacket on cyclist accidents. Safety Science 180, 209-217. doi.org/10.1016/j.ssci.2017.08.001

Madsen, J.C., Andersen, T., & Lahrmann, H.S. (2013). Safety effects of permanent running lights for bicycles: A controlled experiment. Accident Analysis & Prevention 50, 820–829. doi: 10.1016/j.aap.2012.07.006

Madsen, T. K. O., Várhelyi, A., Polders, E., Reumers, S., Hosta, P., Bibiloni, D. J., Ramellini, A., Agerholm, N., & Lahrmann, H. S. (2018). Assessment of Safety of VRUs Based on Self-Reporting of Accidents and Near-Accidents (Deliverable 3.2). Horizon 2020 EC Project, InDeV. Lund, Sweden: Lund University.



CHAPTER 4

Surrogate measures of safety and traffic conflict observations

This chapter focuses on surrogate measures of safety as a tool for site safety analysis. The term ‘surrogate measures’ is limited here to the following definition:

> *Indicators derived from observation and safety gradation of non-accident events in traffic with the ultimate goal to estimate the expected crash/injury frequency as well as to get a better understanding of the crash mechanisms and contributing factors.*

The definition excludes some types of data that might be of relevance for safety, but has a weaker predictive power of expected accidents/injuries. As a result, this chapter will NOT cover:

- Safety Performance Indicators such as seat belt use, share of drivers speeding or being under alcohol influence, usage of helmets by bicyclists and motorcyclists. While these indicators are relevant for safety, the relation of the phenomena they describe to crash risk is not always straightforward and most often the indicators are not directly transferable into crash numbers.

- Other behavioural observations that do not explicitly involve grading the severity of traffic situations. Examples of such data are looking or yielding behaviour, lateral positioning, speed choice, etc. These indicators are described in CHAPTER 5.

The chapter briefly describes the theory underpinning surrogate safety measures. Practical guidance focuses primarily on conducting traffic conflict observations, although there are other ways to collect and analyse surrogate safety data.

The main reason for selecting this approach is that applying more advanced methods inevitably requires fully automated tools that can collect accurate data on road user speeds and trajectories. While such tools exist, they are still in development and are not always available to the practitioner. In contrast, traffic conflict observations can be completed using less sophisticated tools—in the simplest case, using only trained human observers. Examples of the method's use in road safety studies are provided, along with recommendations for further reading.

4.1 What is meant by safety analysis based on surrogate measures?

4.1.1 BASIC CONCEPT

The method is based on the assumption that there are sufficient similarities between actual accidents and almost accidents (traffic conflicts, near-misses, etc.) of the same type—events where a collision was highly probable but was fortunately avoided. If this is so, much can be learned about the underlying factors that contribute to accidents by studying 'almost accidents'.

4.1.2 HISTORICAL NOTE

Traffic conflict technique was first applied in practice in the late 1960s by a team of researchers at General Motors Corporation (Perkins & Harris, 1967), but the idea was known at least a decade earlier (Forbes, 1957). Following the success of early attempts, the method rapidly gained in popularity. The association for International Co-operation in Traffic Conflict Techniques (ICTCT) (ICTCT, 2016) was founded in 1977 and became an important forum for researchers working in this area of traffic safety.

At the first ICTCT workshop in Oslo, Amundsen and Hyden (1977) proposed the following definition of a traffic conflict:

> *A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged.*

As this convenient and intuitive definition allows for many interpretations when applied in practice, it is unsurprising that many different traffic conflict techniques emerged in different countries, including Austria, Belgium, Canada, the Czech Republic, Finland, France, Germany, the Netherlands, the United Kingdom, the United States and Sweden. A calibration study of several techniques used at the same time (Asmussen, 1984) revealed substantial differences in how various teams selected conflicts, but there was quite good agreement in specifying severity scores once conflicts were identified.

From the early 1990s onward, the use of traffic conflict techniques became less frequent, mainly because of the significant costs in time and effort, as most of the data had to be collected by human observers. However, new technologies such as advanced automated video analysis have revived interest in the method. In Western countries, the use of traffic conflicts (or other relevant surrogate indicators of safety) has been driven by road safety improvements that make it increasingly difficult to depend exclusively on registered accident data. In developing countries, accident data are still seldom available and its quality is poor.

4.1.3 THE CONCEPT OF SEVERITY

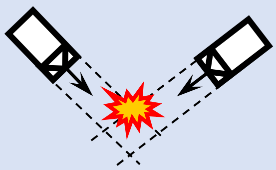
To construct a safety pyramid (as in Figure 1-1), an operational measure is needed to capture the seriousness or severity of the traffic event. Most traffic conflict indicators express severity in terms of proximity to a collision in time or space. The most common indicators of this type are time-to-collision (TTC), post-encroachment time (PET) and multiple variants of deceleration-based indicators (see textbox).

However, proximity to a collision is only one dimension of its severity; the potential consequences of a collision should also be taken into account. For example, minor collisions between cars in parking lots are of little concern for road safety, as these almost never result in injuries for vehicle occupants. On the other hand, a near-miss between a cyclist and a large truck moving at high speed would be perceived as very dangerous.

Ideally, a theoretical definition of severity should incorporate 'nearness to a serious personal injury', in line with the Vision Zero philosophy that 'no one will be killed or seriously injured within the road transport system' (Johansson, 2009). However, it is not clear how risk of injury can be estimated in situations where the collision was actually avoided. For that reason, the most common practices are to either ignore the potential consequences or to apply subjective rules about how those consequences can be integrated into the final severity score.

Time-to-Collision (TTC)

TTC is the time until a collision would occur between road users if each continued on their present course at their present rate (Hayward, 1971).



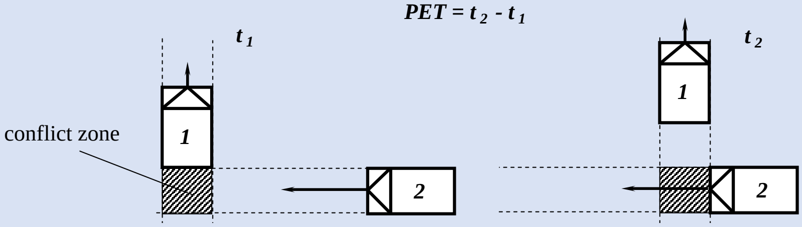
Calculation of TTC requires the presence of a collision course (i.e. the road users will collide if nothing changes). TTC is a continuous indicator, returning a value for any time instance during the collision course. Two such values are commonly used:

- TTC_{min} (the lowest TTC value during the interaction)
- Time-to-Accident (TA) (TTC value at the moment when evasive action is first taken by one of the road users.

Post-Encroachment Time (PET)

PET is calculated as the time between the moment that the first road user leaves the path of the second and the moment that the second reaches the path of the first; in other words, PET indicates the extent to which they have missed each other.

$$PET = t_2 - t_1$$



Time Advantage (TAdv) or predicted PET (pPET) are variations of the PET indicator based on the predicted motion of road users according to their current position, direction and speed (Mohamed & Saunier, 2013; Laureshyn et al., 2010).

Conflict indicators based on acceleration

Deceleration-to-safety (DST) is the minimum deceleration required to avoid a collision (Hupfer, 1997). Note that it is not necessary to come to a complete stop but only to convert a collision course situation into a PET-situation.

Jerk is a derivative of deceleration that describes the suddenness of braking (Bagdadi & Várhelyi, 2011). While accelerations and decelerations are significantly affected by individual driving style—that is, one driver's 'normal' is 'critical' for another)—jerk seems more stable across different drivers, with high values indicating dangerous situations.

While many other acceleration-based indicators have been proposed (e.g. proportion of stopping distance, potential collision speed, deceleration rate to avoid crash), there is very little available validation to support (or reject) their use.

4.1.4 RELIABILITY AND VALIDITY

Reliability is a measuring tool's ability to maintain the same level of accuracy regardless of the conditions in which it is used. As applied to traffic conflict studies, reliability means that the method used for conflict detection and severity scoring should guarantee that observed differences in conflict counts can be attributed to differences in safety rather than to issues such as loss of attention, observation perspective, weather or lighting conditions.

Traditional traffic conflict techniques have been criticised for their use of human observers as the main 'measuring tool'. Specifically, an observer's ability to maintain attention over longer time periods or to objectively estimate indicators like TTC has been called into question. A number of calibration studies (Hydén, 1987; Lightburn & Howarth, 1979) have shown that it is possible to train observers to detect conflicts and judge speeds and distances consistently. It is important, however, that the observers undergo standardised training, which should be refreshed periodically, as these skills tend to deteriorate over time. In general, it takes about a week to train observers for traffic conflict studies.

In recent years, tools like video analysis have become commonplace in traffic conflict studies. Although characterised as 'objective', their accuracy remains dependent on the quality and calibration of the camera, as well as on traffic conditions and weather. However, the rapid progress in this field offers hope that the reliability of these tools will not be of major concern in the near future.

Validity is a more fundamental property, referring to the measuring tool's ability to capture the quality of interest—in the present case, road safety. Given the many different operational definitions of traffic conflicts, it is reasonable to ask whether some are more valid than others. For many of the proposed conflict techniques, few if any validation studies relate observed conflicts to actual accidents at the same sites; probably the only exceptions are the Swedish Traffic Conflict Technique and the Dutch technique DOCTOR (see the separate textboxes in section 4.4).

It is a hard task to convert the conflict counts into the number of accidents expected at the site. However, in many cases, this is not always necessary. For example, if at least the direction of change (less conflicts = less accidents) can be proven, the conflicts can be used to indicate whether a certain safety intervention has succeeded or failed (without knowing the exact number of accidents avoided). Similarly, if the process of conflicts (typical situations, behaviour, mistakes) resembles the process of accidents, this information can be used to better understand the factors contributing to the accidents and how they can be mitigated.

4.2 Advantages and disadvantages of traffic conflict studies

Traffic conflict studies have the following advantages.

- Because traffic conflicts are much more frequent than accidents, data can be collected over a much shorter time rather than waiting for annual accident records.
- As traffic conflicts are actually observed, there is much more available information than in accident reports.
- Traffic conflicts studies are proactive, which means that the safety problem can be detected and addressed BEFORE accidents occur.

The disadvantages/limitations of traffic conflict studies are as follows.

- The method requires trained personnel, video recording equipment and tools for video processing.
- Collecting conflict data requires field work and subsequent video processing to identify conflicts; accident records are ‘already there’ as seen from a practitioner perspective.
- The relation between accidents and conflicts is not always clear for all types of conflict, and conversion of observed conflicts into an expected number of accidents is not very accurate.
- Traffic conflict studies are more often conducted during daylight hours and in good weather conditions. However, with the introduction of video recording and automated tools for conflict detection, this restriction has become less important.

For best results, it is advisable to combine traffic conflict observations with other methods such as accident analyses, behavioural observations or interviews with road users.

4.3 When to conduct traffic conflict observation

Traffic conflict observation is the right method for the following purposes:

- to make a safety diagnosis of a given site when accident data are insufficient or absent;
- to investigate the factors that contribute to accident risk at a given site;
- to compare the safety performance of different road infrastructure features, regulations and rules;
- to quickly evaluate the effects of road safety measures in before-after investigations;
- to monitor the development of a site's traffic safety situation.

As in the case of accident analysis, mapping of traffic conflicts can indicate **where** accidents might be expected. Analysis of conflict manoeuvres and the road users involved serves to indicate **what types** of accidents can be expected. Watching recordings of traffic conflicts enhances understanding of the **process** of accident development and **contributing factors** and helps to generate ideas for **possible countermeasures.**

Traffic conflict observations have been used mainly in urban areas; for rural roads, the available practical knowledge is more limited. This does not mean that the method cannot be used in rural areas, but greater caution is advisable in planning the study and interpreting results.

Many of the traditional traffic conflict techniques were originally designed for car-car situations. Very often, these can still be successfully applied to situations involving vulnerable road users (VRUs). Techniques that consider both collision risk and consequences are more suitable for this purpose.

Evaluation of large-scale introduction of small roundabouts (Hydén & Várhelyi, 2000)

To test the effects of small roundabouts, the Swedish city of Växjö provisionally reconfigured 21 conventional intersections as roundabouts. Safety was among the aspects to be evaluated. As the roundabouts were only provisional and were to be removed after six months, there was insufficient time to collect accident data. Additionally, the intersections were selected on the basis of high accident numbers in previous years; this selection bias meant that conclusions based on the accident counts would be inaccurate. In this case, the Swedish Traffic Conflict Technique was chosen as the method of safety evaluation, and conflict observations were complemented by road user counts, speed measurements, behavioural observations and interviews with road users.

Conflict observations were carried out at 12 intersections for 5 days (30 hours) per site, both before reconfiguration and four months after (to allow road users to get used to the new design). Observations at the 12 studied sites identified 223 serious conflicts before reconfiguration and 231 after. The number of car-car conflicts increased by 43%, but the number of conflicts involving pedestrians and bicyclists decreased by 49%. While the total number of serious conflicts did not decrease, these became less severe. Specifically, the character of the conflicts changed, as front-to-front situations involving left turns and situations involving perpendicular courses were replaced by situations involving a small angle between the conflicting vehicles, which made the conflicts less severe in the after situation. Additionally, the average speed in conflicts decreased from 30.5 km/h in the before situation to 27.2 km/h in the after situation. The average TA value in the before situation was 0.80 seconds; in the after situation, it was 0.81, representing a slight but statistically non-significant improvement.

For VRUs, risk was significantly reduced, but there was no risk reduction for car occupants. An association was found between reduced approach speed and reduction of injury accident risk. Behavioural observations indicated that design details are of decisive importance for road user safety, and that the situation of cyclists warrants special attention. Based on the behavioural observations, important recommendations were made for improving cyclists' situation, including the following. a) The transition between cycle path/lane and junction must be designed with care to integrate cyclists with motorised traffic before they enter the roundabout. b) There should be only one car lane on the approach, in the circulating area and at the exit. c) The roundabout should be as small as possible.

Evaluation of speed management measures in Bangladesh (van der Horst et al., 2017)

Three locations in Bangladesh were selected for testing of the integrated speed management program. A before-after design was applied, combining three research methods to monitor and evaluate the road safety interventions. To overcome the lack of reliable accident statistics in Bangladesh, an individualised system was developed for recording traffic accidents, using trained local record keepers. Secondly, laser-guns were used to measure the speed of motorised traffic (at both intervention and control locations). Finally, the Dutch Objective Conflict Technique for Operation and Research (DOCTOR) was applied for video observation of serious traffic conflicts at the intervention locations.

Prior to the intervention program (according to the alternative accident recording system), the three locations combined accounted on average for about 100 serious accidents, with 10 fatalities and 200 injuries each year (based on the 19-month before period). The after period commenced 4 months after implementation of the infrastructural measures and ran for 9 months. During this after period, the average number of serious accidents per month decreased by 66%; the number of people injured decreased by 73%, and the number of fatalities decreased by 67% (significant at the 1%, 1%, and 10% levels, respectively).

The laser-gun speed measurements of motorised traffic revealed an overall net reduction of 13.3 km/h (or 20% in relative terms) at the intervention locations on correcting for speed measurement outcomes at the two control locations (Vet et al., 2016).Applying Nilsson's power model (Nilsson, 2004), an average speed reduction of this magnitude would result in an expected reduction in fatalities of 59%.

The DOCTOR observations of serious conflicts were based on video recordings at each of the intervention locations for about a week (24 h/day, before and after). The after period commenced about six months after the infrastructural interventions ended to ensure a sufficient habituation period. The DOCTOR method usually requires a total conflict observation period of 18 h. On analysing the first tapes, it became clear that slight conflicts (DOCTOR severity categories 1 and 2) were considered more or less normal behaviour in Bangladesh, and we therefore focused on the more severe conflicts (DOCTOR severity scores 3–5). As the number of serious conflicts was relatively high, it was considered adequate and more efficient in terms of time to reduce the number of hours analysed to 4.5 h per location and per period (before and after). The total number of serious conflicts was significantly reduced from 64 per location before to 29 serious conflicts after, representing a 55% reduction in relative terms. When corrected for changes in traffic volumes, the overall reduction in conflict risk was still 54%.

All three evaluation methods suggest a similar impact of the intervention program, with an improvement in road safety of between 54% and 60%. The speed-reducing measures had a significant impact on the speed of motorised traffic (mean speed and 85th percentile values), reducing both the number and severity of serious conflicts and the actual number of reported accidents. Taking the actual number of accidents at the three intervention locations as the ground truth, both speed measurements and traffic conflict observations were shown to be valid methods of estimating the effects of road safety interventions when no reliable accident data are available.

4.4 Different traffic conflict techniques

Of the many techniques developed by research teams in different countries, some have not evolved since the 1980s and are rarely used today. However, the Swedish and Dutch (DOCTOR) techniques are still widely used, and American and British techniques seem to have found a new lease of life, particularly in developing countries. For the sake of completeness, the following publications describe these techniques.

- Austria: Risser & Schutzenhofer (1984);
- Belgium: Mortelmans et al. (1986);
- UK: Baguley (1984);
- Canada: Sayed & Zein (1999) ;
- Czech Republic: Kocárková (2012);
- Netherlands (DOCTOR): Kraay et al. (2013);
- Finland: Kulmala (1984);
- France: Muhlrad & Dupre (1984);
- Germany: Erke & Gstalter (1985);
- Sweden: Hydén (1987);
- US: Parker & Zegeer (1989).

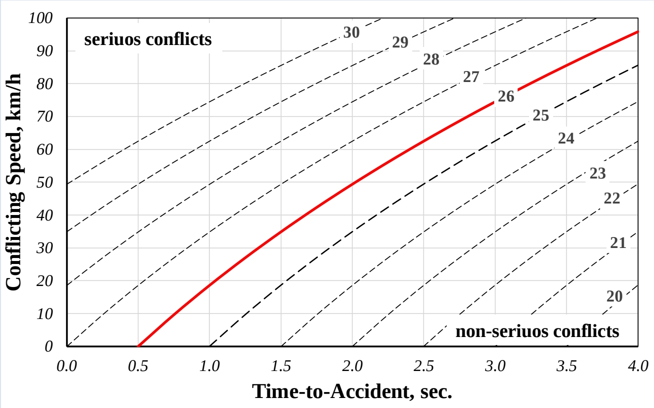
The Swedish Traffic Conflict Technique (TCT)

The Swedish TCT was developed at Lund University during the 1970s and 1980s (Hydén, 1987); the strength of this technique lies in the uniquely solid validation work that underpins it. Several large-scale studies (Svensson, 1992; Hydén, 1987; Gårder, 1982; Linderholm, 1981; Hydén, 1977) have confirmed a strong association between serious conflicts (as defined by the technique) and police-reported accidents.

According to the Swedish TCT, collision course is a necessary condition for conflict. Severity ranking is based on two indicators:

- Time-to-Accident (TA): the time remaining before a collision when a road user takes evasive action;
- Conflicting Speed (CS): road user speed when taking evasive action.

The following graph distinguishes between serious and non-serious conflicts.



Severity increases as TA decreases (reflecting nearness to collision) and CS increases (reflecting to some extent the seriousness of possible consequences in case of collision). If the road users take evasive actions simultaneously, TA and CS are estimated for both. The relevant road user is the one with the lowest severity ranking, which is also the final severity of the conflict.

Conflicts with a severity level higher than 26 (red line on the graph) are categorised as serious. However, there is evidence to suggest that the threshold should be moved down one or two levels if evasive action is taken by a VRU (Svensson, 1998) because VRUs generally travel at lower speeds, resulting in underscoring of conflict severity.

The detailed manual for the Swedish TCT can be downloaded at https://www.bast.de/InDeV/EN/Documents/pdf/TCT-OM.pdf?__blob=publicationFile&v=2

DOCTOR – Dutch Objective Conflict Technique for Operation and Research

The DOCTOR method was developed in the Netherlands by the Institute of Road Safety Research (SWOV) and TNO Human Factors. The method defines a critical situation as one in which the available space for manoeuvre is less than that needed for normal reaction. If at least one of the parties involved needs to take action to avoid a collision, the situation is categorised as a conflict. In some cases, road users narrowly avoid each other without taking any noticeable evasive action. These situations can also be critical, as any small disturbance in the approach process can result in a collision. Conflict severity is scored on a five-point scale, ranging from 1 (least severe) to 5 (collision), taking account of (i) the probability of a collision and (ii) the extent of the consequences if a collision occurred. The probability of a collision is determined by the following parameters:

- minimal Time-To-Collision (TTCmin): the lowest time-to-collision value during the interaction (note that this differs from the Swedish TCT, which uses the TTC value at the commencement of evasive action); TTCmin below 1.5 s is considered critical;
- Post-Encroachment Time (PET): the time between the moment the first road user leaves the path of the second and the moment the second reaches the path of the first (see illustration in PET textbox); in urban conditions, a PET value lower than 1 s is considered critical.

The extent of the consequences is defined by the types of road user involved in the conflict, their speeds and the types of manoeuvre performed. For example, a conflict between a car and a cyclist may have much more serious consequences than a conflict between two cyclists, given their relative vulnerability and speed. The DOCTOR technique includes a subjective component, as the observer must always take account of the road users' behaviour—for example, whether they undertake a controlled or uncontrolled evasive action—and the extent of the consequences if a collision had taken place. Conflicts with an overall severity score of 1 or 2 are considered minor (i.e. more like a disturbance in the traffic process that is still manageable by at least one of the road users involved). Conflicts with a severity score of 3–5 are categorised as serious conflicts with more direct implications for traffic safety.

The detailed manual for the DOCTOR technique can be downloaded at https://www.bast.de/InDeV/EN/Documents/pdf/DOCTOR-Manual.pdf.

4.5 How to conduct traffic conflict observations

4.5.1 MANUAL TRAFFIC CONFLICT OBSERVATIONS

The advantage of manual conflict observations is the minimal equipment required: register forms, a watch and a pencil. This permits a level of high flexibility in terms of when and where the study is conducted. However, it also means that the observer is entirely responsible for detecting and assessing conflicts and making notes, all in real time. It has become increasingly common to combine video recording with observations, enabling the observer to revisit the situations once again when summarising the results. Issues in relation to the use of video recordings are discussed in section 4.8.

Observation period

The number of observation days and observation periods per day is determined by the expected frequency of conflicts, which is usually based on previous experience. For example, Hydén & Várhelyi (2000) concluded that 30 hours of observations at one site produce a sufficient number of serious conflicts to permit a safety analysis of the site. More recent studies (Laureshyn et al., 2017; Madsen & Lahrmann, 2017) have suggested that 75–80 hours of daytime observations is barely adequate and that observation periods should be increased still further. This is because the significant safety improvements in developed countries during last decades, thus lower accident risk is also reflected with lower conflict frequency. In countries with major road safety problems shorter observation periods can be used as the number of conflicts per time unit is still relatively high there (see e.g. Abdul

Manan & Várhelyi, 2015; van der Horst et al., 2013).

Observations are usually performed in 1–2 hour blocks, with breaks to allow the observer to recover. If it proves necessary to monitor a longer continuous period, observers can alternate at the site. Each observation should be of the prescribed length and should start exactly on time. At the appointed time, the observer should be completely ready, with camera installed, clocks synchronised, and observation sheets to hand. For that reason, it is recommended that the observer should arrive at the site at least 10 minutes before the observation is due to start.

In before/after studies, the observation periods should be of the same length. It is also important that before and after observations are carried out during similar traffic conditions (taking account of factors such as school times and climate). The after observations should not be carried out immediately following implementation of an intervention, as experience shows that it may take up to 6 months for road users to adapt to changed traffic conditions (Hydén & Várhelyi, 2000).

In most cases, observations are performed in daylight hours and in dry weather conditions to alleviate hardship for human observers. If the accident pattern at a given site is time-related, observations should be performed during those periods when safety problems are most likely. Observations should not be carried out under unusual conditions—for example when a major event in the vicinity interferes with 'normal' traffic patterns.

Observers

Because observers are the most important 'tool' in manual traffic conflict studies, it is very important to ensure that they are properly educated, with no undue haste or cost savings. For example, the observer training course for the Swedish Traffic Conflict Technique takes one full week and includes theoretical lectures, practical instructions and training based on collected video-recordings of conflicts and with real-life field observation sessions.

Observer reliability is of fundamental importance in ensuring valid results—that is, the same observer should record conflicts consistently over time, and different observers should record the same conflicts in similar fashion. Trained observers need to maintain their skills and should be calibrated against each other from time to time.

The observer's tasks are:

- to detect the conflict;
- to estimate the speeds of the road users involved and distances to projected point of collision (for calculation of the necessary indicators for a particular technique);
- to make a sketch of the conflict;
- to supply other relevant information (road user type, evasive manoeuvres, etc.) and a verbal description of the course of events.

The number of observers required at a given site depends on the site's complexity. Experience suggests that one observer can deal with a simple four-leg intersection with no more than two lanes per approach (AADT up to 22,000 vehicles); larger sites would require an additional observer. When observing only one type of conflict, one observer may be able to manage the task, even at a complex site. In evaluation studies, the observer should have had no involvement of any kind in the proposed countermeasure under evaluation. In before/after studies, it is essential that the same observer should make both *before* and *after* observations.

Training courses in traffic conflict observation		
Swedish Traffic Conflict Technique		Lund University, Department of Technology & Society, LTH www.tft.lth.se/SwedishTCT
DOCTOR (Dutch Objective Conflict Technique for Operation and Research)		Foundation Road Safety for All, Voorburg, Netherlands (Dr. A. Richard A. van der Horst) www.roadsafetyforall.org

Recommended equipment

The observer's equipment usually includes the following:

- conflict register form;
- calculation tables (to convert speeds and distances in TTC, etc., depending on the conflict technique used);
- a watch and a pencil (usually better as they still can be used on slightly wet paper in rainy weather);
- personal identification (supplied by the organisation running the study);
- video camera and mount; the observer's watch should be synchronised with the camera timer before commencing.

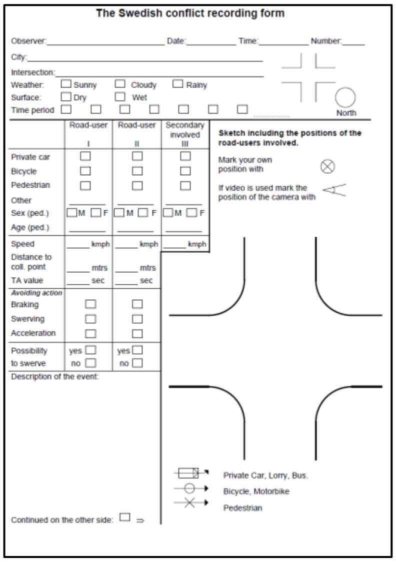
Conflict register form

Register forms vary for the different traffic conflict techniques. Some examples of these forms are shown in Figure 4-1.

