ESTIMATING PEDESTRIAN ACCIDENT RISK USING CONFLICT TECHNIQUES AND DIGITAL IMAGING

by

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ABSTRACT

Accidents are a complex process involving many contributory factors. The understanding of the accident process has often been sought by the use of accident data. Although accident data provide a direct relationship to estimating accident risk, there are many drawbacks associated with the use of these data. The major drawback with the use of accident data is the very fact that traffic engineers have to wait for accidents to occur before any interventions can be made. This alone is significant as the time span required to collect a sample size is often a three-year period. The many deficiencies with accident data have led to alternative measures such as traffic conflict techniques (TCT's) to estimate accident risk.

In this investigation, traffic conflict techniques were used to estimate accident risk. There are four basic traffic conflict concepts and the development of these techniques was based on the accident process. The aim of this investigation was to highlight the differences between these concepts and to assess the applicability of these concepts to vehicle-pedestrian conflicts. The investigation was based on applying the various conflict techniques to data obtained at three intersections in the Durban CBD. In order to record the data an innovative method of using digital imaging was employed. This led to the development of a computer program to analyse conflict events.

Analysis of the intersections based on the conflict techniques indicates that the intersections of Pine-Field and Commercial-Grey have a high probability of road users being involved in a "serious event" once there is an interaction between them. However, the probability for Commercial-Albert intersection is low thus indicating a safe intersection for vehicle-pedestrian interactions. The number of "serious events" at these locations was found to be related to the interacting traffic volumes - the conflict rate increases with increasing traffic volume. The use of conflict-volume models and accident models together with the conflict concepts agree that the accident risk is related to the conflicting traffic volumes and speed of the road users.

PREFACE

The work described in this dissertation was carried out at the School of Civil Engineering, Surveying and Construction, University of Natal, Durban, from February 2002 until August 2003 under the supervision of Professor C S Roebuck, and is in accordance with the requirements of the University for the award of Master of Science in Engineering.

These studies represent the original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use was made of the work of others it has been duly acknowledged in the text.

R Dookhi

As the candidate's supervisor I ~~have~~/have not ~~approved~~ this dissertation for submission

Professor C S Roebuck

Date

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1 INTRODUCTION

1.1 Background

Accidents constitute one of the most serious problems facing society today. Between seven hundred thousand to nine hundred thousand people are killed annually in road traffic accidents worldwide, with the number of people injured exceeding thirty million [World Bank, 1999]. Developing countries are more affected by accidents with approximately seventy-five per cent of the total worldwide fatalities occurring in these countries. The socio-economic cost incurred by these countries amounts to two per cent of their GDP annually [World Bank, 1999]. Despite their low level of motorisation (low percentage of motor vehicle usage), road accidents rates are increasing annually in these developing countries.

Pedestrians are a major feature in road accidents with approximately twenty-two per cent of all fatal road accidents worldwide involving pedestrians. The proportion of pedestrian accidents is twice as high in developing countries [World Bank, 1999]. Road accidents in South Africa are a major concern. South Africa has a total accident rate of over five hundred thousand annually, in which some ten thousand people are killed [National Department of Transport, 1999]. The pedestrian involvement in accidents is approximately forty per cent [National Department of Transport, 1999].

The traditional approach of analysing traffic safety is been based on accident data. Although accidents provide a direct measure of the "safety situation", there are many drawbacks inherent with the use of accident data.

According to Hydèn [1987] the four problems associated with the use of accident data are considered to be as follows:

- The time period to collect a sample size is often too long (generally a three years period is required)
- Paucity of information
- Accuracy concerned with the data
- Under-reporting of accidents

Statistically, accidents are rare, random and unpredictable events.

The major drawback in using accident data is the very fact that engineers have to wait for accidents to occur before any interventions can be made. A three-year sample size is required to perform adequate statistical analysis [Roebuck, 1989].

The paucity of the information and accuracy of the data is often questionable as information on the pre-crash phase is non-existent in accident data [Hydèn, 1987]. Without this information, (separation of road users, speeds, behaviour) solutions for reducing or even eliminating accidents cannot be achieved. This information can only be obtained by using sophisticated equipment such as onboard recording systems [Lehman & Reynolds, 1997]. Further, the reliability of accident records is often questionable [Glennon, Glauz, Sharp & Torson, 1977].

Another major problem associated with the use of accident data is the serious under reporting of accidents. Hauer & Hakkert [1988] concluded that the probability of an accident being reported depends on several factors such as severity, age of victim, number of vehicles involved, etc.

Considering these deficiencies associated with the use of accident data, alternative methods of analysing have been developed. These include exposure studies, behavioural studies, interaction studies, speed measurements and traffic conflict studies. Exposure studies aim to collect data concerned with distance travelled, time spent in traffic, number of trips or traffic situations related to different accident types, while behavioural and interaction studies make observations to check the way a particular infrastructure works [OECD, 1998]. The use of exposure and behavioural data provides insightful information on the probable cause of accidents. The innovation of conflict techniques was aimed at reducing the time period required to estimate the risk or accident frequency (or the projected accident rate) at specific locations [Hydèn, 1987]. A conflict is defined as traffic event involving two road users in which a collision is imminent if their trajectories remain unchanged. Conflicts were studied as researchers proved that the sequence of events leading to a conflict is the same as an accident with the exception of the end result which is a collision [Older & Shippey 1979; Hydèn, 1987]. These researchers found it appropriate to develop conflict techniques with the aim of reducing the time period for estimating accident risk. Therefore, this reduces reliance on accident data and the flaws inherent with these data and hence, an engineer does not have to wait for accidents to occur in order to estimate the accident risk at a location.

1.2 Traffic conflict technique (TCT)

The development of the conflict technique began in the aviation industry, after World War II, in which "pilot errors" or critical incidents were used as measures of safety performance [Fits & Jones, 1947; Flanagan, 1959; cited in Asmussen, 1984].

The introduction of conflict study techniques to the road transportation industry began with Perkins & Harris [1968]. Their technique was designed for studying junctions in order to assess if the cars manufactured by General Motors performed differently from other cars. Perkins & Harris [1968] defined traffic conflicts as any potential accident situation. The traffic conflicts were divided into two categories, namely evasive action of the drivers (as evidenced by vehicle braking or lane change) and traffic violations. Following the development of Perkins & Harris [1968], Spicer [1971], refined the General Motors technique in applying it in the UK. The technique was modified to account for the severity of the evasive manoeuvre. Following these initial developments by Perkins & Harris [1968] and Spicer [1971], a number of conflict techniques were developed in Europe and United States, with variations in their definitions and operational specifications. The first International Traffic Conflict Workshop was held in Oslo in 1977 at which researchers from three continents agreed upon the following general definition of a traffic conflict:

" A conflict is 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."

The various traffic conflict techniques can be grouped into two categories, quantitative or qualitative. The qualitative techniques are those developed by France, UK, Austria, USA and Germany. These techniques have no quantitative measure, instead the observer detects whether a situation is a conflict in accordance with the qualitative descriptions given in the conflict definition. The quantitative techniques are those developed by the Swedish, Canadian, Dutch and Finish. The techniques use time-based measures to record conflicts such as the time to accident (TA) and post encroachment time (PET).

The basic idea behind the development of the traffic conflict technique was that conflicts are far more frequent events than accidents. Hence conflicts, with their accident-like nature, provide the opportunity to investigate the accident risk at any location without waiting for accidents to occur. Conflicts are five thousand to ten thousand times more frequent than accidents and hence, they should reflect small changes in risk [OECD, 1998].

Ever since the introduction of the conflict technique in 1967 (by Perkins & Harris [1968]), many engineers have questioned the validity of traffic conflict techniques as a surrogate for accidents. Studies by Spicer [1971,1972,1973] found high correlation coefficients between serious conflicts and personal injury accidents. Studies by Glauz & Midgletz [1980] and Glauz, Bauer & Midgletz [1985] concluded that conflicts are good surrogates of accident rates and are nearly as accurate and precise as the prediction from historical records. Other researchers [Allen, Shin & Copper, 1978; Hydén, 1987; Paddock, 1974] have also concluded that conflicts are good surrogates for accident data. On the other hand, Glennon, Glauz, Sharp & Thorson [1977] and Williams [1981] have argued to the contrary. The issues underlying the validity of the conflict technique was finally settled by Hauer & Gårder [1986, cited in OECD, 1998], who noted that:

"A technique for estimation of safety is "valid" if it produces unbiased estimates, the variance of which is deemed to be satisfactory."

Further, they concluded that due to the variability in accident numbers, conflicts should only be used for estimating the expected mean number of accidents and not the actual number of accidents.

Reliability is another issue strongly associated with the use of conflict techniques. Due to the two distinct types of conflict techniques, namely qualitative and quantitative, reliability is thus classified accordingly as internal and external. Internal reliability deals with how reliable are observers in detecting and scoring conflicts [Hydén, 1987]. External reliability is concerned with the accuracy of the observers in estimating the quantitative time-based measures such the TA and PET [Kruysse & Wijlhuizen, 1992; Van der Horst, 1984].

1.3 Objectives

Section 1.1 briefly outlines the safety situation world wide and in South Africa, and further discusses the many drawbacks with the use of accident data. This has led to the development of other techniques such as conflict techniques. Section 1.2 outlines developments based on conflict techniques. To summarise, the advantages of using conflict techniques are that short-term observations produce much higher numbers of conflicts than accidents and the severity can be rated. Further, conflict rates are related to accidents rates. The disadvantages are that the observers have to be well trained as it is time consuming to observe the traffic and these techniques require judgements to be made.

Considering the drawbacks with the use of accident data, this study focuses on the use of traffic conflict techniques for estimating accident risk.

There are four basic traffic conflict concepts and the development of these techniques is based on the accident process. Consequently, the first objective of this investigation is as follows:

To assess how well traffic conflict techniques emulate the accident process and also to identify the conceptual differences between these techniques.

In view of the high pedestrian fatality rate in South Africa, the second objective was as follows:

To assess the applicability of conflict techniques to vehicle-pedestrian conflicts and also to assess the use of conflicts for estimating the accident risk.

In general, the data required for the various conflict techniques are obtained by direct observation. This practice requires well-trained observers but even so, a certain amount of subjectivity is involved during the recording of conflicts. In view of the recent developments on digital imaging, the final objective of this investigation was as follows:

To asses the feasibility of using digital imaging for data collection.

1.4 Approach

To meet the above objectives, the following approach was adopted:

- From a detailed literature survey, identify the concepts used in the development of the conflict techniques and highlight the differences between them.

- Empirical testing of the techniques at selected intersections (analysing vehicle-pedestrian conflicts) to estimate the accident risk.

- Compare conflict risk models with accident risk prediction models with the risk estimated from the conflict techniques for vehicle-pedestrian conflicts.

- In order to assist with the data collection and analysis of the conflicts, the development of a computer program based on the use of digital imaging techniques was necessary.

1.5 Overview of chapters

The structure of this dissertation is as follows:

Chapter 2: In this chapter, the traditional approach to traffic safety evaluation is presented (i.e. Accident Analysis) along with a discussion of the drawbacks associated with the use of accident data. An overview of accident analysis is made and accident prediction models are presented.

Chapter 3: This chapter begins with an introduction to the four basic types of traffic conflicts techniques and the relationship of conflicts to accidents. Essentially, this chapter reviews two of the four basic conflict techniques: The American and German techniques. These two techniques represent the qualitative conflict techniques. The review of these techniques starts with a discussion on the first conflict technique as developed by General Motors, which is a qualitative technique.

Chapter 4: Continues the review of the four basic types of conflict techniques but focuses on the two quantitative techniques - the Post encroachment time and Swedish techniques. Lastly, this chapter presents an extended concept of the Swedish conflict technique known as the "severity hierarchy".

Chapter 5: A discussion on the comparison of the conflict techniques is presented in this chapter. The comparison is based on the definition, severity scale, methods for data collection and training of the observers for each technique. In addition to highlighting the differences between these techniques, some key issues regarding the deficiencies in operational aspects of the techniques are discussed. The applicability of these techniques to the recording of pedestrian-vehicle conflicts is also discussed.

Chapter 6: This chapter presents the data collection and requirements for the empirical testing of the conflict techniques. Discussions on the appropriate site selection, data processing procedure, and basic concepts of image processing used in the data collection and processing procedure is provided.

Chapter 7: This chapter presents a comprehensive discussion on the use of digital image processing for the collection of data. All the image-processing methods adopted are discussed. Finally, the chapter presents the computer program developed in this investigation, using image-processing methods to analyse the conflicts.

Chapter 8: Results of the analysis of the conflicts are provided. Firstly, a general comparison is made between the techniques followed by a detailed comparison of each pair of techniques. Secondly, the use of conflict models, risk measures, conflict counts and accident models are used to rank the intersections according to the level of risk. Thirdly, the analysis using the severity hierarchy concept is discussed along with the productions of the safety curves for the intersections. Lastly a discussion of the usefulness of digital imaging to conflict studies is presented.

Chapter 9: Concludes this dissertation summarizing what has been done and the main findings of in this investigation. Directions for future work are suggested

2 ROAD SAFETY AND ACCIDENT FACTORS

This chapter provides a brief overview of the traditional approach to road safety and the use of accident data and in-depth studies for carrying out road safety analysis. Road safety and/or accident analyses are the methods adopted in analysing traffic safety problems (for example risk estimation of collisions, hazardous locations, road design flaws, etc). In-depth studies discussed in this chapter refer to "intermediate" and clinical studies. These in-depth studies are used to identify the factors involved in the accident process and to what extent these factors are related to the road and traffic system. The primary aim of this chapter is to provide a descriptive background on accident analysis and hence to provide a basis for Chapter 3, which deals with traffic conflict techniques. In the last section of this chapter, accident modelling is introduced. This section is not meant to be exhaustive; it describes the development of accident models and the various relationships that have been developed. In this regard, attention is focused on relationships between accidents and volumes and also between accidents and speeds because some traffic conflict techniques are based on these relationships.

2.1 Background

The transport system comprises three basic components: road users, vehicles and the road environment. Safety on a transport system requires the successful interaction between these components [McShane & Roess, 1990]. For the purpose of this discussion, road safety in general can be regarded as concerning all aspects of the prevention and reduction of accidents and of injuries arising from the movement of people and goods on road networks [Roebuck, 1989].

Noting that the transport system has three basic components, traffic engineers have control over only one of these components i.e. the road environment. Consequently, traffic engineers play a vital role in influencing the road user [McShane & Roess, 1990]. Road users rely on the environment for making decisions and hence proper design of the road environment is required not only to provide the road user with information for correct decision-making but also to minimise the risk of incorrect decision-making. Thus a major aim of traffic engineers is to prevent injuries and fatalities to road users that result from events known as accidents. The Concise Oxford English Dictionary [1990] defines an accident as: "an event that is without apparent cause or unexpected".

In this situation a "cause" is defined as "those antecedents that are invariably and unconditionally followed by certain phenomenon" (in this case road accidents) [Roebuck, 1989]. For the road users involved in accidents, the situation can be regarded as an event where the road users have not managed to react in time to avoid a collision. An accident for the road users involved is an event that happens "all of a sudden" or "without apparent cause".

In order to design safety measures, traffic engineers need to understand the processes and factors involved in accidents [OECD, 1998]. Neutralising or eliminating these factors can help to avoid accidents. The study of factors involved in previous accidents can yield information on future accident trends [OECD, 1998]. Broadly speaking, the major factors involved are the road user, road environment and vehicles. An indication of the contributions of each of these factors to traffic accidents is shown in Figure 2.1.

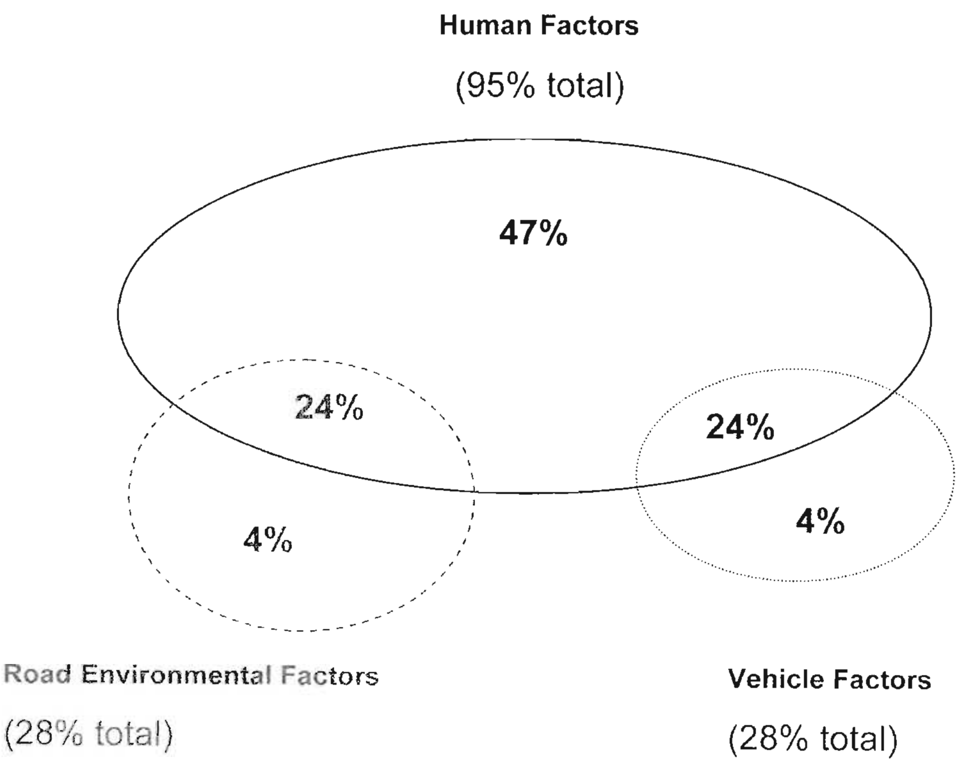


Figure 2.1 Factors contributing to road accidents [Austroads, 1994 cited in National Department of Transport, 1999].

However, in order to understand the influence of these factors in accidents, the accident process must be studied. An example of the accident process is shown in Figure 2.2. The main features of accidents are that they are always preceded by "critical combinations of circumstances" in traffic. Erke [1984] defined these "critical combinations of circumstances" as situations in which: "*with unchanged traffic behaviour and/or unchanged traffic situations, the interaction between man, vehicle, road traffic and environment leads to accidents*" - as shown in Figure 2.2. These "critical combinations of circumstances" in traffic situations are always preceded by decisions. These decisions determine whether the combination of circumstances become critical or not [Erke, 1984]. Examples of such decisions include the purpose of travel, the mode of transport, the speed of the vehicle and alertness of the road user ("provoked traffic behaviour" - refer to Figure 2.2). From Figure 2.2, it is evident that situations exist where road users recognise the critical combination of circumstances in time and anticipatory behaviour is possible to avoid an accident. However, if there is no anticipatory behaviour or it is insufficient, an emergency manoeuvre is required. If the manoeuvre is successful, no accident occurs, but rather a conflict (incident/near-accident) is the result. If the manoeuvre fails, an accident occurs. A conflict is similar in all regards to an accident with the exception of the end result i.e. a collision.

The traditional approach to accident investigation and prevention is to relate accidents to a particular cause. However a single, simple cause is not usually definable [Roebuck, 1989]. As discussed earlier, The Concise Oxford English Dictionary defines cause as those antecedents, which are invariably and unconditionally followed by certain phenomena - in this case, road accidents. Accidents only occur when a whole set of conditions have been fulfilled and can be illustrated by the following example [Roebuck, 1989]:

At a given intersection, 100 000 vehicles turned right in a given period of time and five of these vehicles collided with a vehicle on the major road. Consequently, some 99 995 right-turning vehicles did NOT collide which means that the act of turning right was not invariably or unconditionally followed by an accident.

As there is no single/simple cause of an accident, there is no simple cure [Roebuck, 1989].

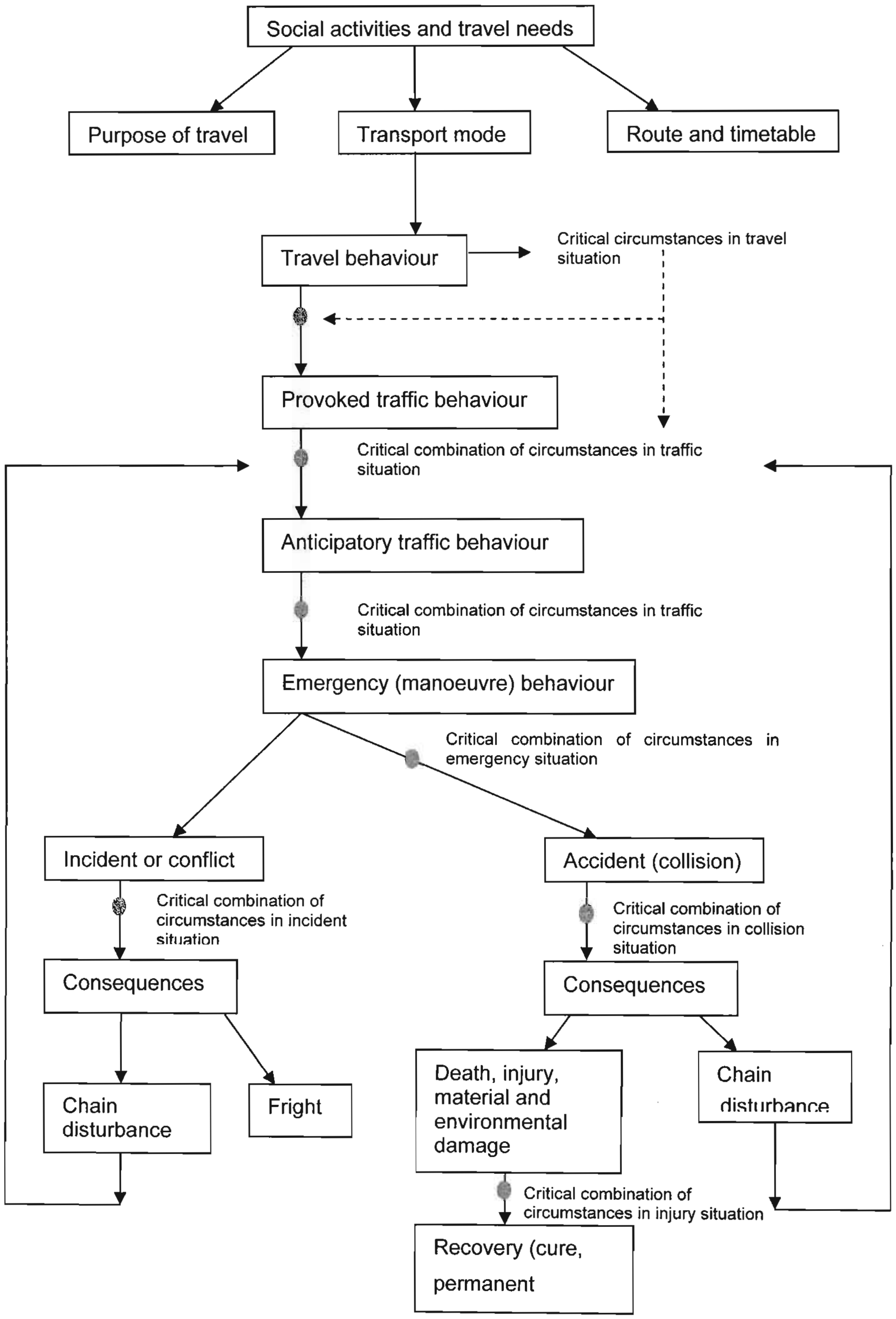


Figure 2.2 Accident process [Adapted from Erke, 1984]

Generally, a systems approach is adopted with the use of accident data to effect a reduction in accidents and the resulting injuries. This approach is based on the "3E"s - Engineering, Education, and Enforcement (with evaluation known as the fourth "E") [Roebuck, 1989]. The "3E" approach is divided into categories relating to the road user, physical environment and the vehicle. Further subdivision is also based on administrative levels at which action is taken and on the stages of a collision – i.e. primary, secondary and tertiary [Roebuck, 1989].

The various subdivisions based on the "3E" approach result in a four-dimensional matrix, as shown in Figure 2.3 of which some 108 categories can be identified [Roebuck, 1989]. These 108 categories represent the potential areas of action. However, only sixty-one categories are valid - for example the road users cannot be engineered.

In addition to identifying the causes of accidents and the process, accident analysis is also concerned with the measurement of risk. As is the case with accident analysis, risk is also measured with the use of accident data. According to The Concise Oxford English Dictionary [1990], risk is defined as "the chance of bad consequences". For the purpose of accident analysis, risk can be regarded as the chances/probability of:

- An accident occurring at a certain spot or along a certain stretch of road
- An accident occurring to an individual road user passing through a certain spot or along a certain stretch of road

The two measurements of risk include average accident totals and average accident rates. The measurement of risk is important as it is used for various reasons:

- Priority ranking of sites for remedial treatment
- Forecast the likely future level of danger if no remedial action is taken
- To estimate the possible accident savings to be derived from different remedial measures

To summarise, an accident is a result of many contributory factors thereby necessitating a systems approach to effect a reduction in accidents by attempting to understand the causes involved. Together with this systems approach, the measurement of risk is important in accident analysis because it is useful in assessing the level of "danger". This section has provided a descriptive background to accident analysis and has drawn attention to the importance of accident data in accident analysis. Although accident data have formed the corner stone for analysing and assessing the road safety situation, there are many drawbacks inherent with the use of these data and this has led to more in depth studies. These studies include "intermediate" and clinical studies, which are introduced in section 2.3.

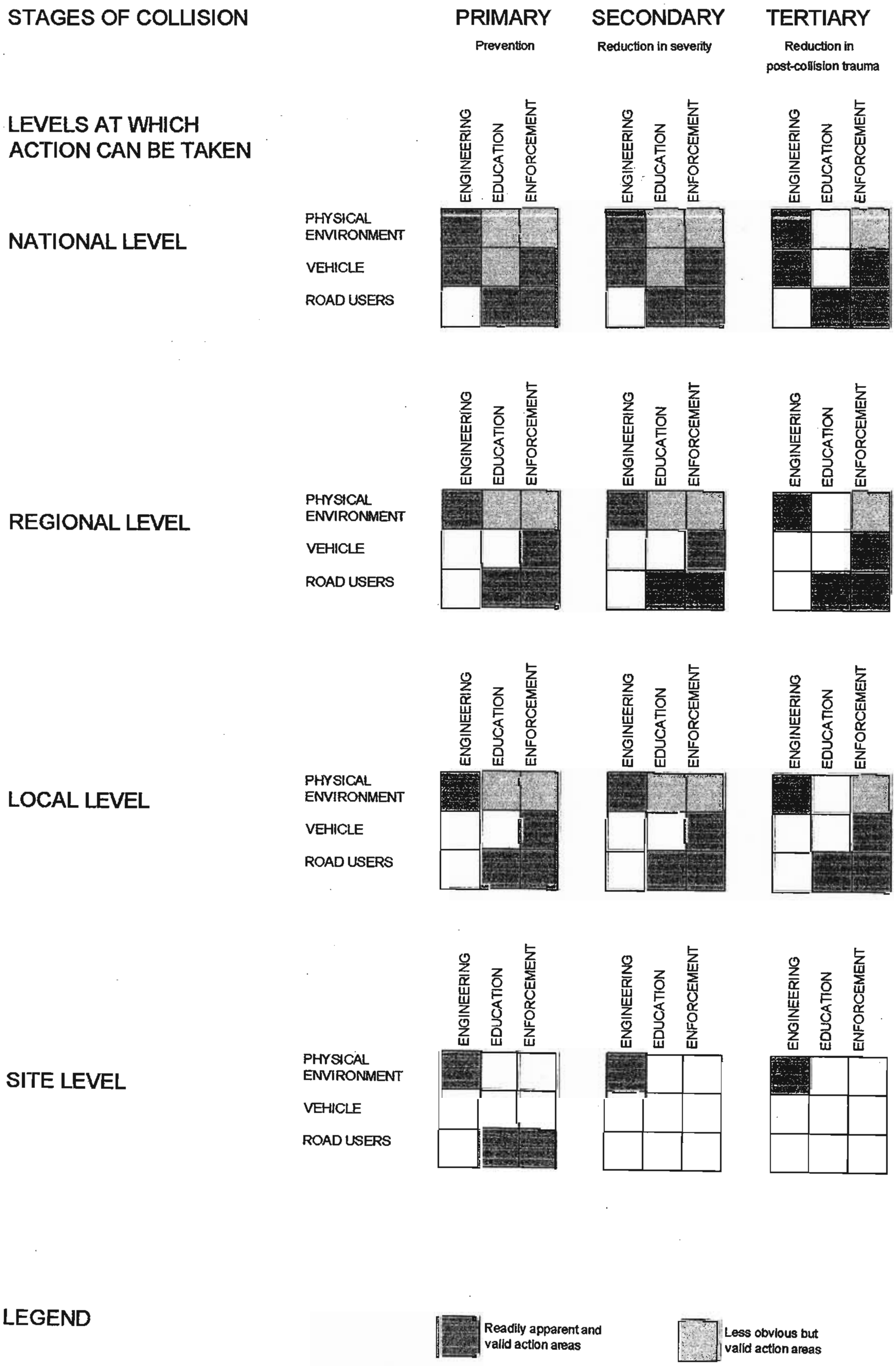


Figure 2.3 Matrix of potential road traffic safety action areas [Roebuck, 1989]

2.2 Accident analysis by use of accident data

Accident data form the basis for road safety studies and are used as a means of measuring the accident risk at specific locations. If the level of accident reporting diminishes, effective solutions for remedying hazardous locations cannot be achieved, hence the safety situation will deteriorate [OECD, 1998]. The problem of under-reporting has serious implications as traffic engineers rely heavily on the use of accident data to identify and remedy hazardous locations. Data on accidents recorded by the police remain the main source of information for road safety. Other sources such as fire departments, insurance companies, etc. are also used [Hauer & Hakkert, 1988].

For road safety management, accident reports are used in a number of ways. These include [Hauer & Hakkert, 1988]:

- Identifying target groups i.e. accident types, high-risk drivers, dangerous vehicles, and hazardous sites.
- To examine the relationship between accident occurrence and various causal factors.
- To assess the effectiveness of countermeasures.

However, the use of accident data has often been questioned because these data suffer from a number of drawbacks. In addition, an accident is a random event because the factors resulting in accidents tend to be random. Consequently for road safety work it is not sufficient to only use accident data [OECD, 1998]. Accidents recorded by the police suffer from a number of disadvantages that restrict the use of accident data for safety evaluation. Accident reports provide little information on the consequences of accidents with regard to the severity, resulting disability, etc [OECD, 1998]. Further, the completeness and accuracy are often questionable, and coupled with this is the problem of under-reporting.

Hauer & Hakkert [1988] concluded that the probability of accidents being reported depends on factors such as the severity of the outcome, the age of the victim, his or her role in the accident, and the number of vehicles involved. Several other studies gave similar results [James, 1991]. However, these studies did conclude that under-reporting is greater for accidents involving pedestrians and two wheeled vehicle riders as compared with vehicle occupants.

Many accidents in which the damage is minor are often handled by the conflicting parties, which compounds the problem of under-reporting. In addition, insurance companies are not informed in cases of minor accidents because of the system of no-claim bonuses [OECD, 1997]. An example of the under-reporting of accidents is illustrated in Table 2.1.

Table 2.1 Level of reporting accidents based on the severity of the accidents in the Netherlands for 1994 [OECD, 1997].

Severity	Police	Total Number	Percentage of reporting
Deaths	1 300	1 300	100
In-Patients	12 000	23 000	52
Out-Patients	19 000	145 000	13
Not Hosp.-Treated	18 000	472 000	4
TOTAL	**50 300**	**640 000**	**8**

The lack of completeness and accuracy of accident records can be attributed to the fact that police officials are not engineering experts, and hence often tend to neglect or understate the severity and causes of accidents [OECD, 1997]. In addition, it must be noted that other sources of information on accidents provide information for their own purposes and not necessarily information that is optimal for traffic safety [OECD, 1997]. For example, fire departments are not interested in the roadworthiness of the vehicle – defective tyres etc - and hence this information is not included in their reports.

2.3 "Intermediate" studies

Due to the drawbacks associated with the use of accident data, these data must be complemented with other approaches (in-depth studies) in order to obtain a range of accident factors on which to base the design of safety measures [OECD, 1998]. An example of an in-depth study is one in which statistical and epidemiological analysis is applied to accident data to describe each accident and its consequences [OECD, 1998]. This approach has been termed "intermediate" because the data collected are more detailed than in standard statistics [OECD, 1998].

Intermediate accident studies use databases (such as hospital records, insurance records and fire departments) that contain more information than basic statistics. These studies carry out a search of all existing databases on accidents starting with only those accidents from police files that are complete in all respects (i.e. police files which do not have any information missing). The next step is to find additional information on these accidents from comparisons with other databases (insurance, hospital). Due to these data requirements, the scope of such studies is restricted to either:

- the size of the geographical area (e.g. local area, regional area);
- specific types of accidents (e.g. only head on collisions)

According to the OECD [1998], intermediate studies are used for the following purposes:

- To assess the validity of existing statistics (e.g. underreporting, accuracy of reports)
- To provide additional data on the consequences of accidents (e.g. level of injuries for specific accidents)
- Identify additional variables which can possibly explain accident variations

The studies are generally carried out at national level and use data from more detailed police reports to provide information on the accident processes. Alternatively, intermediate studies use health statistics to provide information on the consequences of accidents or to check the completeness of causality data [OECD, 1998]. Intermediate studies generally isolate particular categories of accidents for example fatal accidents [OECD, 1998]. In some instances, detailed studies can be performed in limited geographical areas. Some investigations also aim at examining particular features of the road environment and their effects on safety.

2.4 Clinical studies

The accident generating process is a complex event consisting of many variables. Improvement in safety can only be achieved by identifying the factors involved in this process. Clinical studies are undertaken in order to identify these factors [OECD, 1998]. These investigations usually entail the collection of specific data at a number of accident locations followed by the reconstruction of each accident. This procedure enables analysts to identify to what extent the elements of the road and traffic system have played a part in the accident process [OECD, 1998].

On-site investigations take place as soon as possible after the accident occurs. A team of investigators – including trained professionals in road infrastructure, vehicle dynamics and design, and a psychologist - respond to the accident. Observations and measurements are performed on the road, environment and the vehicles involved [OECD, 1998]. On-site interviews are performed with road users involved and witnesses. Interviews in some cases are performed at later stages once the victims have recovered. Reconstruction of the accident process involves the incorporation of mathematical models and photographic libraries of crash vehicles [OCED, 1998].

These studies are confined to a small sample of accidents as more time can be spent on each accident reconstruction. However, this means that only some accidents types are studied and factors relating to the causes of other accident types remain unknown [OECD, 1998].

2.5 Accident modelling

In the study of road accidents, it is important to understand the contributory factors involved in the accident process. Many studies have been carried out under various road environments and traffic conditions. Initially, the study of road accidents led to many accident models relating traffic volume to accidents. However, other researchers (McCullagh & Nelder [1989], Friedstrom & Ingebrigsten [1991] and Baruya & Finch [1994]) soon discovered that the accident process is complex involving many contributory factors. Hence, these additional factors influenced accident modelling in later years and it soon became apparent that speed was one of the major contributory factors in the accident process. In this section, various accident models are presented and the ones of most interest are the speed-based accident models. Speed-accident relationships are important because many studies have concluded that accidents are directly related to speed.

Smeed performed the earliest research on accidents in 1949 [Smeed, 1949]. His study was based on one year's data for twenty western countries. He developed a model relating the number of fatalities (F) in any country for a given year to the number of registered vehicles (N) and the population (P) of that country.

$$F/P = 0.00030(N/P)^{1/3} \quad (2.1)$$

$$F/N = 0.00030(N/P)^{-2/3} \quad (2.2)$$

Smeed [1949] further deduced that the number of deaths (F) involving one vehicle should vary in proportion to the number of vehicles (N); the number of deaths involving two vehicles should vary with N^2; the number of deaths from a single vehicle accident for pedestrians (p) should vary in proportion to the product of N and p. Therefore, the total fatalities (F) is:

$$F = a.N + b.N^2 + c.(N.p) \quad (2.3)$$

2.5.1 Accident-volume relationships

In a later study, Smeed [1972] developed a model that related accidents to vehicle types and distance travelled. The model was calibrated using British data from an eight-year study.

$$y_{ij} = a_{ij}.x_i^p.x_j^q \quad (2.4)$$

y_{ij} = number of accidents between vehicle types i and j.

x_i and x_j are the respective distances travelled by the vehicles i and j, with p and q as the powers.

Satterthwaite [1981] calibrated the model introduced by Smeed [1972] for collisions between cars (c) and goods vehicles (g):

$$y_{cg} = 55.9(x_c^{0.67})(x_g^{0.77}) \quad (2.5)$$

Satterthwaite [1981] also suggested various models and noted that the simplest model relating accidents (y) to traffic volume (Q) is the power relationship:

$$y = a\,Q^p \quad (2.6)$$

in which a and p are constants. Satterthwaite [1981] suggested that p should be 1 for single vehicle collisions and 2 for two vehicle collisions.

Tanner [1953] provided the first attempt at relating accidents at junctions to traffic flow. Tanner carried out studies at eight T-junctions and deduced the following relationship:

$$A = 0.0045Q_r^{0.56}\,Q^{0.62} + 0.0075Q_1^{0.36}\,Q^{0.88} \qquad (2.7)$$

A = number of accidents per year

Q = two way flow across T-junctions (thousand vehicles/day)

Q_r = sum of right turning flow from stem and left turning flow into stem of T-junction

Q_1 = sum of left turning flow from stem and right turning flow into stem of T-junction

Due to scatter in data, Tanner concluded that the powers, except for 0,88 did not vary significantly from 0,5. Hence he suggested a simplified form:

$$A = 0.0045(Q_rQ)^{0.5} + 0.0075(Q_1Q)^{0.5} \qquad (2.8)$$

McDonald [1953] studied 150 rural intersections and developed the following relationship:

$$A = C.Q_1^{0.455}Q_2^{0.633} \qquad (2.9)$$

In which C is a constant, with Q_1 representing the average daily flow from the major to the minor road and Q_2 is the average daily flow from minor to major road.

Roosmark [1966, cited in Bauraya, 1997], developed a similar relationship to that presented by Tanner [1953]:

$$A = C_r\,Q_r^{0.42}\,Q^{0.71} + C_1Q_1^{0.42}\,Q^{1.02} \qquad (2.10)$$

Rossmark [1966] suggested that the powers be rounded to 0,5, except for the powers of Q, which he rounded to 1,0.

Pickering, Hall and Grimmer [1986] developed accident-flow relationships for total accidents after studying 300 rural T-junctions.

$$A = 0.24(Q_1Q_2)^{0.49} \qquad (2.11)$$

QP is the product of the major and minor road inflows in units of thousand vehicles per day.

Gårder [1989] developed an accident prediction model for turning vehicles and pedestrian. The model was calibrated using seven years of accident data from thirty-four intersections. The model was developed using the following variables:

- Street width (i.e. the length of the pedestrians crossing)
- The distance between the crosswalk and curb
- Existence of refuge

The model is of the form:

Accidents/day = $(c((Q_1.Q_2)^2)10^{-2})$/days per year (2.12)

where:

c is a constant, which is calibrated, based on the intersection type:

- Signalised
- Low speed intersection - non-signalised with mean speed on all arms below 30km/h
- High speed intersection - non-signalised with mean speed above 30km/h on at least one arm

Q_1 = pedestrian volume (pedestrians/hour)

Q_2 = vehicle volume (vehicles/hour)

The constant c is using standard tables (refer to Appendix A.1).

2.5.2 Accident-speed relationships

The relationship between speed and accidents was realised by researchers in various countries during the oil shortage period in 1973. At this time, many countries reduced the speed limit [Baruya, 1997]. The effects of the reductions in speed were immediately noticed, an example of which was that the fatality rate on US roads decreased by fifteen per-cent in 1974.

Belmont [1953] provided one of the first relationships between accidents, speeds and volumes for single vehicle accidents:

$y = k_1.v^{1.5}.Q$ (2.13)

where

y = accidents per year

v = average speed of traffic

Q = flow rates (vehicles/hour)

Belmont [1953] also produced models for head-on and rear-end collisions:

$y = k_2.v.Q^2$ (head-on) (2.14)

$y = (k_3 + k_4.v).Q^2$ (rear-end) (2.15)

Solomon [1964] continued the study of the speed-accident relationship and concluded that the relationship between accident involvement rate (number of drivers involved in accidents divided by the vehicle miles of travel) and the travel speed forms a U-shaped curve (see Figure 2.4).

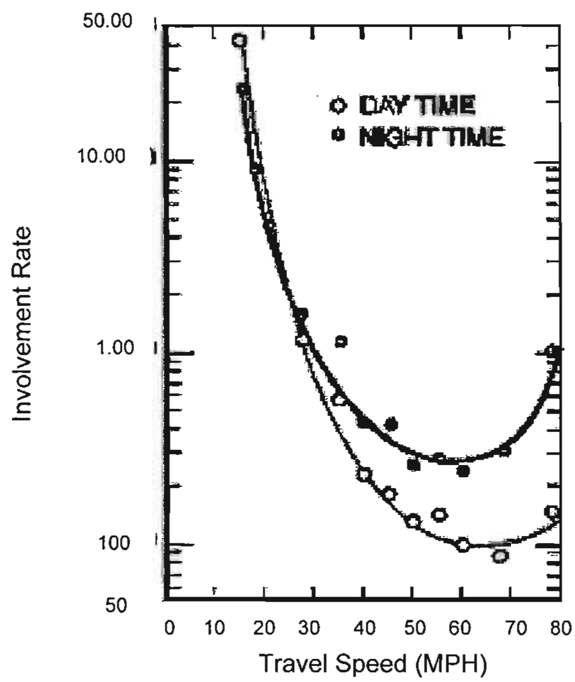


Figure 2.4 Involvement rate by travel speed, day and night [Solomon, 1964]

Hauer [1971] produced the following relationship:

$N = \exp [-2.57 + 0.033v_o]$ (2.16)

Where N is the average number of injured persons per accident and v_o is the mean traffic speed in miles per hour.

Joksch [1975] devised a quantitative relationship between speed and severity to formulate risk factors (relative involvement) – as shown in Table 2.2.

The relative involvement was defined as the risk of being involved in an accident with a certain speed - as the speed increases, the chances of being involved in an accident increases.

Table 2.2 Increase of risk of fatal accident involvement with speed

Speed (mph)	40	50	60	70	80
Relative involvement	1.0	1.5	2.5	6.0	20

Joksch [1975] also produced relationships for fatal involvement per 100-accident involvement for varying speeds - as shown in Table 2.3.

Table 2.3 Fatal involvements per 100 involvements by speed range

Speed range (km/h)	0	0-10	11-20	21-30	31-40	41-50	51-60	61-70	70+
Single vehicle	0	0.5	1.4	0.9	2.4	1.7	2.3	1.9	11
Multiple vehicle	0.1	0.2	0.3	0.1	0.3	1.7	1.9	3.6	9

Webster and Mackie [1996] provided more direct evidence of accident reduction due to speed management. Their study encompassed the effects of traffic calming on speeds and accidents. Before and after studies confirmed a significant reduction in accident frequencies. They derived an accident-speed relationship for traffic-calmed roads:

$$\text{Accident Change (\%)} = -0.60 + 6.1(\text{speed change mph}) \qquad (2.17)$$

This section has presented some accident models so as to demonstrate the range of models that have been developed and the factors that have been incorporated. These models are summarised in Table 2.4.

Table 2.4 Summary of accident models depicting the model type and study area

Author	Dependent Variable	Independent Variable	Model	Study Area
Smeed [1949]	F	N,P	Multiplicative	International
Belmont [1953]	A	Q	Multiplicative	Theoretical
Tanner [1953]	A	Q	Linear	UK
McDonald [1953]	A	Q	Multiplicative	US
Roosmark [1966]	A	Q	Linear	Sweden
Hauer [1971]	C	V	Exponential	Theoretical
Joksch [1975]	A	V	Tabulated results	US
Smeed [1972]	A	xi,xj	Multiplicative	Vehicle types
Gårder [1989]	A	Q	Multiplicative	Sweden
Satterthwaite [1981]	A	Q	Power	Universal

F = fatality rate
A = accidents per year
C = casualty
V = mean speed
Q = traffic flow
x = vehicle mileage
P = population
p = pedestrian

2.6 Summary

The models presented take into account some of the key factors (speed and volumes) involved in accidents. In recent years, various researchers - McCullagh & Nelder [1989], Friedstrom & Ingebrigsten [1991] and Baruya & Finch [1994] have attempted to accommodate other factors with the intention of improving the estimation of accident rates. Hence, the basic model structure is of the following form:

Accidents = (YR).k. [REGIONAL]. [FLOW]. [GEOMETRY]. [TRAFFIC]. [SPEED]. [MISC]. [RESIDUAL]

where
The terms within square brackets are multiplicative components, in the implicit power model.

YR = the period for which accident data are available
k = constant
REGIONAL – takes into account the particular place, example big cities.

FLOW – can be a product function of flow terms.
GEOMETRY – represent the geometric features of the road.
TRAFFIC – traffic composition.
SPEED – speed variables
MISC – other identifiable factors such as daylight, weather.
RESIDUAL – is the random unexplained component.

Accidents are a complex process involving many factors. The approach to traffic safety has been by the use of accident data. Although accident data provide a direct relationship to estimate accident rates, the "accuracy" of the data is often inadequate. Hence, in-depth studies (such as intermediate and clinical studies) have been used to counteract the problems associated with accident data and provide additional information on possible factors leading to accidents. In-depth studies often use trained professionals and sophisticated equipment to reconstruct accidents to identify additional variables in the accident process. However, these studies still rely on accidents and are time consuming and require a large number of professionals.