A form usually contains some general information about the location, as well as the observer's name, date and time of observation, weather and surface conditions.

For each conflict situation, the following information should be recorded:

- time of the event;
- road users involved;
- any secondary road user(s);
- speeds and distances to collision point;
- type(s) of evasive action (braking, acceleration, swerving);
- sketch of conflict (including any secondary road users);
- verbal description of the course of events;
- notes regarding any possible violations of traffic rules, hazardous behaviour or other issues of interest.



The Swedish conflict recording form

Observer: Date: Time: Number:
City:
Intersection:
Weather: Sunny Cloudy Rainy
Surface: Dry Wet
Time period
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 coll. point	mtrs	mtrs	
TA value	sec	sec	
Avoiding action			
Braking			
Swerving			
Acceleration			
Possibility to swerve	yes no	yes no	

Description of the event:

Continued on the other side:

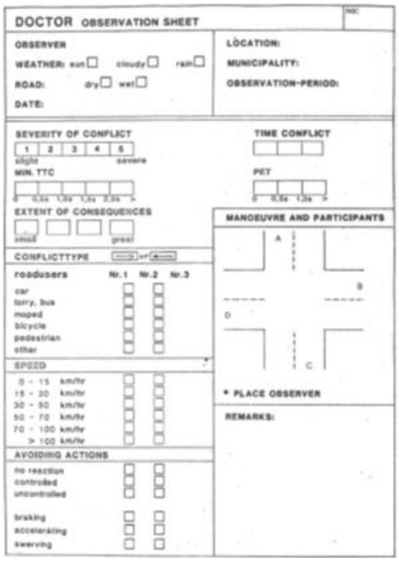
Sketch including the positions of the road-users involved.

Mark your own position with

If video is used mark the position of the camera with

Private Car, Lorry, Bus.
Bicycle, Motorbike
Pedestrian

Swedish TCT



DOCTOR OBSERVATION SHEET

OBSERVER
WEATHER: sun cloudy rain
ROAD: dry wet
DATE:

LOCATION:
MUNICIPALITY:
OBSERVATION-PERIOD:

SEVERITY OF CONFLICT
1 2 3 4 5
slight severe
MIN. TTC

TIME CONFLICT
PET

EXTENT OF CONSEQUENCES
small great

CONFLICTTYPE

roadusers Nr.1 Nr.2 Nr.3
car
lorry, bus
moped
bicycle
pedestrian
other

SPEED
0 - 15 km/hr
15 - 30 km/hr
30 - 50 km/hr
50 - 70 km/hr
70 - 100 km/hr
> 100 km/hr

AVOIDING ACTIONS
no reaction
controlled
uncontrolled

braking
accelerating
swerving

MANOEUVRE AND PARTICIPANTS

• PLACE OBSERVER

REMARKS:

Doctor

Figure 4-1: Examples of the conflict register forms

Prior to observation

Before conducting the actual observation, the following preparatory steps are recommended.

- Collect relevant information about the actual site, including map and drawings of the site, accident history if available, type of regulation, signal settings, traffic volumes.
- Investigate possibilities for camera installation (e.g. balconies, lamp posts or other pieces of road infrastructure).
- Print out a sufficient number of conflict registering sheets. A practical solution is to use a folder with pasted reference tables on the left-hand side and conflict sheets on the right.
- Check the weather forecast and take appropriate clothes.
- Carry a phone number for the supervisor of the study in case of any inquiries.

Performing the observations

On arriving at the observation site, the observer should select a vantage point that offers a clear view of the area to be observed. The location of this point should be marked on the conflict register form, along with an arrow to indicate due north. Alternatively, obvious landmarks should be noted on the sketch of the intersection. This is extremely important in correctly specifying road users' direction of travel and the conflict location.

In before/after studies, the same vantage point should be used before and after. The observer should be unobtrusive so as not to influence road users passing the site—for example, wearing a high-visibility vest is not recommended. At the same time, the observer should not be inside a vehicle or building, as not 'breathing the same air' as the observed road users might cause important information to be lost.

To facilitate estimation of distance and speed, the observer should take some initial measurements on first arriving at the scene so that distances between salient objects or marks can be measured. Estimating speeds by means of a radar gun can help to get a sense of prevailing speeds at the site.

If more than one observer is working at the same site, they should clearly discuss and agree on their respective areas. If a conflict occurs in a place where both observers might record it, this should be noted on a register form so that it can be checked afterwards to avoid double-counting.

Every detected conflict situation should be recorded on an individual register form, as completely and immediately as possible. To save time, some of the fields can be pre-filled (e.g. location, observer's name and position, observation period).

All conflicts should be recorded, even if only the serious ones are used in the subsequent analysis. When a conflict is first detected, it may not be obvious how serious it is until the necessary indicators (TA, PET etc.) have been calculated.

4.6 Presentation and interpretation of results

In a conflict study, the presentation of results usually includes the following:

- a sketch indicating conflict locations (see Figure 4-2);
- a summary table itemising conflicts by type of manoeuvre and road users involved (see Table 4-1);
- depending on the technique, additional diagrams of conflict severity distribution (see Figure 4-3);
- Short video clips containing the recorded conflicts.

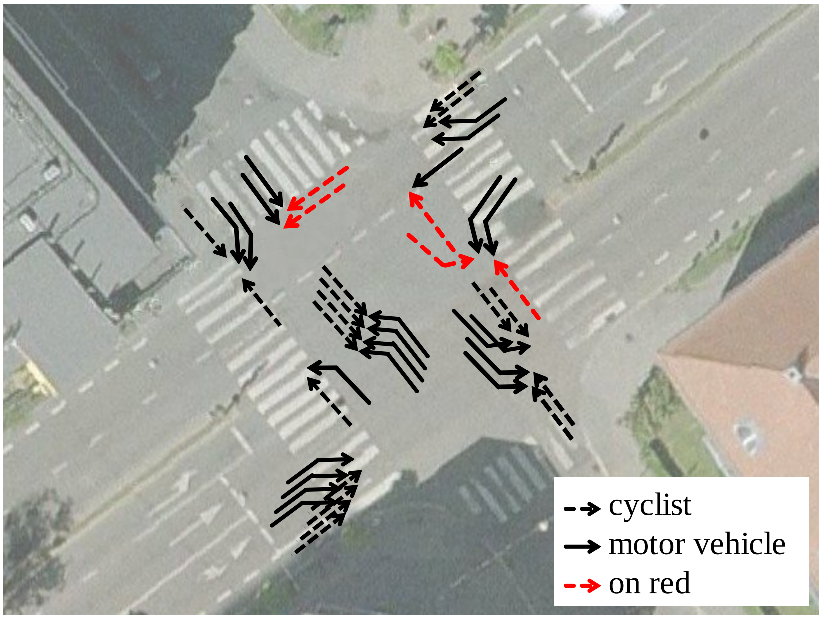


Figure 4-2: Sketch indicating locations and types of conflict

Table 4-1: Summary of conflict observations (based on Swedish TCT approach)

Conflict ID	Date & time	Conflict type	Road user 1	Road user 2	Time-to-accident (sec.)	Conflict-ing speed km/h	Severity
28	2013-09-03, 07:09	Cyclist on red	cyclist	car	1,7	15	24
40	2013-09-03, 07:21	Cyclist on red	cyclist	moped	1,3	9	24
216	2013-09-04, 09:47	Cyclist on red	cyclist	car	1,1	32	26
254	2013-09-05, 07:28	Cyclist on red	cyclist	mc	1,9	14	24
22	2013-09-03, 07:01	Cyclist straight, Motor vehicle right	cyclist	car	1	12	25
32	2013-09-03, 07:12	Cyclist straing, Motor vehicle right	cyclist	car	1,1	10	25
207	2013-09-04, 09:11	Cyclist straight, Motor vehicle right	cyclist	car	1,2	8	25
292	2013-09-05, 08:57	Cyclist straight, Motor vehicle right	cyclist	car	1,6	12	24
396	2013-09-06, 09:50	Cyclist straight, Motor vehicle right	cyclist	car	0,8	11	25

934	2013-09-13, 07:40	Cyclist straight, Motor vehicle right	cyclist	car	1,4	17	25
62	2013-09-03, 07:59	Cyclist straight, Motor vehicle left	cyclist	car	1,5	10	24
496	2013-09-09, 09:28	Cyclist straight, Motor vehicle left	cyclist	car	0,9	12	25
594	2013-09-10, 08:33	Cyclist straight, Motor vehicle left	cyclist	car	1,4	13	24
710	2013-09-11, 08:10	Cyclist straight, Motor vehicle left	cyclist	car	1,7	19	24

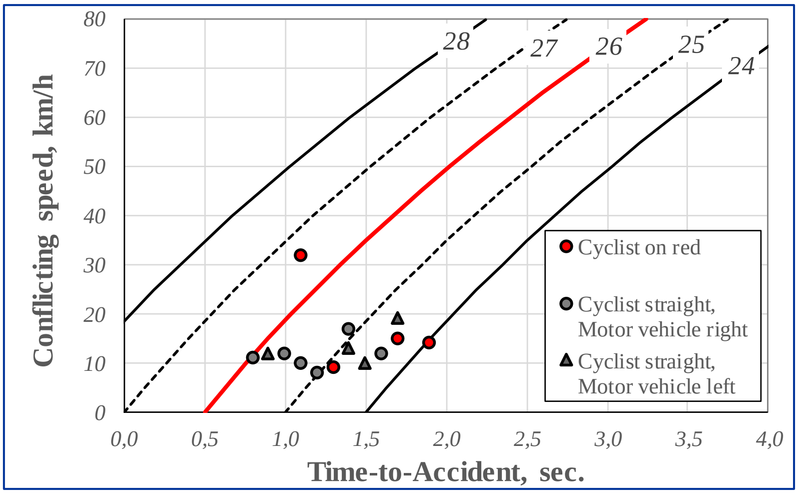


Figure 4-3: Conflict severity diagram (based on Swedish TCT approach)

Interpretation of conflict study results includes the following:

- identification of the common conflict types;
- identification of the locations where conflicts occur;
- identification of the particular circumstances of conflict occurrence (e.g. in the dark, peak or off-peak traffic, parked/stopped vehicles obscuring the view, start or end of green signal);
- calculation of mean speeds and time-related indicators for the road users involved.

When comparing two sites or before/after studies, the following questions should be asked.

- Have accumulations of certain conflict types been eliminated?
- Has there been a general decrease in the severity of conflicts? For specific conflict types?
- Have any new types of conflict emerged?

4.7 Complementary studies

For better understanding of the safety situation, the traffic conflict observations should be complemented with additional types of data collection.

4.7.1 EXPOSURE

The number of traffic conflicts in itself tells us little unless related to the level of traffic activity at the studied site—that is, its exposure. The most theoretically correct measure of exposure is the number of encounters or simultaneous arrivals of two road users, counted separately for each type of interaction or conflict (Elvik, 2015). If the number of encounters is known, it is possible to calculate the conflict rate (i.e. number of conflicts per number of encounters during the same period), indicating the risk that an encounter will become a conflict.

However, it is hard work to count simultaneous arrivals manually. If no automated tool is available to obtain these data, traffic flows can be used as a substitute. The conflict rate can then be expressed, for example, as the number of conflicts involving cyclists per number of cyclists passing during the observation period. An obvious drawback, of course, is that the amount of conflicting traffic is not taken into account in any way.

Traffic counting method is described in detail in the PIARC Road Safety Manual (PIARC, 2003).

4.7.2 SPEED MEASUREMENTS

Vehicle speed plays a decisive role in both risk of accident occurrence and outcome severity. For that reason, safety analyses involving VRUs should always be complemented by vehicle speed measurements at the observed site.

Speed measurement method is described in detail in the PIARC Road Safety Manual (PIARC, 2003).

4.7.3 BEHAVIOURAL OBSERVATIONS

Insights into the different kinds of road user behaviour that occur at the studied site serve as a useful basis for describing what is going on at the site and what makes it ‘unsafe’. Issues such as red-walking, yielding behaviour and informal communication can help to account for safety problems, and conflict observations should be complemented when possible with behavioural observations of ‘normal’ traffic behaviour. Behavioural observations are described in detail in CHAPTER 5 of this handbook.

4.7.4 INTERVIEWS WITH ROAD USERS

Road users who pass the studied site regularly are likely to have some sense of unsafe situations they have been involved in or observed, and an external observer might need lengthy observation to acquire a similar level of knowledge. Short interviews with passing road users may therefore help to identify relevant issues, which in turn provide a basis for subsequent observation of behaviours and conflicts.

4.8 Video recording and analysis

4.8.1 WHY RECORDING?

It can be difficult to perform conflict observations in the field. Detection requires full attention at all times, and when a conflict occurs, the observer gets only one chance to see it and to make the necessary judgements. For that reason, it is recommended that field observations should be complemented by simultaneous video recording. This allows the observer to revisit the identified situations or ask a colleague for a second opinion. When reporting results, the observation sheets can be complemented by short video clips showing each conflict to ensure a well-documented and transparent study. Videos offer a useful way of illustrating safety problems for decision makers or the general public and can also serve as a source of inspiration when envisaging possible safety counter-measures. It would be good practice to always ask “*Would the suggested counter-measure prevent or mitigate unsafe situations of this kind?*”

TIP

Always remember to synchronise your watch with the internal camera clock to make it easier to find recorded conflicts subsequently.

Increasingly, conflict studies are completed directly from video. This is more convenient, as the observer can work at the office and fast-forward when traffic is low and nothing much is happening, taking breaks when necessary. Special video processing tools can also be used to detect potential conflicts or to more accurately measure speeds, distances and other indicators from the video.

At the same time, it is important to realise that a video does not fully represent the traffic environment for a number of reasons, including limited area of view, a perspective that may be unusual for the observer or distortions such as fisheye effects. It is very important, then that the observer actually visits the site and spends some time there in order to understand how the traffic functions and what lies beyond the camera's view.

4.8.2 RECORDING EQUIPMENT

For shorter recordings (for example, those done at the same time as field conflict observations), equipment requirements are minimal, as a simple camcorder will suffice. However, if a longer recording is planned, the following issues must be considered.

- There must be sufficient storage space for the recorded video, and a separate computer or hard drive may be needed for data storage.
- If there is no on-site access to the power network, solutions such as large capacity batteries (e.g. car batteries), solar cells or field generators should be considered.
- To save disc space the recording should be scheduled to exclude the hours of darkness or weekends.
- Equipment may need to be protected from the weather (rain, fog, low temperatures) and from theft or vandalism.
- If several cameras are used to record at the same location, units should be time-synchronised.
- It should be possible to check the status of the equipment without visiting the site.

Figure 4-4 depicts a general scheme for an advanced system for long-term, multi-camera recording. Depending on specific needs, some of these elements can be simplified or removed, and there are commercial products and services that support long-term filming and associated requirements.

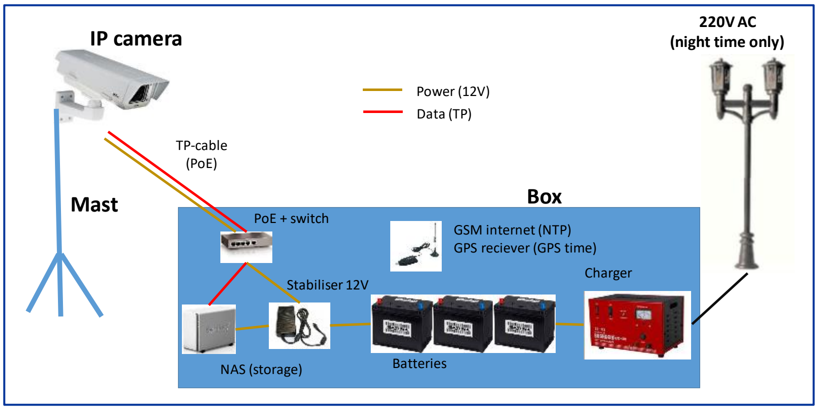


Figure 4-4: General scheme for an advanced video recording system

Another important consideration is the most appropriate camera (sensor). The most common sensor types (i.e. 'normal' video) are RGB, but thermal sensors are becoming increasingly common and affordable.

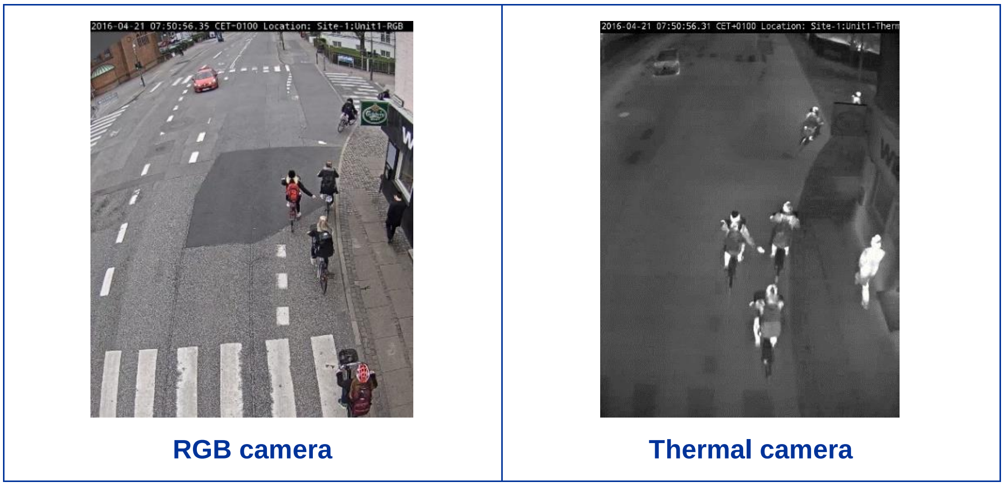


Figure 4-5: Simultaneous views of the same traffic scene using RGB (left) and thermal (right) cameras

The respective advantages and limitations of these camera types can be summarised as follows.

RGB	Thermal
+ "Normal" view	-/+ "Unusual" view but easy to interpret
+ Relatively low price	- Relatively expensive
+ High resolution	- Lower resolution than RGB
- Poor performance in dark conditions	+ Good performance in both light and dark conditions
- Moving shadows create difficulties for automated video processing tools	+ Shadows are not visible and so create no problems
- Sensitive to direct sun light or sun reflection on asphalt, windows, etc.	- Hot weather becomes problematic when asphalt heats up
- Privacy protection issues	+ Personal data (e.g. faces, number plates) are not recognisable

NOTE

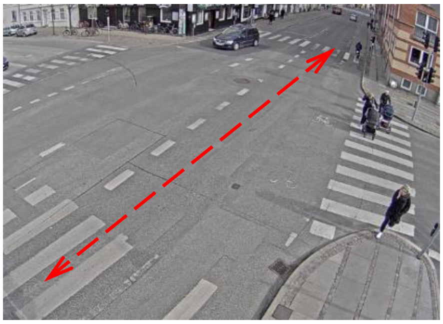
As video recordings are regarded as personal data in many countries, there may be special rules governing whether a camera can be left recording autonomously, what resolution can be used, how the recording is to be handled afterwards, etc. Because these rules differ widely from country to country, it is always a good idea to check them and to seek the required permissions before recording.

4.8.3 POSITIONING THE CAMERA

If the video is to be used only as a backup for the observer in the field, the requirements for positioning the camera are not very strict; it can be placed on a tripod near the observer or on street furniture at a height of 2–3 meters. However, if computer tools for video processing are to be used at some later stage, the requirements become much more specific.

- The camera should be positioned as high and directly downward as possible to obtain a bird's eye view. This helps to mitigate the problem of occlusion, when one road user is not visible behind another. In practice, however, one must compromise, using available lamp posts or balconies. As a rule of a thumb, a height of at least **7-8 meters** is recommended.
- **No sky should be visible**. If the recording involves a longer period, the sun will move; if light then enters the camera objective directly, nothing will be seen because the image will be overexposed. More sky in the view also means that less of the image is devoted to the relevant content.
- It is recommended that the area of interest should be **aligned with the image diagonal**, so ensuring that the available resolution is used in the most efficient way (see example in Figure 4-6).

High positioning (in this case, on top of a nearby building, h≈40m) gives the camera a perfect view of the studied location. In reality, however, one would be very lucky to access such a view. Note also how the trees obstruct the view of the right leg of the intersection, limiting observation of interactions at the pedestrian crossing there.



This view from a camera mounted on a lamp post (h≈8m) is the most common perspective. As the intersection and approaches to it are not fully visible, it was necessary to decide which parts of the intersection are of most interest and to orient the camera accordingly. A two-camera setup would also be an option. Note that the area of interest is oriented diagonally.

In this example of a less successful camera perspective, the sky creates a risk of blinding when the sun gets low (which may not have been obvious when the camera was installed). Although a very long section of the road is visible, the image is unusable because of the very small scale of faraway objects and the difficulty of estimating distance or speed. A preferable camera orientation is shown by the red rectangle.

Here, the camera is installed directly above the pedestrian crossing, creating a very unusual view for the observer. The fisheye lens means that a relatively long section of the approach to the crossing is visible, but the distortion makes it difficult for the observer to judge distance and speed. However, such measurements are possible with a special tools that take distortion parameters into account.

Figure 4-6: Examples of camera views with comments

4.8.4 SEMI-AUTOMATED TOOLS FOR TRAFFIC CONFLICT OBSERVATION

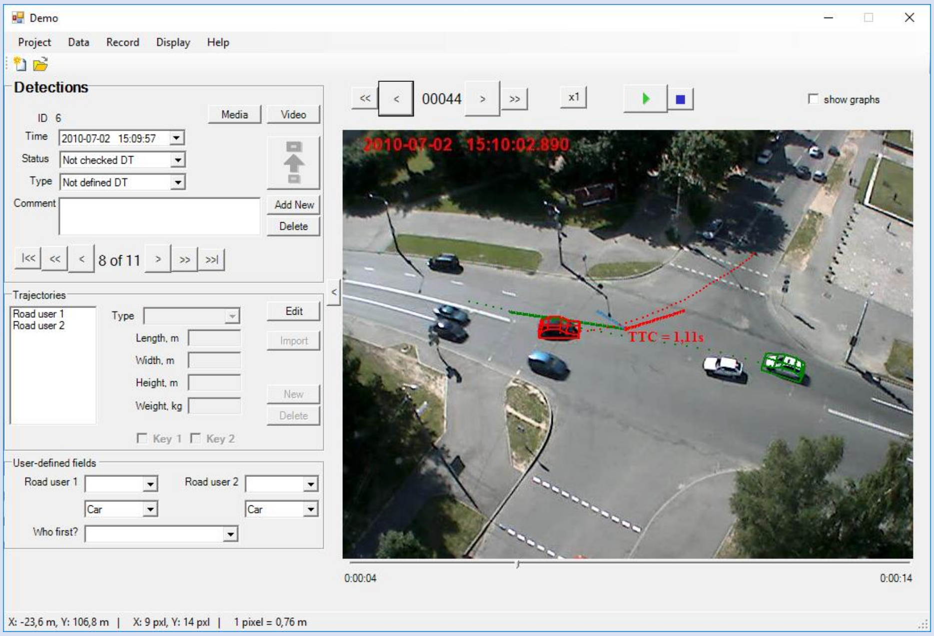
Using semi-automated video processing, some technical tool is used to aid detection and analysis of traffic conflicts, but part of the work is still completed manually. Easily automated functions include the following:

- Managing large collections of video recordings and bookmarks referring to instances of conflict in the original video.
- Database tools for managing conflicts and their descriptions and producing summary reports.
- Manual extraction of road user trajectories, usually by clicking frame by frame on a road user or an adjustable box in the image. Calibration of the camera view is an important pre-task, establishing a model that allows video frame pixels to be transferred to a real-world position in meters.
- Calculation of safety-relevant indicators based on extracted trajectories.
- Watchdog is a relatively simple video processing tool that flags situations in which a conflict might be found. This usually involves a combination of several simple detector units that are triggered when an activity is detected in a certain part of the image, along with a set of rules that define a situation as potentially relevant—for example, the simultaneous arrival of a car and a pedestrian at a pedestrian crossing. It is usually impossible to make a meaningful judgement about the severity of the event, which must subsequently be reviewed by an expert.

Automation of these functions can enhance a conflict study by making the work more efficient, standardising output and ensuring more accurate measurements. However, all the important decisions must still be made by a human observer.

T-Analyst: A tool for processing traffic conflicts

Developed at Lund University in Sweden, this database solution links tables describing identified conflicts to the recorded video, making it simple, for example, to select conflicts of a certain type and to play short video sequences containing only those conflicts.



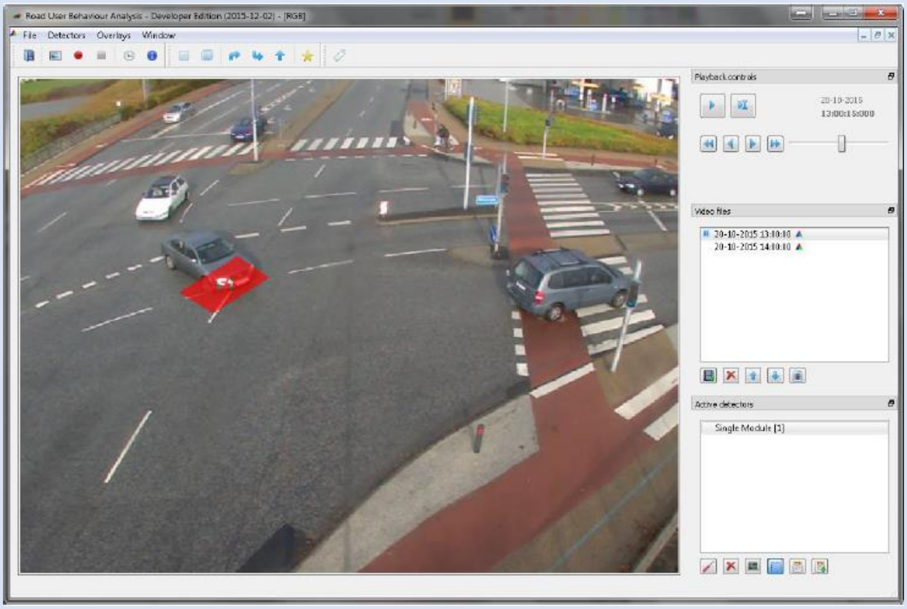
The tool also allows the user to assign a certain time frequency to pre-defined shapes in the image (car, truck, cyclist, pedestrian) and to extract their trajectories and speed profiles. Based on these data, it is possible to calculate the most common safety indicators (e.g. TTC, PET).

The software supports multi-camera recordings and includes a set of tools for video conversion and camera calibration.

For more information, see https://bitbucket.org/TrafficAndRoads/tanalyst/wiki/Home

RUBA: A watchdog software tool

RUBA (Road User Behaviour Analysis) was developed at Aalborg University in Denmark. The tool's basic functional unit is a detector—an area of the image that is monitored constantly for activity. Several detector types are activated by presence, idling (long-term presence) or motion in a certain direction, and one detector recognises traffic light colour.



Several detectors connected by a set of logical rules can be used at the same time. For example, it is possible to detect encounters (a car and a bicycle arriving simultaneously) or pedestrians walking on red.

The tool is most efficient when the frequency of expected events is low. Under favourable conditions, it allows removal of up to 90 % of original footage that does not include relevant situations.

For more information, see https://bitbucket.org/aauvap/ruba/wiki/Home

4.8.5 FULLY AUTOMATED TRAFFIC CONFLICT OBSERVATIONS

Fully automated software relies on complex computer vision algorithms that can detect, track and classify road users and utilise these video data to calculate safety indicators for all events over a period of time, finding conflicts and analysing indicator distributions.

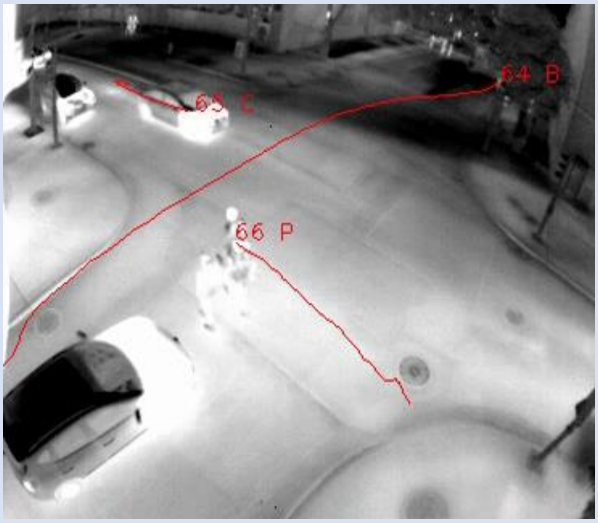
Object recognition and tracking is a rapidly evolving area in computer vision, but it is also a difficult problem to solve. One of the main challenges is the development of algorithms that can achieve stable performance in traffic scenes of all kinds. When the conditions remain the same, it is possible to achieve relatively satisfactory results for a brief period by fine tuning the parameters. However, conflict observations generally involve analysis of long recordings over several days or possibly weeks, day and night, sun and rain, for peak and off-peak traffic.

Promising directions for future development include the use of new types of sensor (thermal video, stereo cameras, radar, lidar) and different combinations of sensors (sensor fusion). For example, a test site in Braunschweig, Germany (Knake-Langhorst et al., 2016) has utilised more than 20 pieces of equipment (mono and stereo cameras, radars, IR flashes) to achieve tracking accuracy of almost 100%. However, for practitioners planning a traffic conflict study, this technology is not easily transferable, and an easier and more portable solution is needed.

Even if fully automated tools are available soon, it will still be very important not to blindly trust a computer program's analysis, and the human in the loop will remain a crucial component in understanding safety problems. For now, a program can only find the things it is programmed to find while an open-minded human observer can react to any unusual situations that may occur. For that reason, it is strongly recommended that an observer spends some time watching normal traffic performance at a given site as well as carefully reviewing situations judged to be safety-relevant by a computer vision-based program.

Traffic Intelligence project

This project at Polytechnique Montréal in Canada includes several tools for detecting, tracking and classifying road users, using a feature-based tracking algorithm for analysis of main outputs, trajectory data and road user interactions, as well as diagnosis of behaviour and safety. It has been applied to many case studies related, for example, to pedestrian behaviour and the safety of cycling facilities, highway entry and exit ramps and roundabouts. The technology has been used by several research teams and companies around the world.



While it includes tools for the most common tasks, it is best thought of as a software library for the user's own scripts. As all the code is open source, researchers can contribute new functionalities and replicate research results, and wider adoption is encouraged.

For more information and the open source code, see https://bitbucket.org/Nicolas/trafficintelligence/

STRUDL: Surveillance Tracking Using Deep Learning

STRUDL is an open-source and free framework for tracking road users in videos filmed by static surveillance cameras. It uses a deep learning object detector, camera calibration and tracking to create trajectories of e.g. road users, in world coordinates. It was designed to facilitate traffic safety analysis, using modern computer vision and deep learning, rather than the traditional methods commonly used despite their many flaws. By creating trajectories in world coordinates, truly meaningful metrics and safety measures can be computed. STRUDL provides a Web user interface that attempts to make it easy to use, even without too much knowledge in computer vision and deep learning.

Using the program involves the following six steps:

1. Import videos
2. Annotate images
3. Train an object detector
4. Provide camera calibration
5. Perform tracking in world coordinates
6. Download the tracks as csv files, and analyse them with whatever tools you like

For more information and the open source code, see https://github.com/ahrnbom/strudl

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4.9 Conclusions and key points

Surrogate measures of safety can be of great value in safety analysis, especially when accident data are limited or is of doubtful quality. The advantages of such analyses include their proactive nature, the relatively short time needed for data collection and the ability to observe conditions that are not usually recorded in accident reports. Over the years, many methods and techniques have been suggested, but only a few have been properly tested and validated.

The weakest feature of traditional traffic conflict techniques is their complete reliance on a human observer for detection and severity rating. Significant progress has recently been made in computer aids for the observer, including automated and semi-automated video analysis tools. However, while fully automated conflict studies are likely to be feasible in the near future, the properly trained traffic conflict observer will continue to play a key role.

4.10 Recommended reading

State-of-the-art review:

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Hydén, C., & Várhelyi, A. (2000). The effects on safety, time consumption and environment of large scale use of roundabouts in an urban area: a case study. Accident Analysis & Prevention, 32, 11-23. doi.org/10.1016/S0001-4575(99)00044-5

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CHAPTER 5

Behavioural observation studies

Road user behaviour is a key aspect of road safety. Road safety literature widely acknowledges that road user behaviour is an important factor in the complex interactions between road users, the road environment and the vehicle. According to several studies (Reason, 2000; Sabey & Taylor, 1980; Treat et al., 1979), road user behaviour is the most important contributing factor in nearly all accidents (94%), while the road environment and the vehicle only partially contribute in 18% and 8% of all accidents, respectively. Therefore, interventions targeted at controlling or altering road user behaviour should increase road safety. To understand road user behaviour, predict it in different situations and, if possible, control and modify it, it is necessary to have a technique or method for observing and identifying behavioural processes. This chapter presents such behavioural observation techniques as valuable tools for diagnosing road safety.

What will this chapter tell me?

- What are behavioural observation studies?
- How can behavioural observation studies be used to assess road safety?
- Why conducting a behavioural observation study?
- How to carry out a behavioural observation study?
- Which data are collected and how these data can be analysed.

Behavioural observation studies can be used to identify and study the frequency of particular characteristics of road user behaviour in different situations (OECD, 1998; van Haperen, 2016). This includes observing road user behaviour in all types of traffic events, from undisturbed passages to serious conflicts. Such study makes it possible to gain knowledge about the behavioural and situational factors at play both in low-risk encounters and preceding serious traffic events. Behavioural observation studies thus provide an opportunity to better understand the contributory factors influencing accident occurrence. Certain factors—such as speeding, red-light running and failure to wear seatbelts or helmets—not only contribute to accident occurrence but also to injury severity. As behavioural observation studies observe these contributing factors and the specific characteristics of related road user behaviour, the results of such studies can be used to identify which target groups or risk-increasing behaviours require attention to reduce road fatalities and serious injury.

Behavioural observation techniques are particularly useful when studying road user behaviour to diagnose road safety problems at specific locations or among specific target groups. Unlike accident data analyses, observing interactive behaviour provides an insight into the road safety process, not only road safety outcomes. For example, observing road user behaviour can reveal the underlying factors as to whether a given measure improves road safety or not. This chapter serves as a guide for applying behavioural observation studies to assess the road safety of vulnerable and other road users.

5.1 Introduction to behavioural observation studies

Identification of the drawbacks of accident data analysis has led to the development of several other road safety evaluation methodologies. These methods largely use safe traffic interactions as a benchmark and are based on the direct observation of traffic events that result from processes similar to those of accidents, or on observations and analyses of the particular characteristics and determinants of traffic behaviour (OECD, 1998). Behavioural studies are an example of such road safety evaluation methods. Typical behaviours in a behavioural observation study include informal communication, yielding behaviours, crossing behaviours, looking behaviours, red-light running, speeding and seatbelt use.

Behavioural studies are among the first road safety evaluation methods to use non-accident-based data. Nearly a century ago, Dodge (1923) argued that observing road user behaviour is crucial to improving road safety. One of the oldest behavioural studies was performed by Greenshields, Thompson, Dickinson and Swinton in 1934. They introduced the technique of taking consecutive pictures as a new data collection method to analyse road user behaviour. Since then, behavioural studies have become common practice and have been applied for various research purposes.

Behavioural studies are a type of naturalistic on-site observation technique, as road user behaviour is observed in the real setting in which the behaviour of interest occurs (Eby, 2011). In road safety research, this setting consists of the road environment, the vehicle and the road users interacting with each other in this environment.

What is a behavioural study?

A type of traffic observation study used to examine road user behaviour. These studies emphasise analysing the actions of road users in their natural settings by means of observable, qualitative variables (e.g. gender, age, interaction type, approaching behaviour, looking behaviour, priority behaviour, distraction, communication behaviour, red-light running, seatbelt use) while they interact with other road users, the road environment and/or their mode of transportation.

The basic principle behind the use of behavioural studies is the paradigm that the behaviour of road users is a prerequisite for road safety. According to Svensson (1998), safety levels are closely linked to the quality of the interactive behaviour and communication that takes place between road users. Consequently, road user behaviour—the most important contributing factor in road accidents—forms the core of behavioural studies. These studies aim to define and observe the principles of safe interaction among road users and the road environment by looking not only at unsafe interactions but also safe ones. The rationale behind this approach is that safe and unsafe interactions relate to each other; a subtle change in the interaction process between road users, the vehicle and the road environment can transform a safe situation into an unsafe one.

In capturing the interactions between these elements and the behavioural and situational aspects that precede accidents, behavioural observation studies offer valuable insights into how safe interactions can evolve into potential accidents and how road user behaviour influences the occurrence of accidents and accident-preceding events. Such study allows us to better understand why road users behave the way they do in different situations and events and to predict how road users will behave in certain situations, allowing safety measures to be implemented proactively (i.e. before accidents occur).

5.1.1 ADVANTAGES AND DISADVANTAGES

Behavioural studies are essential to many empirical data collection efforts but, like any technique, have both advantages and disadvantages.

The six main strengths of this method are described below.

Why should I use behavioural and interactional studies?	
ADVANTAGES	**DISADVANTAGES**
Direct observation of road user behaviour in a natural setting	Only observes revealed behaviours
Practice-ready (convenient to learn & apply)	Difficult generalisability of results
Data can be collected quickly for fast evaluation of road safety situations	Labour-intensive data collection
Inexpensive	Observer bias
Insights into behavioural and situational aspects that precede accidents (supplement to accident data)	Susceptible to adverse weather conditions, difficult at night
Can be combined with other techniques (i.e. supplement to accident data)	

First, these behavioural studies allow the direct observation of road user behaviour in a natural setting, making for strong face and construct validity (Eby, 2011). Their interpretation does not rely on road user behaviour proxies as self-reporting techniques do (Eby, 2011), and the results of these studies are more likely to reflect reality than those of other research methods (such as driving simulators). Further, observing road user behaviour in a natural setting reduces the effects of behavioural adaptation that can lead to risky or aggressive behaviour while driving (Shinar, 1998).

Second, these studies are practice-ready and convenient to learn and apply. Human observers can be trained in as little as two days because of the method's ease of use. These studies are so easy to use because no complex research resources are required; collecting road user behavioural data requires only trained human observers. These human observers can be complemented or even replaced by video cameras, but the locations of such cameras and the privacy legislations that can restrict their use should be considered properly.

Third, behavioural studies allow road safety situations to be diagnosed very quickly, as the data necessary for such diagnoses can be collected in a short period of time. These studies thus offer the advantage of responsibility, as road safety can be diagnosed and evaluated at locations perceived as unsafe before serious accidents occur.

Fourth, behavioural studies are inexpensive compared to other safety diagnostic methods, as they do not require costly training programmes or tools. This opens opportunities for road safety research in developing countries.

Fifth, these studies provide insights into the causes of accidents by describing the behavioural and situational aspects that precede them, as well as the specific characteristics of a location that may influence observed road user behaviour. This allows for the selection of location-specific road safety solutions.

Finally, behavioural studies can be used in combination with other techniques. To maximise the benefits gained from behavioural studies, it is recommended to combine results of these studies with traffic violation data, accident data analyses, self-reports and traffic intensity measurements (Lötter, 2001). When combined with these techniques, behavioural studies—which can be easily adapted to the requirements of a specific situation—are an effective tool for diagnosing road safety problems at specific locations or for specific target groups.

As a road safety diagnostic method, behavioural studies also have some disadvantages. The main shortcoming of these studies is that only variables describing the revealed behaviours of road users can be observed and collected, meaning the underlying causes of these behaviours remain undetected (Eby, 2011).

Another disadvantage is the lack of results generalisability (Eby, 2011). Because the observations of road user behaviour are location-specific, it is difficult to verify that the observed behaviours will also occur at locations where no behavioural study has been performed. As such, results interpretation requires caution.

Another drawback is the labour-intensive quality of the method's data collection. It is very time-consuming to conduct a behavioural observation study, as the observers must study the road user behaviour on-site for several hours. This requires significant endurance from the observers, who must remain focused during the entire observation period. Although the use of video cameras can reduce this intensity of labour (events can be replayed multiple times and the continuous observation period split into smaller blocks), it cannot eliminate it.

Another disadvantage is that the human observers on whom the studies rely may have biases that affect what they see and record (Eby, 2011). This observer bias can be mitigated through training or the use of video cameras to register road user interactions.

Finally, the execution of these studies is susceptible to adverse weather conditions and relies on daytime hours as these aspects limit the visibility of human observers to accurately record road user behaviour. Additionally, not all video cameras are able to sustain adverse weather conditions.

5.2 When to conduct behavioural observation studies

Behavioural observation studies provide information about the frequency of specific characteristics of road user behaviour in different situations. Unlike traffic conflict observation studies, these studies are not used to quantify road safety levels in terms of the expected number of injury-inducing accidents (OECD, 1998; van Haperen, 2016). On-site behavioural observation studies can be used for a wide variety of purposes and are especially useful when assessing road safety situations where there is no accident data available, or when the available accident data lacks detail (OECD, 1998). In the context of diagnosing and evaluating road safety, behavioural observation studies are used primarily for the following (OECD, 1998; van Haperen, 2016):

- Monitoring the frequency of road user behaviour;
- Checking the findings of accident and traffic conflict studies regarding possible accident factors;
- Evaluating the effects of road safety countermeasures or strategies;
- Developing behavioural models for simulation purposes; and
- Developing and testing automated video analysis software.

When behavioural studies are used for monitoring purposes, their focus lies in observing the frequency and characteristics of road user behaviour at one or multiple (i.e. identical) locations to determine the most prevalent behaviours. An example of such a study is that by Langbroek et al. (2012), who used behavioural indicators to investigate interactions between pedestrians and motor vehicles at signalised intersections.

Results based on accident and/or conflict data alone can be insufficient for determining possible accident factors or providing detailed insights into the causes and behavioural elements behind road safety problems. This is especially the case in situations where there is little accident or conflict data available, or when the available data lacks detail. Behavioural observation studies can help assess the road safety situation by checking the findings of accident and traffic conflict studies regarding possible accident factors. An example is the study by De Ceunynck, Daniels, Polders and Vernyns (2015), who aimed to gain a better understanding of the interactions between drivers of motor vehicles and cyclists at roundabouts with separated cycle paths to identify the road safety issues facing cyclists at these locations. Earlier studies based on accident data had been unable to determine whether it was safer to implement priority for cyclists crossing the exit and entry lanes of roundabouts with separate bicycle paths.

Behavioural studies are also effective when evaluating whether a measure has had its intended effect and to identify unwanted side effects at an early stage. The observation of ‘normal’ interactive behaviour is particularly relevant when determining why a given measure is an improvement to road safety or not. Unlike accident data analyses, interactive behaviour observation provides insights into the road safety process in addition to road safety outcomes, as demonstrated by Polders et al. (2015).

Finally, behavioural observation studies can be used for software and model development. With model development, behavioural observation data can be used as input to develop, calibrate and/or validate behavioural models such as microsimulation models (van Haperen et al., 2018). For example, Kadali et al. (2015) used behavioural observation data based on a video graphic survey as input to develop a pedestrian gap acceptance model. Behavioural video data of road user interactions can be used to develop and test automated video analysis tools (van Haperen et al., 2018). An example of such work is that by Zaki and Sayed (2014), who studied non-conforming pedestrian behaviour at an intersection in Vancouver, Canada. In this study, the authors developed and tested an automated system for identifying pedestrian crossing non-conformance to traffic regulations based on pattern matching. Their results revealed a high rate of noncompliance among different pedestrian populations and provided general information on the behaviour of crossing pedestrians (e.g. illegal crossing rate at the facility).

To summarise, behavioural observation studies are applied predominantly for monitoring and evaluation purposes, but are also used (to a lesser extent) to develop behavioural models and software (van Haperen et al., 2018).

Interactions between pedestrians and motor vehicles at signalized intersections (Langbroek et al., 2012)

A joint Belgian–Swedish study analysed interactions between pedestrians and motor vehicles at two-phase signalised intersections by means of video-based behavioural observations at three intersections in Sweden and Belgium. The study collected the following behavioural indicators: number of pedestrians, age and gender of involved road users and behavioural aspects like yielding, crossing and looking behaviours.

The analysis of the behavioural aspects revealed that men and young road users violated red traffic signals more often than women and older road users. Red light violation was also more prevalent at Swedish intersections than at Belgian ones. No differences were noted between pedestrians walking alone and pedestrians walking in groups. One interesting result was the fact that red traffic violations appeared to be independent of the presence of an approaching vehicle. Further, pedestrians often did not yield when violating a red traffic signal. Regarding looking behaviours, around 30% of pedestrians in general did not look both ways before crossing. Pedestrians who did not look both ways before crossing were involved in more traffic conflict situations than those who did.

Motorcyclists' road safety-related behaviour at access points on primary roads in Malaysia: A case study (Abdul Manan & Várhelyi, 2015)

An observational study focusing on motorcyclists was conducted at access points on straight sections of primary roads in Malaysia to gain more insight into actual road traffic situations at these sites. Motorcyclist behaviour was observed by means of video recordings and trained human observers at selected locations. The video camera was installed unobtrusively inside a parked car. Two observers were seated in the car; one operated the video camera while the other noted all the interactions and associated characteristics (e.g. identification of serious conflicts, course of events preceding the conflict, road user behaviours influencing the course of events).

The results revealed that the majority of motorcyclists kept to the speed limit and reduced speed when approaching an access point, especially in the presence of other road users. Motorcyclists tended to participate in a risky right turn movement (i.e. Opposite Indirect Right Turn [OIRT]) from the access point onto the primary road. Most of the motorcyclists who engaged in the OIRT manoeuvre did not comply with the stop line rule. The motorcyclists exhibited high compliance with helmet and headlight usage but were poor at utilising the turning indicator.

Yielding behaviour at roundabouts with separated cycle paths (De Ceunynck, Daniels, Polders, & Vernyns, 2015)

This Belgian study observed interactions between drivers of motor vehicles and cyclists at six roundabouts with separated cycle paths—three with priority for cyclists and three with no priority for cyclists.

By means of a standardised observation form, detailed information about 165 interactions was collected in a structured way. The observations showed that there were substantial differences between the two types of roundabouts concerning interaction behaviours between cyclists and motor vehicle drivers. At the roundabouts with priority for cyclists, the cyclists usually were given priority from the motor vehicle drivers. At roundabouts with no priority for cyclists, situations in which the motor vehicle drivers took priority occurred most frequently.

Looking behaviour also played a role in the interaction process. When a motor vehicle driver looked in the direction of a cyclist, the probability of the cyclist continuing to ride increased significantly. This probability was also higher among male cyclists. At roundabouts without priority for cyclists, motor vehicle drivers often were denied priority by male cyclists. Similarly, motor vehicle drivers took their priority less frequently when interacting with male cyclists than with female cyclists. Notably, the share of motor vehicle drivers who did not use direction indicators was quite high at 29%.

In sum, there was a high degree of heterogeneity among the interactions between cyclists and motor vehicle drivers, especially at roundabouts without priority for cyclists. This could indicate a potential safety risk for cyclists.

Drivers' behavioural responses to speed and red light cameras (Polders et al., 2015)

Many signalised intersections worldwide have been equipped with enforcement cameras to tackle red-light running or to enforce speed limits. However, various impact evaluation studies of red-light cameras (RLCs) show that the presence of these cameras leads to increases in rear-end collisions (up to 44%). The principal objective of this study was to provide possible explanations for the increase in rear-end collisions at combined speed and red-light camera (SRLC) installation sites.

Real-world behavioural observations and driving simulator-based observations were used. Video recordings at two signalised intersections where SRLCs were about to be installed were used to analyse rear-end conflicts, interactions and driver behaviours under two conditions (with and without the SRLC). One of these intersections was also built into a driving simulator equipped with an eye tracking system. At this location, two test conditions (SRLC and SRLC with a warning sign) and one control condition (no SRLC) were set for examination. Data from 63 participants were used to estimate the risk of rear-end collisions via a Monte Carlo Simulation.

The results of the on-site behavioural observation study revealed decreases in red and yellow light violations, a shift in the dilemma zone (closer to the stop line) and a time headway reduction after SRLC installation. Based on the driving simulator data, the odds of rear-end collisions (compared to the control condition) for the conditions with SRLC and SRLC + warning sign were 6.42 and 4.01, respectively. To conclude, the real-world and driving simulator observations indicated that the risk of rear-end collisions increased when SRLCs were installed. However, this risk might decrease with installation of an early warning sign.

5.3 Methods for observing road user behaviour

Behavioural observation studies for diagnostic purposes are usually designed according to the behaviour of interest or situation under observation. From a methodological point of view, behavioural observation studies can be divided into two categories: unstructured and structured.

In *unstructured behavioural observation studies*, researchers look with an 'open mind' at road user behaviours and record any observable action or behaviour that seems interesting or conspicuous. In this sense, these studies help researchers to 'get acquainted' with the research site. Unstructured behavioural observations typically complement traffic conflict observation studies; interesting situations are identified and collected when analysing the conflict observation data. Behavioural observations are not the goal of the research, but rather provide the bonus of rich qualitative information about road safety at a specified location. An example of an unstructured behavioural observation study is that by Manan and Várhelyi (2015).

In contrast, *structured behavioural observations* are well-prepared and can expand on results from unstructured observation studies. These studies conduct explicit and detailed observations of specific safety-related behaviours such as crossing and looking behaviours or traffic rule compliance at a certain location. In most cases, standardised forms of observation are used to study the behaviour of interest. These studies, especially when combined with other research methods, are essential for understanding complex road safety problems. An example of a structured behavioural observation study is that by Langbroek et al. (2012).

Regardless of the type of behavioural observation study, the two most common methods for collecting behavioural observation data are on-site human observers and video cameras (or a combination of the two, as mentioned by van Haperen et al., 2018). Both methods are easy to apply, can be used to observe all types of road users and allow the collection of a wide variety of behavioural indicators. The applied data collection method depends on the purpose of the study and the type of behavioural indicators under observation. Table 5-1 provides an overview of the two data collection methods and their characteristics.

Table 5-1: Overview of data collection methods

Method	Costs	Time consumption	Suitable target group	Suitable sample size	Type of behavioural indicators
Human observers	Medium	High	All types of road users	Small to medium	Yes/No
Video cameras	Medium	Medium to high	All types of road users	Large	Yes/No and more detailed measurements

Types of behavioural indicators (adopted from van Haperen et al., 2018)	
Yes / No	**More detailed**
Red-light running Gap acceptance Evasive action Protective clothing Carrying items Use of pedestrian push button Mobile phone use Wrong-way driving Turn indicator Lane change Stop-sign compliance Lights Stop/go decision Yellow-light running Overtaking Smoking Seatbelt use Child restraint use Speed (related) Looking Yielding Merging	Crossing path Waiting time Waiting position Lateral position Crossing time Gap size Headway Yielding distance Other distractions Other violations Lane choice Distance to stop line Merging distance Overtaking attempts Intersection entry time Speed (related) Looking Yielding Merging
Behavioural observation studies also register variables describing the personal characteristics of individual road users (e.g. age and sex) and informal communication actions like head, eye and hand movements and eye contact.	

5.3.1 HUMAN OBSERVERS

On-site trained human observers are a flexible and basic means to collect behavioural observation data. Researchers or observers stand next to roadways and intersections, look into vehicles and at vulnerable road users (VRUs) and record what they see (Eby, 2011). Behavioural observation studies by means of trained human observers have the advantage of only needing a watch, pen and behavioural observation form to register the revealed road user behaviour. The variables that are registered on the behavioural observation form are mostly 'yes/no' and 'single value' indicators. Further, the data of interest can be collected very quickly and efficiently (van Haperen et al., 2018). This method is useful when collecting behavioural data at different types of locations (e.g. roundabouts, intersections, part of an intersection) and for all types of road users.

The costs of using human observers for data collection primarily involve labour costs and depend on the number of observers for each project. The number of observers depends on the purpose of the research and the size and complexity of the study location. For instance, for a moderately sized intersection or a not-too-complex location, one observer is generally sufficient; more than one observer is recommended for more complex intersections or locations. When using multiple observers, some observation data will overlap, but this is compensated by the gain of additional information that can be observed and registered. The use of several observers is most useful in situations where multiple events occur simultaneously. It should be noted that in all projects involving human observers, the collected data must be digitised before data analysis may commence.

A disadvantage of behavioural observation studies using trained human observers is that the data collection process is influenced by inter- and intra-coder reliability (Williams, 1981), subjectivity (Grayson, 1984) and possible registration errors when the human observers are involved in operations for extended time periods. According to van Haperen et al. (2018), these drawbacks become more significant when the data collection process is complex and when the measurements are based on estimations that cannot be verified after the fact. Due to these limitations, it is recommended to only apply this data collection method for small-to-medium sample sizes (e.g. observe for two hours, then take a break before resuming observations). Further, the observers must be trained prior to collecting the data to ensure that the observations are performed as systematically and objectively as possible to yield valid results. Currently, many behavioural observations that use human observers also use video recordings. This allows the observer to review the observed interactions and behaviours when analysing the results. An example of a behavioural observation study by means of trained human observers is that by Langbroek et al. (2012).