Accident models have also played a role in estimating accident risk/accident rates. Many researchers have developed models relating accidents to a range of variables such as: number of vehicles, population, traffic volumes, and speeds. One of the major relationships developed is the accident-speed relationship. This has gained widespread acceptance because many countries have experienced a large reduction in accident rates through reductions in speed. In recent years however, accident modelling has changed to incorporate additional variables to accurately predict accident rates. These models take into account the location, road geometry, traffic composition, flow, speed, and weather conditions.

3 TRAFFIC CONFLICT TECHNIQUES

A discussion of traffic conflict techniques is given in this chapter and is continued in Chapter 4. There are some twelve conflict techniques but these are variations on four basic conflict techniques. The four basic conflict techniques are the American (based on the General Motors Technique), German, Swedish and Post encroachment time (PET) techniques. Broadly speaking, there exist two classifications for conflict techniques - techniques that use qualitative descriptions and those that use quantitative measures for recording conflicts. This chapter focuses on the qualitative techniques. In this chapter, the first traffic conflict technique (TCT) as developed by the General Motors is discussed followed by reviews of the American, and the German technique. Chapter 4 continues the review of conflict techniques and focuses on the quantitative techniques (Swedish and PET). For each conflict description, the left hand driving rule applies.

3.1 Introduction

Chapter 2 presents an overview of the general approach to accident analysis that uses historic accident data to estimate accident risk. As discussed, the main drawbacks with the use of accident data are the time required to collect an adequate sample size and the questionable accuracy of the data - notably under-reporting.

Knowing the shortfalls of the use of accident data, alternative techniques such as traffic conflict techniques have been developed to assist with accident risk estimation. A conflict is defined as an event in which road users approach each other in space and time to a point where a collision is imminent if their trajectories remain unchanged. The question arises as to how conflicts can assist with accident analysis and to what extent are conflict rates a surrogate for accident data.

The answer to these questions lies in the accident process - as depicted by Figure 2.1 in Chapter 2 from which it can be seen that conflicts result from the same situations as accidents. However, the end result (i.e. the actual collision of road users is avoided) is the only difference. Simplifying Figure 2.1 to only consider the events just before the road users encounter each other - as illustrated in Figure 3.1 - it can be seen that the collision of road users is the difference between conflicts and accidents.

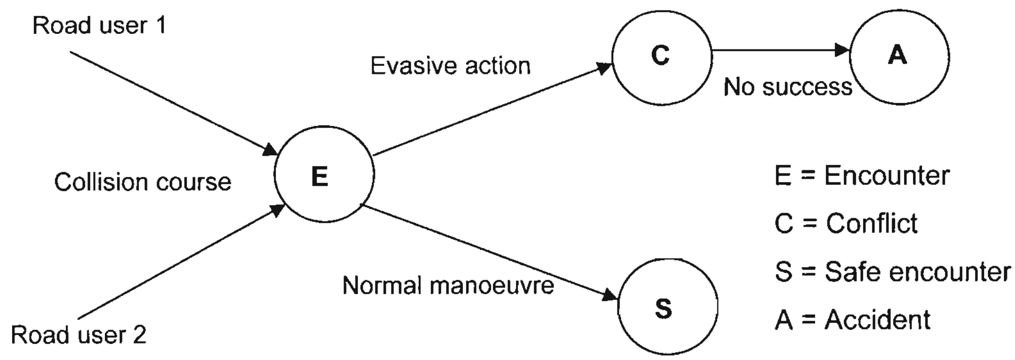


Figure 3.1 Sequence of events leading to an accident [adapted from Older & Shippey, 1979]

It should be noted that the result of no collision is a result of the anticipatory behaviour of the road users involved in the conflict - the road users were able to detect each other in time to just avoid a collision

The main reasons for studying conflicts according to [Hydèn, 1987] are as follows:

- To forecast the future accident potential at sites where historic accident data is unavailable or too sparse or where environmental change took place which invalidated the accident data.
- To obtain "pre-crash data" (speed and distances of the road users involved in conflicts), which is not available from historic accident data – this stems from the fact that conflicts are observable events.
- To test the effectiveness of remedial actions without waiting for several years to collect sufficient accident data.

Conflicts generally are graded in various classes representing the seriousness of the event. The seriousness of the event, no matter who defines it, is regarded as being the proximity (in space and time) of the conflict to an accident. Serious conflicts necessitate the fulfilment of most but not all of the conditions for an accident to occur. If all conditions were fulfilled then by definition an accident would have occurred [Roebuck, 1989].

The following sections present a discussion on the qualitative techniques i.e. the American and German conflict techniques. The discussion begins with the General

Motors conflict technique because all qualitative techniques (American, German, French, Austrian and Danish) have evolved directly from this technique.

3.2 The General Motors traffic conflict technique

In 1967, the first known conflict technique was introduced by Perkins and Harris of the General Motors Laboratory [Perkins & Harris, 1968]. Their definition of a conflict encompassed any potential accident situation. Conflicts were divided into two categories, namely evasive action of drivers and traffic violations. Evasive manoeuvres are evidenced by brake-light indications or lane-changes.

"A traffic conflict is any potential accident situation in which the driver brakes or swerves to avoid a collision." – [Perkins & Harris, 1968]. The conflict technique was developed with the aims of evaluating accident potential and operational deficiencies in a short period of time without waiting for accidents to occur.

Perkins & Harris [1968] defined over twenty conflict categories based on specific potential accident patterns at intersections (refer to Appendix A.2). These categories include the following manoeuvres: weave conflicts, slow for left-turn conflicts, rear-end conflicts, etc. An example of a conflict type is:

- Slow for left turn

This occurs when a vehicle abruptly decelerates to make a left turn thereby causing the following vehicle to brake or swerve to avoid a collision.

In addition to the recording of conflicts, other data are collected: directional vehicle counts and the proportion of through vehicles that are stopped by traffic signals [Perkins & Harris, 1968]. Additionally, illegal movements along with improper lane use are also noted. Since the brake-light indication is used to determine conflicts, a check is performed in which counts of vehicles that are stopping are observed to detect if they have operating brake lights [Perkins & Harris, 1968].

3.3 The American traffic conflict technique

3.3.1 Introduction

The American TCT follows the general definition as agreed upon at the first international workshop on traffic conflict techniques (as discussed in Section 1.2), and has been applied to both signalised and un-signalised urban intersections. This technique does not possess a severity scale. Like the other techniques, direct observation by trained observers is required. The development of the American traffic conflict technique is based on the General Motors traffic conflict technique and has predefined conflict categories.

3.3.2 Definition

"A traffic conflict is an event involving two or more road users, in which one user performs some atypical or unusual action, such as a change in direction or speed, that places another user in jeopardy of a collision unless an evasive manoeuvre is undertaken." [NCHRP, 1980]

The road users are generally motorists but the definition also includes pedestrians and cyclists [NCHRP, 1980]. The definition rules out actions that nearly all drivers perform under the same conditions such obeying signs [NCHRP, 1980]. For example - normal stopping for a stop sign.

An event is classified a conflict when road users are on a collision course [NCHRP, 1980]. The essential condition for a conflict is that the action adopted by the first user places the second user on a collision course. The action referred to is any manoeuvre for example - opposing right turn across the path of a through vehicle just as it enters the intersection or a slow left turn placing the following vehicle in danger of a rear end collision - a collision is imminent unless the second user takes an evasive action.

In the event that the second road user does not perform an evasive manoeuvre (due to poor judgement of time and distance estimations or being unaware of the situation) and a collision or near miss situation occurs, the event is still recorded as a conflict [NCHRP, 1980]. Hence, an evasive action is not necessary in terms of this general definition. Simply, the actions of the first road user governs the situation in that the manoeuvre threatens the second road user and hence the second road user may then need to take evasive action. Allen, Shin and Copper [1978] have shown that many accidents can occur without evasive actions. In order to cater for events that occur without evasive actions, the American technique broadened the definition of a conflict to encompass these events - generally these situations would be included as extreme cases.

According to the NCHRP [1980], a conflict at an intersection can be described by the following stages:

Stage 1: the first vehicle makes a manoeuvre.
Stage 2: a second vehicle is placed in danger of a collision.
Stage 3: the driver of the second vehicle reacts by braking or swerving.
Stage 4: the second vehicle then continues to proceed through the intersection area.

The last stage is necessary to convince the observer that the second vehicle was responding to the offending manoeuvre of the first vehicle and not for example to a traffic control device [NCHRP, 1980]. The evasive manoeuvre of the second vehicle is confirmed by braking or swerving. The brake light indicates braking. In the case of inoperative brake lights, the diving (lowering/dipping) of the vehicle or the screeching of tyres provides the evidence.

In the development of the technique, two key attributes relating to the operational use of the definition had to be evaluated [NCHRP, 1980]:

- Reliability
- Repeatability

3.3.3 Reliability and Repeatability

Extensive field test were conducted in the city of Kansas during 1978 for the development of the American traffic conflict technique. The study involved conflict surveys at 24 intersections.

In this study, the variance σ_y^2 in the recording of each conflict type (predefined categories - refer to Section 3.7.4 - and Appendix A.3) was tested. The variance of each conflict type (Y) is function of identifiable factors such as observer variance σ_o^2 (reliability), the residual variance σ_e^2 (repeatability), the variance between days of the week, etc. In all, some ten factors were recognised [NCHRP, 1980].

$$\sigma_y^2 = \sigma_o^2 + \sigma_e^2 + \ldots\text{etc}$$

The analyses dealt with some 4000 hours of conflict observation.

Reliability: *"the definition should provide minimum variation between different observers who record the same event"* - [NCHRP, 1980]

The reliability was quantified by the inter-observer variance σ_o^2 [NCHR, 1980]. The variances were calculated for each conflict type. According to the study, in general the observer variance (reliability) accounts for approximately five per-cent of the total variance for each conflict type.

Repeatability: *"the definition should result in acceptable level of variance in repeated observations by the same observer at the same site under nominally identical conditions"* - [NCHRP, 1980].

According to the study, the lack of repeatability accounts for approximately 84 per-cent of the total variance.

3.3.4 Operational use of the traffic conflict technique

The general definition of the conflict makes this technique applicable to observations at any type of road geometric element such as driveways, traffic circles, bus - stops etc [NCHRP, 1980].

The technique has predefined conflict definitions for intersections [NCHRP, 1980]:

- Same direction
- Opposing right turn
- Cross traffic
- Left - turn on - red

- Pedestrian
- Secondary

These categories form the primary conflict types for intersection movements, of which variations exist to form eighteen specific categories of conflicts (refer to Appendix A.3). An example of some of these conflicts include:

- Left turn same direction:
  Occurs when the first vehicle slows to make a left turn thus placing a second following vehicle in danger of a rear-end collision.
- Pedestrian conflict:
  Occurs when a pedestrian (the road user causing the conflict) crosses in front of a vehicle that has the right-of-way, thus creating a possible collision situation.
  Situations in which the pedestrian has right-of-way, such as WALK phases (green man phase) are generally not considered as conflicts
- Secondary conflicts
  This occurs when the second vehicle makes an evasive manoeuvre and places another road user (third road user) in danger of collision.

The recording of conflicts is performed by onsite observers stationed at an intersection approach for a specified time period [FHWA, 1989]. Other observers record conflicts that occur on other approaches or if only one observer is used, then the observer spends specific time intervals at each approach [FHWA, 1989]. Observers are required to record conflicts according to the general definition and/or the predefined conflict definitions. The objective for the observer is to recognise specific conflict types from a wide range of traffic events [FHWA, 1989]. The following examples illustrate the concept of the conflict definition and the recording of conflicts. Consider an intersection layout as shown in Figure 3.2

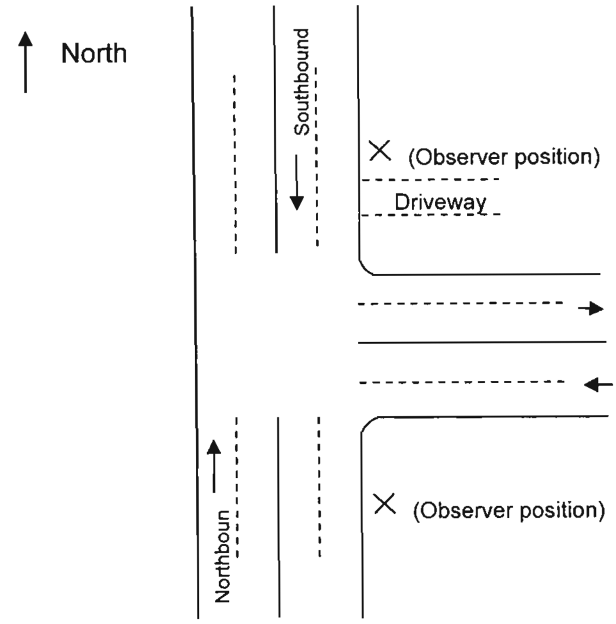


Figure 3.2 Layout of intersection for conflict examples

For these examples, an observer is on the south approach of the intersection viewing northbound vehicles and an observer is on the north approach viewing southbound vehicles.

Observer on northern approach:

- A Southbound car slows and turns left. Another car immediately behind it, brakes severely and then it, too, turns left.

This event could be debated, however it should be considered to be a left-turn, same-direction conflict. If the second vehicle, however, turns into a driveway or attempts to change lanes to make a right turn, it should not be recorded as a conflict because according to the definition it is not clear as to whether the second vehicle braked because of the first vehicle or because the driver was attempting to turn into a driveway or due to the driver being in the wrong lane thereby attempting to change lanes to make a right turn. If the second vehicle proceeds through the intersection instead of turning right or going into a driveway, the event is recorded as a conflict.

- A car on the eastern approach stops, starts to pull out to make a right turn then stops abruptly because the driver sees a southbound vehicle that just passed the observer position (observer on northern approach).

This situation is not recorded as a conflict because according to the definition, a conflict is recorded only when the southbound vehicles reacts to an impending collision. If the southbound vehicle braked or swerved and the right turning vehicle was far enough to be in the path of the southbound vehicle then a conflict is recorded.

Observer on southern approach:

- A northbound vehicle makes a right turn at the intersection crossing the path of a through southbound vehicle. The observer hears the tyres squeal from the southbound vehicle and sees the front of the vehicle dip forward indicating sudden deceleration, but there are no brake light indications and the southbound driver did not attempt to swerve to avoid the impending collision.

This event would be recorded as an opposing right-turn conflict. A small percentage of vehicles have brake lights that are inoperative [Perkins & Harris, 1968]. To record a conflict, however, there must be some visual and/or audible evidence such as the squealing of tyres to convince the observer that the driver was attempting an evasive action.

- A northbound vehicle executes a U-turn and heads south. Another vehicle following behind this vehicle is forced to brake and swerve to avoid the U-turning vehicle

The event would be recorded as a conflict because the actions of the first road user places the second road user in a position whereby an evasive manoeuvre is necessary.

These examples although simple, illustrate the fundamental concepts of the American conflict definition. The examples further indicate the qualitative nature used in the recording of the conflicts based on this definition. There is no severity scale to distinguish the severity of the events. From the examples and in general, observers are required to make judgments based on a combination of the following:

- Brake light indication
- Audible evidence - squealing of tyres
- Visual evidence – swerving, dipping of the front of vehicles during deceleration

3.4 The German traffic conflict technique

3.4.1 Introduction

The German traffic conflict technique follows a qualitative approach to recording of conflicts. This technique has been applied both to signalised and un-signalised intersections. The development of the technique began in 1973 - [Erke, 1984] and was based on the definitions produced by Perkins & Harris [1968] and Spicer [1971, 1972, 1973].

3.4.2 Definition

A traffic conflict is defined as: *"an observable situation in which two or more road users approach each other in time and space to such an extent that a collision is imminent if their movements remain unchanged "* [Erke, 1984].
The event of a traffic conflict is indicated by what is termed a critical manoeuvre (commonly known as evasive action) of one of the road users [Erke, 1984]. The following evasive actions are recognised:

- For vehicles: braking, accelerating and swerving.
- For pedestrians: stopping, running and jumping.

The definition excludes actions in response to traffic control devices and signage [Erke, 1984].

3.4.3 Severity of conflicts

The degree of severity of conflicts is determined by the following factors [Erke, 1984]:

- the distance between the two road users.
- the difference in speeds of the road users.
- the rate of acceleration or deceleration.

The above factors are assessed according to the perception of the observers - the observers have to qualitatively judge the conflict in line with the above factors. These factors are used to determine the severity of the conflict. The time span, which is available for the road users to execute a critical driving manoeuvre, is often used to give an indication of the severity of the conflict [Erke, 1984]. If the time remaining for the road users to execute a manoeuvre to avoid a collision is zero then this implies that a collision has occurred. Therefore, small time periods indicate more dangerous situations hence the greater the severity - for example if road users detect each other at a later time in the conflict situation, then the road users have a lesser time to execute the necessary action therefore necessitating in some cases a more severe action to be taken (e.g. rapid braking - deceleration, or serving) to avoid a collision.

Following the recognition of the conflict, the next step is to class the conflicts according to the severity of the evasive action. The German TCT distinguishes four categories of severity [Erke, 1984]:

- Controlled braking or lane changing to avoid a collision but with ample time for manoeuvring safely
- Rapid deceleration, lane change or stopping to avoid a collision resulting in a near miss situation (no time for steady controlled manoeuvre)
- Emergency braking or violent swerve to avoid a collision resulting in a very near miss situation or a minor collision
- Emergency evasive action followed by collision

During observations, the first category is classed as non-serious; the second category is classed as moderate with the last two categories representing serious conflicts.

3.4.4 Operational use of the traffic conflict technique

The German conflict technique has thirteen predefined conflicts for intersections – listed in Appendix A.4. An example of some of these conflict categories include:

- **Right (opposing) turn conflict**

  This can happen when a right turning vehicle obstructs a vehicle approaching from the opposite direction. Should any of the drivers of the vehicles concerned have to take an evasive action, a right turn conflict occurs.

- **Joining conflict**

  This happens when a vehicle joins other traffic from a side street, a parking area or driveway. Should the driver of the joining vehicle and/or the driver of an oncoming vehicle have to take evasive action, a joining conflict occurs.

- **Intersection conflict**

  This happens when a vehicle driver ignores a red traffic light, a stop sign, or yield sign controlling an intersection and passes the intersection in front of an oncoming vehicle which has right of way from the cross road. Should either driver take evasive action, an intersection conflict occurs.

The conflicts are recorded using onsite observers and are classified into the predefined categories. Generally, two conflict observers are used per intersection. In addition to the recording of the conflicts, the observers are required to give an account of the situation such as - other road users who could have influenced the conflict or the actions of the road users before the conflict, etc.

4 QUANTITATIVE TRAFFIC CONFLICT TECHNIQUES

This chapter focuses on the quantitative traffic conflicts techniques that include the Swedish and post encroachment time (PET). The chapter begins with a review of the first quantitative measure developed for the recording of conflicts (by Hayward [1972]). Lastly, this chapter describes a new conflict approach that is derived from Swedish traffic conflict technique known as the "Severity Hierarchy" concept. Essentially, this is an extended version of the Swedish conflict technique.

Quantitative techniques are those techniques that use measurable variables such as time and speed to record conflicts. These techniques include the post encroachment time and Swedish techniques. Other techniques, which are derived from these techniques, are the Dutch, Finnish, Canadian and Israeli.

4.1 Time Measured to Collision concept

Hayward [1972] presented the concept of time-measured-to-collision (TMTC). He devised this method for "near-miss" (conflicts) traffic events. Near-miss traffic events are closely related to accident patterns and hence can be used as a predictor for accident rates [Perkins & Harris, 1968; Spicer, 1971,1972,1973].

In order to assess the severity of a near-miss event, a time based measure known as the time-measured-to-collision (TMTC) was devised. TMTC is the time required for two vehicles to collide if they continue with present speeds and on the same path. Hayward [1972] presented a theoretical curve of TMTC for a near-miss event suggesting that the curve is concaved upward representing the increasing and decreasing danger - as shown in Figure 4.1.

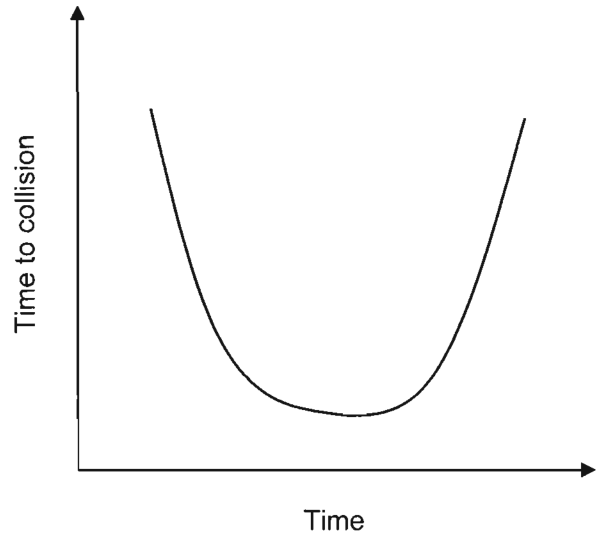


Figure 4.1 Theoretical TMTC curve [Hayward, 1972]

In the study, Hayward [1972] used cameras to record traffic events at an intersection. Dangerous traffic events were selected for recording by observing real-time television in a control room. When, it appeared that two vehicles would be in a dangerous situation, the event was recorded for subsequent analysis. The vehicle interactions were analysed using motion picture film, in which sequences of frames were analysed. Each point of interest on a frame was transformed into ground coordinates using regression equations. A computer program was used to achieve this task and the resultant output was the distances, speeds, accelerations and coordinate positions of the vehicles. Thus, the TMTC was determined using this information. Points on the wing of the vehicles were used for transformation of coordinates and motion parameters.

Hayward [1972] claims that the maximum TMTC is infinity, as drivers do not ordinarily drive on a collision course. While the minimum TMTC is the sum of the drivers perception and reaction time. If the TMTC drops below this value, a collision occurs because there is not enough time to avoid the collision. Hayward [1972] suggests a numerical value of 0,5 seconds for the minimum TMTC based on the results of the investigation. Hayward's field study produced 38-filmed sequences, which yielded curves with minimum TMTC values. Figures 4.2, 4.3 and 4.4 are illustrations of the curves produced by Hayward.