TIP: Training of observers

Observers should be trained properly in conducting behavioural observation studies. During a short, multi-day training course, the observers participate in:

- Theoretical lectures
  - How to compose a behavioural observation form;
  - How to perform a behavioural observation study;
  - Points of attention.
- Practical instructions:
  - Exercises are done to learn how to observe road user behaviour accurately and efficiently on location;

- Real-life field observation sessions take place at a study location to ensure everyone gets acquainted with the behavioural observation form, knows which behaviours/interactions to observe and to check consistency in the recorded observations;
- Camera placement (if used);
- Processing, analysing and interpreting the data and results;
- Taking a good position with respect to the point of observation

Three main issues that need to be addressed during training (Eby, 2011):

- Training for consistency and accuracy: each observer should collect the behavioural data by following the same procedures (protocols and identical data coding). This should be practiced before starting the actual study.
- Inter-observer reliability: when using multiple observers, all observers should be trained together and tested for inter-observer reliability to ensure the collected data are comparable. This can be achieved by checking and comparing the recorded results of each observer after the practice session. If the inter-observer reliability is low (i.e. less than 85%), the observers should discuss how they are coding data and continue practicing until the comparability between the results is greater than 85%.
- Intra-observer reliability: the variability in the recordings of a single observer over time (Archer, 2005). The discrepancies of an individual observer can be attributed to different factors, including lack of training, inadequate definitions of the observed situations, fatigue, excessive conflicts and the occurrence of complex conflict types (Chin & Quek, 1997). These inconsistencies can be overcome through training programmes and video analysis techniques.

At the study location, observer(s) should have unobstructed visibility (i.e., a good overall view) and should wear unobtrusive clothing so as not to influence road user behaviour (Lötter, 2001).

5.3.2 VIDEO CAMERAS

Video cameras are a more objective and accurate means of collecting behavioural observation data. Per this method, one or multiple cameras are installed inconspicuously at the location(s) of interest and record road user interactions and behaviours (Eby, 2011). This method can be used to collect behavioural data at different types of locations (e.g. roundabouts, intersections, part of an intersection) and for all types of road users. Video cameras allow the continuous observation of road user behaviour, and the recorded interactions can be replayed and reviewed to verify the results. Registerable variables include both ‘yes/no’ and more detailed indicators.

Data collection by means of video cameras is less labour-intensive due to the approach not requiring the presence of a trained observer during data collection. The subsequent data analysis is still time-consuming, however, as automated video analysis tools are currently still under development (see chapter 4). An example of a behavioural observation study by means of video cameras is that by van Haperen et al. (2018). For more information on using video recordings for observation purposes, please consult section 4.8 of CHAPTER 4 of this handbook.

TIP: Using video cameras

The following points should be considered when using cameras:

- Authorisation from the road authority is required to place a camera.
- A good location (e.g. lamp post, building) is required to place the equipment. This place should be inconspicuous.
- The availability of electricity is an important factor.
- The camera's point of view must include the entire research area.
- Weather and lighting conditions must be accounted for (e.g. provision of a protective rain cover).
- The equipment must have some protection against theft.
- Privacy issues must be taken seriously. Video footage is a type of personal data, so all privacy regulations must be respected. These rules specify how the recorded video footage must be handled (e.g. blur license plates or faces, type of resolution to be used while recording). These rules vary from country to country, with some requiring permission from the privacy commission or authority before recording may commence.
- Available data storage space (e.g. hard drives, SD cards) must be monitored to avoid the overwriting of data and keep data loss to a minimum.

Conventional video cameras suffice for recording video footage at certain locations, but for longer observation periods (e.g. one week or more), the use of professional video cameras is recommended. These cameras can be rented from companies specialised in equipment for traffic studies.

Yielding behaviour and traffic conflicts at cyclist crossing facilities on channelized right-turn lanes (van Haperen et al., 2018)

A Belgian study investigated the safety performance of crossing facilities for cyclists using channelized right-turn lanes (CRTLs). Site-based observations of yielding behaviours were used to evaluate the effect of the priority rule on cyclists' safety in two CRTL designs. Four locations in Belgium were selected for video observations: two where the priority rule favoured cyclists and two where motorists had priority.

With regard to yielding, four types of crossing behaviours were identified and defined. Independent of the priority rule, cyclists crossed the conflict zone first in most interactions without taking the initiative to cross first. Underlying reasons for motorists willingly yielding their right-of-way could not be determined, but courtesy or fear of inflicting injuries on VRUs may have been of influence. The results lightly suggested that locations with motorist priority and right-to-left cyclist crossings (from the driver's point of view) produce the highest proportion of safety-critical events.

5.4 How to collect behavioural observation data

Behavioural observation studies typically follow a well-defined study plan. This section provides a step-by-step guide for setting up a behavioural observation study. The basic stages of a behavioural observation study are as follows:

1. Deciding to apply a behavioural observation study;
2. Selecting locations for observations;
3. Determining what road user behaviours to observe;
4. Formulating observation protocols;
5. Defining the research design;
6. Defining a data collection methodology;
7. Conducting the behavioural observation study.

These stages are described in greater detail in the subsections below.

5.4.1 DECIDING TO APPLY A BEHAVIOURAL OBSERVATION STUDY

Behavioural observation studies are a useful method for diagnosing many road safety issues. However, not all road safety issues can be assessed by means of this naturalistic observation method. Therefore, the following four qualities should be considered before deciding to use behavioural observation studies as a method (Eby, 2011):

1. Purpose of the study (research objective);
2. Reliability;
3. Population of interest;
4. Resources.

First, the purpose of the study needs to be determined. Behavioural observation studies are suitable when examining the frequency or occurrence of road user behaviours but are not appropriate for gaining an in-depth understanding of the underlying causes (e.g. motivations, beliefs, attitudes) of the revealed behaviours (Eby, 2011). Determining the purpose of the study or research objective is a crucial step in applying behavioural studies, as doing so dictates the entire study design (e.g. location, target group, behaviours for observation, observation time and duration). Second, you must determine whether it is possible to judge the behaviour of interest accurately and reliably through visual inspection (Eby, 2011). Third, it is important to identify the population of interest (Eby, 2011). In some cases, it can be difficult to design a behavioural observation study that both represents a large population and is cost-effective. Further, the population must occur in natural settings. Finally, you must have access to sufficient resources to conduct such studies, which can be very costly due to reliance on labour-intensive work and depending on the study's scope and design.

5.4.2 SELECTING LOCATIONS FOR OBSERVATIONS

Once you have decided to conduct a behavioural observation study, it is important to determine where the observations will take place. This decision relates closely to the study's purpose and the research objective. For example, your focus could be to evaluate road infrastructure re-designs at a certain location or to monitor the frequency and characteristics of road user behaviours at one or multiple locations to identify prevalent behaviours; such studies would require entirely different locations.

When selecting observation sites, it is crucial that they represent the behaviour of interest accurately—simply put, the behaviour for study must occur naturally at the chosen location. Generally, behavioural observation studies are applied at intersections in urban settings because VRUs appear more frequently in urban areas, as do road user interactions.

Selection of study location(s)
(van Haperen et al. 2018)

Based on accident data: Locations with reasonably high numbers of reported accidents are selected for the behavioural observation study.

Based on infrastructural characteristics**:** Locations are selected based on their infrastructural characteristics. These characteristics should be as similar as possible to limit the influence of confounding factors.

To guarantee the transferability of results, behavioural studies should focus on locations free of location-specific factors that may influence road safety conditions.

5.4.3 DETERMINING WHAT ROAD USER BEHAVIOURS TO OBSERVE

Once you have set your study location, it is important to select the variables for observation. These variables can relate to:

- The road user type to be observed: all road users or a specific group (e.g. only VRUs, only drivers).
- Personal characteristics of the road user: age, gender, helmet use, etc.
- Road user behaviour: looking, yielding, crossing, communication (e.g. use of directional indicators, hand gestures) and other behaviours.
- Infrastructural elements: priority rules at the location, colour of the traffic light while crossing, etc.

Laureshyn (2010) provides a detailed overview of the different variables that can be used to observe individual road user behaviours and interactions. These variables are clustered according to the main road user group for study (i.e. drivers of motor vehicles, cyclists or pedestrians). This overview indicates the data type and preferred data collection method for each variable. For more information regarding this topic, consult Laureshyn (2010). Interesting variables can also be selected based on the available road safety data at the study location; variables can be tailored to reflect the types of accidents for which additional information about road user behaviour is needed. Another option is to observe an intersection without any preparation; this method brings the advantage of obtaining an overall picture of the location's road safety and traffic situation (see section 5.3).

In observations using trained observers, the selected variables are noted on a standardised behavioural observation form specifically developed for the study. On this form, the various behavioural and situational aspects of the interaction are represented in the form of binary (yes/no) or categorical variables. By structuring and standardising interactions in such a way, it is possible to carry out quantitative analyses on the collected data. An example of such a standardised behavioural observation form is provided in Annex 1 of CHAPTER 5.

5.4.4 FORMULATING OBSERVATION PROTOCOLS

An observation protocol defines when and for how long the behavioural observation study will take place. The observation period should be determined according to the purpose of the behavioural observation study. If, for example, the road safety problem or behaviour of interest relates to specific weather conditions, traffic conditions or time of day (e.g. peak hours, night), the behavioural observations will need to be conducted at an appropriate time to meet these conditions (Lötter, 2001). Before starting formal observations, you should collect background information to acquaint yourself with the road safety problems at the study location. Accident data and inquiries with the local police department or residents near the study location can provide valuable insights (Lötter, 2001). It is crucial to consider the entire observation period thoroughly. When defining this period, you must ensure that it is reliable and representative of the road user behaviour under study. You can assure this representativeness by spacing the observations evenly throughout the hours of the day and days of the week (including weekends if necessary) to avoid possible biases.

The duration of the behavioural observations will depend on the situation under study, the desired reliability level, traffic density and the number of interactions at the location. In most cases, 30 hours of behavioural observations at a site are sufficient to provide an overview of the prevalent road user behaviours and allow for a road safety analysis. Generally, observations carried out by human observers (see section 5.3.1) are divided into blocks of no longer than two to three hours, each followed by a break of 10 to 15 minutes. To ensure each observation period begins on time, the observers should arrive at the study location at least 10 minutes before the start of the behavioural observations.

Observation protocol example

There are no standardised observation protocols currently available. Instead, researchers develop individual protocols tailored to their specific studies. Researchers do not uniformly describe study characteristics at the same level of detail, significantly limiting the transparency and transferability of research results (van Haperen et al., 2018).

The following observation protocol example has been taken from De Ceunynck et al. (2013, p. 41), who used it to observe vehicle–vehicle interactions at two non-signalised intersections:

Each intersection was observed for 30 h during the November 24 through December 5, 2011, period. All observations took place in dry weather conditions during the daytime because of the need to look inside the vehicles to collect information about the drivers' gender, age and looking behaviour. Twilight, night, and rainy conditions did not allow this. The observations were done in blocks of 2 to 3 h, spread evenly throughout the hours of the day and days of the week (including weekends) for both intersections to avoid possible biases. All observations were executed by one observer using a standardised observation form. All variables were objectified and standardised as binary or categorical variables to allow quantitative analyses of the interactions.

5.4.5 DEFINING THE RESEARCH DESIGN

The research design of a behavioural observation study is linked to the purpose of the study. For instance, if the purpose of the study is to evaluate road infrastructure re-designs, a before-and-after design is recommended. In such a study, road user behaviours are observed before and after the implementation of the infrastructural measure of interest to see whether the measure has its intended effect and results in positive road safety changes.

Behavioural observation studies can also use a single observation design, which focuses on observing the frequency of road user behaviours at a location. For example, the crossing behaviours of VRUs at signalised intersections could be observed. Variables could include the number of times pedestrians violate red traffic signals, whether they look both ways before crossing or whether they yield.

TIP: before and after study design

The same observation periods must be applied before and after the studied measure's implementation, and the characteristics of these observation periods (e.g. weather conditions, traffic conditions) must be as identical as possible. The 'after' observations should begin at least six weeks after the implementation of the measure to reduce the influence of the novelty effect and ensure road user behaviours have adapted to the changed traffic conditions (Polders et al., 2015).

Another option for research design is the cross-sectional approach. With this design, two or more locations (e.g. intersections) are selected. These locations must be as comparable as possible in terms of infrastructural design characteristics, vehicle speeds and traffic flows, but differ in one aspect (e.g. right-of-way rules). The behavioural observations at all the locations then examine how this one difference influences road user behaviour.

5.4.6 DEFINING A DATA COLLECTION METHODOLOGY

The data collection method you choose to apply will depend on the purpose of the study and the type of behavioural indicators that need to be observed. The two most common data collection methods are on-site human observers and video cameras (or a combination of the two, as mentioned by van Haperen et al., 2018). For more information, consult section 5.3.

Video camera vs trained observers (van Haperen et al.,2018)

Variables such as gender, age and communication between road users (e.g. informal signals, eye contact) cannot be obtained easily from video data and should be collected by on-site observers.

Video cameras offer the advantage of continuous data collection for longer time periods, whereas trained observers may take only a sample of a situation. Video data allow the registration of continuous variables (e.g. speeds), which can then be analysed accurately using video analysis. Video data also create the possibility of verifying the quality of measurements and replaying the videos as many times necessary to extract all relevant information (van Haperen et al., 2018). Finally, videos are very efficient in communicating research findings to other researchers and the public. However, only events happening in view of the camera can be analysed.

5.4.7 CONDUCTING THE BEHAVIOURAL OBSERVATION STUDY

Once you have completed all preparations, it is time for the actual behavioural observation study. Trained human observers must be present at the study location during the entire observation period. If using multiple observers, they will need to synchronise their watches before the start of the study so as to record road user behaviour occurrences on the behavioural observation form accurately. Time synchronisation also simplifies the data analysis process to follow. If using a camera at the study location, all human observers should synchronise their watches with the internal clock of the video camera to make it easier to retrieve interesting behaviours during the data analysis stage. You should also verify that the camera is working properly at the start of the study.

5.5 Presentation and interpretation of results

Descriptive statistics are commonly used to present the results of behavioural observation studies (see Table 5-2 and Figure 5-1). These statistics indicate the frequency of certain behaviours and are completed using the following information:

- Identification of common road user behaviours;
- Identification of the situations and circumstances in which the observed behaviour takes place;
- Characteristics of the road user exhibiting the behaviour.

Table 5-2: Descriptive analysis example of possible yielding events between cyclists and motor vehicles and the distribution of crossing directions (adopted from van Haperen, Daniels, & De Ceunynck, 2016).

Location	**"No crossing" events**		**Interactions**		
			Crossing direction		Total
	Total (#)	Unnecessary yield (#)	L → R (#)	L ← R (#)	
C (Z)	4	3	58	59	117
C	103	54 [52%]	330	225	555
M (Z)	385	109 [28%]	397	145	542
M	2	2	116	36	152
Total (n)	494	168	901	465	1366

Note:

C (Z) = cyclist right-of-way (with zebra crossing);
C = cyclist right-of-way (no zebra crossing);
M (Z) = motor vehicle right-of-way (with zebra crossing);
M = motor vehicle right-of-way (no zebra crossing);

L = left;
R = right

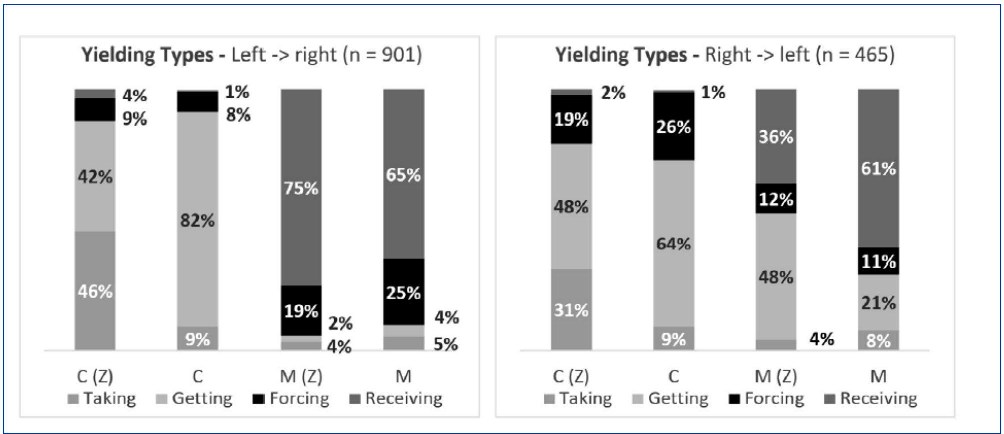

Figure 5-1: Illustration of analysis of yielding behaviour between cyclists and motor vehicles (adopted from van Haperen et al., 2018)

If using a before-and-after study design, the following questions should be addressed:

- Did the implemented measure result in a reduction of the targeted behaviour?
- Did the implemented measure lead to the occurrence of other behaviours?

As mentioned earlier, the generalisability of behavioural observation study results is an issue. Because road user behaviours are observed at specific locations, it is difficult to guarantee that the observed behaviours also occur at other locations where no behavioural studies have been performed. Therefore, some caution is required when interpreting results.

5.6 Complementary studies

Behavioural observation studies are usually complemented by other road safety data collection methods to create a comprehensive picture of the road safety situation at a given location. The study of Polders et al. (2015) is an example of an integrated study in which behavioural observations, traffic conflict observations and driving simulator research are combined to diagnose road safety holistically. These complementary studies are described in greater detail in the subsections below.

5.6.1 TRAFFIC COUNTS

The amount of cyclist, pedestrian and other traffic correlates positively to the number of encounters among the various road users. Exposure is a useful addition of traffic safety analysis and is important when proposing safety countermeasures. For more information regarding the collection of traffic counts or exposure data, consult the PIARC Road Safety Manual (PIARC, 2003).

5.6.2 SPEED MEASUREMENTS

Vehicle speed plays a critical role in accident occurrence and injury outcomes. As such, speed measurements can be used as a background reference and diagnostic tool to conduct behavioural observation studies (e.g. identify locations where VRUs might be at a higher accident risk due to fast-moving vehicles). As speed is a major determinant of VRUs' risk of injury, studies seeking to diagnose the safety of VRUs should always include speed measurements. Behavioural observation can then be applied to gain a better understanding of the relevant road user behaviours and their determining features at the specified location. For more information regarding the use of speed measurements, consult the PIARC Road Safety Manual (PIARC, 2003).

5.6.3 ACCIDENT DATA

Sometimes there is little accident data available, or the available data lacks the detail necessary to obtain a satisfactory evaluation or diagnosis. In such cases, behavioural observations can complement accident analyses to support the action design and, where appropriate, can even compensate for shortages of information on accident-generating processes (Muhlrad, 1993). The behavioural items to observe and locations of interest are determined primarily by the accident analysis findings. Often, behavioural observations are used to verify the findings of accident studies regarding possible accident factors. For more information on the use of accident data, consult CHAPTER 2 of this handbook.

5.6.4 TRAFFIC CONFLICT OBSERVATION STUDIES

Behavioural observation studies are often combined with traffic conflict studies to cover diverse aspects of the road safety situation of interest. Unstructured behavioural observations are typically additions to traffic conflict observation studies. Interesting situations are identified and compiled when analysing conflict observation data. In this way, behavioural observations add value to traffic conflict studies by providing more insight into the behavioural aspects and elements that affect traffic conflict occurrence. For more information on traffic conflict observation studies, consult CHAPTER 4 of this handbook.

5.6.5 DRIVING SIMULATOR STUDIES

A driving simulator consists of a mock-up vehicle surrounded by screens displaying a virtual road environment. Participants in driving simulator studies navigate the simulated road environment by controlling the vehicle actuators (steering wheel, brake pedal, throttle, gears). The simulators log detailed information about the user's driving behaviours and performance parameters.

Driving simulators allow for the proactive and detailed modelling of driving performance. These studies provide insights into how driver, vehicle and roadway characteristics influence driving safety and monitor how road safety improvements or measures influence driver performance (Boyle & Lee, 2010). Driver awareness of and response to risky situations, near-accidents and even accidents can be monitored in a simulator (McGehee & Carsten, 2010). Simulator studies also provide insights into the underlying mechanisms of safety-critical events (Boyle & Lee, 2010). Driving simulators have the potential to identify road design problems, explore effective infrastructural countermeasures, test advanced vehicle technologies and investigate a variety of driver impairments. Consequently, they provide very rich information about road safety.

Driving simulators do not only focus on the road safety of car and truck drivers. Driving simulators for motorcyclists and cyclists are also applied to assess the road safety of VRUs. For more information regarding driving simulator studies, consult Carsten and Jamson (2011) and Fisher, Rizzo, Caird and Lee (2011).

5.6.6 STATED PREFERENCE STUDIES

Interviews can aid the collection of information from road users of a location of interest and can provide data about safety-related phenomena. Even brief interviews with passing road users can yield critical information about the site that the observer might not have noticed in a short period of time. As such, these opinions form a solid basis for consecutive behavioural observations. The main reason for combining behavioural studies with stated preference studies is to determine the extent to which self-reported behaviours, attitudes, beliefs and opinions resemble the observed behaviour (see Geller, Casali & Johnson, 1980; Hakkert, Zaidel & Sarelle, 1981).

5.7 Conclusions and key points

Behavioural observation studies have a long history in the examination of road user behaviour and road safety and are still in common use today. These studies are particularly useful when seeking to diagnose road safety problems at specific locations or for specific target groups in order to identify which target groups and risk-increasing behaviours require attention. Typical behaviours in a behavioural observation study include informal communication, yielding behaviours, crossing behaviours, looking behaviours, red-light running, speeding and seatbelt use.

In the context of road safety evaluation and diagnosis, behavioural observation studies are used mainly to monitor the frequency of road user behaviours, to support findings from accident and traffic conflict studies regarding possible accident factors and to evaluate the effects of road safety countermeasures and strategies. Observing road user behaviours in their natural settings is a valuable method because it yields critical knowledge about effective road user behaviour and provides a means to identify and describe the determining features of such behaviour.

Behavioural observation studies are designed according to the specific behaviour and/or situation of interest, and as such require a well-prepared study design, established protocols, extensive observer training and adequate resources to yield valid results. The two most common methods to collect behavioural observation data are on-site trained human observers and video cameras (or a combination). The main remaining issue with these studies is the generalisability (or lack thereof) of results. Because road user behaviour is observed at a specific location, conclusions that the behaviour will also occur at locations not under study are difficult to secure. To combat this limitation, behavioural observation studies are often supported by other road safety data collection methods (accident data, traffic conflict observation studies, driving simulator research, speed and exposure measurements) to compile a comprehensive picture of the road safety situation at a certain location.

5.8 Recommended reading

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Annex 1

Date: Time: Weather conditions:	Pavement conditions: Intersection name:

	Pedestrian characteristics / Behaviour											
ID	Gender		Age				Yielding		Traffic light		Directional light	
	M	F	C	Y	M	O	Yielding	Not Yielding	G	R	Yes	No
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

	Interaction characteristics			Arrival	
ID		Presence of a car			
	Number of pedestrians	Yes	No	Pedestrian arrives first	Motor vehicle arrives first
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

	Characteristics / behaviour car driver											
ID	Gender		Age				Yielding		Traffic light		Directional light	
	M	F	C	Y	M	O	Yielding	Not Yielding	G	R	Yes	No
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

ID:
ID of observed interaction

Gender:
M = Male
F = Female

Age:
C = Child (age 0-17 years)
Y = Young adult (19-30 years)
M = Middle age (31-65 years)
O = Old (65+ years)

Traffic light colour:
G = Green
R = Red

CHAPTER 6

Naturalistic cycling and walking studies

This chapter focuses on naturalistic studies in road safety evaluations. Naturalistic studies can be used to study the behaviour of road users continuously. Hence, they cover all types of traffic events, from undisturbed passages with no other road users in sight to traffic conflicts. Even the most severe and rare events – accidents - can potentially be collected from naturalistic studies in case of a large number of participants and a long data collection period.

Naturalistic studies are particularly useful for studying the behaviour of road users in cases where the aspect studied is not related to a specific location. For instance, this method can be used to identify locations that involve a high safety risk due to lack of interaction between the road users.

Naturalistic studies are also known as Naturalistic Driving Studies (FOT-Net Data 2017), but the vast majority of datasets presented in FOT-Net Data was based on car driving.

In this chapter, the term “naturalistic studies” is used to describe naturalistic studies for all modes of transport, whereby information is collected while driving, walking or cycling. As this handbook focuses on techniques to assess vulnerable road user (VRU) safety, most examples presented in this chapter are related to VRUs. If more information on naturalistic studies from video-equipped cars is desired, the FOT-Net Data homepage is the most comprehensive source of information on this topic. See http://fot-net.eu/network/.

In this chapter, naturalistic studies are described and guidance is given on when and how to collect naturalistic data.

What will this chapter tell me?

- What are naturalistic studies?
- How can naturalistic studies be used to assess traffic safety?
- Why should a naturalistic study be conducted?
- How to carry out a naturalistic study?
- What data are collected and how to analyse them.

6.1 Introduction to naturalistic studies

Naturalistic studies are a method to conduct behavioural studies in transportation. The behaviour is observed discretely by the use of equipment to collect behavioural information such as position, speed, acceleration/deceleration patterns, swerving and performed manoeuvres. Furthermore, situational information such as the road condition, the presence of other road users and the look of the surroundings can be collected to describe all aspects of the trip. In most naturalistic studies, the road user is observed over a long time while they travel in their own means of transport during their daily trips, as they would normally do. Although road users are observed through a multitude of equipment and are aware of it at first, studies have shown that they tend to forget that any equipment is present after a few days (Jørgensen, 2010, Lahrmann et al. 2012). In practice, the equipment will thus not influence the behaviour of the road user.

What is a naturalistic study?

A method for the collection of continuous data (position, speed, acceleration, swerving, manoeuvres and video of surroundings) unobtrusively from the road users' own means of transport during his/her daily travel to study road user behaviour.