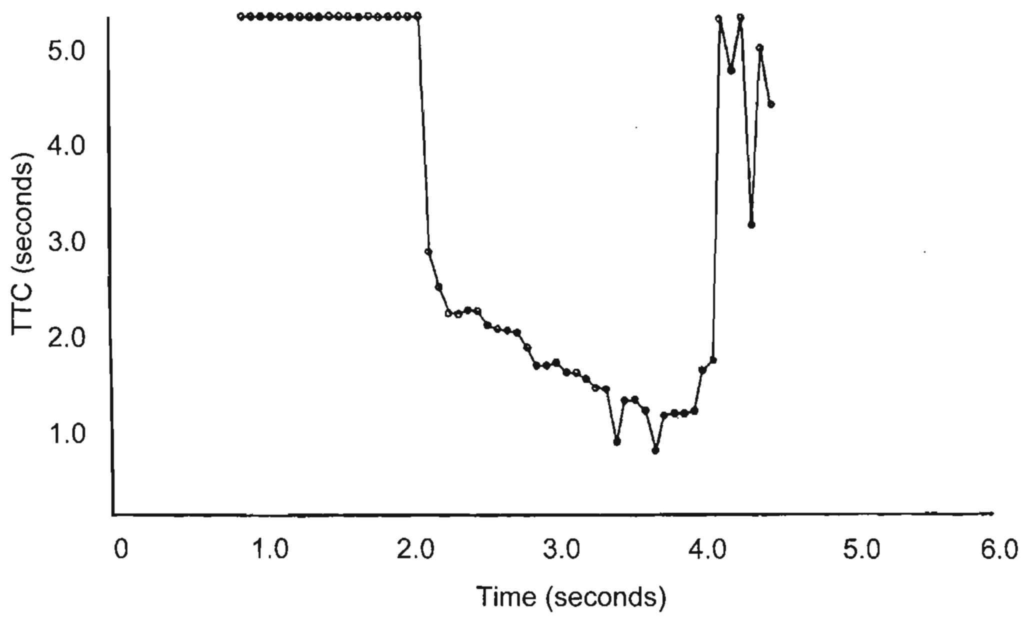


Figure 4.2 Typical empirical TMTC curve [Hayward, 1972].

The measurements shown in Figure 4.2, illustrate the increasing, then decreasing danger as discussed in the theory. However, other cases can occur as shown in Figures 4.3 and 4.4. Figure 4.3 shows a TMTC curve in which a double minimum exists. This case occurred when the driver made a second manoeuvre in addition to the initial avoiding manoeuvre. Another special case is the horizontal TMTC curve. In this case (Figure 4.4), drivers drive aggressively in which case they are on collision courses for long periods.

Studies by Hydén [1987] disputed the inclusion of the reaction time in the minimum TMTC as proposed by Hayward [1972]. Hydén [1987] demonstrated that the minimum TMTC could go to zero when the distance to collision approaches zero. Further, Hydén [1987] demonstrated that the minimum TMTC is not dependant on the braking reaction time. Hydén then developed a similar concept to the TMTC and named it time-to-accident (TA) upon which the Swedish traffic conflict technique is based.

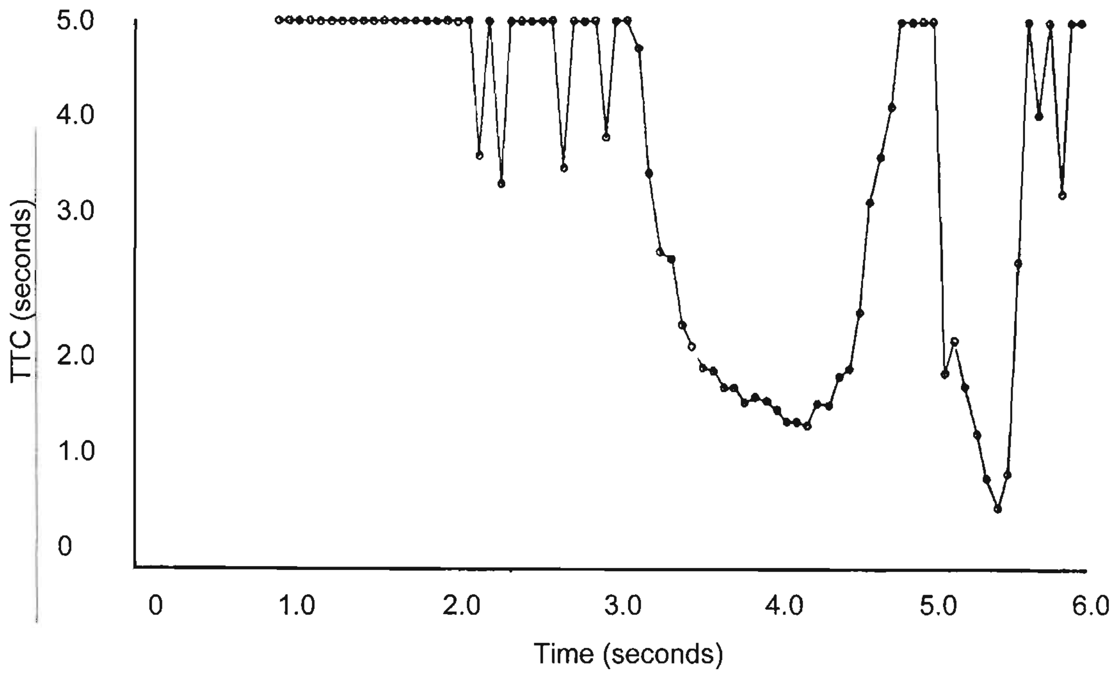


Figure 4.3. Double minimum TMTC curve [Hayward, 1972].

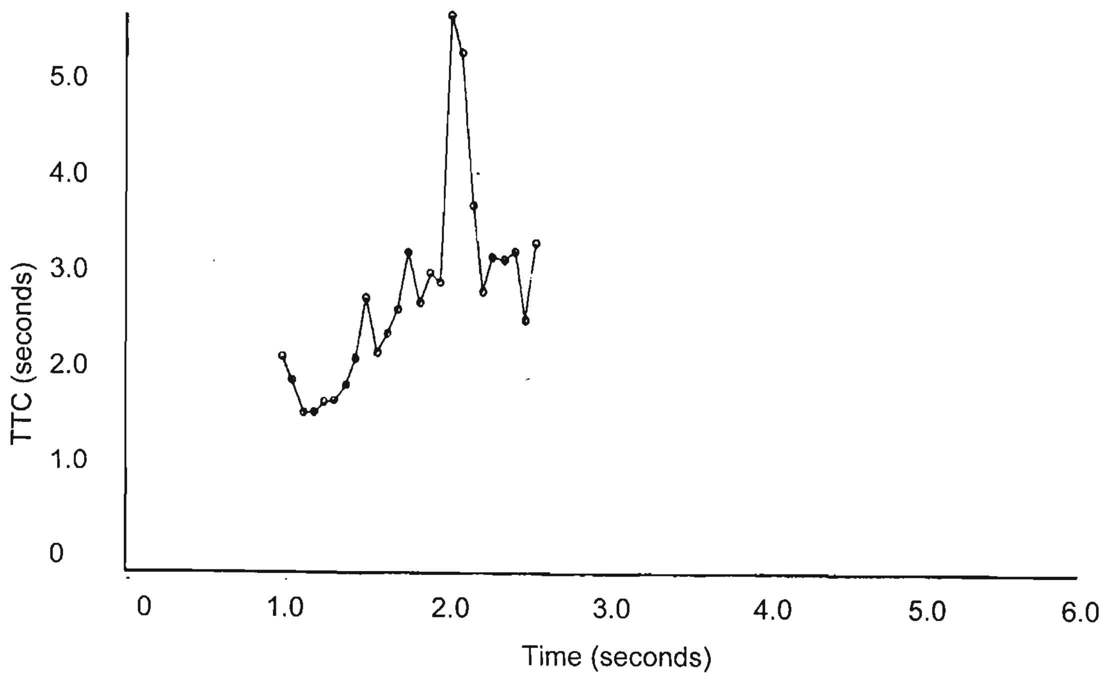


Figure 4.4. Horizontal TMTC curve [Hayward, 1972]

4.2 Post Encroachment Time conflict technique

4.2.1 Overview of technique

The post encroachment time (PET) concept was developed as an alternative technique to conflict recording. There is no formal definition for a conflict in this technique. Instead, the conflict is specified using the collision generation process as shown in Figure 4.5.

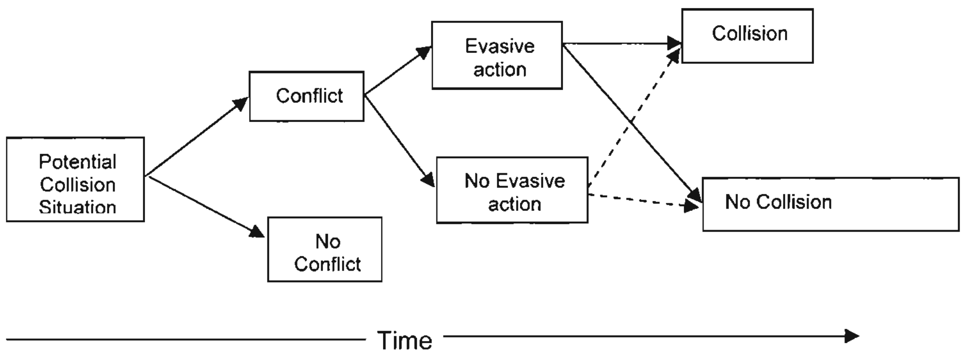


Figure 4.5 Collision generating process defining a conflict [Allen, Shin & Copper [1978]

Although the specification of the conflict follows the concept of an "evasive action" (i.e. it is assumed that evasive action is necessary by one or both road users to avoid a collision), Allen et al [1978] also note that accidents can occur with no evasive action. Therefore, the development of the proposed measure (PET) used to rate the severity of the conflict does not require evasive action to be taken. The definition of the PET illustrates this concept. The PET is defined as: "*the difference between the encroachment end time for one road user and the time the through vehicle arrives at the potential conflict/collision point*" [Allen et al 1978]. Simply, if two vehicles are involved in a situation where their trajectories cross each other, then PET is the clearance interval between these two vehicles. By definition, the PET is measured irrespective of whether an evasive action is taken by either road users. A small PET value indicates that the road users involved passed each other with a small distance between them - therefore it is almost a collision. In the PET measure, the road user that enters the collision point first is known as the "encroaching" road user and other road user is known as the "through" road user.

The following example is used to illustrate the PET concept. An opposing right turn situation is considered - as shown in Figure 4.6. In this example, it is assumed that one of the road users involved takes evasive action.

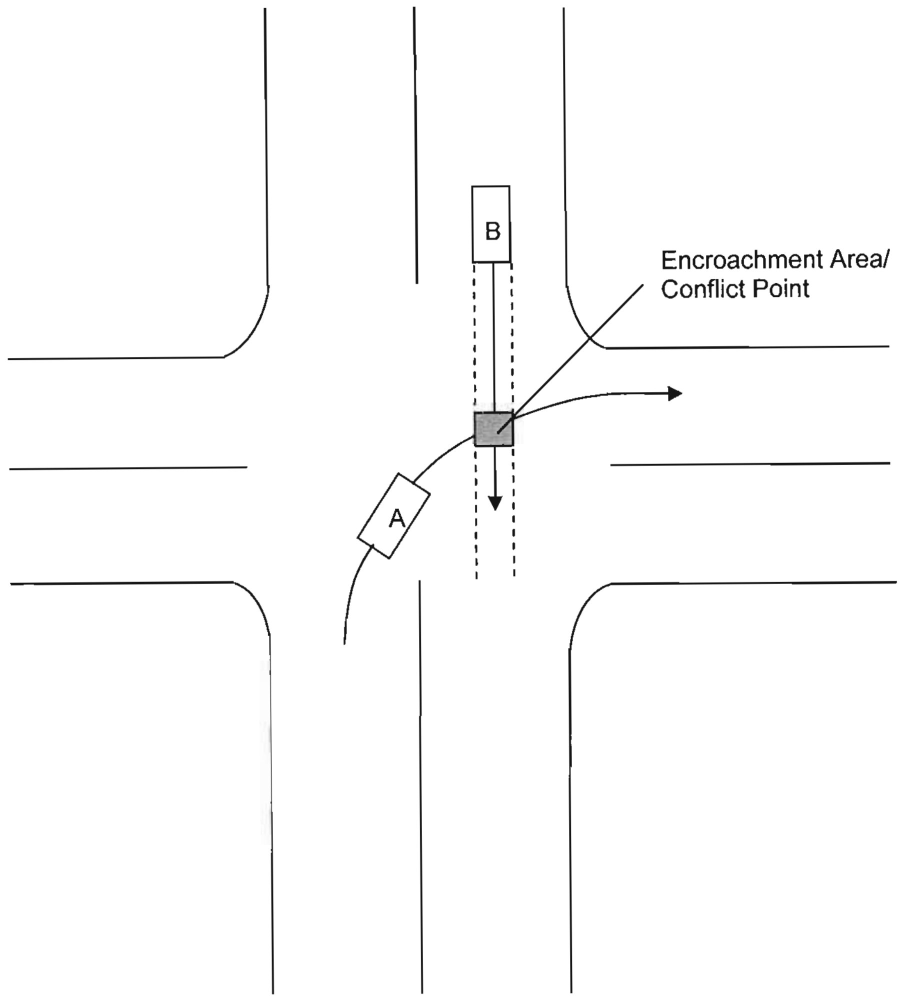


Figure 4.6 Opposing right turn conflict example

The PET value for this example would be the time taken for road user B to arrive at the collision point after road user A has cleared this point. The word encroachment is used in the definition because it illustrates (in the case of this example) the encroachment of the right-turning vehicle on the through lane that is occupied by another road user (Road user B).

A theoretical analysis of this conflict is carried out and is depicted by the use of a time-space diagram (see Figure 4.7). The initial speeds of road users A and B are 9m/s and 15m/s. The analysis begins when road users A and B are 33m and 100 from the imaginary collision point. From Figure 4.7, road user B notices road user A making a right turn and at time t = 7s and takes the necessary evasive action (in this case braking). Road user B continues to brake until road user A clears the collision area at time T_1 (9,125s). At this point, road user B proceeds to accelerate and reaches the collision point at t = 10,8s. The PET value for this event is 1,7s (10,8 – 9,125). In this example, the case of one road user (road user B) taking evasive action is considered. Noting that this technique is also valid if the road users do not take evasive action – in this case the PET is 0,54s (T2-T1).

The PET value is obtained onsite by trained observers using a stopwatch. The key tasks of the observers in the recording of conflicts is:

- to identify the collision point
- start the stop watch from the moment one road user exits the collision point
- stop the stopwatch the moment the other road user enters the collision point

The following sections highlight the development of the PET technique.

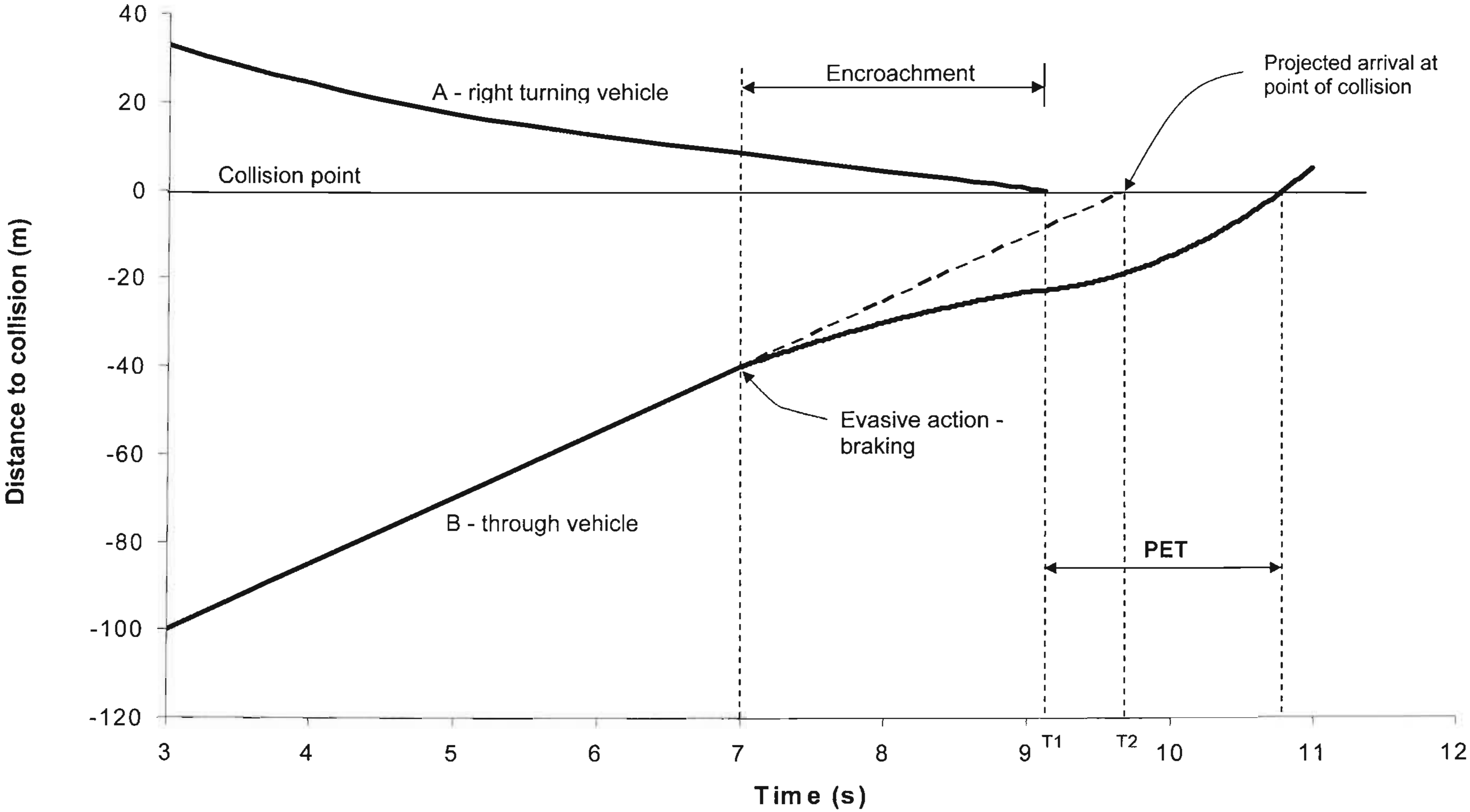


Figure 4.7 Time-Space diagram for conflict event

4.2.2 Development of PET traffic conflict technique

Allen et al [1978] presented the concept of the Post Encroachment Time (PET) as a criteria for a traffic conflict technique. The time-based measure was developed to address certain criticisms of the General Motors technique and the time measured to collision (TMTC) concept.

Allen et al [1978] criticized the TMTC concept, because this method requires accurate speed and distance information. Further, they argue that if a collision is avoided by a small margin, and no evasive action was taken, then TMTC would go to infinity. The General Motors technique as discussed in Chapter 3 - defines a conflict by identification of evasive actions - braking (which is identified by the brake light) or lane change. The following are the advantages and disadvantages of using the brake light as an indicator of a conflict [Allen et al, 1978].

Advantages:

- Brake indications are easily identified and counted
- Subjectivity in the data can be avoided
- Brakes are generally applied in all categories of conflict types

Disadvantages:

- Braking habits differ from driver to driver as some drivers tend to be more cautious than others and apply brakes on entering intersections regardless of the situation, hence this leads to recording events that are not of a conflict nature.
- In some cases, acceleration is used to avoid collisions and hence these situations are not recorded.
- Brake lights may not be operational or could be faulty

Due to the deficiencies of the above mentioned methods, other alternatives were explored. Studies were performed by filming an intersection over a period of one year from 1975 to 1976. In this time some twenty-five-collision scenes were recorded [Allen et al, 1978]. The study resulted in the following findings:

- Traffic conflicts can generally be described as a situation in which a driver perceives that an evasive action is necessary to avoid a collision or to secure a safe manoeuvre.

- In some cases the evasive action may not easily be observable and in other cases, a collision can occur without evasive action. Hence, some of the conflict techniques may fail to include situations that could lead to collisions.

Due to the above-mentioned factors, many new measures were proposed to record conflicts [Allen et al, 1978]:

- Proportion of stopping distance (PSD)
- Gap Time (GT)
- Deceleration rate (DR)
- Encroachment time (ET)
- Post encroachment time (PET)
- Initially attempted post encroachment time (IPAE)

Proportion of stopping sight distance (PSD)

The basis of this measure is that when road users are involved in a dangerous situation, the road users will attempt to stop or decelerate to avoid a collision. The ratio of the *remaining distance for the driver to manoeuvre to the projected distance to collision* (RD) can be used to estimate the seriousness of the situation.

$$PSD = RD/MSD \qquad (4.1)$$

where

RD = remaining distance to potential point of collision

MSD = acceptable minimum stopping distance = $V^2/2D$

D = acceptable maximum deceleration rate

Gap Time (GT)

Gap Time (GT) is used to describe a conflict event in the initial stages. It is defined as the time difference between the time taken for one road user to arrive at the potential point of collision provided the road user maintained original speed and direction and the time taken for another road user to end the encroachment (clear the collision point). Hence gap time can be positive or negative. The magnitude of the gap time indicates the severity of the conflict.

Deceleration Rate (DR)

Deceleration rate was employed to grade the severity of conflicts. The severity of the conflicts is graded based on the distance at which evasive action is taken from the imaginary point of collision. The evasive action in this method is considered to be braking. Predefined distances on a roadway are used to identify zones in which evasive actions are taken in order to grade the severity of the event. The further away the evasive action is taken from the potential point of collision, the less severe is the event. Deceleration rate (DR) is used to grade the severity of an event.

Encroachment Time (ET)

Encroachment Time (ET) is defined as the time taken for a road user to exit the encroachment area.

Initially attempted post encroachment time (IAPE)

This measure is an extension of the PET concept, which incorporates the speed of the road user involved.

$$IAPE = T - T_1 \qquad (4.2)$$

$T = T_e + (D/V)$

T_1 = time taken for the encroaching vehicle to end the period of encroachment.

T_e = time of commencement of encroachment

D = distance of the through vehicle to the probable point of collision at the beginning of encroachment.

V = average speed of the through vehicle during the period of encroachment.

In order to assess which of the above mentioned measures are best suited to conflict recording, a study was undertaken that involved the examination of conflicts from video recordings [Allen et al, 1978]. Statistical analyses were performed in order to determine the relationship with each of the proposed conflict measures with regard to the following:

- Relationship to collision history
- Relationship amongst each other
- Consistency at different observation periods
- Relation to brake application
- Applicability to various conflict types
- Ease of measurement (using onsite observers using simple equipment such as stopwatches)

The recommended measures from the study included post encroachment time, (PET) encroachment time (ET) and deceleration rate (DR) as these could easily be measured in the field using a simple device such as a stopwatch. However Allen et al [1978], recommended PET above the rest as it describes the conflict phase with a significant amount of detail and correlates well with accidents.

Using the PET measure, three levels of conflict severity was defined:
Severe conflicts have a PET range of 0-1,5 seconds; while moderate conflicts are 1,5-2,5 seconds and minor conflicts are 2,5-3,5 seconds.