Naturalistic studies make it possible to collect a wide range of data to describe all aspects of road users' behaviour as it is reflected in interaction with other road users and the road environment. From a traffic safety perspective, the collection of continuous data in a naturalistic study is particularly interesting, because it makes it possible to collect data from near-accidents and accidents and other driving activities in its widest understanding *while* they occur. Because events related to traffic safety are relatively rare (Agerholm, Lahrmann 2012), naturalistic studies often involve a large number of road users and a long data collection period, e.g. months or years, which increases the probability of capturing these events. In most studies so far, it has been found that it is mainly an identification of typical incidents rather than sufficient incidents to enumerate actual accident patterns that has been documented. However, some of the larger naturalistic studies such as the American SHRP2 Naturalistic Driving Study, but also some of the largest Field Operational Tests (FOT) in Europe have sufficient data collected for reliable accident statistical inputs (FOT-Net Data 2017, Virginia Tech Transportation Institute 2017). From large-scale naturalistic studies with a high number of registered accidents, the severity of registered injured road user accidents can be compared with other sorts of accident data collection methods in order to verify if there are any dark figures in the data. This approach, however, requires additional data collection parallel to the naturalistic studies. It could e.g. be self-reporting, although it faces the same limitations as mentioned in CHAPTER 3

Data collected before, during and after near-accidents and accidents contain relevant information about the interplay between the road user, the vehicle, the road design and the environment, as well as the interaction between road users involved in the situation. By observing and analysing data collected around these events, an increased knowledge about factor(s), which alone or together result an accident or near-accident. Furthermore, it is worth noting that most tests of autonomous vehicles/driving from levels 1–4 require substantial volumes of data from a large range of sources and fusion of these, and that in many cases these data collections also are/have been in connection with naturalistic studies.

6.1.1 ADVANTAGES AND DISADVANTAGES

Naturalistic studies are a useful tool to collect data about road user behaviour. As opposed to behavioural studies, which observe road users at a specific location, behavioural information is collected continuously in the naturalistic study. It means that knowledge in naturalistic studies is based on the behaviours of a sample of road users, but covering a wider part of the road infrastructure gives a coherent view on various incidents under different conditions, compared to covering all road users' behaviour in one particular area or point. This feature makes it possible to follow the road user during entire trips, thus allowing for an extensive insight into their behaviour under various conditions as well as how it changes over time. Furthermore, it is possible to assess the behaviour of the individual road user across locations. An important feature of naturalistic studies is that they reflect the actual behaviour of the road users in the way they act in traffic, with no instructions and no intervention as regards to how, where and when to travel. After installation, data are collected automatically with no or limited need for human resources. Thus there are virtually no limitations on the duration of the data collection and it is possible to collect data over several months or years. For example, in SHRP2, video data have been collected for more than one year per vehicle. As data are collected continuously, conflicts, near-accidents and accidents will eventually be captured. Hence, such data contains important information about the behaviour and the surroundings in the moment before and during any incident, and can contribute to a better understanding of the causes of accidents. In this respect, naturalistic studies can also be a means to compensate for the under-reporting of accidents in the official statistics (Agerholm, Andersen 2015, Schepers et al. 2015), as all accidents and near-accidents during the duration of the study will be registered. A more in-depth perspective on under-reporting is presented in CHAPTER 3 (Self-reporting of accidents and near-accidents). Naturalistic studies can be used in combination with other techniques. For instance, it can be combined with self-reports to get insights into psychological factors and behavioural aspects that are not measured by the sensors used for data collection (e.g. fatigue, stress and alcohol intake). Overall, the availability of coherent knowledge of the recorded incidents is an advantage and such reporting covers virtually all types of road designs.

There are also some challenges from using naturalistic studies. The data volume grows rapidly and the volume of data will often be in terabyte (TB). In case of especially naturalistic studies, including those using different data sources, e.g. video, radar and/or onboard diagnostics (OBD-II)-based data (from the car's internal system) the volume of data can be extremely high. It means either the vehicle in question must have a large server capacity or a high-speed 4G/Wi-Fi connection to other server facilities. The requested sensors depends on the data needed. Despite the fact that a significant part of the data types today can be collected by smartphones, is it far from easy to make different sensor types to provide data in a readable format. This means that a planned collection of a certain data type in some cases can be much more difficult than expected due to lack of data readability. Probably the most common challenge of naturalistic studies is the planned analyses of data. In the majority of cases, the needed resources for analyses has been either underestimated manifold or used to compensate for higher than expected operation cost. A majority of the large naturalistic studies based on Global Navigation Satellite System (GNSS) data, video data or LiDAR/Radar data has faced the reality that even several years after the finalisation of the project, hardly any of the planned analyses have been conducted. Privacy issues regarding the collected data might make it difficult to use the datasets, as with the new General Data Protection Regulation (GDPR) of 2018 all persons' behaviour recorded in one way or the other has 1) to be sufficiently anonymised and 2) be withdrawn from the data sample on request of the single user. The latter might sound trivial, but with large data volumes, it is often a challenging task to solve.

Why should I conduct naturalistic studies?	
ADVANTAGES	**DISADVANTAGES**
Continuous data collection	Data volume is big
Reflects actual behaviour	Time-consuming data analysis
Data collected virtually automatically	Special equipment needed
Contains information about the time before and during near-accidents and accidents	Privacy issues
Compensates for under-reporting of accidents in official statistics	
Can be used in combination with other data collection methods	

6.2 When to conduct naturalistic studies?

Naturalistic studies can be used to identify and assess factors related to driving behaviour and traffic safety issues, and used to identify hazardous road locations in situations where accident data are insufficient, either because there are too few accidents registered or because there is a desire to assess other behavioural aspects. In general, the method can be used for:

- Identification and assessment of factors leading to near-accidents and accidents;
- Identification of hazardous road locations;
- Evaluation of the effect of traffic safety measures on road user behaviour;
- Monitoring of general road user behaviour.

Naturalistic studies are well-suited to identify and assess combination of driving behaviour and surroundings and their combined effects on traffic safety. As they collect data continuously, they can also be used to assess accident causation, i.e. which factors lead to the occurrence of an accident. The same applies for studies of near-accidents. Minor naturalistic studies can point out any behaviour, which seems to increase accident or near-accident risk. Major naturalistic studies can provide knowledge of statistical correlations between driving behaviour and surroundings in order to identify specific activities and/or locations that increase accident risk to a rate that is higher than expected.

In case of low registration rate of accidents, identification of hazardous road locations becomes uncertain. This is due to the fact that the number of accidents is small and might be random.

Large-scale naturalistic studies can contribute to increasing the amount of data so the most dangerous locations can be identified. Specifically, motion data, e.g. GNSS and video data, from a naturalistic study can be analysed in order to identify near-accidents and use as a supplement to accident data. Similarly, other indicators, e.g. speed patterns or data obtained from the vehicle itself, can be used to identify locations of interest.

The effect of traffic safety measures on road user behaviour can be evaluated via naturalistic studies. For instance, the effect of campaigns, infrastructural modifications or regulation changes (e.g. to reduce speed, seat belt use, red light right turn) can be evaluated based motion patterns (e.g. speed), manoeuvres (e.g. head turning, braking) or video to assess if there has been a general effect of the measure.

Finally, general road user behaviour can be monitored based on the data collected in a naturalistic study. With this information, the frequency of a particular behaviour can be estimated, and trends over time can be found.

Identification of hazardous road locations: an example

An Australian naturalistic cycling study (Johnson et al., 2014) collected data from 36 cyclists who were equipped with a video camera and a GPS data logger on their helmet to capture data. Over a period of four weeks, 8,986 km of cycling data were collected, corresponding to 466 hours.

The video footage was manually reviewed in order to identify interactions between cyclists and drivers, which were either accidents, near-accidents or incidents (i.e. events with a less sudden evasive manoeuvre). A total of 91 safety-critical interactions were identified; no collisions, 1 near-accident and 90 incidents. Many of those involved road users travelling in the same direction with the driver making a left turn in front of the cyclist, vehicles from an adjacent road, and open vehicle doors.

GPS data was used to map trip routes and locations of identified safety-critical interactions. Although not performed in the study, the latter can for instance be used for the identification of hazardous road locations.

Assessment of factors leading to near-accidents: an example

In the German Naturalistic Cycling Study (Schleinitz et al., 2015b), 31 cyclists had their bicycles equipped with two video cameras on the handlebars—one filming the cyclist's face, one filming forward—and a speed sensor on the front wheel. Data were collected for a period of four weeks. In total, data from 1,667 trips were collected, corresponding to 5,280 km or 372 hours. The video footage was reviewed manually in order to identify near-accidents.

A total of 77 near-accidents were found in the study. An assessment of the near-accidents showed that those between the cyclist and a motorised vehicle were often caused by the driver's failure to yield the right of way to the cyclist. For instance, this occurred when right-turning vehicles crossed the bike path and apparently neglected to check for cyclists. In near-accidents between two cyclists, the near-accident was often a result of sudden and unexpected manoeuvres by the other cyclist. In 45% of the near-accidents, one or both road users made traffic violations just before the near-accident occurred. The cyclists often used the wrong infrastructure (e.g. cycling on the pavement), failed to yield or cycled in the wrong direction. The opposing road user mainly failed to yield or left the parking space without signalling.

Evaluation of traffic safety measures on behaviour: an example

In a study of motorcyclists (Smith et al., 2013), naturalistic riding data are collected from novice and experienced motorcyclists to assess the effect of motorcycle rider training on the visual scanning patterns and the frequency of situations with stopping distances greater than the sight distance. Thirty-one motorcyclists completed the study by collecting data via eye trackers and a portable data acquisition system to measure the position, speed and orientation of the motorcycle. In total, more than 30 hours of naturalistic riding data were collected during the study.

The results show that untrained novice riders more frequently than trained riders (novice and experienced) rode with stopping distances higher than the sight distance and that they do a visual scanning of a wider area than experienced riders.

Monitoring road user behaviour: an example

Based on the German Naturalistic Cycling Study (Schleinitz et al., 2015a) the speed behaviour of cyclists using conventional bicycles and electrical bicycles (pedelecs: up to 25 km/h, S-pedelecs: up to 45 km/h) was compared. Ninety participants had their bicycles equipped with a speed sensor on the front wheel and two video cameras on the handlebar. The study lasted four weeks. A total of 4,327 trips were captured with a total mileage of 16,873 km.

Analysis of the speed data revealed that cyclists on S-pedelecs rode significantly longer trips than cyclists on pedelecs and conventional bicycles. The average speeds for conventional bicycles, pedelecs and S-pedelecs were 15.3, 17.4, and 24.5 km/h, respectively. Cyclists on S-pedelecs rode a considerable larger share of the total distance with speeds above 20, 25 and 30 km/h compared to the other cyclists. Furthermore, they accelerated faster than cyclists on conventional bicycles and pedelecs.

Video footage was manually reviewed to identify the type of infrastructure (e.g. carriageway, bicycle infrastructure, pavement) and free flow situations.

The actions of drivers: Between legal norms and practice

A naturalistic study with the aim to trace how legal norms are embedded in the legal consciousness of Danish drivers, and how this influences their driving practices was conducted by (Jørgensen 2010). By exploring how legal consciousness unfolds in dynamic processes, through the interpretation of everyday life activities, the research was based on a pragmatic hermeneutic approach. Thirty drivers were selected and interviewed. Ten of them participated in a naturalistic study with three cameras installed in their car. The aim was to differentiate analytically between three types of legal consciousness: pragmatic, ethical and rational.

Analysis of the video recordings indicates that the different types of legal consciousness appear in practice as entwined in various ways. E.g. stopping at red lights is perceived by all those interviewed as the most natural thing to do. At the same time, it is perceived to be associated with the risk of harming others if this legal norm is disobeyed. When the practical legal consciousness is rule ethical and pragmatic, legal norms play a significant role in practice. This manifests itself by drivers experiencing their own violations of this legal norm as frightening or shameful.

6.3 Methods for collecting naturalistic traffic data

Data in a naturalistic study can be collected in various ways depending on the type of road user, the selected sensors and the scope of the study.

For the data collection in naturalistic studies, there are overall three types of equipment: factory-installed, fixed and portable. All these types can collect data about the road user's actions, the vehicle and the surrounding environment but differ in how the equipment is installed.

Factory-installed equipment means equipment that is installed in the vehicle before start using it. Traditional it has been a range of sensors built-in to the car and accessed via the OBD-II plug. This plug gives access to a range of data such as speed, acceleration, revolution, and fuel consumption. Also, a range of other data to diagnose the car is available, but for car mechanics only. Increasingly, cars are equipped with other sensors, which can deliver data if accessibility is given. It includes built-in navigation, and various advanced driver assistance equipment as lane-keeping assistance, following distance warnings and adaptive cruise control. Data from these are, however, hard to access for non-car companies or car mechanics.

Fixed equipment is installed in/on the vehicle as an aftermarket installation, e.g., it can be installed on the handlebar or in the wheels of the bicycle, moped or motorcycle. The equipment is powered by the vehicle's battery, via external batteries that are installed together with the equipment, by internal batteries in the equipment or, potentially, via a dynamo. Once installed, the position of the equipment will remain the same. The advantages of this equipment are that the data are collected in the same manner and that information is only collected when the particular vehicle is in use. However, this method is not applicable for pedestrian studies.

Portable equipment is carried by the road user and can easily be removed. It can be placed in different positions each time, (prior it was often an independent device, as e.g. GNSS unit, cameras or Bluetooth readers. However, with the rapidly increased volume of functions and computer capacities of smartphones, most portable equipment is or will be substituted with smart phone-based counterparts. The portable device can be placed in pockets or a backpack) but may also be worn in the same position each time (e.g. smartwatch on the wrist or video camera on the helmet). The implication of this is that the position is unknown and may change from trip to trip, which complicates the data analysis if the device is dependent on acceleration pattern or slope. On the other hand, this type of equipment is usually lightweight, flexible and can be used independent of the means of transport, e.g. to collect data from the participant both when cycling and walking.

In naturalistic studies of VRUs, the weight and size of the equipment is important. Independent of the choice of installation, low weight and small size should be ensured. In this respect, e.g. smartphones are relevant since many road users already carry a smartphone while travelling and most new smartphones have built-in sensors which can be used for data collection and cover a range of data types of relevance.

Depending on the objectives of the study, different sensor types can be used for collecting data. The most common sensor types are:

- Accelerometer;
- Gyroscope;
- GNSS logger;
- Video camera;
- Switches;
- OBD-II with a range of data types available;
- Radar/LiDAR (laser scanner).

Accelerometers are used to collect information about acceleration and deceleration patterns of the road user. Usually, the information is collected with a high frequency i.e. several times each second and in three directions (X, Y, and Z axes). This information can be used in traffic safety studies, e.g. to indicate if a road user decelerates or swerves. Also, it can be used to identify sudden changes in the acceleration—so-called jerks—which may indicate that the road user has stopped quickly, e.g. due to an accident. Furthermore it is useful as a supplementing source of data, which can improve the precision of GNSS positions in case of low or no access from the GNSS devise to the sky.

Gyroscopes collect information about rotation of the sensor based on how the sensor is positioned. Similar to acceleration, rotation is typically collected with high frequency and in three directions (X, Y, and Z axes). With this information, one can register changes in the orientation of the vehicle or road user. For instance, rotation can occur if the road user falls or the vehicle tips over. As for the accelerometer, it can be a supplementing source of data to improve the precision of GNSS (GPS) positions, i.e. dead reckoning.

GNSS loggers register the position of the road user continuously. Hence, the selected route of the road the user can be recorded. The position can be used to map where accidents and near-accidents happen. GNSS data can also be used to estimate the speed of the road user. Furthermore, if the GNSS device is programmed with Kalman filtering, it can under some conditions work as a crude accelerometer.

Video cameras are usually installed to supplement motion data from other sensors with video recordings of the surroundings as well as of the road user. For instance, one camera can point forward to capture the surroundings while another points on the road user to record facial expressions and reactions or any body language. In addition to the video recordings, eye tracking devices can be used to track where the road user has directed their attention to and for how long. It can be done in real time or in after analyses of video recordings. Additionally, cameras can be based on traditional video data and thermal video data.

Switches can be mounted on the vehicle to register specific manoeuvres; turning of the handlebar, pedal use, use of the brake handles, etc. Switches can also be mounted in the wheel to register the speed of the vehicle.

Radar/LiDAR are most used for permanent or long-term placement but can be installed in cars. Both allows for 3-D registration of surroundings and absolute and relative speed for moving elements in the surroundings. Radar/LiDAR is an essential part of the data collection of autonomous vehicles on different levels and will be wide-spread in many cars concurrent with increasing automation.

6.4 How to conduct naturalistic studies?

The decision on which technique should be applied for data collection is based on the objective of the study and the resources available. If the most possible data are required for an in-depth knowledge about the processes leading up to accidents or near-accidents, naturalistic studies based on one or several cameras and combined with other sensors are suitable. Conversely, if the study aims to clarify the surface quality of a bicycle path network, an accelerometer combined with a GNSS device might result in the most valid selection of sensor type. Additionally, some practical considerations should be taken into account as part the planning of the study. The costs of a naturalistic study are high due to the need of special equipment and the large data samples that need to be collected. These data collection costs have recently decreased due to the development of smartphone-based sensors. Despite this development, the data analysis process remains labour-intensive.

6.4.1 BEFORE

Which type of data to collect?

Depending on the objective of the study, different types of data are interesting to collect; position, acceleration, rotation, speed, manoeuvres, video footage or Radar/LiDAR of the road user and the surroundings. In some cases, it is also relevant to combine the naturalistic study with other techniques to collect the relevant data. For instance, self-reporting (e.g. questionnaires, trip diaries) can provide information to supplement the naturalistic data and cover the gaps left by the selected data collection method.

Equipment

As the next step, it should be decided whether the equipment for data collection should be factory installed, fixed on the means of transport or portable. For VRUs, the size and weight must be kept low. Thus, power consumption of the sensors should be considered to reduce the need of large batteries. Also, if especially factory installed, but also to a certain degree fixed sensors are required, it might affect the user group considerably.

How many and which type of participants?

Due to the need of equipment for data collection and the costs related to this, the number of participants in a naturalistic study is often low. Many naturalistic studies of VRUs have used up to 40 participants, although some have been carried out with more than 100 participants and few with more than 1,000 participants (Madsen et al., 2016). Particularly for safety studies aiming to register accidents or near-accidents, the number of participants should be high.

Permissions

Personal information is collected in a naturalistic study. Thus, privacy issues and especially GDPR and its new requirements must be dealt with and the necessary permissions granted (e.g. from the national data protection agency) before the study can start. Furthermore, participants should be notified about which personal information is collected and how this information is stored and treated and how they can request their personal data deleted from the data collection.

Recruitment

Participants for a naturalistic study are mostly recruited from volunteers, e.g. based on criteria regarding how often they use a particular means of transport, but also as a part of the available volume of potential participants, which might be quite low (Lahrmann et al. 2012, Lahrmann 2013). For instance, participants can be recruited via network, interest organisations and media (social, news). It should be noted that recruitment among volunteers often implies that it is difficult to obtain a representative sample, which may influence the generalisability of results.

Installation of equipment

Before the study starts, all participants should have equipment installed. Fixed equipment should be mounted on each vehicle and calibrated, if required. Portable equipment should be sent to participants and instructions of how to use it (e.g. how often batteries must be charged) should be given. It is highly recommended that the equipment is tested by each participant before the study start. In many cases the equipment is non-existent, because it is smartphone-based. In such cases, it might be recommendable to have a sort of hotline, as many apps can malfunction depending on the operating system and version.

6.4.2 DURING

Hotline

During the data collection, it is advised to establish a hotline for providing support to the participants. For instance, participants may experience problems with the equipment, replace their vehicle, which then needs to be equipped with sensors, move to another area, stop using the particular means of transport, have questions to the study, want to quit the study, etc. It is advisable to have an online hotline, e.g. e-mail. Also, it has to be mentioned that even social media such as Facebook are superior in communication, it is advisable not only to rely on one social media, as a minority of the population will not use the specific social media tool.

6.5 Interpretation of results based on naturalistic studies

Large amounts of data are collected in a naturalistic study. From this data, relevant situations should be identified. With months or years of data from each participant, it is neither feasible nor possible to conduct a manual analysis of data. Depending on the objective of the study, tools to reduce the amount of data should be considered, e.g. video analysis to analyse video footage or algorithms to process motion data. For instance, accidents and near-accidents can be identified based on indicators such as acceleration, jerks and rotation. Likewise, the combination of source data, as e.g. position and a certain activity in the recorded video can be a suitable approach to filter the collected data.

Also, consideration on data management, data storage and privacy issues including the new GDPR has to be planned and operated during as well as after data collection. Last but not least, it has to be kept in mind that data analysis in most cases is much more time-consuming than expected. It is therefore advisable to include extra time (often years) for data analyses in the planning as well as any agreement with the test persons. It is furthermore advisable to read the report on data management and data protection on the FOT-Net Data homepage, http://fot-net.eu/network/.

6.6 Conclusions and key points

Naturalistic studies are used when the aim is to observe road user behaviour continuously and unobtrusively from the road users' point of view. Therefore, data collected before and during near-accidents and in some cases even accidents can provide an in-depth knowledge of the factors contributing to these incidents. Naturalistic studies can also be used to evaluate the effect of traffic safety measures on road user behaviour and monitoring of road user behaviour.

Generally, data are collected via special equipment such as:

- Accelerometers;
- Gyroscopes;
- GPS loggers;
- Video cameras;
- Switches mounted on the vehicle;
- OBD-II with a range of data types available;
- Radar/LiDAR (Laser scanner).

Based on the data collected from this equipment, a large volume of information can be extracted from the data and used for the assessment of behavioural and safety-related aspects. It is, in this regard, important to remember, that data analysis is often very time-consuming. In studies of VRUs, the weight of the equipment is an important factor and should preferably be kept low.

A number of issues should be considered before deciding and conducting a naturalistic study:

- Resources (human and financial).
- Which type of data to collect?
- Which type of equipment is appropriate to collect data?
- How many participants?
- Permissions and GDPR
- How to recruit participants?
- Installation, operation and maintenance of equipment.
- Establishment of a hotline during data collection.

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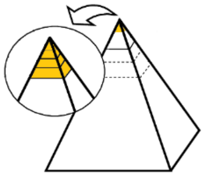
CHAPTER 7



Site observations of traffic infrastructure

The Star Rating protocol of the iRAP/EuroRAP programme is complementary to Road Safety Audits/Inspections in the sense that it provides a quick assessment of the general risk standard of a road whereas Road Safety Audits/Inspections focus on identifying detailed safety deficiencies EuroRAP, 2018; iRAP, 2018). The focus of this chapter lies on the latter. Therefore, this chapter focuses on Road Safety Inspections (RSI). An overview of tools of the EuroRAP/iRAP programme can be consulted in section 2.4.3 of CHAPTER 2. Some references to Road Safety Audits (RSA) will be made in order to expound the differences and similarities between RSI and RSA. It will be based on a literature review (general description and definitions) and some examples of the RSI/RSA.

Both RSI and RSA aim to reduce road accidents by analysing road infrastructure elements that could influence accident risk. These techniques allow the mapping of the risks of accidents across the entire European road network, which allows a comparison of the safety levels of roads across Europe. Within these techniques accident patterns on new and existing roads are studied. Additionally, the self-explaining and forgiving character of the roads are evaluated by assessing the crash-friendliness of the road infrastructure elements. In this respect, both techniques assist in reducing fatal and serious injuries among road users as it is highly recognised that the self-explaining and forgiving roads concepts assist in reducing injury severity.

The difference between inspection and audit is related to the phase in which the infrastructure is found. RSI are performed if the road is already build and opened to traffic for a time period sufficient for accidents to have been registered. On the contrary, RSA are performed for roads in the preliminary stages before opening to traffic. This includes the phases from planning to construction (and also the first months with traffic). Therefore, one determinant that must be taken into account is that for RSI we have accidents to analyse, and for RSA we analyse only the infrastructure without accidents. The European Directive 2008/96/EC (European Parliament & European Council, 2008) defines an RSI as 'an ordinary periodic assessment of a road's features and deficiencies which from a road safety perspective make maintenance necessary' (see section 7.1).

Road safety audits and inspections were introduced in road safety management by the European Traffic Safety Council on behalf of the European Commission. The council produced the report 'Road Safety Audit and Safety Impact Assessment' in 1997. The report focused on the benefits of RSA and recommended all Member States to introduce the tool. Before that, there had been a progressive shift in road safety management thinking and practices in high-income countries. Four main development phases for road safety management can be considered, progressively increasing the ambitions in terms of results (OECD, 2008):

- From the 1950s to the 1960s the focus was on driver interventions – for example, focusing on rules, penalties, education and training.
- From the 1970s to the 1980s the focus was on system-wide interventions – for example, focusing on infrastructure, vehicles and users in the pre-crash, in-crash and post-crash phases.
- In the early 90s, the focus was on system-wide interventions, targeted results and institutional leadership.
- From the late 90s onward, the focus has been on system-wide interventions, long-term elimination of deaths and serious injuries and shared responsibility.

The objective of this chapter is to identify the key elements that help to assess and treat the risk, focused on vulnerable road users (VRUs).According to the World Road Association, RSA and RSI are proactive approaches that can be applied to avoid future accidents by (PIARC, 2015):

- Ensuring that the safest road design scheme is selected for construction;
- Checking that the proposed road infrastructure or feature is designed and built to minimise the occurrence of road safety problems; and
- Treating safety issues on existing road networks before accidents occur at these locations.

It is generally accepted that RSI are performed on existing roads, and RSA are performed during the design process.

However, some countries refer to both for similar processes.

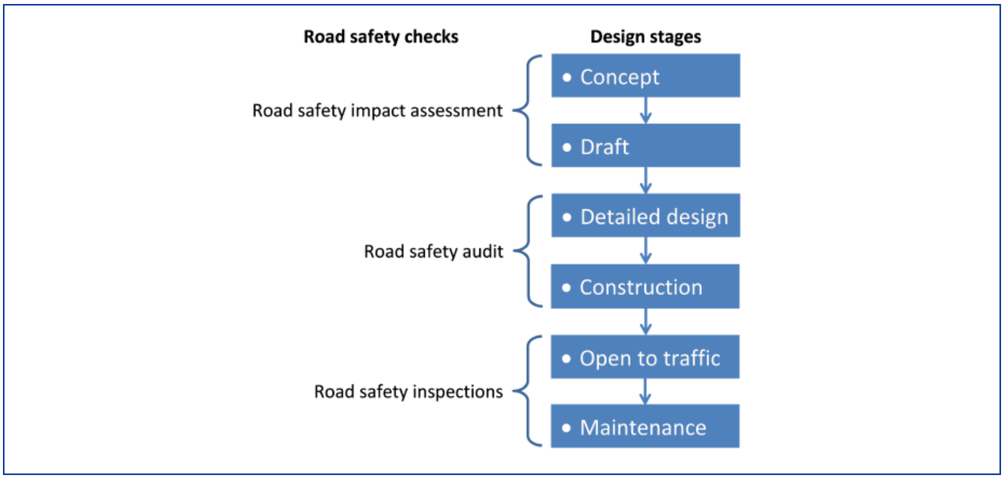


Figure 7-1: Sequence of road safety checks during the design stages (PIARC, 2011 and PIARC, 2015)

7.1 European Directive on road infrastructure safety management

In recent years, the palliative road safety policies that have traditionally been applied by all road administrations have been accompanied by preventive road safety measures. These preventive measures aim to address potential road safety problems before accidents occur. Within this framework, RSAs are established in Europe as one of the most useful tools to improve road safety.

The European Union already addressed the need to implement RSAs and other preventive tools for new and existing roads in a systematic way, in their third Road Safety Action Plan covering the period between 2002 and 2010. However, the true step forward took place with Directive 2008/96/EC of the European Parliament and of the Council on Road Infrastructure Safety Management that was issued on 19 November 2008. The rationale behind this Directive implies that road safety infrastructure management offers a wide margin of improvement. Directive 2008/96/EC has recently been amended by a proposal of the European Commission and European Council (European Commission and European Council, 2018). This proposal sets out that VRUs and their road safety needs should be mandatory and systematically taken into account in all road safety management procedures.

Establishing adequate management procedures is an essential tool to improve the safety of road infrastructure. Thus, the Directive "requires the establishment and application of procedures related to road safety impact assessments, RSAs, road network safety management and safety inspections by Members States" (European Parliament & European Council, 2008):

- Road safety impact assessments have to show what the implications of different planning alternatives for an infrastructure project are at a strategic level. It constitutes the comparative strategic analysis of the impact of a new road or the substantial modification of an existing road.

- RSAs should determine in detail the risk elements of an infrastructure project, that is, the verification of the safety of a road infrastructure project from the planning phase to the initial exploitation phase.

- Safety management of the road network in operation aims to increase the safety level of the existing roads by investing specifically those sections where there is a greater concentration of accidents or a greater potential for reducing them.

  To determine road sections with a high concentration of accidents; the number of fatal accidents per unit of road length in relation to the traffic volume must be taken into account. This also applies to intersections. Next, the road sections will be classified into categories. For each road category, the classification of network safety will be translated into priority lists of road sections in which an improvement of the infrastructure is expected to be highly effective.

  It must be ensured that teams of experts evaluate the sections with the highest priority through site visits. Furthermore, corrective actions should be directed at the road sections with the highest rate of return.

- The classification of network safety presents great potential in the period immediately after application. Once the road sections with a high concentration of accidents have been treated and the appropriate corrective measures have been adopted, safety inspections should acquire an important role as preventive actions. Periodic inspections are an essential tool for preventing potential dangers that threaten all road users, including VRUs.

The Directive includes the need to carry out safety inspections on roads in operation as a means to identify road safety characteristics and prevent accidents (European Parliament & European Council, 2008). RSIs include periodic inspections of the road network and safety checks of the traffic flow. Such inspections are carried out frequently enough to ensure an adequate level of safety.

Furthermore it is important to clarify that, when referring to the different procedures of road safety management, the Directive reserves the concept of audit, in a strict sense, to the "verification of a road infrastructure project, applied to the different phases from the planning to the exploitation in its initial phase" (European Parliament & European Council, 2008). It refers to other terminology such as the impact assessment when it focuses on new construction projects (planning) or when it refers to the verification of existing roads (safety ranking and management of the road network in operation and safety inspections).

In this light, it can be assumed that there are different management levels to which the different strategies correspond according to the different causes of the problem and the possible solutions.

Finally, the Directive "will apply to all roads in the Trans-European Road Network (TERN), regardless of whether they are in the design, construction or operation phase" (European Parliament & European Council, 2008). Additionally, it is included that "Member States may apply the provisions of the Directive, as a set of good practices, also for the national road transport infrastructure, not included in the TERN, which has been built through the resource total or partial community funds" (European Parliament & European Council, 2008). Therefore, although in its literal meaning, the Directive is limited to the integral roads of the Trans-European Road Network, the regulation enables, and in some way recommends, its application to the rest of the road network.

7.2 Basic concepts in RSA/RSI

RSA and RSI are procedures to test the safety level of the road infrastructure. RSA test the design of new roads or the reconstruction of existing roads, whereas the RSI are implemented for testing existing roads (SWOV, 2012). An RSA, therefore, aims to improve road safety before the road is built or reconstructed (SWOV, 2012).

RSI also contribute to road safety, although in Directive 2008/96/EC they may give them a more limited purpose than they may have. An RSI can be carried out periodically on an entire network but also on road sections that have an above-average number of accidents (SWOV, 2012). Currently, no standardized procedure exists for RSIs whereas standardisation is desirable for a more systematic use of this assessment method (SWOV, 2012).

Most practices agree on certain similar characteristics of RSIs:

- An RSI is systematic: it will be carried out in a methodical way following a formal procedure.
- An RSI is proactive: safety deficiencies are to be identified for remedial actions in order to prevent accidents.
- An RSI is performed on existing infrastructures.
- An RSI identifies potential safety hazards for each road user perspective.
- An RSI should be performed by a qualified and independent professional team.

As a critical thought, RSAs are based on predictions, because new roads are designed according to a regulation from which it is expected to result in adequate safety levels. For existing roads, it is not always the adaptation to the regulations that provides safety but the improvement of the issues detected. Therefore, many people believe that certainties should always have priority over forecasts, no matter how sophisticated the measurement methods or prediction models are.

7.3 Actors in the RSA/RSI

A qualified team carries out the inspection or audit. This team must fulfil the following requirements (European Parliament & European Council, 2008 and Austroads, 2009):

7.3.1 SKILLS

It is essential that RSAs or RSIs are conducted by an experienced team in road safety engineering. This means that the team should be familiar with traffic engineering and management, road design and construction techniques and road user behaviour. The team should be transversal in an organisational sense, this means that the team is able to cut across multiple functions or elements of the RSA or RSI.

It is convenient that the team members have different skills and experience so they analyse the road project from several points of view. It is crucial that RSAs and RSIs are performed from all road user perspectives.

7.3.2 EXPERIENCE

The auditor team should consist of members with adequate road safety engineering experience. There should be one team leader with road safety experience and training, named the Senior Road Safety Auditor.

A Senior Road Safety Auditor has:

- Successfully completed a recognised audit training course. Each country should organise audit courses to train road safety professionals to become road safety auditors;
- At least five years of experience in a relevant road design, road construction or traffic engineering field (this is a minimum that the Directive requires, it is generally considered that team leaders for audits of more

complicated projects should have significantly more experience);
- Undertaken at least five formal RSAs, including at least three at design stages; and
- Kept his/her professional experience updated by undertaking at least one audit per year.

The expert criteria of the auditors should be based on an in-depth knowledge of the principles of road design, of the risk factors according to the context and of the safety elements of the road infrastructure.

7.3.3 INDEPENDENCE AND SUBJECTIVITY

The inspection team must be different and independent from the conservation and exploitation team.

If the road safety auditor is independent, the project is critically assessed. Even though, RSI is a process included in the field of exploitation of the road in which the people responsible for conservation and exploitation of the inspected section contribute and offer added value. Therefore, communication between the parties must be established and maintained if the audit is to be done effectively and without wasted time and effort.

Auditors need to be objective in their assessments and consider all road users (pedestrians, bicyclists, public transport users, powered two-wheeler drivers, truck and bus drivers, etc.). They have to avoid just analysing the roads from the car-driver perspective. Designers and clients need to consider audit recommendations objectively and gain from the experience.

7.3.4 NUMBER OF AUDITORS

The road safety audit team should at least consist of two experienced and qualified professionals. The benefits of having a multi-member audit team, rather than a single person, include (Austroads, 2009):

- The diverse backgrounds and different approaches of different people;
- The cross-fertilisation of ideas which can result from discussions; and
- Having more pairs of eyes in order to successfully assess all the deficiencies.

The road management institution designates the auditors that are part of the audit team. If needed, the team will also include technical specialists.

7.4 A step-by-step guide for inspections and audits

A RSA or RSI is a relatively straightforward process. The steps in the process are illustrated in the flow chart in Figure 7-2. In some organisational structures, and for some minor projects, some of the steps may be brief, but the sequence of steps will still apply. The steps apply equally to design-stage audits and other audits.

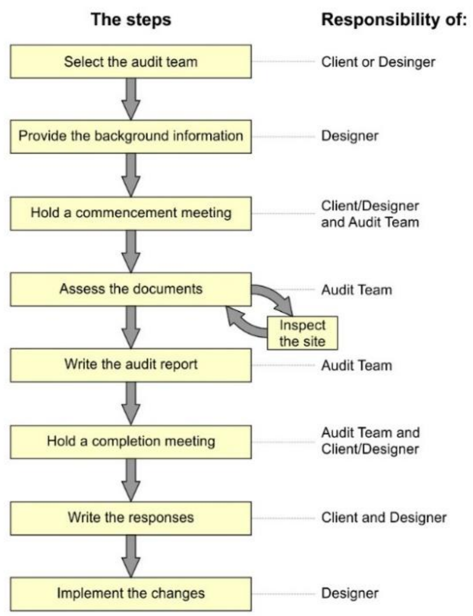


Figure 7-2: Audit process (based on European Parliament & European Council, 2008 and Austroads, 2009)

Each step of the process should be considered in every RSA or RSI regardless of the nature or scale of a particular infrastructure project. This means that even when a small-scale audit needs to be performed, is important to select the expert team carefully, collect all the available information, organise meetings and write the audit/inspection report. However, the number of meetings or the length of the report increases with the complexity of the project.

7.4.1 PREPARATION WORK IN THE OFFICE

Basic material

The audit team must have all the information necessary to carry out the audit or inspection. This includes documentation related to the project, legal documentation, internal information regarding traffic volumes, accidents, any road safety study or investigation carried out in the area of influence or that may be of interest for the case. The audit team must also know if a previous RSA was conducted and should have access to these results.

The documentation related to the project must include a set of drawings with enough detail to be able to analyse the vertical and horizontal alignment and other items relevant at the particular phase of the audit. When the audit is conducted in the planning stage, the layout of the road plans are essential. At detailed design and pre-opening stages, signage, line-marking and street lighting plans are more important. It is also necessary that the audit team has information not only from the project area but also from the surrounding area that the project may affect. The delivered information must be digital, compatible and editable. The plans must allow measurements.

Site data also needs to be considered, such as any environmental effects relevant to the location or the design – for example, weather conditions (ice, fog, snow, etc.), animals, services, historic buildings, special road users, factories and topography. Data related to traffic volumes should also be delivered to the audit team, including data from VRUs if known.

The analyses of available information must be done rigorously and, when useful, on the ground, before and after each inspection.

Simple accident study

Once the inspection team has the basic material, it is important to study the registered accidents.

When considering the accident situation on a road section, it is important to think proactively, that is, not just focusing on what has happened but also on anticipating what can happen in the future.

One should be focused on previous accidents on the road section in order to identify the hazard points in the road. Inspectors should also gain a rough overview of the accident situation along the section. Past occurrences give as information about the actual road situation, but inspectors should not overlook other hazardous conditions that may affect general road safety.

It is the general accident picture of the section that should be focused on but always based on the locations where the individual accidents have occurred. This is achieved through a simple accident study. Which accident types dominated on the section and which have resulted in serious injury should be revealed. Moreover, it would be appropriate to check if there are other factors that typify the accident picture, such as the time of the year, time of the day, etc.

The accident study must reveal the type of road users that were injured in the section. In this respect, inspectors must know if there is any safety problem regarding VRUs.

Inspectors should also look at the previous black-spot reports and check if there is any black-spot or zone in the analysed road section.

It is recommended to carry out the accident study before the inspection is completed and to check whether the accident picture confirms the hazard locations in the road section.

In accident studies, it is very interesting that the audit team is consists of experts in road safety, traffic management and road design. The number of accidents, the typology of the most frequent accidents, the traffic conditions, the traffic volumes, the capacity of the road and congestion are already known in RSIs. Therefore, it is important that the auditors have extensive knowledge of accident characteristics of different road types, specific knowledge of accident reconstruction, the ability to relate the identified problems with possible solutions and knowledge about the needs of all road users that use the road section – including pedestrians, cyclists, motorists, light-vehicles users and heavy-vehicles users.

7.4.2 ON-SITE FIELD STUDY

It is essential for the RSI team to visit the site in daylight to identify any problems relating to the present configuration and, if appropriate, to visualise the future proposals and their effects. In addition, it is a good practice to visit the road at night-time. Aspects related to luminosity and reflectivity can be better analysed without daylight. The audit team should carefully select the most effective periods to inspect the site as traffic conditions can vary throughout the day or week.

A night-time inspection is also essential except where, in the experience of the client, there will be nothing additional to observe. However, these circumstances should be rare. The visual information available to road users can be markedly different at night-time, and it can be surprising what additional issues can be identified on a night-time inspection, even where work has not yet commenced.

When the audit team is on site, they must look beyond the limits of the design plans (or the limits of works at the pre-opening stage): the inspection should include the adjacent road sections.

Transition or terminal zones, where the new (and usually higher standard) road transitions into the existing road system can often be locations of greater hazard as

- Road layouts and devices which previously operated safely can fail to do so once traffic volumes, speeds or movements alter; and
- Motorcyclists may be unaware of the need to adjust their behaviour.

In addition, new roads or new traffic arrangements can often disrupt existing traffic and pedestrian movement patterns.

The inspection should be undertaken from the point of view of all the likely road user groups and not just motorists. Young and elderly pedestrians, truck drivers, cyclists, elderly and disabled drivers have quite different safety needs.

- Child pedestrians have a lower eye-height to observe vehicles. Being small, they can be easily out of the field of vision of a car driver. Moreover, they can act impulsively.
- Elderly pedestrians may be less agile, have poorer sight or hearing or may have a poorer ability in judging gaps and the speed of traffic.
- Truck drivers have a higher eye-height, but this can lead to delineation issues, and their visibility can be more easily affected by overhanging foliage. Their vehicles take longer to stop and start moving, they are wider and blind spots can be a problem.
- Cyclists are more seriously affected by surface conditions (for example, grates, potholes and gravel) and gradients.
- Elderly drivers may be less able to recognise certain traffic control features or judge gaps due to cognitive difficulties.
- People with disabilities can be affected by poor eyesight, poor hearing or difficulties moving around objects, moving near edges, moving between levels or moving at typical pedestrian speeds.
- Motorcyclists have rapid acceleration but are susceptible to poor pavement conditions and 'squeeze points', such as when the road turns from two lanes to one lane.

Consider how well the design caters for the different types of movements, such as crossing the road and entering the traffic stream or leaving it as well as for travelling along the road. Consider these for the different user groups and the effects of different weather conditions.

Taking photographs or videotapes allows for later reference and possible inclusion in the report, but such materials must not be used as a substitute for a site inspection: all audit team members should inspect the site.

7.4.3 RSI REPORT WRITING

The main focus of the RSI report is to describe the aspects of the project that involve safety risk and make recommendations about corrective actions. The recommendations will usually indicate the nature or direction of a solution rather than precise details. The report provides the formal documentation on which decisions about corrective actions will be based.

A positive element of the design that improves safety can be mentioned in a RSA or RSI report, but it is not necessary to mention them. The purpose of the report is not to rate the design but rather to address any road safety concerns.

In some cases, safety problems may be identified but a recommendation may not come to mind. In this case, the safety issue should not be ignored: simply record the finding (i.e. the safety concern), and write 'Investigate treatment and implement it' under the item 'Recommendation''.

There is no unique procedure of ordering findings and recommendations in a RSI report, but the most important consideration is that the order needs to be logical and helpful for the report's recipients when they study the road to implement road safety measures. For example, in the situation of different intersections and ramps, where the identified problems are related to four elements – alignment, cross section, delineation and visibility – it may be better to define each site separately rather than write about each design element from the different sites. On the contrary, for long road section projects, it may be more appropriate to divide the project into sections. In any case, recommendations for similar safety problems related to different road sections of the project should be cross-referenced in the report. The usual way to order safety problems if they are not related is by significance and risk, starting with the critical ones and finalising with the slight ones.

7.4.4 REMEDIAL MEASURES AND FOLLOW-UP

Recommendations included in RSA and RSI should be based where possible on proven collision reduction techniques, and the road safety inspectors should have experience in this area. The experience gained in proposing appropriate remedial measures provides the Road Safety Auditor with the skills needed to identify solutions most likely to be effective in addressing the specific risks identified. These include monitoring the site to identify the success of the remedial measures and building up control data from similar sites. Road Safety Auditors should also be aware of the issues that are known to affect the road safety of all road users.

Any safety issue that is considered to be of sufficient hazard to warrant immediate attention for removal, protection or warning should be identified in the recommendations with the words 'URGENT'. Similarly, any safety problem which the auditor considers as great potential danger can be identified as 'IMPORTANT'. These two categories are not mutually exclusive. Their use does not imply that other identified problems are not important.

To maintain good communication with the designer, the auditor should endeavour to resolve any uncertainties or misunderstandings by talking with the designer before drawing conclusions. However, the auditor is independent and should not, for example, be required to provide a draft of the RSA report to the client or designer. Depending on the project type, the findings and recommendations of the audit may be written in 'prose style' or in a tabular format. A tabular format has the advantage that it can be used directly by the client to create a table of corrective action responses.

7.5 Road safety incidences templates

For a better performance of the on-site field study works, the use of templates is recommended. The templates can be useful for the audit team and used as a checklist guide in order to follow a formal process in each inspection. The road safety incidences templates must consider six sections, as follows:

7.5.1 GENERAL DATA

Table 7-1: General data from road safety audit/inspection template (Catalan Government (2017) and NPRA (2014))

Form code [1]				**Number of forms in a same section** [2]	
Incidence title [3]					
Incidence family [4]			**Incidence group** [5]		
Involves vulnerable users? [6]	Pedestrians	Cyclists	Motorcyclists	Other	
Location of incidence [7]		**Date created** [8]		**Date updated** [9]	
Audit type [10]		**Code**		**Author** [11]	
Notes					

[1] **Form code:** code of the form

[2] **Number form:** correlated number of forms of incidences in a same stretch

[3] **Incidence title:** brief description of the incidence detected

[4] **Family incidence:** general elements / functional elements / pending

[5] **Group of incidence:** according to the table of families of incidences

[6] **Involves vulnerable users?** whether the incidence detected involves potentially vulnerable users: pedestrians, cyclists, motorcyclists, other

[7] **Type of incidence:** general / punctual / stretch / pending

[8] **Creation date**: date of initial creation of the first card

[9] **Update date:** date of the last update of the card

[10] **Audit type:**

- RSA: Road Safety Audit (design and construction)
- RSI: Road Safety Inspection (operation)

[11] **Author:** name of the component of the inspection team that has filled in the form

7.5.2 LOCATION

Table 7-2: Location data from road safety audit/inspection template (Catalan Government (2017) and NPRA (2014))

Road / street [1]		**Direction [2]**	
Initial km [3]		**Final km [4]**	
UTM initial x [5]		**UTM final x [6]**	
UTM initial y [5]		**UTM final y [6]**	
Notes			

[1] **Road/street:** code of the road or name of the street

[2] **Direction:** ascending / descending / not applicable

[3] **Initial km:** indicates the kilometre and hectometre separate (example: 12+550)

[4] **Final km:** indicates the kilometre and hectometre separate (example: 12+550)

[5] **UTM Initial:** indicates the coordinates X and Y in UTM of the initial point of the incidence

[6] **UTM Final:** indicates the coordinates X and Y in UTM of the final point of the incidence

7.5.3 ANALYSIS

Table 7-3: Incident analysis from road safety audit/inspection template (Catalan Government (2017) and NPRA (2014))

Incidence description [1]	
Level of risk [2]	
Risk justification [3]	
Consequences of the accident [4]	

[1] **Incidence description:** analysis of the incidence detected

[2] **Level of risk:** normal / low / medium / high

The level of risk will be defined by the inspectors analysing the data on traffic, speed of route, outline, quality of equipment, etc. This value is related to the probability that an accident will happen. There are four categories of risk:

- Normal low risk
- Low half risk or no significant risk
- Medium high or significant risk
- High top risk

[3] **Risk justification:** brief description of the risk that supposes the incidence detected and justification of its level of risk.

[4] **Consequences of the accident:** slight / severe / very severe

This identifies the type of accident that could occur and the consequences of this accident.

Evaluation of the incidence: determination of the level of incidence, I/II/III/IV/V. The level of incidence will be determined in a standard way following Table 7-4, combining the two previous concepts of establishing the four levels of risk – normal/low/medium/high – and the five levels of incidence – I/II/III/IV/V. The highest incidence corresponds to grade I and the lowest incidence corresponds to grade V.

Table 7-4: Determination of the level of incidence when completing the template (Catalan Government (2017) and NPRA (2014))

Level of incidence		Consequences of the accident		
		Slight	Severe	Very severe
Level of risk	Normal	V	IV	IV
	Low	V	III	III
	Medium	IV	III	II
	High	III	II	I

7.5.4 PHOTO AND MAP/AERIAL PHOTO

Photos, maps and/or aerial photos are necessary to better define the incidences detected.

7.5.5 ADDITIONAL DOCUMENTS

Additional photos, documents, schemes, etc. can be included.

7.5.6 IDENTIFICATION CODE

The incidences are identified according to a specific functional coding based on the following classification of family and group:

- **General elements of road security** include ergonomics, coherence, readability, visibility, user expectations, perception of the risk, speed, exploitation, typology of users and other general elements of road security. In this group we find incidences such as traffic signals obstructed by urban vegetation, contradictory traffic signals, a pedestrian crossing too far from the intersection, a pedestrian crossing obstructed by other urban elements, a lack of secure zones for pedestrians in an intersection, excessive road space for motor vehicles with respect to VRUs, etc.
- **Functional elements of road security** include layout, cross section, pavement and drainage capacity, signage, markings, containment systems, intersections, roundabouts and links, access points, special sections, security elements for other users, rest areas, obsolete sections and other functional elements of road security. In this group we find incidences such as cracks in pavement, floods due to drain system failure, erased marks, lack of space for handicapped users, etc.

7.6 Checklists

Checklists are developed to facilitate the realisation of RSA and RSI in all stages. The aim of these checklists is to provide inspectors a support to be consulted so that no road safety aspect is overlooked. Checklists establish a relation between aspects that must be checked at each stage.

Although the checklists can facilitate the preparation of the audit, this cannot be limited to a routine check of the points reflected in the lists; it is essential that for each specific case the team in charge applies their criteria and their experience to detect the problems. The checklists are just another tool for the audit team. In this sense, the audit reports should include in the body of the document the review of the general aspects that are included in them.

7.6.1 WHEN DO WE USE CHECKLISTS?

The checklists as a tool should be used in the RSA of road projects in the design, construction and operation stages (in the pre-opening phase) and in the RSI in full-operation roads, as appropriate. For this, the specialist who applies the checklist must have experience in RSAs and must establish, according to their criteria, the total or partial applicability of them since it depends to a large extent on the characteristics of the project to audit the aspects considered in them.

The application of the checklists must be in homogeneous sections, for which the division of the sections or intersections to be applied must be defined in advance. Subsequently, each question must be answered by noting georeferenced information and making all the annotations that are considered permanent and that allow the full identification each of the elements of the infrastructure that have been evaluated.

It is recommended *not* to include the checklists in the audit report. However, the obligation to include them as annexes to the report depends on the contracting entity.

7.6.2 HOW DO WE USE CHECKLISTS?

In the stage of the development of an RSA or RSI, the audit team must perform a review of the primary and secondary information available, with the purpose of defining the aspects to be evaluated and in this way define and construct the checklists.

The checklists can be structured as general or specific. The *general* lists contain the broad aspects to be considered, for which it is recommended that the audit team define the topics that should be incorporated in the audit according to the characteristics of the project to be evaluated and depending on the phase in which the RSA/RSI will be performed. In the same way, special aspects of the project must be identified and not listed in the formats presented in the manual. The *specific* checklists contain in detail each of the aspects to be evaluated, disaggregating the content established in the general checklist, in order to identify the findings that affect the road safety of the evaluated project. In the specific checklists the magnitude and the risk of the deficiency are normally assessed. The magnitude refers to the grade of the deficiency, and it is normally ranked in three levels (very bad, bad and medium). For example, we can find a deteriorated pedestrian crossing, but this deterioration can be ranked to give an idea of the actual condition of the pedestrian crossing. The risk refers to the impact that deficiencies have on users' safety, and it is ranked in four levels (continuous, frequent, sometimes and sporadic).

Given that the format presented in this handbook is general, the audit team should adjust their formats to allow them to record as much information as possible for each of the items or aspects evaluated.

7.6.3 ASPECTS TO BE ANALYSED

The audit team must carry out an evaluation of the key aspects that the checklists consider from the point of view of road safety. These aspects differ according to the stage in which the RSA or RSI is being carried out.

Environment

The generalities of the project are discussed, such as the function or origin, how the project is framed within the road network and for whom the road infrastructure designed will serve. This information allows an evaluation of the context of general project security. It is necessary to analyse aspects such as changes from the previous stages (if applicable), drainage, climatic conditions, landscaping, services, access to properties and important developments in the environment, access to emergency vehicles, future extensions and/or future realignments, construction by stages of the project, planning by stages of the works, stability of slopes and embankments and compliance with technical requirements for signalling, road clearance, side areas and other users.

Infrastructure

Evaluate whether a previous RSA or RSI has been performed, which allows knowledge of aspects that require special attention and the changes that have been generated in the project. The audit team must consider additional aspects to those outlined in the handbook in accordance with the characteristics of the project.

In this section, the corridor is analysed. When performing an RSI, based on a field visit in combination with the construction drawings, we can determine the sites that may have security problems. Here we analyse aspects related to visibility distances, design speed, speed limits, homogeneous sectors, geometry of horizontal and vertical alignment, overtaking, cross section, bridges and gauges, culverts and boxes, transverse slopes and banks, friction, defects of the pavement and slopes of inclines.

Intersections also play an important role. The intersections must be easy to understand for the user, and the design should strive to use the same type of intersection throughout the project, or a typology according to the types of roads that intersect, with the aim of preventing the user from deciphering each intersection individually, which generates insecurity and can lead to mistakes.

Special road users

Special users are pedestrians, cyclists, motorcyclists, cargo transport vehicles, public transport and road maintenance vehicles. The project environment should be evaluated with the aim of providing complete solutions for special users. In this section, we seek to evaluate from the perspective of road safety whether the facilities required by these special users have been taken into account and if their use allows safe travel throughout the project.

Transit and transportation

For RSA, it is highly important to know which types of users are going to use the infrastructure or which type of users are going to cross it. How traffic is distributed in time is basic to anticipating road safety problems.

One of the most important aspects in road projects is related to signage, so this must be evaluated judiciously since it is the communication language of the users with the road project to achieve safe and fluid movement. In addition to a good design, it is necessary to provide all the necessary and sufficient information to the user of a road so that he can manoeuvre safely and with sufficient advance notice. The most important aspects to be evaluated are lighting, traffic lights, vertical signage, demarcation and road delineation, central barriers, lateral containment barriers, poles and other obstructions and finally bridges, culverts and gutters.