4.3 The Swedish traffic conflict technique

4.3.1 Overview of technique

The basic concept behind the development of the Swedish conflict technique is that the interactions between road users can be described as a continuum of events. The interaction referred to is explained as follows:

Any road user using any part of a road system has to continuously evaluate the current proceedings on that system in order to make decisions to enable successful passage through that system. This can be termed the interaction between road users and the system. Evaluation of the proceedings can be, for example, the evaluation of the current state of various factors: traffic control devices, the movements of other road users, the distance between road users, the pedestrian movements, etc. In order to proceed through the road system without incident (accidents, serious events), the road user has to have a successful interpretation of the current proceedings on the road system to enable correct decision-making. The interaction between road users means the evaluation of the movements, distances and time spacing between each other. For example any road user executing a left turn has to evaluate such factors as, whether pedestrians are on the pedestrian crossing, the distance from pedestrians, consider the movement of the pedestrian, other road users turning alongside, etc - this can be a left turning vehicle-pedestrian interaction.

These events (interactions) can occur with different probabilities and various degrees of seriousness. These events can be visualised as a pyramid - which is known as a safety pyramid - as shown in Figure 4.8 [Hydén, 1987]. In this pyramid, accidents are found at the top whilst at the bottom are the undisturbed passages (normal driving situation). In between these two extremes are the various grades of conflicts. Serious conflicts are characterised as the breakdown in the interaction between road users i.e. "*the perceived accident potential is so high that at least one of the road users would not like to be involved in the creation of a similar event deliberately*", [Hydèn, 1987].

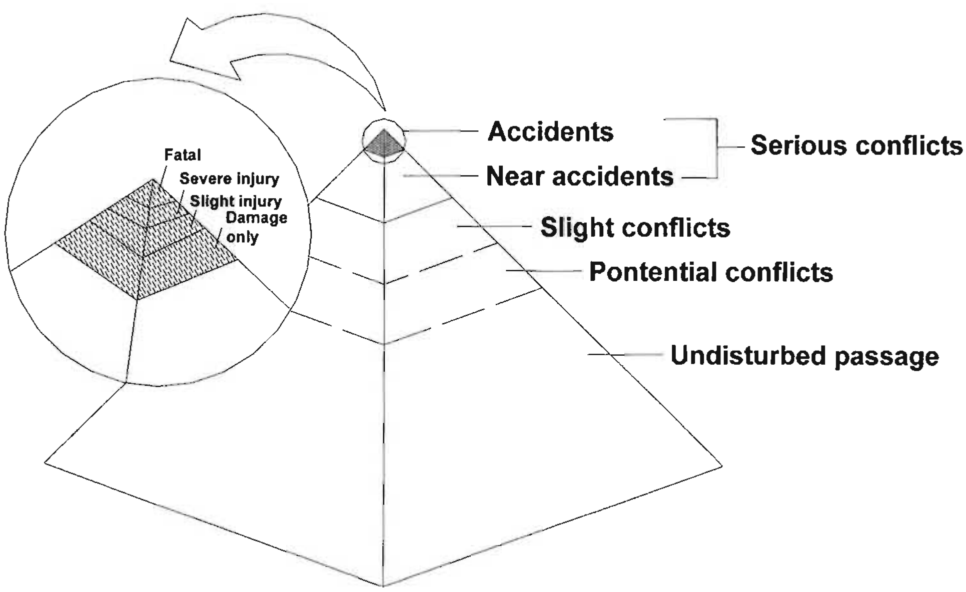


Figure 4.8 The safety pyramid [Adapted from Hydén, 1987].

The Swedish conflict technique defines a conflict as: "*an event where two road users with crossing paths would have collided if they had continued with unchanged speeds and directions (one or two road users take evasive action)*" - Hydèn [1987].
In this technique, two conflict grades or severities are considered:

- Slight conflicts
- Serious conflicts

Clear distinction is made between these two conflict grades. A serious conflict is defined as a conflict with a very small margin of not becoming an accident. A slight conflict is defined as a conflict in which ample time margin is available to either road user to take the necessary action. The distinction between a slight and a serious conflict is based on the time measured to collision (TMTC) concept as presented in Section 4.1. The TMTC is defined as the minimum time remaining to collision if the road users continue with unchanged speed and direction. However, the Swedish technique uses the value of time to accident (TA) to assess the severity of the conflict. Time to accident is defined as the time remaining from when evasive action is taken until the collision would have occurred if the road users continue with unchanged speeds and directions. The TA value is obtained from estimates made on site by trained observers of:

- the speed (v) of the road user (taking evasive action) at the moment evasive action is taken - this is called the conflicting speed and;
- the distance (d) of the road user taking evasive action to the potential point of collision (imaginary point of collision).

The evasive action referred to above includes braking, swerving, accelerating for vehicles and bicycles and in the case of pedestrians, running, stopping or jumping.

For the purpose of this discussion an example is used to illustrate the concept of this technique:

Consider two motor vehicle road users (A) and (B) on a potential collision course at say right angles to each other - as shown in Figure 4.9. Assume the speeds of road users A and B are 9m/s and 15m/s respectively. For this example, the case of only one road user taking evasive action is considered. A time-space diagram is used to illustrate the event. The analysis of the event begins when A is 60m from the collision point and B is 100m from the collision point. Road users A and B travel at constant speeds. For this example, B is the road user that takes evasive action. From the time-space diagram (Figure 4.10) road user B takes evasive action at a distance of 10m from the collision point.

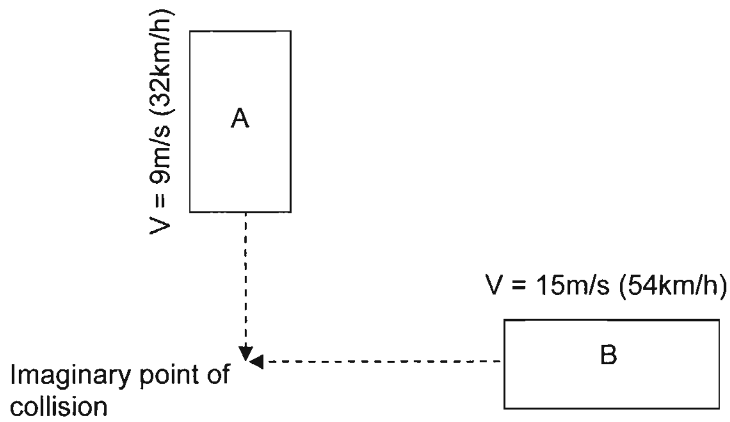


Figure 4.9 Swedish conflict technique example

The TA value for road user B value is 0,67 seconds (10/15) - as shown in Figure 4.10. From this figure, it is evident that the evasive action taken by road user B is braking. The time-space diagram illustrates the fundamental concepts of this technique. Had road user B not taken evasive action, a collision would have occurred with road user A.

After obtaining the TA-value, the next step is to rate the severity of the event. This is achieved by using a standard TA-Speed graph (discussed in Section 4.3.3). Using the information (speed before evasive action and TA value) for the road user that took evasive action, the severity of the event is determined. In this example, using the TA-Speed graph, the event would be defined as a serious conflict.

For this example, one road user (i.e. road user B) took evasive action. However, if both road users take evasive action, then TA values are estimated for both road users and the severity of both evasive actions is estimated. The least severe action determines whether the conflict is slight or serious. This approach is adopted because, if one of the evasive actions is slight then that road user has the potential to easily avoid the situation and thereby nullify the effect of the evasive action taken by the other road user, therefore, the conflict situation as a whole is nullified. For example:

- slight conflict + serious conflict = slight conflict or
- serious conflict + slight = slight conflict

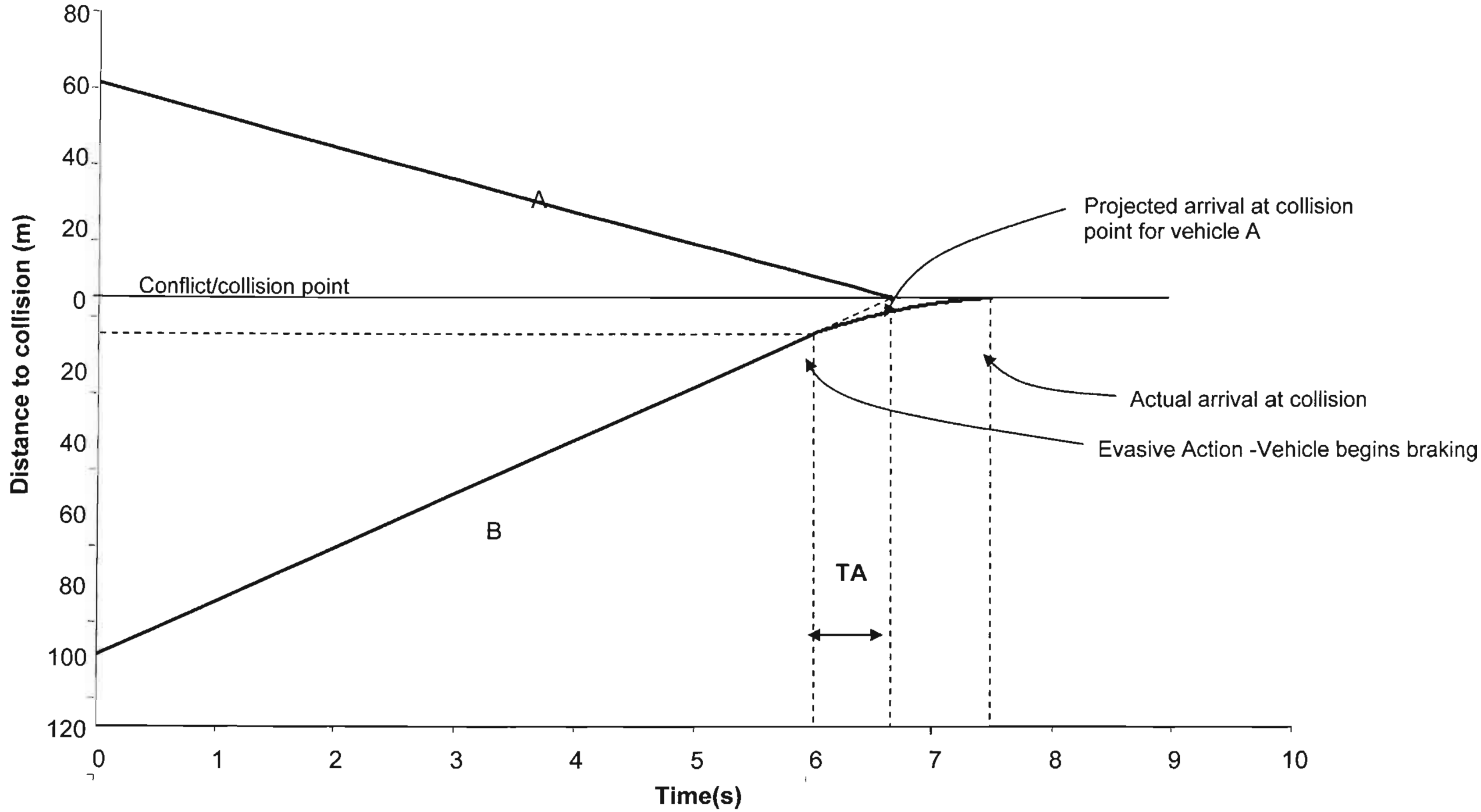


Figure 4.10 Time space diagram from conflict example

The following sections present the development of the Swedish traffic conflict technique. In these sections, a discussion is given on the development of the TA value as well as the validity and reliability of the technique. The development of the Swedish conflict technique can be described in two stages. Firstly, the development of the initial or original technique and secondly the modification of this original technique to what is presently used.

4.3.2 Development of the Swedish traffic conflict technique

The development of the Swedish technique required a method for rating the severity of the conflict (how close was the conflict to an accident). In addition to the severity of the conflict, some threshold level was required to distinguish between slight and serious conflicts.

Hydèn [1987] considered three methods for severity rating:

- Distance in space to collision point
- Time to a collision point
- Deceleration rate required to avoid an accident

There were various problems noted by Hydèn [1987] with the above mentioned measures:

- A small distance may be linked to low speed, thereby creating a small accident potential;
- An extremely dangerous situation can be resolved with an ample margin of distance between road users;
- A certain deceleration rate can be linked to any distance, in both space and time;
- A conflict where the evasive manoeuvre is swerving cannot be defined in terms of deceleration.

Noting the problems, Hydèn [1987] noted that time reflects distance, speed and the deceleration rate (or swerving) necessary to avoid an accident. A small time value for a collision can reflect limited distance and/or high speeds. In order to avoid complex recording methods for the conflicts, Hydèn [1987], required that only a single measure be recorded that would adequately describe the severity of the conflict.
From the alternatives listed above, the time measure was selected.

The time measured was based on the time measured to collision (TMTC) concept introduced by Hayward [1972] - Section 4.1. Hydèn [1987] decided to use the TMTC value at the moment the road users took evasive action. This value was selected as it represents the time margin to a collision when the road users has detected the danger and started on an evasive action [Hydèn, 1987]. Time to accident (TA) value was defined as the measure to rate the severity of the conflicts. The following are the definitions of the time measures and are illustrated in Figure 4.11.

- TMTC (time measured to collision): this is the time until the collision, assuming the users kept their unchanged movements and speeds (time measured continuously).
- MTTC (minimum time to collision): the minimum value for the occurrence of the TMTC.
- TA (time to accident): is the time that remains to an accident at the moment when evasive action has just started, assuming that the users maintain unchanged directions and speeds.

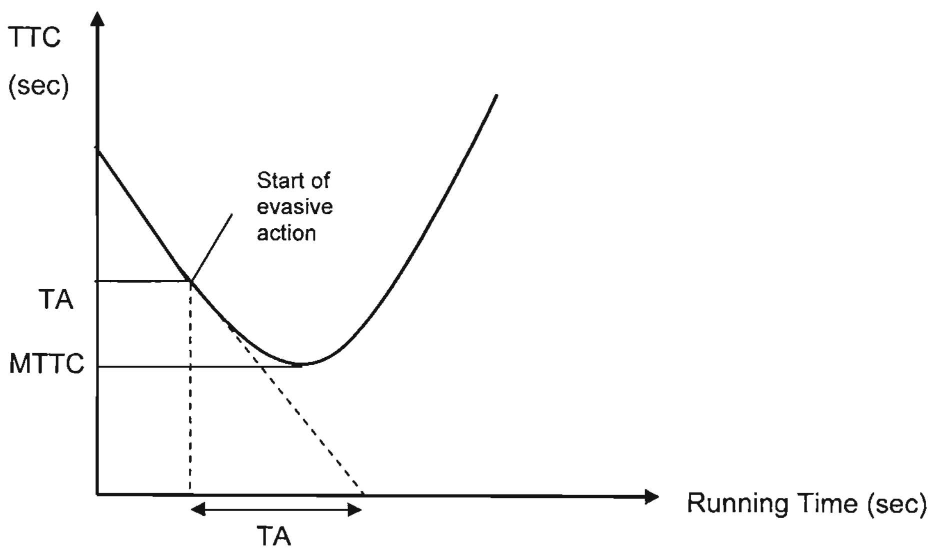


Figure 4.11. A time to collision graph illustrating TA and MTTC [Adapted from Hydén, 1987].

The next step in the development was to establish a threshold level to distinguish between slight and serious conflicts using the TA concept developed. Studies were carried out at urban intersection using video recording to establish the threshold for the TA value [Hydèn, 1987]. The following are the findings that resulted from the observations made from the video recording:

- There exists a relationship between the action taken by the road users and the TA value - lower TA values produced more sudden and harsh actions.
- Conflicts with a TA value of three seconds and more are difficult to detect since it can be assumed to be part of the normal interaction pattern.
- A lower limit for the TA value was observed for when the road users took evasive action at the "last possible instant" - TA value around 1,5 seconds.

The aim of the investigation was to obtain a threshold to distinguish serious conflicts from slight conflicts. Using the suddenness and harshness together with the TA for the conflict, it was concluded that a *serious conflict occurs when the TA value ≤ 1,5 seconds* [Hydèn, 1987]. This served as the original Swedish traffic conflict technique.

4.3.3 Modification of the traffic conflict technique

The original definition of a serious conflict (TA ≤ 1,5 seconds) was used for a number of years in both research and practical applications [Hydèn, 1987]. However, it was evident that there were shortfalls with the use of this definition. From the numerous studies carried out with the original definition, it was noted that a speed dependent threshold for the time margin (TA-value) was necessary [Hydèn, 1987]. The major problem with the use of the original definition was that it worked well in urban areas where the speeds on average are low; but not in areas were the speeds are higher - for example rural areas [Hydèn, 1987].

Linderholm [1981 cited in Hydèn, 1987] was the first to stress the need to establish a definition based on the speeds of the involved road users and the TA values. Linderholm investigated the relationships between speeds and the TA value as a function of the type of evasive manoeuvre taken. He developed TA-Speed graphs for braking and swerving - as shown in Figure 4.12.

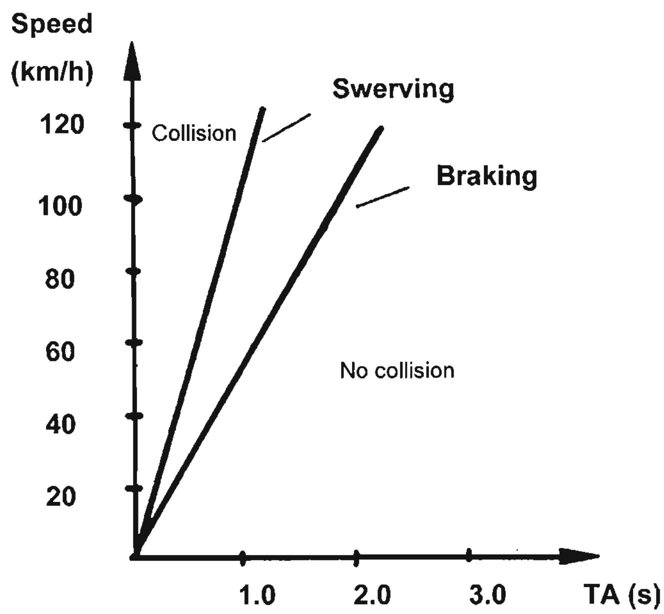


Figure 4.12 The threshold level between collision and no collision at braking and swerving [Linderholm, 1981 cited in Hydén, 1987]

From Figure 4.12, it can be seen that for the same situation, a swerving manoeuvre has a lower TA value than a braking manoeuvre therefore implying that swerving has a greater safety margin [Hydèn, 1987]. A vehicle could be in a collision if the evasive action was braking but alternatively, if the evasive action were swerving, no collision would occur.

The curves in Figure 4.12 are the regression lines for accidents and TA values. Investigations were carried in which the TA values for the accidents were obtained using the measurement of brake marks from detailed police reports and interviews and also interrogations of witnesses and road users involved [Hydèn, 1987].

Gårder [1982] first proposed a conflict definition that was based on a TA-Speed graph. Gårder defined a serious conflict as follows: "*A serious conflict takes place when two road users are involved in a conflict and a collision would have happened with the sum of 0,5 seconds and the braking time for heavy braking on slightly damped pavement*" [Gårder, 1982 cited in Shbeeb, 2000]. He presented the first TA-Speed graph as shown in Figure 4.13

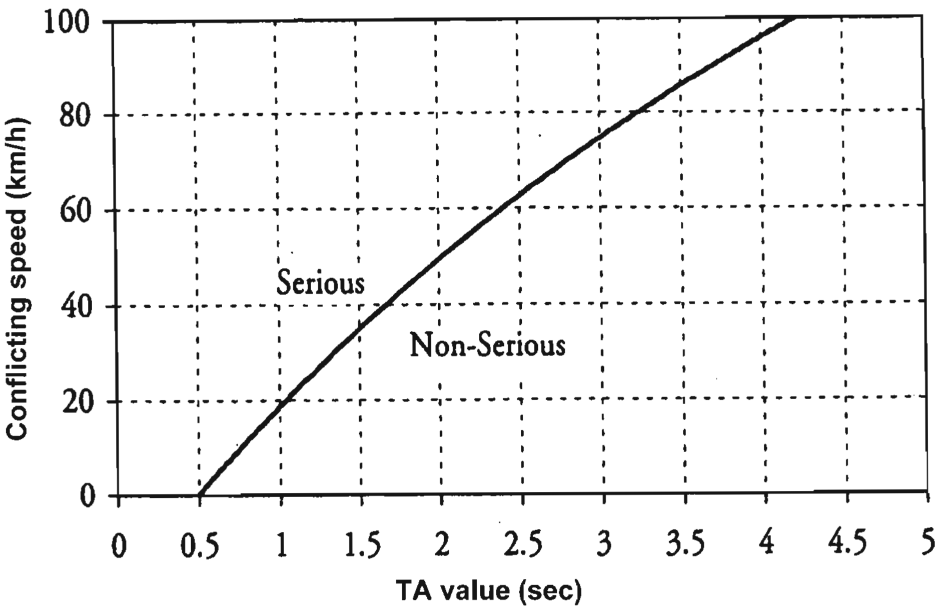


Figure 4.13 The threshold used to distinguish serious conflicts from non-serious conflicts [Gårder, 1982 cited in Shbeeb, 2000]

From the definition proposed by Gårder, the threshold defining serious and slight conflicts was based on braking as the evasive action. Hydèn [1987] adopted similar definition as proposed by Gårder to develop the threshold defining serious and slight for what is presently used in the Swedish technique - as shown in Figure 4.14. The threshold in Figure 4.13 is based on the TA value and approach speed assuming that the road users 'just' manage to stop before the point of collision (using braking as the evasive manoeuvre)[Hydèn, 1987]. The minimum TA value is calculated as follows [Hydèn, 1987]:

$$TA_{\min} = \frac{s}{v_1} = \frac{v_1^2}{2gf} \cdot \frac{1}{v_1} = \frac{v_1}{2gf}$$

where s = distance to point of collision at the start of evasive action

v_1 = initial speed at just before evasive action

f = friction coefficient

However, Hydèn [1987] questioned the use of braking as the evasive action when defining the threshold between serious and slight conflicts. In order to validate this definition, two key issues relating to the use of the definition had to be confirmed:

- Reliability of the technique
- Validity of the technique

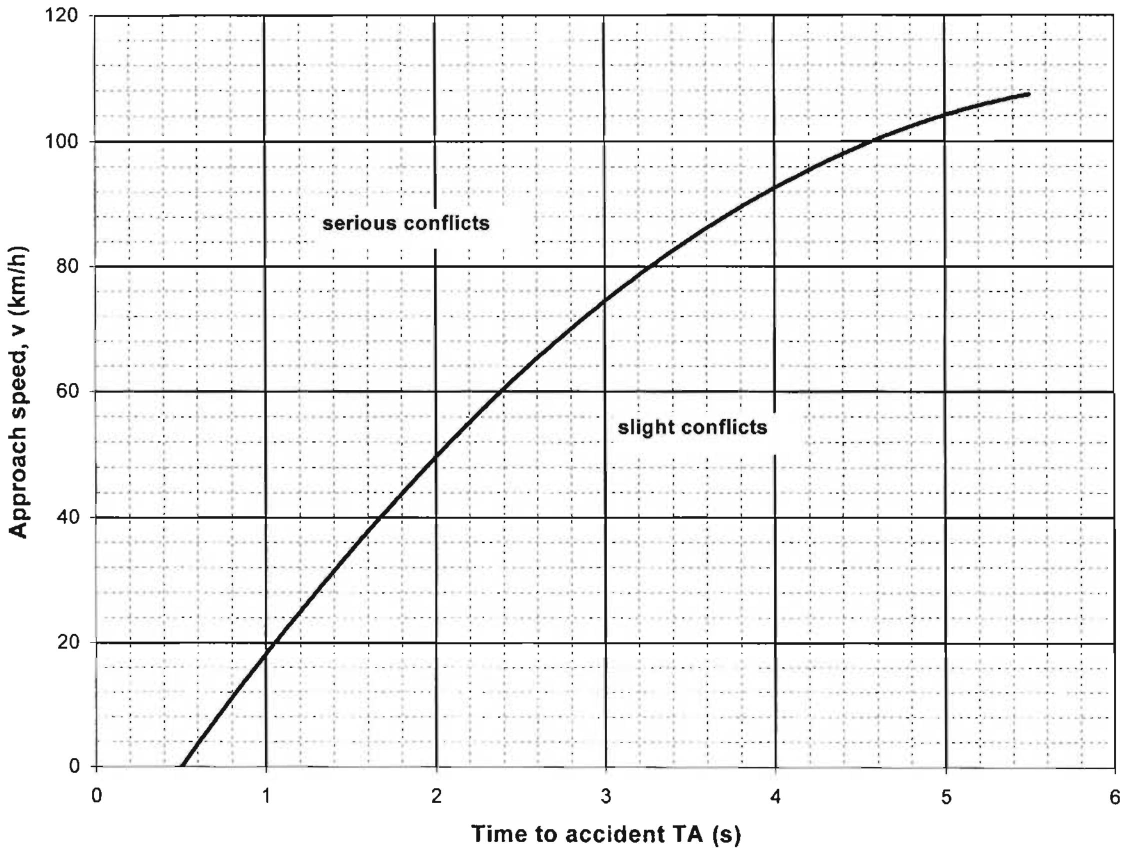


Figure 4.14 The graph used to distinguish between serious and slight conflicts for various approach speeds [Adapted from Hydèn, 1987]

4.3.4 Reliability

The reliability of the technique is concerned with the accuracy of the recording of conflicts with regard to the criteria of the technique and is separated into two categories:

- Internal reliability
- External reliability

The internal reliability measures the observers' ability to detect conflicts - i.e. are observers able to agree that an event is a conflict. Two tests were carried out to test the inter-reliability [Hydèn, 1987]. The results indicated that:

- In total, some fourteen per cent of serious conflicts were not registered.
- Few events were registered as serious conflicts (about 5%).