Table 7-5: Road aspects to be analysed when performing an RSI (MINITRANSPORTE, 2017)

Aspect	General topic	Particular topic
Environment	General environment	Weather conditions
	Landscaping	Landscaping and terrain
Infrastructure	Corridor	Visibility and visibility distance
		Design speed
		Horizontal and vertical alignment
		Speed limit/speed zoning
		Overtaking
		Readability
		Rail widths
		Berms
		Bridges
		Culverts
		Transverse slopes and banks
		Slip resistance
		Puddles
		Functional defects of the pavement
		Traverse slopes
	Intersections	Location
		Horizontal and vertical layout
		Visibility to and from the intersection
		Horizontal signage
		Vertical signage
		Lateral banks
		Illumination
		Others
	Auxiliary lanes	Length and transitions
		Visibility
		Vertical signage and demarcation
	Associate infrastructure	Public and private equipment
		Areas of services and rest
		Access to properties and urban developments
		Accesses for emergency vehicles
	Vulnerable road users	General topics
		Pedestrians
		Cyclists

		Motorcyclists
	Special road users	Public transport
		Maintenance vehicles
	Other road safety aspects	Parking lots
		Provision for heavy vehicles
		Temporary road works
		Activities on the edge of the road
		Rest areas
		Crossing of animals
		Furniture
		Urban landscaping
Traffic and transportation	Signage, facilities and obstructions	Illumination
		General topics of vertical signalling
		Centre line, edge line and lane line
		Legibility of signals
		Devices for traffic regulation
		Lateral zones
		Barriers and defences
		Visibility of barriers and defences
		Traffic light

7.7 Conclusions and key points

This chapter has described the results of the review on Road Safety Audits (RSA) and Road Safety Inspections (RSI) methodologies that could be included in road safety management, focusing on VRUs.

The chapter focused specifically on the following topics:

- Basic concepts, steps and authors in RSA/RSI;
- RSI forms;
- Checklists for VRU.

The developed topics were mainly based on the European Directive on Road Infrastructure Safety Management. Nevertheless, RSI for VRU are not generally as of yet applied in road safety management, so an adaptation from general RSI and RSA background materials has been made.

7.8 Recommended reading

Austroads (2009). Guide to Road Safety Part 6: Road Safety Audit (No. AGRS06/09). Sydney, Australia: Austroads.

Baltris (2012). Road Safety Inspection Guidelines and Checklists. Vilnius, Lithuania: Tallinn University of Technology.

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FHWA (2006). Federal Highway Administration Road Safety Audit Guidelines (No. FHWA-SA-06-06). Washington D.C., USA: U.S. Department of Transportation.

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References Chapter 7

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PIARC. (2015). Road safety manual: A Manual for Practitioners and Decision Makers on Implementing Safe System Infrastructure. Paris, France: PIARC - World Road Association. Retrieved from: from http://roadsafety.piarc.org/en

SWOV (2012). The Road Safety Audit and Road Safety Inspection. SWOV-factsheet, July 2012, The Hague, The Netherlands: SWOV – Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid.

Annex 1: RSI template

Road safety inspection template (Catalan Government (2017) and NPRA (2014))

GENERAL DATA

Form code				**Number of forms in a same section**	
Incidence title					
Incidence family			**Incidence group**		
Involves vulnerable road users	Pedestrians	Cyclists	Motorcyclists	Other	
Location of incidence		**Date created**		**Date updated**	
Audit type		**Code**		**Author**	
Notes					

LOCATION

Road / street		**Direction**	
Initial km		**Final km**	
UTM initial x		**UTM final x**	
UTM initial y		**UTM final y**	
Notes			

ANALYSIS

Incidence description	
Level of risk	
Risk justification	
Consequences of the accident	

Evaluation of the incidence

Level of incidence		Consequences of the accident		
		Slight	Severe	Very severe
Level of risk	Normal	V	IV	IV
	Low	V	III	III
	Medium	IV	III	II
	High	III	II	I

Notes	

PHOTO	**MAP / AERIAL PHOTO**

ADDITIONAL DOCUMENTS

Annex 2: RSI checklist

Checklist for a road safety inspection (MINITRANSPORTE (2017))

ASPECTS	COMMENTS
PEDESTRIAN SPACE	
Presence, design and location	
Are platforms provided along the street?	
If there is no platform, is there an accessible berm (for example, wide enough to accommodate cyclists / pedestrians) on the road or other nearby trail?	
Are berms / platforms provided on both sides of the bridges?	
Is the width of the platform suitable for pedestrian volumes?	
Is there an adequate separation distance between vehicular traffic and pedestrians?	
Can people with visual impairment distinguish the limits of the platform / street?	
Are ramps offered as an alternative to stairs?	
Does the wide platform radius increase the pedestrian crossing distances and increase high-speed in right turns?	
Do the channelized right turn lanes minimise conflicts with pedestrians?	
Does a skewed intersection prevent drivers from concentrating on pedestrian crossing?	
Are pedestrian crossings found in areas where viewing distance can be a problem?	
Do high roadway dividers provide a safe waiting area (shelter) for pedestrians?	
Are the pedestrian crossing marks wide enough?	
Are rail crossings safe for pedestrians?	
Are pedestrian crossings located along pedestrian flow lines?	
Are corners and platform ramps properly planned and designed for each approach to the crossing?	
Do the platforms / paths connect the street and the adjacent uses of the land?	
Are the platforms / paths properly designed?	
Are building entrances located and designed to be obvious and easily accessible to pedestrians?	
Are the bus stops conveniently located?	
Are pedestrian crossings adequate and safe, especially for the population with reduced mobility and the school population?	
Is the visibility distance to bus stops adequate?	
Are the stops properly designed and placed for the safety and comfort of pedestrians?	
Are the waiting areas at the locations sized according to the prevailing demand?	
Quality, condition and obstructions	
Is the pedestrian path clear in case of temporary or permanent obstructions?	
Is the walking surface too steep?	

Is the surface of the walk (platform or pedestrian path) adequate and well maintained?	
Is the crossing pavement adequate and well maintained?	
At intersections is the junction between the road surface and the pavement of the road adequate?	
Are parked vehicles clogging pedestrian crossings?	
Is the seating area at a safe and comfortable distance from the vehicle and bicycle lanes?	
Do the seats (or people sitting on them) block the sidewalk or reduce its useful width?	
Is a sufficient landing area provided to accommodate passengers waiting, boarding / alighting and passing through pedestrian traffic during peak hours?	
In whereabouts, is the landing zone paved and free of problems such as uneven surfaces, standing water or steep slopes?	
Is the platform free of temporary / permanent obstructions that restrict its width or block access to the bus stop?	
Continuity and connectivity	
Are the platforms and berms continuous and on both sides of the street?	
Are measures needed to direct pedestrians to safe crossing points and pedestrian access roads?	
Does the connectivity of the pedestrian network continue through the crossings by means of adequate waiting areas at the corners, platform ramps and marked pedestrian crossings?	
Are pedestrians clearly oriented to crossing points and pedestrian accesses?	
Are pedestrian facilities continuous? Do they provide adequate connections for pedestrian traffic?	
Are the transitions of pedestrian facilities between developments / projects adequate?	
Is the nearest crossing opportunity free of potential hazards to pedestrians?	
Are the stops, stations and terminals part of a continuous network of pedestrian facilities?	
Illumination	
Is the platform adequately illuminated?	
Does street lighting improve pedestrian visibility at night?	
Is the crosswalk properly lit?	
Are the access roads to the transit facilities well-lit to accommodate the early morning, afternoon and evening?	
Visibility	
Is the visibility of pedestrians walking along the platform / berm adequate?	
Can pedestrians see vehicles approaching at all intersection / junction accesses and vice versa?	
Is the distance from the stop line (or give way) to a crosswalk sufficient for drivers to see pedestrians?	
Are there other conditions in which stopped vehicles can obstruct the visibility of pedestrians?	
Is the visibility and distance of visibility adequate?	
Are open lines of sight maintained between the approaching buses and the waiting and loading areas of the passengers?	

TRAFFIC AND TRANSPORTATION	
Access management	
Do the roads that cross continuous platforms have the necessary adjustments that reduce the danger to pedestrians?	
In existing pedestrian crossings, does the number of lanes make the route unsafe for pedestrians?	
Are access roads for pedestrians and other vehicle modes clearly bounded on open roads?	
Do drivers look for and give way to pedestrians when entering and leaving roads?	
Transit	
Are there conflicts between bicycles and pedestrians on the sidewalks?	
Do vehicles that turn represent a danger to pedestrians?	
Are there enough gaps in traffic to allow pedestrians to cross the road?	
Do traffic operations (especially during peak periods) create a safety problem for pedestrians?	
Does the behaviour of pedestrians or drivers increase the risk of being run over?	
Are buses, cars, bicycles and pedestrians separated on the site and provided with their own designated areas for travel?	
Are pedestrians entering and leaving buses in conflict with vehicles, bicycles or other pedestrians?	
Road signs	
Are pedestrian areas clearly delimited from other modes of transit through the use of stripes, coloured pavements and/or textures, signs and other methods?	
Is the visibility of horizontal and vertical signage adequate during the day and night?	
Is the condition of the paint on the stop lines and pedestrian crossings adequate, or are there any worn, missing or damaged signs?	
Are crosswalks for pedestrians properly marked and/or demarcated?	
Traffic lights	
Are traffic lights provided for pedestrians, and are they adequate?	
Are pedestrian traffic lights timed so that waiting times and crossing times are reasonable?	
Is there a problem due to an inconsistency in pedestrian activation or detection systems?	
Are all pedestrian signals and push buttons working correctly and safely?	
Are the access buttons provided and located properly for pedestrians in a disability condition?	

Annex 3: RSI examples

Road safety inspection examples

GENERAL DATA					
Form code	ASV-006			**Number of forms in a same section**	03
Incidence title	Lack of proper signalling of a bike lane.				
Incidence family	Functional elements		**Incidence group**	Markings	
Involves vulnerable road users	~~Pedestrians~~	Cyclists	~~Motorcyclists~~	~~Other~~	
Location of incidence	General	**Date created**	29/11/2016	**Date updated**	
Audit type	Operation	**Code**		**Author**	Jordi Parés
Notes					

LOCATION			
Road / street	Puente Santa Madre Laura (Medellín)	**Direction**	Not applicable
Initial km	All the bridge	**Final km**	All the bridge
UTM initial x	6,28547	**UTM final x**	6,28723
UTM initial y	-75,56312	**UTM final y**	-75,56795
Notes			

ANALYSIS	
Incidence description	Lack of proper signalling of a bike lane in platforms through the section, as they are located in spaces without physical separation between them.
Level of risk	Normal
Risk justification	Pedestrian-cyclist interference and the possibility of trouble between them.
Consequences of the accident	Slight
Evaluation of the incidence	V

Level of incidence		Consequences of the accident		
		Slight	Severe	Very severe
Level of risk	Normal	V	IV	IV
	Low	V	III	III
	Medium	IV	III	II
	High	III	II	I

Notes	

PHOTO

MAP / AERIAL PHOTO

GENERAL DATA

Form code	ASV-011			**Number of forms in a same section**	03
Incidence title	Pedestrian crossings outside junctions.				
Incidence family	Pending		**Incidence group**	Access points	
Involves vulnerable road users	Pedestrians	~~Cyclists~~	~~Motorcyclists~~	~~Other~~	
Location of incidence	General	**Date created**	29/11/2016	**Date updated**	
Audit type	Operation	**Code**		**Author**	Jordi Parés
Notes					

LOCATION

Road / street	Puente Santa Madre Laura (Medellín)	**Direction**	Not applicable
Initial km		**Final km**	
UTM initial x	6,285512	**UTM final x**	6,285512
UTM initial y	-75,563593	**UTM final y**	-75,563593
Notes			

ANALYSIS

Incidence description	Pedestrian crossing outside junctions in the eastern area of the bridge. Noted by marked paths in the grass.
Level of risk	Medium
Risk justification	Increase the risk of accidents with pedestrians involved.
Consequences of the accident	Very severe
Evaluation of the incidence	II

Level of incidence		Consequences of the accident		
		Slight	Severe	Very severe
Level of risk	Normal	V	IV	IV
	Low	V	III	III
	Medium	IV	III	II
	High	III	II	I

Notes	

PHOTO

MAP / AERIAL PHOTO

GENERAL DATA

Form code	ASV-012			**Number of forms in a same section**	03
Incidence title	Inadequate traffic light cast for pedestrian crossing.				
Incidence family	Pending		**Incidence group**	Intersections, roundabouts and links	
Involves vulnerable road users	Pedestrians	~~Cyclists~~	~~Motorcyclists~~	~~Other~~	
Location of incidence	General	**Date created**	29/11/2016	**Date updated**	
Audit type	Operation	**Code**		**Author**	Jordi Parés
Notes					

LOCATION

Road / street	Puente Santa Madre Laura (Medellín)	**Direction**	Not applicable
Initial km		**Final km**	
UTM initial x	6,284842	**UTM final x**	6,284842
UTM initial y	-75,564736	**UTM final y**	-75,564736
Notes			

ANALYSIS

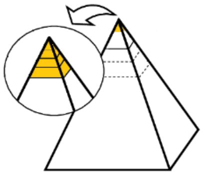
Incidence description	Inadequate traffic light cast for pedestrian crossing in a traffic light with push button. The program works only for the first part of the crosswalk forcing pedestrians to wait on the central waiting area.
Level of risk	Low
Risk justification	Increase the risk of accident with pedestrians involved as it entails pedestrian misbehaviour.
Consequences of the accident	Very severe
Evaluation of the incidence	III

Level of incidence		Consequences of the accident		
		Slight	Severe	Very severe
Level of risk	Normal	V	IV	IV
	Low	V	III	**III**
	Medium	IV	III	II
	High	III	II	I

Notes	

PHOTO

MAP / AERIAL PHOTO



CHAPTER 8

Estimating socio-economic costs of injuries to vulnerable road users

The objective of this chapter is to explain what the societal costs of injuries to vulnerable road users (VRUs) consist of and what the uses are for these cost estimates. The chapter also explains where readers can find estimates for the costs of injuries to VRUs.

8.1 Introduction to socio-economic costs of accidents

The monetary valuation of accidents and injuries, often referred to as costs of accidents or injuries, is a key element of cost-benefit analyses of road safety measures. Virtually all European countries have official estimates of road accident costs. In conjunction with the Horizon 2020 project SafetyCube, InDeV has collected data on official road accident costs for 31 European countries (Kasnatscheew et al., 2016). The main cost components are:

1. Medical costs, including treatment, transport and permanent medical costs (e.g. for appliances needed);
2. Loss of productive capacity, including both short-term absence from work and permanent losses if the victim dies or leaves the labour force;
3. Human costs, which are the loss of welfare associated with death or lost quality of life as a result of an injury;
4. Property damage costs, which include damage to vehicles, infrastructure and other property (clothes, etc.);
5. Administrative costs, of which insurance administration is the largest item but also include police costs and the costs of social security administration;
6. Other costs, which may include costs of traffic congestion caused by accidents, costs of replacement vehicles or funeral costs.

For fatalities, human costs are the largest item in countries relying on the willingness-to-pay approach for obtaining monetary values. The second-largest item is usually the loss of productive capacity.

Official accident costs apply to all road accidents and injuries. The costs are usually specified according to accident or injury severity, but it is not usual to specify costs for different road user groups or different types of accidents. Nevertheless, several approaches have been suggested within InDeV to emphasise the high exposure of VRUs to injuries within the framework of accident cost calculation (Kasnatscheew et al., 2018). In addition, SafetyCube has developed harmonised cost estimates, which are standardised with respect to the valuation method and the cost components included (Wijnen et al., 2018).

Furthermore, to meaningfully estimate the costs of injuries to VRUs, it is important to account for the incomplete reporting of injuries in official accident statistics. Moreover, it should be noted that the mean cost of injuries that are not reported in official statistics are likely to be lower than the mean cost of reported injuries, since the unreported injuries tend to be less severe.

For a further description and discussion of costs of injuries, see deliverables 5.1 and 5.3 of InDeV and deliverable 3.2 of SafetyCube.

8.2 Recommended reading

Kasnatscheew, A., Heinl, F., Schönebeck, S., Lerner, M., Hosta, P. (2016). Review of European accident cost calculation methods – with regard to vulnerable road users (Deliverable 5.1). Horizon 2020 EC Project, InDeV. Lund, Sweden: Lund University.

Kasnatscheew, A., Hiselius, L., Veisten, K., Vilar, P., Heinl, F., Schönebeck, S. (2018). Considering vulnerable road users in accident cost calculation (Deliverable 5.3). Horizon 2020 EC Project, InDeV. Lund, Sweden: Lund University.

Wijnen, W., Weijermars, W., Van den Berghe, W., Schoeters, A., Bauer, R., Carnis, L., Elvik, R., Theofilatos, A., Filtness, A., Reed, S., Perez, C., Martensen, H. (2017). Crash cost estimates for European countries (Deliverable 3.2). Horizon 2020 EC Project, SafetyCube. Loughborough, UK: Loughborough University.

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Wijnen, W., Weijermars, W., Van den Berghe, W., Schoeters, A., Bauer, R., Carnis, L., Elvik, R., Theofilatos, A., Filtness, A., Reed, S., Perez, C., Martensen, H. (2017). Crash cost estimates for European countries (Deliverable 3.2). Horizon 2020 EC Project, SafetyCube. Loughborough, UK: Loughborough University.

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CHAPTER 9

Conclusion

The purpose of this handbook is to compile current knowledge on road safety diagnostic techniques into a detailed, practical overview. The described road safety methods include accident data analysis, surrogate safety indicators, self-reported accidents and naturalistic behavioural data and primarily addresses the case of vulnerable road users (VRUs). The handbook is intended to help road safety practitioners, professionals and researchers diagnose road safety problems by gaining more insights into the mistakes by road users that lead to collisions. This handbook assists in linking accident causal factors to accident risk and so contributes to further improving road safety and generating a better, in-depth understanding of the causal factors contributing to unsafety. These enhanced insights allow us to better understand mistakes by road users that are essential to develop and select targeted countermeasures to reduce deaths and serious injuries. The handbook thus also indirectly contributes to the European Commission's (2018) road safety objective to further reduce the number of fatalities and serious injuries by 2030. In general, road safety in Europe has greatly improved in recent decades. Despite this positive development, VRUs still experience elevated accident and injury risk. The InDeV research project, therefore, specifically focused on improving the road safety of VRUs. Consequently, this handbook mainly addresses how different road safety techniques can be used to identify the accident causal factors for VRUs. Nevertheless, these techniques can also be applied to assess the safety of other road users.

Moreover, depending on the study objectives, various techniques can be used to gain insights into the accident causal factors for VRUs. Overall, six different techniques can be used to collect such data: accident data analysis, self-reported data, behavioural observation studies, traffic conflict observation studies, naturalistic cycling and walking studies and RSA and RSI. The previous chapters provide a detailed, practical-oriented overview of the application areas, characteristics and considerations that should be kept in mind when deciding which particular technique to use. In this chapter, the most important aspects of these six road safety diagnostic techniques are summarised in Table 9-1. This easily accessible summary table helps practitioners to find the appropriate technique to gain insights into a specific road safety problem for all groups of road users and, in particular, VRUs. Table 9-1 provides a quick, detailed overview of the different techniques by discussing their main characteristics:

- Context: scope of a technique;
- Variables: type of data that can be collected with a technique;
- Data collection techniques: possible methods that can be used to collect data;
- Study area: geography within a road traffic system for which a technique can be used to collect data;
- Data processing efforts: estimated time needed to analyse collected data;
- Costs: estimated monetary resources to apply a technique;
- External validity: extent to which the results collected through a technique can be generalised to other situations or the whole population of road users;
- Experimental control: extent to which a researcher can influence situations and behaviours occurring in the road environment during the data collection phase;
- Time: estimated average time needed to apply a technique in a study;
- Advantages: descriptions of the desirable features of a technique;
- Challenges: specific challenges related to the adoption of a technique.

Throughout this handbook, the road safety techniques discussed are unquestionably proven to have added value for performing evidence-based road safety research aimed at identifying accident causal factors for VRUs. This is also illustrated in Table 9-1. For instance, accident data analyses are very useful to assess and monitor road safety situations in areas of interest, identify the time trends of accident occurrence and resulting injury severity and compare the safety situation among countries, regions and cities. Furthermore, the following three techniques can be used to directly collect information from road users. First, self-reporting is especially useful for gaining knowledge of near-accidents, which are usually not registered, and less severe accidents (e.g. resulting in slight injuries or only property damage), which are largely under-reported in official statistics. Second, on-site behavioural observation studies are used to study the frequency of and to identify particular characteristics of road user behaviour in normal traffic events and near-accidents. On-site traffic conflict observation studies only focus on identifying relevant road user behaviour in near-accidents. It, therefore, is possible to gain knowledge about the behavioural and situational aspects that play a role in encounters with low safety risk, as well as the aspects that precede serious traffic events. These studies thus provide the opportunity to better understand the various contributing factors that influence accident occurrence. Consequently, these studies' results can be used as a basis to identify which target groups and risk-increasing behaviours require attention to reduce road fatalities and serious injuries. Third, naturalistic cycling and walking studies allow unobtrusively and continuously observing road user behaviour in the real world before and during near-accidents and in some cases even accidents to gain in-depth knowledge of the factors contributing to these incidents. Finally, RSA audits and RSI are road infrastructure assessment techniques specifically used to assess which infrastructural elements of new and existing roads influence accident risk.

Table 9-1: Overview of road safety diagnostic techniques

Road safety diagnostic technique	Accident data analysis	Self-reported data	Behavioural observation study	Traffic conflict observation study	Naturalistic cycling and walking study	Road safety audit/inspection	EuroRAP/iRAP methodology
Context	Accidents (ranging from only material damage to fatal injuries)	Accidents and near-accidents	Road user behaviour in undisturbed passages and near-accidents	Traffic conflicts (i.e. near-accidents)	Road user behaviour in accidents, near-accidents and undisturbed passages	Road infrastructure assessment of new and existing roads	Risk assessment of individual roads and road networks
Variables	Accidents and their related characteristics, exposure data, infrastructure data and collision diagram information	Accidents, near-accidents and their descriptions (e.g. location, incident, involved parties and circumstances)	Variables related to road user behaviour (e.g. looking behaviour, priority behaviour and communication), road user characteristics (e.g. gender and age) and more detailed indicators when video cameras are used	Measurable (continuous in the case of video-based observation) parameters of road user behaviour in traffic conflict situations	Detailed and continuously logged data (e.g. speed, acceleration and position), road user behaviour data and characteristics of traffic situations in normal and safety-critical events	Elements of road infrastructure that could influence accident risk	Elements of road infrastructure that could influence accident and injury risk
Data collection techniques	Desk research in national accident databases and police-reported accident data (especially for only material damage), possibly enriched with hospital data	Interviews and questionnaires	Human observers and video-based behavioural data	Human observers and video-based trajectory data	Instrumented vehicles (e.g. bicycles, mopeds and motorcycles) and portable equipment (e.g. smartphones and activity bands)	Trained road safety auditors and inspectors	Desk research in case of risk mapping, safer road investment plans and performance plans. Trained road inspectors in case of star rating protocol

Road safety diagnostic technique	Accident data analysis	Self-reported data	Behavioural observation study	Traffic conflict observation study	Naturalistic cycling and walking study	Road safety audit/inspection	Euro-RAP/iRAP methodology
Study area	Dependent on the study objectives, ranging from country based to network and site based	Dependent on the study objectives, ranging from country to region based	On site	On site	Real-world traffic environment ranging from country based to network based and site based	On site	Dependent on the study objectives, ranging from country based to network and site based
Data processing efforts	Low (general traffic safety reports and collision diagram analysis) to moderate (black spot analysis, network safety analysis and accident prediction modelling)	Low to moderate depending on the number of respondents and data collection technique (online or not)	Moderate to high depending on the number of registered events and use of (semi-)automated video analysis techniques	Moderate to high depending on the number of registered events and use of (semi-)automated video analysis techniques	High	Low	Low to moderate depending on the protocol used (star rating requires more efforts)
Costs	Low	Medium	Low to medium	Low to medium	Medium to high	Low (mostly labour costs)	Low to medium
External validity	Low-moderate depending on the number of analysed accidents and the typical characteristics of accident locations	Low-moderate depending on the number of respondents	Low-moderate: natural setting, unobtrusive data collection and actual safety-critical situations and behaviours, but valid study results only for the location studied, difficult to establish link with accidents	Low-moderate: natural setting, unobtrusive data collection and actual safety-critical situations and behaviours, but valid study results only for the location studied	Very high: natural setting, unobtrusive data collection and actual safety-critical situations and behaviour	Low: valid results only for the location studied	Low: valid results only for the location studied

Road safety diagnostic technique	Accident data analysis	Self-reported data	Behavioural observation study	Traffic conflict observation study	Naturalistic cycling and walking study	Road safety audit/inspection	Euro-RAP/iRAP methodology
Experimental control	No control over road users' interactions or the traffic environment	No control over road users' interactions or the traffic environment	No control over road users' interactions or the traffic environment	No control over road users' interactions or the traffic environment	No control over road users' interactions or the traffic environment	Not applicable	Not applicable
Average study duration	1 to several years	Several weeks to months	Several days to weeks	Several days to weeks	Several months, up to one year or longer	Several days (RSI), months to years (RSA)	Several days to weeks
Specific advantages	Direct assessment of the outcome indicator of road safety (e.g. number and severity of accidents)	First-hand information, correction for underreporting (data on slight accidents), near-accident information, tailored study design and swift road safety diagnosis and evaluation	Direct observation of road user behaviour, non-intrusive data collection, practice ready, large sample size, swift road safety diagnosis, inexpensive and insights into accident development process	Direct observation of road user behaviour in safety-critical events, non-intrusive data collection, practice ready, large sample size, swift road safety diagnosis and possible supplement or replacement for accident data	In-depth understanding of road users' natural behaviour, possibility to study behaviour over extended time periods, compensation for underreporting of accidents, automatic data collection, reflection of actual behaviour, information on the accident development process and study of normal, conflict and accident situations	Reduced accident risk, safer facilities for vulnerable and other road users and better road safety targets, standards and design guidelines, detailed overview of the safety deficiencies of a road	Easy to apply, standardized protocols for risk mapping, star rating, performance tracking and safer road investment plans; also applicable when no accident is available; complementary to RSA/RSI

Road safety diagnostic technique	Accident data analysis	Self-reported data	Behavioural observation study	Traffic conflict observation study	Naturalistic cycling and walking study	Road safety audit/inspection	EuroRAP/iRAP methodology
Challenges	Underreporting, random variation, ethical concerns, no information on road user behaviour and accident development process and slow road safety diagnosis and evaluation (extensive accident data needed for 3–5 years)	Privacy issues, no expert information, response bias, data from only one of the involved road users and no data on severe and fatal accidents	Generalisability, findings on only revealed road user behaviour (i.e. not on underlying motives of behaviour), observer bias, labour-intensive data collection (observers) and susceptible to adverse weather conditions and difficult at night	Labour-intensive data collection (observers), generalisability, validity, inter- and intra-observer variability, advanced video analysis techniques still under development and susceptible to adverse weather conditions and difficult at night	High set-up costs, time-consuming data–analysis process, selection bias, data from only one of the involved road users, privacy issues and limited sample size due to high costs	No standardised approach to RSI	Provides a quick assessment of the general risk standard of a road but a detailed overview of the safety deficiencies of the road or network is missing.