The external reliability measures the observers' ability to estimate the speed and TA value as compared with the use of recording devices - for example speed surveys or image-processing techniques to obtain speeds. Hydèn [1987] used a semi automatic detection system (image processing) to test the observers' reliability. From the study, Hydèn [1987] showed that in total, observers failed to record twenty-six per cent of the conflicts that should have been recorded. Hydèn [1987] showed that on average, the TA values scored by observers differed by 0,05 from the recording devices. From fifty per cent of all conflicts, the observers' estimation of the TA value was within 0,2 seconds of the values from the recording device. However, the estimation of the speed by the observers was on average 3km/h lower than the values from the recording device. According to Hydèn [1987], these results are acceptable and indicate that Swedish observers are reliable in detecting and recording of the conflict measures (speed and TA values).

4.3.5 Validity

The validity of the technique can be described in two categories:

- Product validity
- Process validity

The product validity is the ability of the technique to predict the expected number of accidents from conflicts [Hydèn, 1987]. The process validity was a new concept proposed by Hydèn [1987] that dealt with the measure of the similarities in the process that leads to accident and conflicts.

The product validity of the technique was tested at 115 intersections in the cities of Stockholm and Malmö during the 1970's [Hydèn, 1987]. The aim of the investigation was to produce a conversion model between serious conflicts and injury accidents [Hydèn, 1987]. The model was calibrated based on the types of intersection, road users, and speed. In addition, the model was based on the assumption that both conflicts and accidents follow the Poisson distribution [Hydèn, 1987]. The conversion factors are determined as follows [Hydèn, 1987]:

$$\pi = \frac{\text{number of accidents per unit time}}{\text{number of serious conflicts per unit time}}$$

In order to ensure that the traffic volume conditions at the time of accidents and at the time of the conflict observations were similar, corrections were made to account for the different traffic volumes between the two periods [Hydèn, 1987]. An illustration of the results obtained from the study is shown in Table 4.1.

Table 4.1 Conversion factors (π x 10^{-5}) between conflicts and accidents [Hydèn, 1987]

Situation / Conflict class	Car – Car "parallel"	Car – Car "perpendicular"	Car-pedestrian Car-bicycle
Class1: Speed < 35km/h $1.0 \leq TA \leq 1.5s$	0	2.4	9.6
Class 2: Other conflicts When $TA \leq 1.5s$	2.8	11.9	33.9

Svensson [1992 cited in Shbeeb, 2000] also carried out validation studies and confirmed the findings (conversion factors) produced from the validation study of the 1970's. Sevnsson [1992] also concluded that the three days of conflict studies gives better estimation of future accident rates at intersections than the three-year accident history.

Hydèn [1987] introduced the concept of process validity to compare the process of the last stages of an accident to that of serious conflicts. Hydèn [1987] used accident data from police files and conflicts recorded at the same intersections where the accidents occurred. The following factors were obtained for both accidents and conflicts in order to make the comparisons [Hydèn, 1987]:

- TA values
- Speeds of the road users at the time of evasive action (conflicting speed)
- Type of evasive action

The analysis of the results included the plotting of TA values and conflicting speeds for both accident and conflicts. Graphs were produced for various road users (vehicle-vehicle, vehicle-pedestrian and vehicle-bicycle). Regression lines were produced for each data set and the inclination in each case was similar [Hydèn, 1987]. From the distributions of the curves, it was noted that accidents are located more to the left of the graph as compared with conflicts and that the TA values are lower for accidents [Hydèn, 1987].

The type of evasive action for both conflicts and accidents were also studied. The threshold for the Swedish technique is based on braking as the evasive action. Therefore it was necessary to validate this approach to establish the most common type of evasive manoeuvre used in both accidents and conflicts. The results of the study are shown in Table 4.2.

Table 4.2 A comparison of different evasive actions taken during serious conflicts and accidents [Hydèn, 1987]

Evasive action	Serious conflicts (%)	Accidents (%)
Braking only	79	68
Braking and swerving	14	20
Swerving only	5	10
Accelerating	2	2
Total	100	100

From the above table and the studies of speeds and TA values, the conclusion is that accidents and conflicts are similar with regard to the type of evasive action and the process involved [Hydèn, 1987]. The major result of the product validity test is that serious conflicts and accidents are similar and hence serious conflicts are a surrogate for accidents [Hydèn, 1987].

4.3.6 Operational use of the traffic conflict technique

After defining the theoretical aspects of the technique, the practical application of the concept was vital since the technique had to be simple to use. The technique requires judgements to be made of the road users speeds and distances to potential point of collision. Hydèn [1987] considered two alternatives:

- Direct observation
- Observations from video recording

After considering the advantages and disadvantages of both video recordings and direct observation, Hydèn [1987] concluded that direct observation was the more viable technique to record conflicts. Subjectivity introduced by the observers in the recording of conflicts was the only concern with the use of direct observation. A training program was devised that dealt with the detection of conflicts and estimation of speeds and distances.

The conflict technique requires that the observers record information as soon as one of the road users involved in a conflict takes an evasive action. The information required is the estimated speed at the moment of evasive action and the distance to the potential point of collision. These data are then used to obtain the TA value. In addition to the recording of these parameters, observers are required to provide a sketch of the conflict and give a brief description of the events leading to and after the conflict [Hydèn, 1987].

The number of observers required for recording conflicts depends on the type of intersection studied. Generally, one or two conflict observers are required at each arm of a signalised intersection [Hydè, 1987]. For non-signalised intersections, one or two observers are required at both arms of the priority road [Hydèn, 1987].

4.4 Severity Hierarchy Concept – "Extended Swedish Conflict Technique"

The Swedish conflict technique is based on the underlying principle that the interaction between road users can be described as a continuum of events [Hydèn, 1987]. This continuum of events can be visualised as a pyramid as discussed in Section 4.3. Svensson [1998] has extended the concept of the TA-Speed relationship to describe the shape of the pyramid. Svensson [1998] termed the shape of the pyramid, the severity hierarchy in which all interactions between road users are considered and not only those that are severe.

Svensson [1998] worked on producing the shape of the severity hierarchy for various traffic interactions and types of intersections. The shape of the hierarchy is used to measure the safety condition at a particular location. It assists in visualising the relationship between events of different severities. The shape is used for predicting the frequency of more severe events based on observations of less severe events and also for describing differences in road user behaviour.

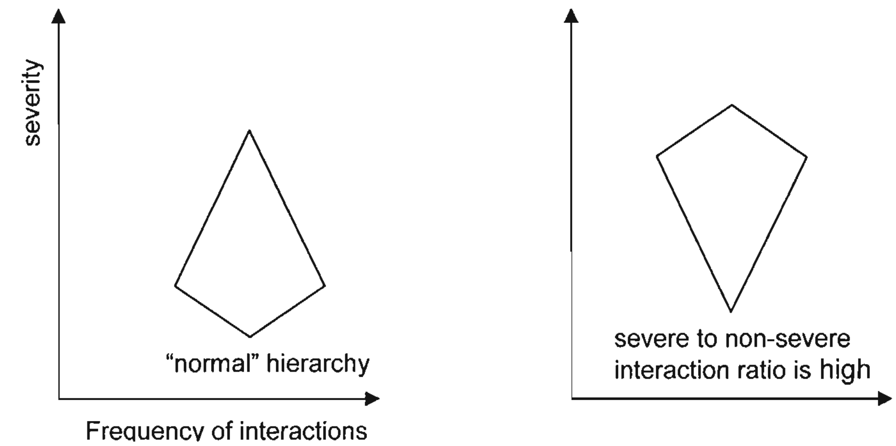


Figure 4.15 Severity shapes illustrating the ratio between severe and non-severe interactions

In Figure 4.15, a normal hierarchy is shown. In this hierarchy, the top of the hierarchy is small thereby representing a small amount of serious events with the base of the hierarchy large indicating that a large proportion of the traffic passes with no severe events. A shape in which the ratio between severe and non-severe interactions is high indicates that once there is an interaction, there is a high probability that the interaction would be serious (Figure 4.15). A low ratio between severe and non-severe interactions indicates a small probability of a severe event once there is an interaction. This of course is an ideal situation from a safety point of view and indicates a safe location for road users.

The severity hierarchy is constructed by analysing events with collision courses as in the case of the Swedish technique and assigning a severity scale to the event using the standard TA-Speed graph of the Swedish technique. The Swedish technique uses a single threshold level (as shown in Figure 4.14) and therefore only has a two-scale severity rating. In order to produce the severity hierarchy, "finer gradations" of the TA-Speed graph are required. The hierarchy concept uses the same threshold level as the Swedish but in addition 29 more threshold levels at 0,5 second intervals are used to define a thirty scale rating - as shown in Figure 4.16. Each event is recorded as in the

Swedish conflict technique and the new TA-Speed graph (Figure 4.16) is used to obtain the severity scale.

After obtaining and rating all the events, the severity hierarchy is constructed by positing the events in the hierarchy - as shown in Figure 4.17.

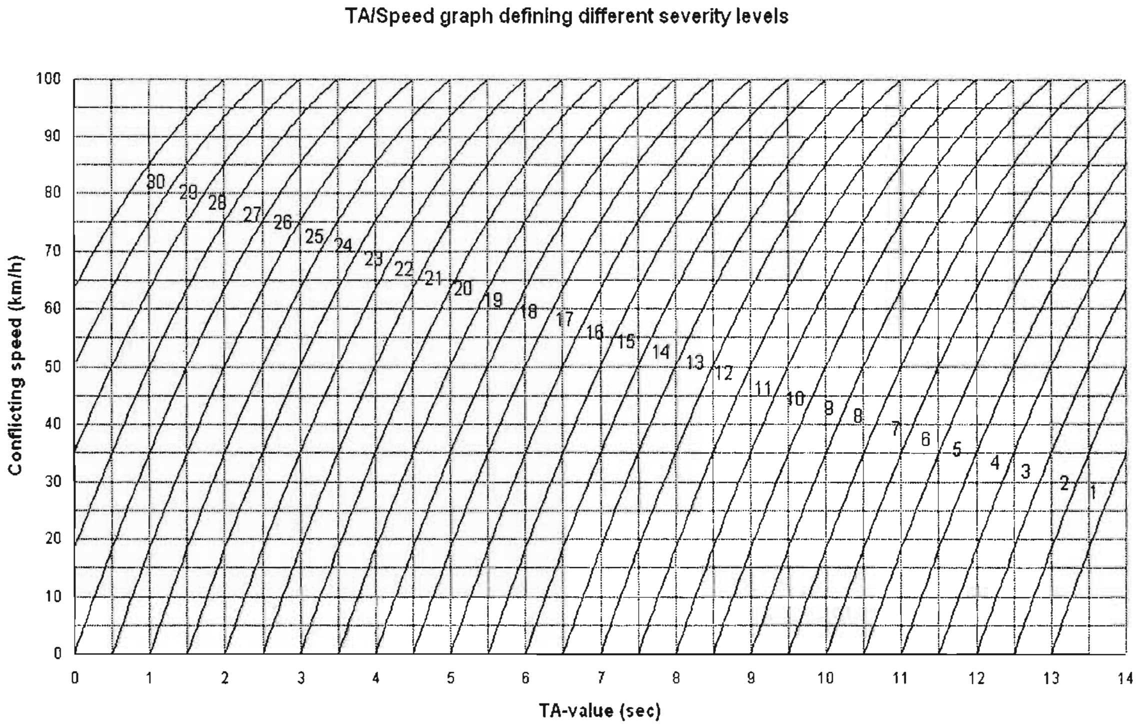


Figure 4.16 TA-Speed graph defining a thirty-scale severity [Svensson, 1998]

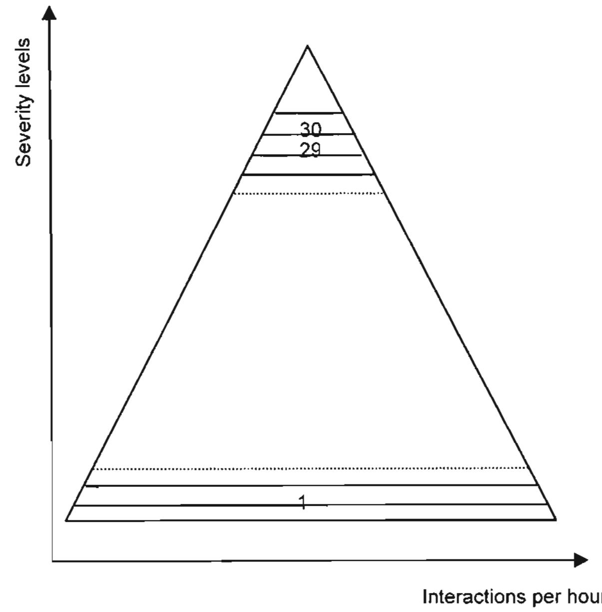


Figure 4.17 Hypothetical severity hierarchy defining various severity levels as defined in Figure 4.16 [Svensson, 1998]

4.5 Summary

The four types of conflict techniques have been discussed with the aim of explaining the operational aspects and the theory on the development of these techniques. It is evident that some techniques (Swedish) have carried out extensive developments with the objective of providing a technique that relates to the accident process. Other techniques such as the German and American adopt a qualitative approach to the definition of a conflict technique. Although each technique has adopted different views with regard to the recording of conflicts, the aim of all of the techniques is the prediction of future accident rates. The last section of this chapter dealt with a new concept of the Swedish traffic conflict technique that uses interactions between road users to estimate accident risk. In the next chapter, a comparison of these techniques is made with the aim of highlighting the differences in operational use.

5 COMPARISON OF CONFLICT TECHNIQUES

This section highlights the differences between the four techniques (Swedish, PET, American and German) discussed in Chapters 3 and 4. Comparisons are made between the definitions, severity scales, observations required and also the operational practicality of the techniques. The relevance of the conflict techniques to pedestrian safety is discussed and finally, a brief presentation of conflict-accident correlations is presented.

5.1 General definition

Each of the four techniques discussed in Chapters 3 and 4 adopt various approaches in the definition of a conflict. It must be noted that the definition of a conflict in each of these techniques is fundamental in terms of the following:

- Conceptual relationship to accidents
- Operational practicality

The conceptual relationship to accidents is described as follows:
Conflicts should be related to or be a part of the accident process - as discussed in Chapter 2. In addition, conflicts should be statistically related to accidents - conflict counts and accident counts should be comparable.

The operational practicality of the definition deals with the concept of applying the definition to collect the necessary data in a reasonable amount of time and with reasonable resource expenses.

The following are the general definitions for the conflict techniques reviewed in Chapters 3 and 4.

American
"A traffic conflict is an event involving two or more road users, in which one user performs some atypical or unusual action, such as a change in direction or speed, that places another user in jeopardy of a collision unless an evasive manoeuvre is undertaken" [NCHRP, 1980].

German

A traffic conflict is defined as: *"an observable situation in which two or more road users approach each other in time and space to such an extent that a collision is imminent if their movements remain unchanged* " [Erke, 1984].

Post encroachment time

There is no formal definition for a conflict in this technique. Instead, the conflict is specified using the collision generation process as shown in Figure 5.1 [Allen et al, 1978].

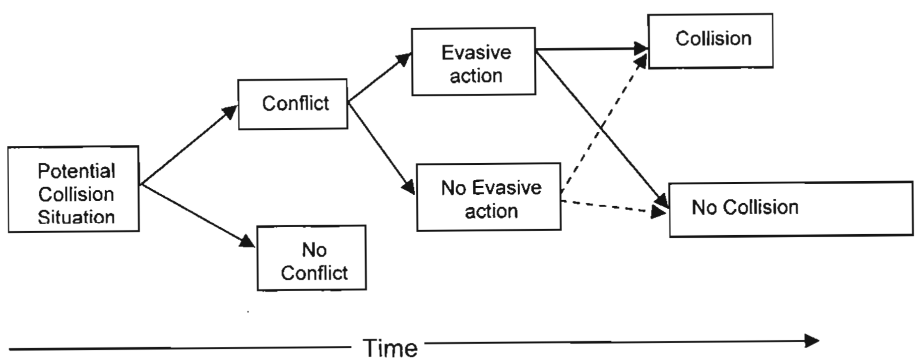


Figure 5.1 Collision generating process defining a conflict [Allen et al, 1978]

According to this technique, a conflict occurs as a series of identifiable events as shown in Figure 5.1.

Swedish

The Swedish technique defines a conflict as: "*an event where two road users with crossing paths would have collided if they had continued with unchanged speed and direction (one or two road users take evasive action)*" - Hydèn [1987].

The general concept of each definition is that a change in manoeuvre (evasive action) is required to avoid an impending collision. However, consider the situation when road users are involved in an 'almost collision' with none of the road users taking evasive action. For this situation, the American and post encroachment time definitions are suited to record these types of interactions – as discussed in Sections 3.3.2 and 4.2.1. Within the context of the American definition, it is not necessary that there be an actual evasive manoeuvre to record conflicts. It suffices that the action of one-road users threatens the other with the possibility of a collision. Likewise, the post encroachment time definition also recognises that interactions can lead to near miss situations or even collisions without the road users being aware of the situation - as shown in Figure 5.1. Observable evasive actions are required by both the Swedish and German techniques. Table 5.1 summarises the observable actions required by each definition.

Table 5.1 Comparison of definitions for observable actions

Observation / Definition	Evasive action only	Evasive action – and/or no evasive action required to record conflicts
American		*
German	*	
PET		*
Swedish	*	

5.2 Severity aspect of the conflict definition

In order to relate conflicts to accidents, the German, post encroachment time (PET) and Swedish techniques have added to their general definitions the concept of "nearness" to an accident.

This concept is known as the severity of an interaction. In these techniques, the severity definition is used for the actual identification and recording of the conflicts. The German technique uses qualitative severity definitions for the recording of conflicts - as discussed in Section 3.4.3. Conflicts are recorded when certain observable actions are performed by road users involved in a conflict- such as controlled braking, rapid declaration, emergency braking or violent swerve, etc. Four severity definitions are used to grade conflicts to the closeness to an accident based on the type of evasive action taken. The more "predominant" the evasive action (for example rapid deceleration-braking or violent swerve) the more severe is the conflict in relation to the closeness to an accident.

The Swedish and PET techniques adopt a time-based measure for their severity definition. In these techniques, a threshold level is selected such that all interactions between road users of a certain value are called a conflict. Often, these time-based measures are further subdivided into slight, moderate and serious conflicts. Extreme situations occur when the time measure is zero in which case, a collision occurs.

The American conflict technique definition is not extended to record conflicts according to the “nearness to collision”. An interaction is recorded as a conflict in accordance with the general definition.

5.3 Practicality of the definition

Conflicts are recorded based on the conflict definition and ‘severity definition’ for each technique. The conflict definition must be practical in terms of applying it for data collection without the use of sophisticated equipment and also one that yields sufficient data (in statistical terms) in a short period of time – this is related directly to the definition of a conflict. If the definition attempts to establish a rigorous relationship of a conflict to an accident then the conflict would be as rare an occurrence as an accident.

The American and German definitions use observable actions (visual and audible indicators such as brake light indication, swerving, squealing of tyres) to record conflicts. These definitions are suited to direct observation because they reduce the subjectivity of conflict recording between observers because they are based on the identification of observable actions. Hence observers can easily be trained to make judgments to recognise conflicts.

The post encroachment time (PET) and Swedish definitions use time-based measures to record conflicts. These techniques require in addition to the identification of observable actions (like the American and German), the estimation of distances and speeds of road users.

The PET value is used to record conflicts and is defined as the clearance interval between two road users with intersecting paths. The practical application of the definition using direct observation (as compared to the American and German techniques) is more difficult. This technique employs direct observation. Observers use a stopwatch to record the clearance interval between road users as discussed in Section 4.2. The difficulty in applying this technique is the accurate identification of the potential point of collision by the observers.

The Swedish technique is the most difficult technique to apply by direct observation in comparison to the other techniques discussed. Conflicts are recorded using the time-to-accident (TA) value. Time to accident is defined as the time remaining from when evasive action is taken until when the collision would have occurred if the road users continued with unchanged speeds and directions. TA value requires that observers estimate the road user's speed and distance to a potential point of collision - as described in Section 4.3.1

Conflict definitions that use quantitative measures for the recording of conflicts are prone to observer error because observers are required to accurately estimate actual parameters (speeds, distance). Table 5.2 summaries the various observations required for each conflict technique. Basically, the more observations required to be made by observers the more errors are likely to occur. It must be noted that the observations required are based directly on the definition of a conflict.

Table 5.2 Observation requirements for each technique

Observation / Technique	Evasive action (braking, swerving,etc.)	Audible evidence	Identification of potential collision point	Estimate distance to potential point of collision	Estimate speed of the road users
American	*	*			
German	*	*			
PET	*	*	*		
Swedish	*	*	*	*	*

5.4 Conflict categories

Conflicts can be grouped according to the type of interaction occurring between road users on a road element. For example a pedestrian who is crossing at a pedestrian crossing and has a near-miss event with a right-turning vehicle would be regarded as a right turning vehicle-pedestrian conflict. As a result, the American and German techniques have adopted predefined conflict categories based on the various movements that occur at intersections. Basically, sets of operational definitions have been developed based on the different types of instigating manoeuvres. An example of a definition is:

Opposing Right Turn Conflict:

This occurs when an oncoming vehicle makes a right turn across the path of a through vehicle that has the right of way.

The conflict is termed an opposing right turn because the right turning vehicle is the instigator. The use of predefined conflicts makes for easier observations by assisting the observer in identifying conflicts according to the rules of the definition.

The Swedish and PET techniques do not adopt predefined conflict definitions. Instead any interaction that has a time-based measure below their respective defined threshold levels are recorded as a conflict.

In all conflict techniques, the road users are motor vehicles, pedestrians and bicycles. Each technique requires that at least one of the road users involved in a conflict be using a motorized vehicle. All conflict techniques exclude single vehicle conflicts and traffic violation. Traffic violations are recorded if another vehicle is in jeopardy of a potential collision. Secondary conflicts (i.e. conflicts that result from an initial conflict) are only recorded by the American technique. Table 5.3 is a summary of the conflict types.

Table 5.3 Summary of conflict types

Category / Technique	Road users (vehicles, pedestrians, bicycles)	Predefined conflict definitions	Secondary conflicts
American	*	*	*
German	*	*	
PET	*		
Swedish	*		

5.5 Operational difficulties for specific conflict types

The rear end conflict situation ("car-following") is extremely difficult to observe using the Swedish and PET techniques. Remembering that these techniques use the identification of the possible collision zone and in addition, the Swedish technique requires the distance to the potential point of collision and speed of the road users (see Section 4.3.1). Consequently, in a car following situation, the visualisation of the imaginary collision point is extremely difficult because the trajectories of both vehicles are in the same direction and not on a crossing path - the point of collision is often beyond the leading vehicle and this often tends to obscure the potential point of collision for the observer. The following example illustrates this concept. Consider two vehicles in a car following situation - Figure 5.2. In this example, vehicle A rapidly decelerates causing the following vehicle (B) to take evasive action. As shown in Figure 5.2, the imaginary point of collision is in front of both vehicles A and B. Therefore, observers can have difficulty in recording rear end conflicts because the task requires the estimation of both vehicle speeds (in the Swedish technique), the identification of the collision point (for both Swedish and PET techniques) and the time when vehicle B took evasive action (for both Swedish and PET techniques).

In general, the PET concept can be prone to operational errors for virtually all conflict types. The PET value is defined as the clearance interval (in time) between road users with intersecting paths. The definition of this technique can in some instances lead to misinterpretation of the conflict event. For example, in the event that a vehicle involved in a conflict accelerates towards the completion of an evasive manoeuvre, the vehicle would reach the imaginary point of collision in a shorter time resulting in the PET value to be much less than it actually is - i.e. the event would seem more severe then it would appear to be. In addition, the opposite can occur. If a vehicle takes evasive action and comes to a complete stop before the collision point then the PET value would tend to 'infinity' and as a result, the event would be ignored.

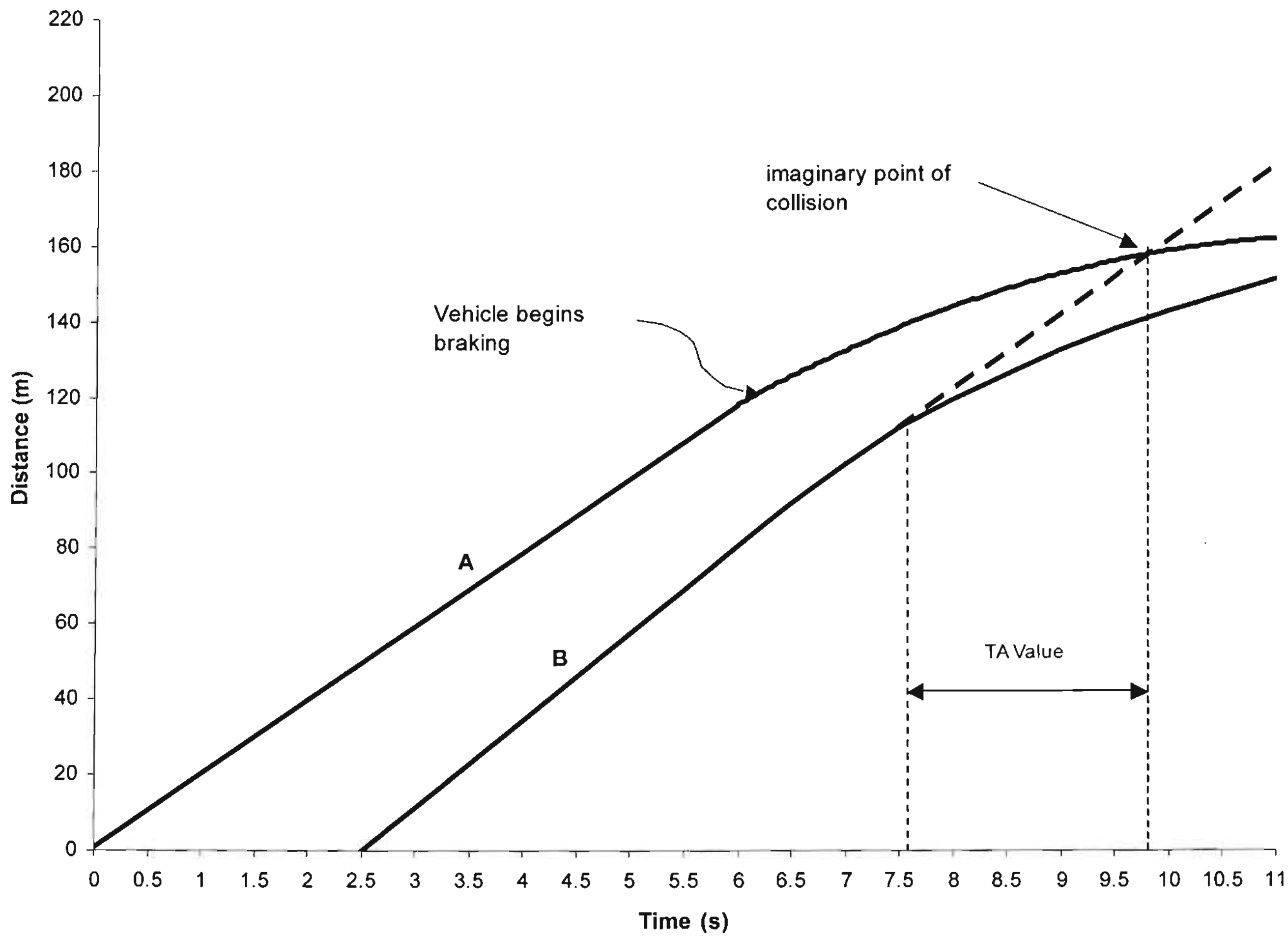


Figure 5.2 Rear end car following conflict example using the Swedish technique

5.6 Applicability of conflict techniques to pedestrian conflicts

The initial development of conflict techniques was aimed specifically at vehicle-vehicle interactions. Vehicle movements are far different from pedestrians in that they can be anticipated to a large extent because they cannot change direction instantaneously. Additionally they are required by law to move within certain limitations of the roadway. Pedestrians on the other hand are relatively unpredictable: pedestrians have the ability to stop, accelerate or change direction almost instantaneously.

The Swedish technique has no predefined conflict categories and places no restriction on the types of road users except that one of the road users involved has to be using a motorized vehicle. Therefore, vehicle-pedestrian conflicts are recorded in the same manner as vehicle-vehicle conflicts using the estimate of the speeds and distances of the road users. Pedestrian speeds are often low (3 to 7 km/h, results from this investigation – Appendix D.2) and in addition, their movements can be unpredictable therefore it can be difficult to apply the Swedish technique to vehicle pedestrian conflicts especially when direct observation is used. Pedestrian speeds have to be estimated accurately in order to ensure the correct estimation of the time to accident (TA) value. Further, pedestrians can change direction in an "instant" hence requiring accurate estimation of the imaginary point of collision. Therefore, direct observation may not be suitable for the recording of vehicle-pedestrian conflicts especially when the conflict involves turning vehicles. Turning vehicle have low speeds thus requiring accurate speed estimation and the path of these vehicles are combinations of arcs and transitions and hence the estimation of the distance to the imaginary point of collision can be difficult for observers.

The PET technique like the Swedish has no predefined conflict categories hence pedestrian conflicts can be accommodated. Observers can also have difficulty in recording conflicts because, as with the Swedish technique, the identification of the collision point is necessary.

Predefined conflict categories exist in both the German and American techniques and in addition places restrictions on the type of pedestrian conflict that should be recorded.

The German technique identifies two conflict categories:

- Vehicle/pedestrian conflict:

  This happens when the driver of a vehicle, turning left or right or proceeding straight through, has to swerve or brake to prevent a collision with a pedestrian, in this case, the pedestrian has right of way
- Pedestrian/vehicle conflict

  This can happen when a pedestrian moves in front of an oncoming vehicle (vehicle has right of way) forcing the driver of the vehicle to take evasive action (brake or swerve).

The American technique defines vehicle-pedestrian conflict as:

- An event in which a pedestrian (the road users causing the conflict) crosses in front of a vehicle that has the right of way, thus creating a possible conflict situation.

In the American approach, situations in which the pedestrian have right of way are not considered to be conflicts - such as a "green man" phase. Consequently, certain vehicle-pedestrian conflicts are ignored thereby creating deficiencies in the data collection. This can result in the incorrect estimation of the accident risk for vehicle-pedestrian interactions.

Generally, conflict techniques are suited to the recording of pedestrian conflicts. However, each technique has operational difficulties and caution is required when applying the techniques to pedestrian conflicts. The quantitative techniques (Swedish and PET) are particularly prone to errors with regard to estimating speeds and distance in the case of pedestrian-vehicle conflicts (as noted above). During the validation studies of the Swedish technique, it was found that the observers' estimates of speeds differ on average by 3 km/h from the actual speeds [Hydèn, 1987]. In those studies, there is no mention of the error in the estimation of the distance to point of collision. As discussed, estimation of turning vehicles distance to point of collisions is more difficult than it is for vehicles moving on a straight path. Therefore, errors to the estimation of the TA value can be compounded by the distance error.

5.7 Observers and collection of data

All of the techniques employ trained observers for the recording of conflicts. Each country stresses the need to develop a definition that is practical and simple to use and one that is cost effective. That is to say; can use direct observation and not sophisticated equipment. Observers have to record conflicts in accordance with the criteria of the technique. Some techniques require more stringent judgments than others and are accordingly classified as qualitative or quantitative. It must be stated that all techniques are subjective because direct observation is used for recording conflicts. The reason is that observers can make errors such as not recording conflicts or recognising conflicts. The quantitative techniques are those that use "objective measures" such as time to accident (TA) and Post encroachment time (PET) to record conflicts. Objective measures are those that are "quantifiable" however, these objective measures are obtained using direct observation. The qualitative techniques are those that use descriptions such as "sudden" manoeuvre or "harsh" braking, or "unexpected" like the German and American techniques to record conflicts.

The Swedish technique requires a high level of competency and skill from observers and a comprehensive training programme, thus increasing the cost. The PET technique is less stringent than the Swedish and can be thought of as a simplified Swedish technique in which the observers use a stopwatch to record the PET value. The training programme is less intensive. The German technique allows for simpler observation and consequently requires lower levels of competency and skill from observers and therefore a less extensive training programme, thus decreasing the cost. The American technique is the simplest technique from all of the above because observers only record the type of conflict and do not have to grade the conflicts to the closeness to an accident. Although this technique is the simplest, it has the longest training period (ten days). A five-day training period is used for the Swedish with the PET and German at three days each.

The recording periods vary depending on the nature of the study. However, the American technique has guidelines for the number of observation hours required for predefined conflict categories. All techniques suggest a position for the observers at a study location. The Americans suggest that an observer be positioned approximately 30 to 100m from an intersection on the right hand side of the approach depending on the approach speeds of the vehicles. At higher speed intersections, the observer is positioned further back form the intersection. However, each technique recommends that the observers be positioned according to the nature of the study.

All techniques advocate that conflict recording be carried out on weekdays, covering peak and non-peak periods, except were the study has predefined objectives. The observation period depends on the study that is to be performed. Generally, accidents give and indication of when the surveys should be performed. However in the event that the practitioners are unsure or if there is a lack of accident data, a 06:00 to 18:00 observation period is recommended [Lötter, 2001].

5.8 Comparison between conflicts and accidents

This section provides a brief comparison between conflicts and accidents. Many studies were performed as discussed in Section 1.2 regarding the correlation between conflicts and accidents and it was concluded that conflicts are good surrogates for accident data.

Tables 5.4, 5.5, 5.6 and 5.7 present conflict-accident correlations (using linear regression) for various conflict types. In each of the studies the researchers noted that poor correlations occurred due to lack of accident data relating to the type of conflicts observed [Brown, 1994; Erke, 1984; Cooper, 1984 and Glauz & Midgletz, 1985]. In general, when significant accident data relating to the specific type of conflicts were available, the correlation coefficients were greater than 0,6.

Table 5.4 Conflict-accident correlation coefficients German moderate/serious conflicts

Conflict category	Number of Locations	Correlation coefficient
Left turn	24	0.77
Right turn	24	0.29
Through	24	0.23
Vehicle-pedestrian	24	0.36
Pedestrian-vehicle	12	0.72

Four year accident data

Table 5.5 Conflict-accident correlation coefficients for Swedish serious conflicts

Conflict category	Number of Locations	Correlation coefficient
Opposing-right turn	13	0.66
Left turn	13	0.61
Crossing	13	0.78
Weaving	13	0.40
Rear-end	13	0.17
Right – turn crossing	13	0.75
Pedestrian	13	0.72

Five year accident data

Table 5.6 Conflict-accident correlation coefficients for American conflicts

Conflict category	Number of Locations	Correlation coefficient
Opposing – right turn	28	0.62
Crossing	28	0.67

Three year accident data

5.9 Summary

Various definitions of conflicts exist. These range from definitions that use qualitative descriptions to quantitative measure for the recording of conflicts. The qualitative techniques do not provide a theoretical relationship between a conflict and an accident. The quantitative definitions, i.e. time-based measures (TA, TMTC and PET) used in the recording of conflicts are possibly the best surrogate safety measure. From a theoretical standpoint, an accident occurs when road users attempt to occupy the same space at the same time. From this basic concept of an accident, it seems relevant to relate traffic events to accidents with a time-based measure. Consider a typical situation in which road users are in a car following situation - as shown in Figure 5.3. Each road user has preferred distance spacing (d) from the leading vehicle.

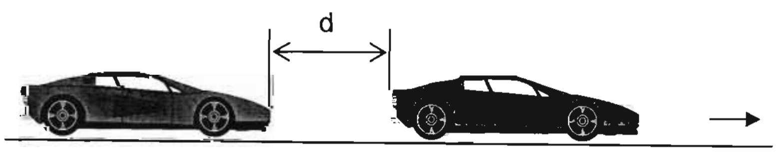


Figure 5.3 "Car-following" interaction between two road users

Although this is a simple example, it illustrates the fundamental concept as to why a time-based measure is best suited for conflict recording. Now if the distance (d) between these two vehicles gets smaller then it can be thought that vehicle B is attempting to occupy the space of vehicle A. If d = 0 then vehicle A and B are in contact and as a result a collision occurs. Therefore in terms of TA and PET smaller time values indicate smaller distance spacing between road users and hence more serious events (i.e. as these values approach zero then it is considered an almost accident or if they are zero then an accident occurred). A time-based measure represents a direct and simple measure of the relationship of a traffic event to an accident.

Another key issue not covered in the conflicts techniques is the difference between severity of a conflict and severity of the potential collision. Accidents have various grades ranging from slight (property damage) to fatal. When using the conflict techniques, a location may appear to have a high serious conflict rate but in terms of safety the resulting accidents could be minor (property damage). However, locations can have fewer serious conflicts but those events that do occur do so with a very high severity (serious injury or fatal). These are the types of locations that are of most interest in terms of prioritising locations for safety remedies. As discussed in Section 2.5.2, speed is the major contributory factor involved in both accidents and the severity thereof. Therefore, conflict techniques ought to develop a relationship between the severity of the conflict and the severity of the possible collision. Currently, no conflict technique adopts such an approach.

6 EMPIRICAL STUDY: DATA NEEDS AND CAPTURE

As discussed in Chapter 1, the rate of pedestrian involvement in accidents in South Africa is high and the majority of these accidents occur in urban areas. Consequently, one of the objectives of this research was to assess the applicability of conflict techniques to vehicle-pedestrian conflicts and the estimation of pedestrian accident risk using these conflict techniques. In order to achieve this objective, empirical testing of the conflict techniques at intersections was considered necessary. Empirical testing is required because the estimation of accident risk using conflict techniques requires the recording of conflicts to obtain conflict data to estimate risk. This chapter presents a discussion on the data requirements.

6.1 Data requirements

In order to estimate the pedestrian accident risk using conflict techniques, various data are required. These include conflict data and traffic volume data. Conflict data refers to the recording of conflicts according to each conflict technique. Some conflict techniques require speed, time and distance information to record conflicts as discussed in Chapters 3 and 4. Consequently, there are two basic methods for collecting the relevant data to estimate the accident risk:

- Direct observation
- Video recording

In order to assess the applicability of the conflict techniques to vehicle-pedestrian conflicts and also to estimate the accident risk, simultaneous observations of the same traffic situations (vehicle-pedestrian interaction) using each of the conflict techniques are necessary. Considering that the conflict techniques are to be applied simultaneously to the same conflict situation it would necessitate the training of observers for each conflict technique. A team comprising of the following would be required - four conflict observers (one for each technique) and at least two observers for the traffic volume counts (one for pedestrians and one for the vehicles). At high pedestrian volume sites, it is necessary to have two observers for pedestrian volumes as there are two directional flows at the pedestrian crossing.

The use of observers requires that they undergo a training programme in each conflict technique, which is often on average a one-week program. Therefore a total of four weeks would be necessary to train the observers. However, as discussed in Chapters 3 and 4, the use of observers introduces subjectivity in the recording of conflicts. Although observers undergo training programs, each person often has a different viewpoint when recording conflicts. The major concern with the use of observers with regard to the subjectivity is the appropriate identification of a conflict with regard to the definitions of the various techniques. For example, the Swedish and PET techniques require the observers to estimate speeds, distances and times. Although these techniques claim to achieve a relatively high degree of accuracy, they are still based on the subjective judgement of the observer and variability in the recording of conflicts can occur (refer to Section 4.3.4).

An alternative approach to obtaining the data without having to train observers and introduce subjectivity is to use video recording. The advantages of this are [Hydèn, 1987]:

- Play-back facility makes it possible to review conflicts until all information of interest are collected
- Video allows for many persons to watch the same sequence under the same conditions together, thus enabling discussions to take place

The disadvantage is that it takes at least twice as long to obtain the data as compared to direct field observation.

Considering these two alternatives, a choice had to be made between direct observation and video recording. The ultimate aim is to use the method that reduces the subjectivity involved in recording conflicts. Direct observation was ruled out because of the subjectivity involved in identifying conflicts and the estimation of speeds and distances is questionable. Therefore video recording was selected for this investigation.

In view of the recent development in digital imaging, video recording has an additional advantage in that the development of a semi or fully automatic system for the detection of traffic movements can be achieved. The system referred to is the use of digital imaging equipment with the development of a computer program that assists in the recording of conflicts. In terms of conflict observation, a system can be developed to track the paths of the road users involved in a conflict. Thus the coordinate positions of the road users at specific time intervals are obtained with a high degree of accuracy. This can then be used to estimate the speeds of the road users at each time interval. For the purpose of this investigation the method of video recording together with digital imaging was employed to obtain the necessary conflict data. The advantage of this method is that it provides a method for reducing or even eliminating the subjectivity involved in recording conflict. This is achieved since the digital imaging method provides the opportunity for plotting the paths of the road users and also obtaining the speeds of the road users. With this information available, it is possible to detect changes in speeds and movements and thus obtaining the time and place at which the evasive action was taken. Therefore, other persons can agree unanimously as to when the evasive action was taken and agree that a conflict occurred. Using this method requires the development of a computer program. Since no program is readily available it was decided to develop a computer program using digital imaging methods to obtain the conflict data from video recordings.

6.2 Selection of the appropriate intersections

Due to the high pedestrian fatality rate in South Africa and the high percentage of pedestrian accidents that occur in urban areas, it was necessary to select appropriate intersections in urban areas. The central business district (CBD) represents a possible area for studying vehicle-pedestrian interactions. The following criteria were used to appraise intersections as possible data sources:

- Traffic - sufficient traffic volumes to result in vehicle-pedestrian interactions to occur
- Geometric - pedestrian crossings preferably with level approaches so as to eliminate factors (such as poor sight distance for drivers) that may contribute to the cause of an accident (although not a rigorous requirement)
- Control - to allow vehicles and pedestrians to share an area of space at the same time - as occurs at signalised intersections where turning vehicles and pedestrians share the same green time
- Since video recording is used, it is an advantage to have a building in close proximity to allow for a vantage point

Applying the above criteria, the following three intersections located in the Durban CBD were identified for data collection:

- Pine Street and Field Street
- Commercial Road and Albert Street
- Commercial Road and Grey Street

Generally, intersections in a CBD are on a one-way grid system and have high pedestrian volumes. The pedestrian volumes at these intersections ranged from 600 to 2000 pedestrians per hour. In addition, these intersections meet the criteria (as defined above) with regard to pedestrian crossing. Furthermore, these intersections were located next to parking garages thereby providing a vantage point to obtain unobstructed views of the intersections.

The Pine-Field intersection along with the Commercial-Grey intersection is on a one-way grid system with four lanes on each approach. Commercial-Albert has a two lane two-way system on Albert Street with Commercial Road as a one-way street with four lanes. All intersections are signalised and have pedestrian crossings on all approaches. Due to the layout of these intersections, two possible types of vehicle-pedestrian interactions were identified:

- Left turning vehicle-pedestrian
- Right turning vehicle-pedestrian

The vehicle moving straight ahead and interacting with a pedestrian was not considered because pedestrians are not allowed to walk during this phase at these intersections and as a result, very few traffic events of this nature would occur. A choice had to be made between the left turning and right turning vehicles. At these intersections, pedestrians are allowed to cross during the left turning and right turning vehicles phases. As a result, this would present an opportunity for the vehicle and pedestrians to interact.