Each technique, in its own way, can provide valuable insights into the road safety situation of VRUs. However, based on the information presented in this handbook, it can be concluded that there is no perfect technique to assess road safety but only the most suitable technique given the study's scope, time frame, available human and monetary resources and expected outcomes. However, each technique also suffers from limitations, so it is very difficult to gain a sound picture of the road safety situation based on one technique alone (see Table 9-1). Consequently, a crucial opportunity lies in complementing the results from different road safety techniques to overcome the limitations of individual techniques. Exploring the different opportunities for such an integrated approach was also the rationale of the InDeV-project (and this handbook).

Based on the information presented in this handbook, the following recommendations for combining different road safety techniques can be suggested.

1. Accident data and self-reported data

Accident data analysis is the most commonly used technique to assess the road safety situation of VRUs and other road users. However, accident data suffer from underreporting and injury misclassification. The degree of underreporting in police accident records is the highest for accidents with VRUs and of a less severe nature, such as accidents with slight injuries or only property damage. Combining police-reported accident data with hospital data can help to overcome some of these problems and is becoming a more widely adopted approach in the road safety field. The use of self-reported accident data in combination with police-reported accident data is a useful approach especially for gaining more knowledge about less severe accidents because it can capture more less-severe accidents, thus overcoming underreporting and the associated potential for biased data.

Combining self- and police-reported accident data thus can contribute to better, more complete insights into the current state of traffic safety. However, combining police-reported accident data with hospital data remains the recommended approach to address the underreporting of accidents with serious and fatal injuries.

2. Accident data and behavioural observation and traffic conflict data

Accident data analysis directly examines the phenomenon one wants to avoid from a safety perspective—namely, accidents and their related consequences. This direct assessment can be regarded as the main advantage of accident data analysis. However, such data contain information on the outcomes of accidents (the severity of accident-related injuries) but lack information on accident causal factors (situational and behavioural aspects preceding accidents). The accident development process, therefore, remains unclear.

To overcome this limitation, accident data can be combined with behavioural and traffic conflict observation data. Both techniques are used to study the frequency of and to identify particular characteristics of road user behaviour in normal traffic events and near-accidents. These techniques, therefore, are very useful to gain knowledge on the behavioural and situational aspects that play a role in encounters with low safety risk, as well as the aspects that lead to accident occurrence.

Road safety evaluation and assessment based on accident data also require extensive accident data (typically 3–5 years) to produce reliable results. Sometimes, there are little accident data available, or the available data are insufficiently detailed to obtain a good evaluation or diagnosis. In such cases, behavioural and traffic conflict observations provide a vital complement to accident analysis as a support for action design and, where appropriate, may even compensate for a shortage of information on accident-generating processes. Furthermore, the behavioural and conflict items observed and the locations of interest for both observations are mostly determined by the findings of accident analysis.

3. Self-reported data and traffic conflict data

Similarly to accident data, traffic conflict data on slight conflicts and near-accidents can be combined with self-reported data to gain more knowledge on the occurrence of less severe conflict situations.

4. Behavioural observation data and traffic conflict data

Behavioural observation studies are often combined with traffic conflict studies to broaden coverage of different aspects of road safety situations. Insights into the different road user behaviours that occur at studied sites serve as a useful basis for describing what is going on at sites and makes them unsafe. Behavioural observations, therefore, offer added value to traffic conflict studies by providing more insight into the risk-increasing behavioural aspects and elements that play a role in traffic conflicts.

5. Naturalistic cycling and walking studies and behavioural observation and traffic conflict data

Naturalistic cycling and walking studies are a useful technique to continuously collect data on road user behaviour. In these studies, data are collected with instrumented vehicles and portable measuring devices. Continuously collecting data, these studies can evaluate not only the last movements and constellations leading to accidents but also the underlying factors that may have led to road users ending up in safety-critical situations. However, this technique only collects data from the viewpoint of one of the involved road users (the road user with a portable measuring device or using an instrumented vehicle). Consequently, the collected information on the other road user is sometimes limited as the measuring devices might not have detected evasive action or behaviour by the other road user. This complicates obtaining a complete understanding of accidents' contributing factors.

However, this issue can be solved by combing naturalistic walking and cycling studies with behavioural and conflict observation studies on designated sites of the road network, such as intersections. These site-based observation studies create the opportunity to collect supplementary information on the position and speed of other road users in the vicinity of participants in naturalistic cycling and walking studies. The added value of combining both techniques lies in the opportunities to obtain a more in-depth understanding of road safety and to relate the behaviour of participants and non-participants in naturalistic walking and cycling studies.

To conclude, these insights make a strong case for an integrated approach to assessing the road safety of VRUs and other road users. The added value of this integrated approach lies in the opportunity to enrich the results from one technique with the complementary results from another and to check whether the techniques' findings align. This approach not only overcomes the limitations of each individual technique but also allows drawing highly detailed, sound road safety inferences, ultimately producing a more comprehensive picture of the road safety situation. Furthermore, higher road safety levels on the road traffic system have gradually evolved over recent decades. If this positive trend continues, accidents will become even rarer and thus less suitable for reliable road safety analyses. An integrated approach based on a combination of the road safety techniques discussed in this handbook, therefore, will perform an important role in future road safety evaluation policies.

Additionally, in light of the Safe System and Vision Zero approach, a strong case has been made in the scientific community for adopting a system approach to conducting road safety research. The new European road safety vision, moreover, recommends the Safe System approach as a common framework to achieve further reductions in road fatalities and serious injuries during 2020–2030 (European Commission, 2018).

Throughout this handbook, it has become apparent that the most important merit of combining different techniques to study the road safety of VRUs lies in the possibility to study road user behaviour from a system perspective. It, therefore, can be recommended that countries pursuing a system-based road safety vision adopt an integrated approach based on a combination of techniques to observe road user behaviour in interactions, near-accidents and accidents. Besides road user behavioural factors, vehicle, road and emergency medical system factors are also critical to a Safe System Approach. Even though, the latter factors are not the focus of this handbook, it can be suggested that the proposed integrated approach to study road user behaviour is a first and important step to further reduce the number of road fatalities and serious injuries and to formulate policy priorities in order to eventually establish an inherently safe road traffic system.

References Chapter 9

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PART 3

Glossary

List of abbreviations

A	AADT	Annual Average Daily Traffic
	AIS	Abbreviated Injury Scale
	AMF	Accident Modification Factor
B	BSM	Black Spot Management
C	Cadas	Common Accident Dataset
	CARE	Community Road Accident Database For Europe
	CRS	Civil Registration System
	CRTL	Channelised Right Turns
	CS	Conflicting Speed
D	Dacota	Road Safety Data, Collection, Transfer and Analysis
	DALY	Disability-Adjusted Life Years
	DOCTOR	Dutch Objective Conflict Technique for Operation and Research
	DST	Deceleration-To-Safety
E	EACS	European Accident Causation Study
	EB	Empirical Bayes (Method)
	EC	European Commission
	ERSO	European Road Safety Observatory
	ETAC	European Truck Accident Causation Study
F	FARS	Fatality Analysis Reporting System
G	GIDAS	German In-Depth Accident Study
I	ICD10	International Classification of Diseases
	InDeV	In-Depth Understanding of Accident Causation for Vulnerable Road Users
	IRF	International Road Federation
	IRTAD	International Road Traffic and Accident Database
	ISS	Injury Severity Score

M	MAIDS	Motorcycle Accident In-depth Study
	MAIS	Maximum Abbreviated Injury Scale
	MAIS3+	MAIS With Score 3 Or More
N	NISS	New Injury Severity Score
	NSM	Network Safety Management
O	OECD	Organisation For Economic Co-Operation And Development
P	PET	Post-Encroachment Time
	Ppet	Predicted PET
	PTW	Powered Two Wheelers (Motorcycle/Moped)
R	RAIDS	Road Accident In Depth Studies
	RCT	Randomised Controlled Trial
	RLC	Red Light Cameras
	RLS	Reaction Level Scale
	RSA	Road Safety Audits
	RSI	Road Safety Inspections
	RUBA	Road User Behaviour Analysis
S	SNACS	SafetyNet Accident Causation System
	SRLC	Speed and Red Light Cameras
	SSM	Surrogate Safety Measure
	STCT	Swedish Traffic Conflict Technique
	STRADA	Swedish Traffic Accident Data Acquisition
	SWOV	Institute of Road Safety Research
T	TA	Time-To-Accident
	Tadv	Time Advantage
	TCT	Traffic Conflict Technique
	TEN	Trans-European Road Network
	TTC	Time-To-Collision
	TTC_{min}	Minimum Time-To-Collision
U	UNECE	United Nations Economic Commission For Europe
V	VRU	Vulnerable Road User
W	WHO	World Health Organisation

Concepts and definitions

A

Annual average daily traffic
The number of vehicles passing a road during one year, divided by the number of days in that year.

Abbreviated injury scale
A medical scale used to indicate the severity of injuries. The scores on the injury scale range from AIS 1 (minor injury) to 6 (fatal injury).

Accident
Event between road users on public roads involving at least one moving vehicle resulting in injury, fatality or property damage.

Accident black spot
Any location in the road network that has a higher expected number of accidents than other similar locations as a result of a local risk factor; sometimes also referred to as a hazardous road location.

Accident cost
The value of all resources lost or used as a result of an accident; comprehensive costs also include a monetary valuation of lost quality of life as a result of accidents.

Accident counts
The number of accidents.

Accident density
The rate at which road users are being killed or seriously injured.

Accident frequencies
Number of accidents (or number of accident victims) in a given area recorded during a given time period.

Accident modification factor
A multiplicative factor used to compute the safety effectiveness (in terms of the expected number of accidents) after implementing a particular countermeasure at a specific site. Also known as crash modification factor (CMF).

Accident prediction model
Statistical model used for estimating the expected accident frequencies of various roadway entities (highways, intersections, interstates, etc.) in terms of the geometric, environmental and operational factors that are associated with the occurrence of accidents.

Accident rate
The number of accidents per unit of exposure; most commonly, the number of accidents per million vehicle kilometres of travel.

Accident reporting
Formal systems established to report road traffic accidents to public authorities. In general, police departments are entrusted to report accidents.

Accident risk
Probability of accident occurrence in a given location or area and during a definite period of time. Accident risk is estimated through statistical procedures, based on data of observed accidents and exposure.

Accident severity
Measure describing the outcome of an accident usually categorised as fatal, severe or minor injuries and property-damage-only.

Accident statistics
Records of reported accidents kept by highway authorities, police departments or other governmental bodies.

Active safety equipment
Any technology that automatically assists in preventing an accident such as forward collision warning systems, lane departure warning systems, electronic stability control, anti-lock braking systems, brake assist.

B

Before and After study
A study design used to evaluate the effects of road safety measures by comparing the number of accidents before and after introduction of the measure.

Behavioural observation study
A type of traffic observation study used to examine road user behaviour. In these studies, the emphasis lies on analysing the actions of road users in their natural setting by means of (mostly) observable qualitative variables (i.e. gender, age, interaction type, approaching behaviour, looking behaviour, priority behaviour, distraction, communication behaviour, etc.) while they interact with other road users and the road environment.

Bias
Systematic errors; a sample is biased if observations made in the sample cannot be generalised to the population of interest.

Black spot
Road locations with a (relatively) high accident potential or locations with a higher expected number of accidents than other similar locations (intersections or short road sections, less than 0.5 km long); sometimes referred to as a hazardous road location.

Black spot analysis
A method of identifying high-risk accident locations (i.e. locations with a high concentration of accidents) in the road network.

Black spot management programme
A programme designed to identify, analyse, and treat black spots on the road network (black spots are seldom longer than 0.5 kilometres).

C

Collision
Impact event between two or more road users/vehicles, or a road-user (vehicle) and stationary object.

Collision course
A situation in which the road users will collide eventually if they continue to move with unchanged speeds and directions.

Collision diagram
A visual representation of accidents at a given location (intersection, road segment) by means of symbols to denote different accident types, their location

and manoeuvres of vehicles/road users involved.

Collision point
Location of the first physical contact (projected on a road plane) when two road users collide.

Conflict diagram
A visual representation of conflicts at a given location (intersection, road segment) by means of symbols to denote different conflict types, their location and manoeuvres of vehicles/road users involved.

Conflict distance
A temporary measurement of (spatial) distance to a common conflict point, for a road user/vehicle in a conflict situation.

Conflict indicator
An objective and measurable parameter that has a relation to a studied quality of the traffic system (e.g. efficiency, safety, comfort, etc.).

Conflict severity
Seriousness of a potential collision or near-accident measured by temporal or spatial proximity.

Conflicting speed
In the Swedish Traffic Conflict Technique: the speed of the road user who undertakes the first evasive action.

Construct validity
The extent to which a study or method observes the concept for what it is specifically designed to measure or observe.

Continuous data
A variable that can be measured to any level of precision. Time is an example of a continuous variable.

Cost-benefit-analysis
A formal analysis of costs and benefits of a programme, in which all relevant impacts are converted to monetary terms.

Crash
See accident. The term 'crash' used in the USA includes both injury accidents and property-damage-only crashes. For the sake of consistency the authors use the term 'accident' in this handbook to both denote injury and property-damage-only accidents as they do not differentiate between the terms in relation to the context.

Cross-sectional study
A study design used to evaluate the effects of road safety measures by comparing the number of accidents at two or more locations (at least one location with and one location without the measure). These locations must be as comparable as possible in terms of infrastructural design characteristics, vehicle speeds and traffic flows, but differ in the presence of the road safety measure.

D

Deceleration-to-safety
Conflict indicator expressing the minimal necessary deceleration to avoid a collision.

Disability-adjusted life year
A measure indicating the number of life years lost due to ill-health, disability or early death. It conveys additional information about the influence of an accident on the future life of the person involved in the accident.

E

Empirical Bayes
Method that corrects for regression-to-the-mean. This method compares accident numbers after the implementation of the measure with the before period, increases the precision of estimation and is widely accepted as the best standard in the evaluation of traffic safety measures.

Encounter
See interaction.

Entity
Spatial extent or analysis, be it a single site, a set of sites, or a region.

Evasive action
Action taken by a road user to diverge from a collision course and resolve a conflict situation by changing speed or direction. Examples of evasive actions are braking, accelerating, and/or swerving.

Event
Any kind of incident or occurrence in traffic.

Expected number of accidents
The mean number of accidents (per unit of time) expected to occur in the long run for a given exposure and a given level of risk. Technically, the expected number of accidents is the mean value of a random variable whose sampling space consists of the recorded number of accidents.

Exposure
The amount of activity exposed to risk. In road safety studies, exposure usually denotes the amount of travel either by vehicle or on foot in which accidents may occur.

Eye-tracking
The process of measuring the point of gaze (where one is looking) or the movement of the point of gaze. An eye tracker, a device that records eye movement and positions, carries out these measurements.

F

Face validity
The extent to which a study or method is subjectively perceived as covering the concept it means to measure.

Face-to-face interview
A data collection method in which the interviewer directly communicates with the respondent in accordance with the prepared questionnaire.

Fatal injury
According to the Vienna convention, a fatal injury is one that results in death within 30 days of the accident.

Fatality rate
Numbers of fatalities divided by some measure of exposure such as fatalities per million inhabitants or per number of person kilometres of travelled.

Focus group interview
A qualitative data collection method in which a group of people are selected and questioned about their opinion or perceptions about a particular topic. Focus group interviews take place in an interactive setting as the participants discuss their opinions in small groups.

G

Generalisability
The degree to which the research findings and conclusions from a study can be transferred to other situations or the population at large.

H

Hazard
A hazard is anything that may cause damage or injury in the event of an accident.

Hazardous behaviour
Any behaviour in traffic that could result in injury or damage to yourself and/or other road users.

Hazardous road section
Any section at which the site-specific expected number of accidents is higher than for similar sections, due to local and section-based risk factors present at the site.

I

Incomplete accident reporting
Refers to the fact that the accidents recorded in the official accident statistics suffer from misreporting and underreporting.

Injury
Bodily harm. In this handbook, this refers to injury caused by a road accident.

Injury accident
An accident with at least one fatal, seriously or slightly injured individual.

Injury severity score
An anatomical scoring system that indicates the overall severity for people with multiple injuries.

Interaction
Basic traffic event that is necessary for an accident to occur. It typically refers to a situation in which two road users are close enough in time and space that they may be aware of each other, influence each other's behaviour and have to interact.

International Classification of Diseases
International standard diagnostic tool used to classify and monitor causes of injury and death and that maintains information for health analyses (i.e. mortality and morbidity studies).

J

Jerk
A conflict indicator describing the suddenness of braking. Jerk is a derivative of deceleration.

M

Maximum Abbreviated Injury Scale
The maximum AIS score for an individual with one or multiple injuries.

Minimal Time-to-Collision
The lowest TTC-value during the interaction indicating the closeness of the interaction/conflict situation to an accident. TTCmin indicates the TTC at the time the potential collision is avoided.

Misreporting
Misclassification of injury severity or inappropriate reporting of the injury severity of road traffic victims (for example, classifying a severe injury as a slight injury).

N

Naturalistic study
Data collection method in which the topic of interest is observed in its natural setting. Applied to road safety, this setting consists of the road environment and the road users who interact with each other in this environment.

Naturalistic driving
A road safety technique in which the everyday behaviour of road users is observed unobtrusively in a natural road environment. Data are normally collected for a long period of time, which allows to collect data about safe road user interactions and safety-critical events such as near-accidents and accidents.

Naturalistic cycling and walking studies
Naturalistic driving applied to vulnerable road users. Instead of instrumented vehicles, data are collected by means of portable measuring devices (smartphones, activity bands).

Near-accident
A situation when two road users unintentionally pass each other with very small margins in time and space, so that the general feeling is that a collision/accident was "near". Synonym for traffic conflict.

Near-miss
See near-accident.

Network safety analysis
A method of ranking of road sections with high accident concentration. It is a method to identify, analyse and rank sections of the road network where a large number of accidents occurred in proportion to the traffic flow and road length.

Network safety management
Safety analysis of road networks focusing on longer road sections of normally 2-10 kilometres.

New Injury Severity Score
A medical scoring system that provides an overall score for people with multiple injuries. Calculated as the sum of the squares of the Abbreviated Injury Scale scores of each of the individual's three most severe injury regardless of the body region in which they occur.

O

Observer bias
Systematic error caused when a researcher unconsciously affects results, data, or a participant in an experiment due to subjective influence.

Overdispersion

Phenomenon indicating the presence of greater variability (statistical dispersion) in a data set than would be expected based on a given statistical model. In terms of accident data, it means that the count variability is greater than required by the Poisson distribution, i.e. the variance of accident counts is greater than the mean.

P

Passive safety equipment

Any device that automatically provides protection for the occupant of a vehicle during an accident, such as seat-belts, padded dashboard, bumpers, laminated windshield, head restraints, collapsible steering columns and airbags.

Poisson distribution

Statistical distribution for rare events named after the French mathematician Simeon Denis Poisson, who first described it. The Poisson distribution is generally used as a model to describe pure random variation in the number of accidents.

Post encroachment time

A conflict indicator representing a measure of the temporal difference between two road users over a common spatial point or area. It is calculated as the time between the moment that the first road user leaves the path of the second and the moment that the second reaches the path of the first; i.e. PET indicates the extent to which they have missed each other.

Predicted PET

See time advantage.

Probability

The long-term frequency of occurrence of an event in repeated trials that have the event as one of the possible outcomes; how likely something is to happen.

Property-damage-only accident

Accident with no injuries or fatalities.

R

Random variation in the number of accidents

Variation in the recorded number of accidents around a given expected number of accidents.

Reaction level scale

Scale to evaluate the neurologic status of individuals after a head trauma or neurosurgery.

Regression-to-the-mean

The tendency for an abnormally high number of accidents to return to values closer to the long-term mean; conversely, abnormally low numbers of accidents tend to be succeeded by higher numbers.

Relevant road user

In the Swedish Traffic Conflict Technique: the road user that determines the severity of a traffic conflict.

Reliability

The ability of a measure or technique to produce consistent results regardless of the conditions in which it is used.

Risk factor

Any factor that affects the probability of accident occurrence or the severity of the consequences of an accident.

Road network safety analysis
See network safety analysis.

Road network safety management process
See network safety management.

Road safety
Quality of the transport system, usually measured in terms of the number of accidents and casualties resulting from these accidents. The ultimate goal of road safety researchers is to decrease or eliminate the hazardous conditions in the road network that cause accidents and causalities.

Road safety audit
A systematic procedure to assess the accident potential and road safety performance of the road infrastructure elements of future roads or intersections by an independent, multidisciplinary team.

Road safety diagnosis
A formal procedure for identifying and understanding types of safety problems/issues. The purpose is to understand patterns in the accident or surrogate safety measure data and to identify accident causal factors.

Road safety impact assessment
As defined by European Directive 2008/96/EC, a strategic comparative analysis of the impact of a new road or a substantial modification to the existing network on the safety performance of the road network.

Road safety inspection
A systematic, periodic, objective and proactive safety assessment of an existing road or intersection. The objectives of RSI are to identify and eliminate hazardous conditions, faults and deficiencies in order to improve the safety for the road users.

Road section
A stretch of road of 2-10 kilometres.

Road traffic accident
See accident.

Road user
Any individual who uses the road network such as pedestrians, bicyclists, motorists, powered two-wheelers, motorcyclists and bus drivers.

S

Safety critical event
Term used to describe an event with an identified accident potential or for which a surrogate safety measure or conflict indicator indicates a threshold value.

Safety pyramid
Conceptions of unsafety and severity of an event. Developed by Hydén (1984). The fatal injury accident forms the top of the pyramid.

Self-reported (near-) accident
The road user himself reports the (near-) accident in which he was involved e.g. when and where it happened, a description of the incident, who was involved and the circumstances of the incident. Several data collection techniques can be used for this purpose: including questionnaires and inventories, interviews, focus groups, and driving diaries.

Self-reporting
Method to collect detailed information directly from road users or individuals by using interviews or questionnaires.

Semi-Automated Video Processing
Processing in which some technical tool is used as an aid in detection and analysis of the traffic conflicts, but part of the work is still done manually.

Serious conflict
An event/interaction where the evasive action started late and whereby the interaction could have resulted in an accident or collision.

Seriously injured
According to the European accident database (CARE), injured (although not killed) in the road accident and hospitalised at least 24 hours.

Severity hierarchy
Severity dimension common to all traffic events illustrated by the safety pyramid of Hydén (1984). This dimension is expressed by measureable parameters based on presumptions regarding the closeness of the traffic event to an accident and the potential accident severity.

Severity level
Level in the severity hierarchy.

Single vehicle accident
An accident involving just one vehicle or road user.

Slight conflict
An event/interaction where two or more road users are on a collision course and initiate an evasive action.

Slightly injured
According to the European accident database (CARE), injured (although not killed) in the road accident and hospitalised less than 24 hours or not hospitalised.

Socio-economic cost calculation
Method to calculate the costs of accidents or injuries. This monetary valuation of accidents and injuries is based on medical costs, loss of productive capacity, human costs, property damage costs, administrative and other costs.

Structured behavioural observation studies
Studies which focus on the explicit and detailed observation of a specific safety-related behaviour, for instance, crossing and looking behaviour or traffic rule compliance at a certain location. Structured behavioural observations are well prepared and can originate from the results of unstructured observation studies.

Surrogate safety measure
Measure of safety that does not require observing accidents with different meanings for a traffic event or an entity.

For a traffic event, it measures the probability of such an event to develop into an accident and/or the severity of that potential accident.

For an entity, it measures its safety, i.e. the expected number of accidents over the long run, by levels of severity.

T

Time Advantage (TAdv)
An extension of the PET indicator based on the predicted motion of road users according to their current position, direction and speed. Also known as predicted PET (pPET).

Time-to-Accident
In the Swedish Traffic Conflict Technique: the time remaining from the first evasive action taken by one of the road users up to the collision that might have taken place had they continued with unchanged speeds and directions. More specifically, it is the TTC value at the moment an evasive action is first taken by one of the road users involved in the traffic conflict.

Time-to-collision
A continuous parameter of time. In collision course situations, it indicates the remaining time for two road users to collide if they continue with unchanged speeds and directions.

Traffic conflict
An observable situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged.

Traffic conflict technique
A technique to assess road safety based on the observation of traffic conflicts (near-accidents). The rationale behind these techniques is that accidents and conflicts are related as they originate from the same type of traffic processes.

U

Underreporting
Accident casualties who are not recorded in police-reported accident data, but can possibly be found in hospital data.

Unobtrusive
Not conspicuous or attracting attention.

Unstructured behavioural observation studies
Observations in which researchers look with an 'open mind' at road user behaviour and record any observable action or behaviour that seems interesting or conspicuous. Unstructured behavioural observations require no preparation.

V

Validity
Evidence that a study allows correct inferences about the question it was aimed to answer or that a road safety technique/indicator measures what it set out to measure conceptually.

Vulnerable road user
Non-motorised road users, such as pedestrians and cyclists as well as motorcyclists and moped riders. Children, older people and disabled people can also be included in this category.

W

Willingness-to-pay
Cost calculation approach based on the amount of money a victim is willing to pay for not being hurt or killed respectively for a risk reduction.

Layout by
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How to analyse accident causation?

A handbook with focus on vulnerable road users

This handbook is designed to offer road safety professionals a detailed and practical overview of the various road safety diagnostic techniques available for studying road users' behaviour during interactions, near-misses and accidents. It describes various road safety methods that can be applied for studying the safety of vulnerable (and other) road users, including: accident data analysis, con lict and behavioural observations, self-reporting and naturalistic studies and road safety audit and inspection. The handbook also focuses on delivering better calculations of the socio-economic costs of vulnerable road user accidents. The authors discuss when those techniques function best, when they are not entirely suitable, and how they can bene it each other when used in conjunction. Applying the principles described in this handbook will contribute to the further improvement of road safety and a better, in-depth understanding of the causal factors contributing to vulnerable road user unsafety.