The right turning vehicle-pedestrian interaction was ruled out due to the following reasons:

- Studies carried out by Fruin [1972] showed that the right front roof support is a significant cause of right turning vehicle-pedestrian accidents. Allen [1970] further showed that the roof support occupies five to seventeen degrees of the driver's vision.

Due to the above factor affecting the right turning vehicle-pedestrian accidents, the left turning vehicle-pedestrian interaction was studied.

6.3 Surveys

In order to estimate the accident risk at the chosen intersections, data are required from these intersections. Svensson [1998] suggested that a sample size for the interaction (vehicle-pedestrian interaction) data should be at least 100 interactions for analysing a specific manoeuvre type (in this case the left turning vehicle-pedestrian). The necessary data for this investigation was obtained using the sample size proposed by Svensson [1998], as an estimate.

The observation periods for this investigation were dependent on the battery life of the camera. Typically, in conflict/interaction studies, a period of eight hours is sufficient to collect the necessary data as used by Svensson [1998]; however, this is a guide and depends on whether the necessary amount of data are acquired in this time. In this investigation, an eight-hour observation period for the data collection at each intersection was used, with the observation periods divided into 1-hour periods covering various days (Appendix B contains the data for the three intersections). The 1-hour periods on various days are necessary in order to cater for whatever, variations in traffic flow that might occur [Svensson, 1998]. Appendix B contains a complete listing of the survey periods including the traffic volume, and conflict data.

6.4 Observations from video recording

All interactions were observed from the video recordings using the digital imaging method with the exception for the American TCT in which on site observation was performed. As discussed in Chapter 3, the American TCT only registers vehicle-pedestrian conflicts if the pedestrian makes an illegal manoeuvre. All intersections, provide pedestrian phases hence, with regard to the American definition, a conflict is registered when the pedestrian walks during the "RED-MAN" phase. Therefore, observations were performed on site to register conflicts during the sighting of the "RED-MAN" phase.

All other conflict techniques were observed from the video recordings. For the PET technique, frame-by-frame analysis was used to estimate the PET value for the conflict. The video equipment allowed for frame-by-frame movement through the video, which was recorded at a frame rate of twenty-five frames per second (fps). The time difference between each frame was 0,04 seconds. This allowed the PET value to be estimated with an accuracy of 0,04 seconds.

All interactions involving left-turning vehicles and pedestrians with a collision course were analysed. Interactions were analysed using the digital image processing software developed (in this investigation) to estimate the speed and trajectories of the road users. For each conflict event, every fifth frame (of twenty-five fps), corresponding to a 0,2 second interval was used to produce the trajectories and speeds of the road users. Every fifth frame was chosen as this represents a good compromise between accuracy and the amount of data to be analysed. Considering that the interactions involved turning vehicles and pedestrians at intersections, in which case the vehicle speed seldom reaches 30 km/h (onsite measurement) and pedestrian walking speeds are in the region of 5 km/h (onsite measurement), every fifth frame represents a good compromise between accuracy and volume of data abstraction.

For the recording of the conflicts, the identification of the conflict area is important. This area can be imagined as a zone in which the pedestrian and vehicle would be involved in an accident. For this analysis, the conflict zone depends on the width of the vehicle. Typically, the zone would be the width of the vehicle bounded by the pedestrian crossing lines. A typical conflict zone is shown in Figure 6.1.

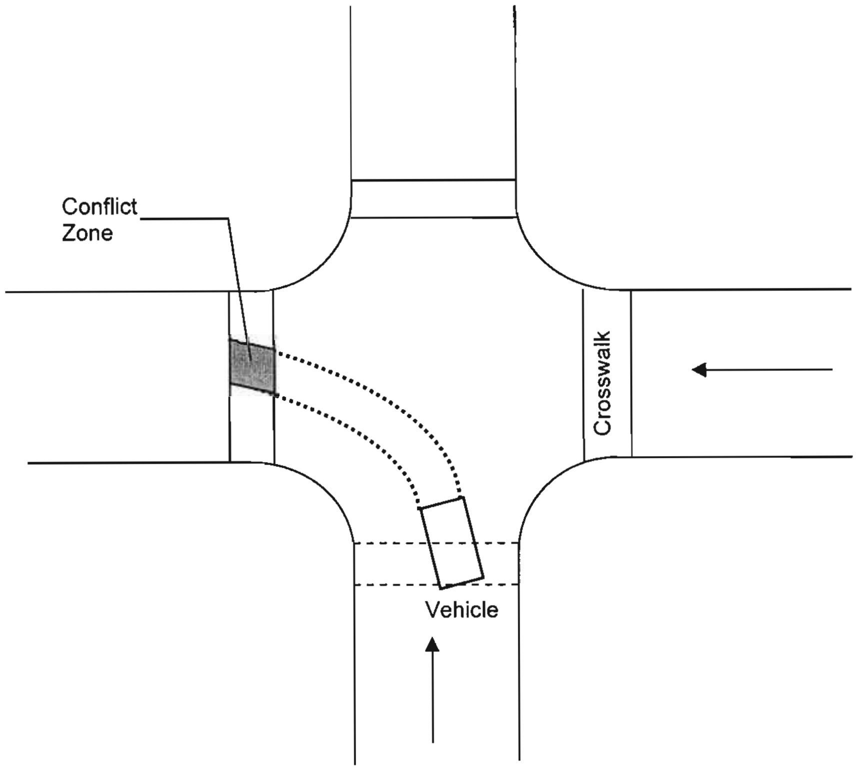


Figure 6.1 Conflict zone for a left-turning vehicle-pedestrian conflict

6.5 Data processing

A digital video camera was used to collect the data (video recording of traffic) from the intersections at which the application of digital image processing techniques was used. Chapter 7 presents a discussion of the digital techniques used. For the purpose of this discussion, a brief overview of the entire data collection and data reduction procedure is presented.

The basic procedure adopted was as follows:

- Use digital imaging equipment to record vehicle-pedestrian movements at intersections
- Extract sequences of digital images of conflict events from video
- Process the digital images to obtain coordinate positions of road users (rectification process)
- Use coordinate positions to plot trajectories, determine speeds and distances

- Determine conflicts using this information (for example-severity of conflict)

Figure 6.2 is a flow diagram describing the data processing procedure.

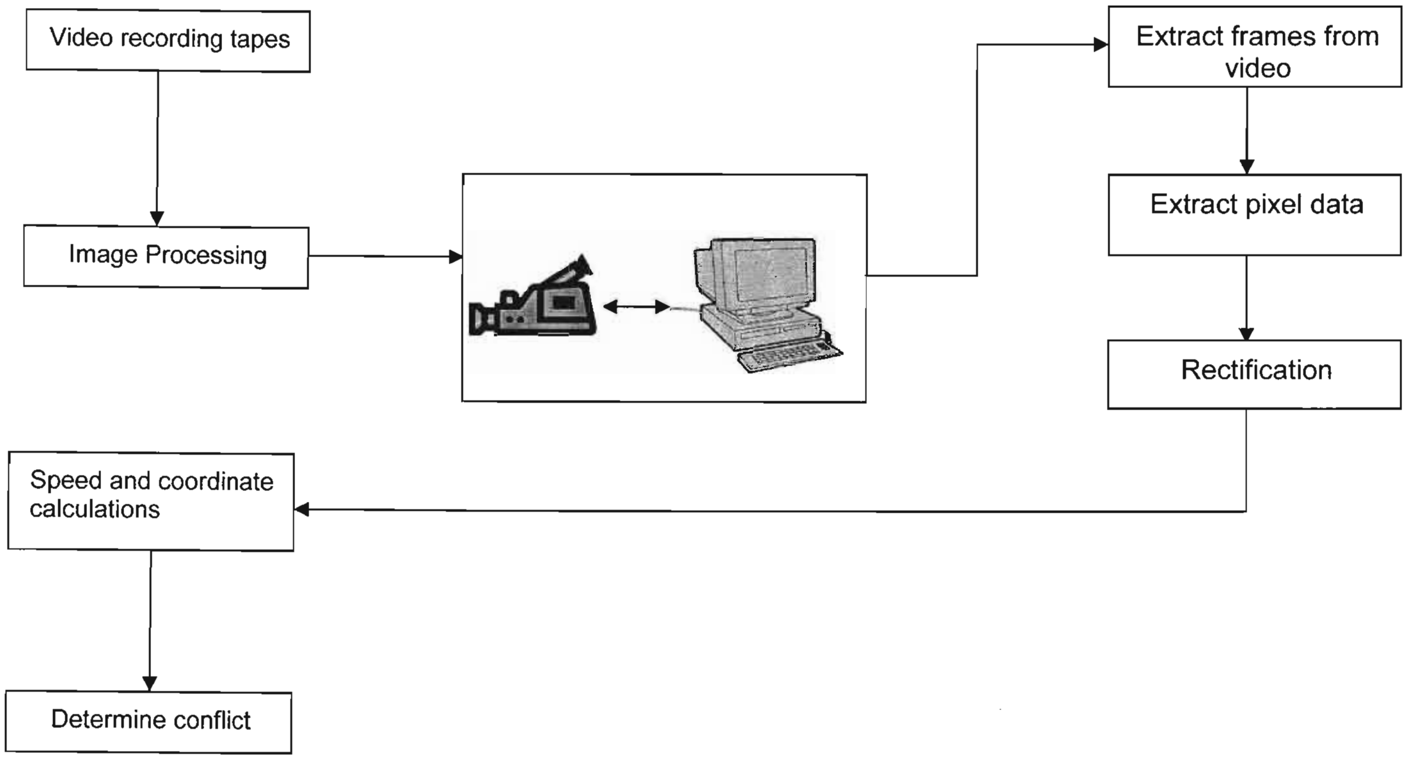


Figure 6.2 Data processing procedure

6.5.1 Digital image processing

The digital imaging method adopted for this investigation was used to develop a computer program for the recording and analysis of conflicts. Briefly, the program plays a video of the conflict situation. The user, after entering some basic parameters has to chose the points (pixels) on the road users for tracking - in this case a point on the vehicle and one on the pedestrian. The digital imaging algorithm developed then literally tracks the road users for the remaining frames in the video and outputs the plot of the trajectories of the road users and coordinates along with the speeds and distances. Chapter 7 presents a comprehensive discussion on the digital imaging method and computer program developed. This discussion focuses on an explanation of image processing concepts and the equipment used in this investigation.

6.5.2 Image processing concepts

A few basic concepts on digital video are discussed, as it is important to understand the reason for choosing the digital video format. The concepts presented here are not meant to be exhaustive, but to merely present the relevant terminology used in the digital industry. These concepts are introduced in order to build to the next chapter.

There are two basic types of video format, namely digital and analogue. Digital video is superior to analogue video in terms of quality and susceptibility to loss due to transmission noise effects [Basith, 1996]. There are four major factors that contribute to digital video resolution [Basith, 1996]:

- Frame rate
- Spatial resolution
- Colour resolution
- Image quality

There are various video-displaying formats of which PAL (Phase Alternative system) and NTSC (National Television Standards Committee) are the most common types. PAL has a frame rate of 25 frames per second (fps) with NTSC at 30 frames per second (fps). Colour resolution refers to the to the number of colours displayed on a screen at one time. Computers deal with colours in terms of RGB (red, green and blue) format with varying colour depths.

Spatial resolution refers to "how big is the picture". Most computers generally have a resolution of more than 640 x 480 pixels. This means that a single image comprises 307200 pixels. The higher the resolution, the greater is the image quality. This helps in clarifying and identifying smaller objects in an image.

Image quality is an important factor in obtaining data from the video. This varies and can be a quarter screen, 15 frames per second (fps), at 8 bits per pixel or a full screen (768 by 484), full frame rate video, at 24 bits per pixel (16.7 million colours). The higher the bit per pixel, the better is the image quality.

The digital video camera used for this investigation was a Panasonic AG-EZ35E (the technical specification for the camera can be found in Appendix C.1). In order to determine and analyse the conflicts, the camera had to be connected to a computer to perform the necessary task as shown in Figure 6.2. Using the technical specifications of this camera and doing simple calculations a transfer rate of 30 megabytes per second between the camera and computer was required - as discussed in Appendix C.1.

Digital video interface (*IEEE 1394, Firewire™* – capture card) is available on the camera, thus allowing it to be connected to a personal computer for the transfer of video from the camera to the computer - refer to Appendix C.1 for technical specifications. Using a computer with an installed capture card, video was transferred from the camera to the computer.

Software (*"MotoDv" by Digital Origin*) was used to transfer video from the camera to the computer in digital format. The software allowed the user to specify the time or frame rate interval to capture images which were then saved directly to the computer hard disk. With the video captured to the computer, the processing (such as speeds, distances, identification of evasive action) of the images could be achieved.

7 DIGITAL IMAGING METHODS

Chapter 6 presents the data processing method adopted for this investigation. As discussed, a computer program was developed using digital image processing methods. This chapter presents the theory for the development of the computer program, which covers the development of the algorithm and methods adopted. The structure of this chapter follows the data processing procedure presented in Chapter 6 and finally discusses the concepts of the computer program developed.

7.1 Pixel data extraction

The computer program developed requires the user to input the basic parameters and to select the points (pixels) on the road users to track via means of electronic crosshairs. A brief structure of the execution of the program is shown in Figure 7.1. In this section, a discussion is given on the selection of the points (pixels) necessary to track the road users.

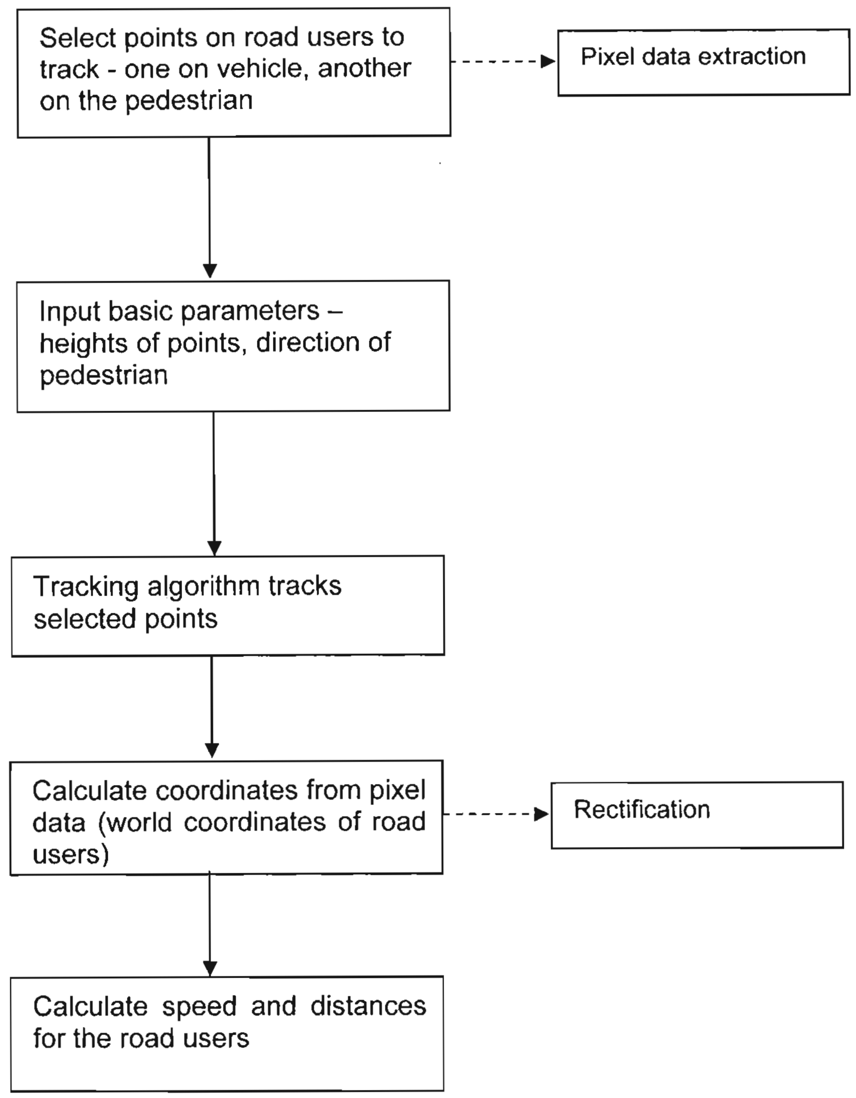


Figure 7.1 Flow diagram illustrating the processing procedure

In order to estimate the trajectories of the road users, two sets of pixel data per image are required (one for the vehicle and one for the pedestrian – see Figure 7.2). With these pixel data, the coordinates of the road users can be determined. Using the coordinates, the speeds and distances to a possible point of collision are calculated.

Figure 7.2 A typical conflict event showing the pixel data required per image

Point 1: point on right side of the vehicle bumper
Point 2: point on left shoulder of the pedestrian

Point 1 is chosen in order to track the vehicle path. This point is chosen because the bumper is usually a standard height from the ground. However, dimensions of 'all' types of vehicles studied were obtained to ensure that proper heights were chosen. Essentially any point on the extreme ends of the vehicle could be used for the analysis, as long as the height above ground level is known. Further, only two possible points for the vehicle were considered in the analysis. These are the points of the left and right bumper. The choice between the left and right bumper, depends on the visibility of these points during the sequence of frames. In Figure 7.2, the point on the right bumper is chosen, because it remains visible throughout the duration of the conflict. Due to the turning movement (Figure 7.2) of the vehicle, the left point on the bumper is not visible towards the completion of the turning manoeuvre.

Point 2 is chosen for the pedestrian because the left shoulder represents the 'outer body' (refer to Figure 7.3 for description of the outer body) of the person. If for example the head is chosen, then an appropriate width must be used to represent the 'outer body' because this is where a vehicle would strike the pedestrian in an accident situation. Various height measurements of objects (street poles, sign boards, etc) were recorded at each intersection in order accurately estimate the pedestrian heights. This was achieved by calculating the number of pixels in the vertical direction of the image (y – axis) for the heights of the measured objects and thus obtaining a ratio between pixels (y – direction) and measured heights.

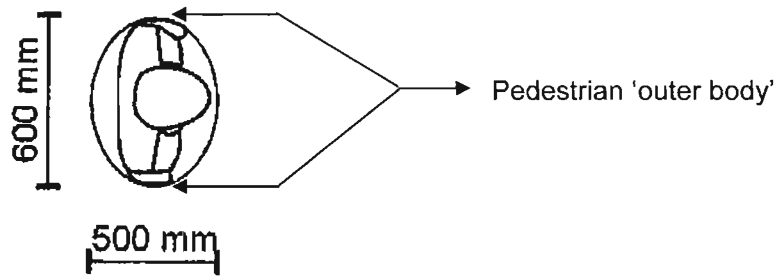


Figure 7.3 Pedestrian body ellipses showing the 'outer body' [Department of Transport, 2002].

Figure 7.4 represents a vehicle-pedestrian conflict and the points of interest required to plot the trajectories of the road users. In this conflict event, the bus is the motorized road user and the point of interest is the right bumper and for the pedestrian, the point on the left shoulder represents the point of interest.

Figure 7.4 Image showing a typical vehicle-pedestrian conflict and points of interest

7.2 Rectification

Upon selection of the points of interest for the road users, the next step of the program is to transform these (points) pixels into geographical coordinates. In order to achieve this transformation, a process known as rectification was used. Rectification is a procedure whereby the pixel coordinates of an image are converted into geographical coordinates. Any point on an image has, x and y pixel coordinates and not ground (X,Y) coordinates. In order to plot the trajectories of the road users and perform the necessary calculations, a transformation between pixel coordinates and ground coordinates has to be established.

Holland, Holman and Lippman [1997] presented a method for rectification. Figure 7.5 illustrates the geometric relationship between the ground coordinates (X,Y) and pixel coordinates (x,y).

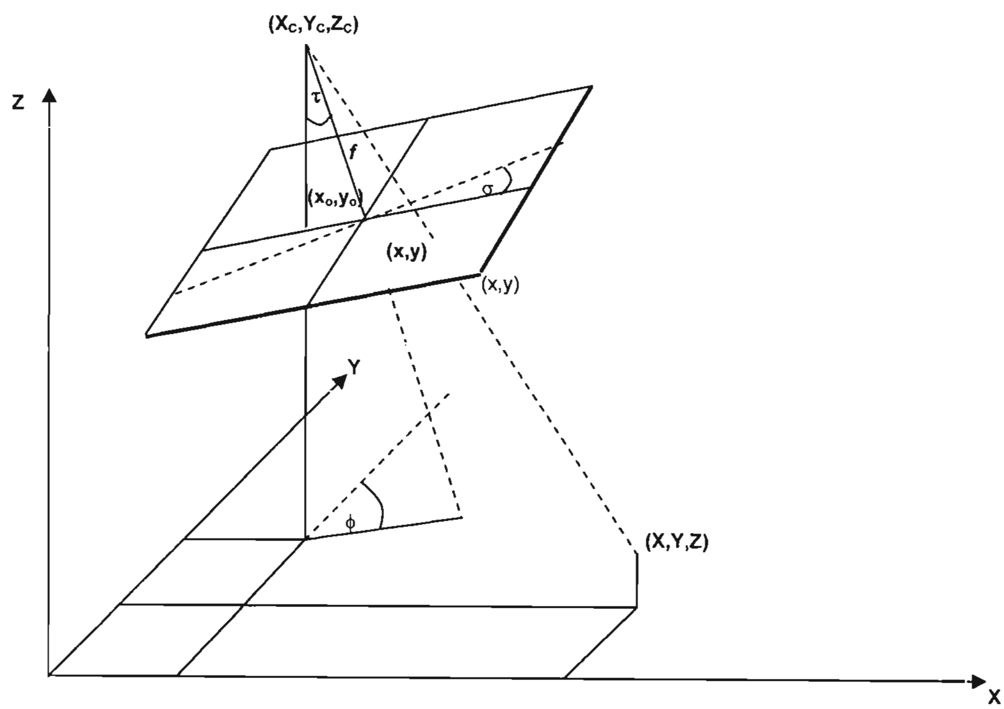


Figure 7.5 Collinearity relationship between camera (X_c, Y_c, Z_c), image (x, y), and world (X, Y, Z) coordinates and rotation angles (ϕ, τ, σ) used in the orientation definition [Adapted from Holland et. al 1997].

Figure 7.5 represents a typical point in a three dimensional coordinate system (X,Y,Z), which can be seen in a two dimensional image plane represented by pixel coordinates (x,y). The idealised image plane is at a distance *f* (focal length) from the optical centre of the camera (X_c, Y_c, Z_c). The image centre is given by (x_0,y_0), with the image reference system relative to the right hand upper corner of the image plane. Using these parameters, the transformation between image and world coordinates can be achieved in terms of the following collinearity equations:

$$x - x_0 = -\frac{f}{\lambda_x}\left[\frac{m_{11}(X - X_c) + m_{12}(Y - Y_c) + m_{13}(Z - Z_c)}{m_{31}(X - X_c) + m_{32}(Y - Y_c) + m_{33}(Z - Z_c)}\right] \tag{7.1}$$

$$y - y_0 = -\frac{f}{\lambda_y}\left[\frac{m_{21}(X - X_c) + m_{22}(Y - y_c) + m_{23}(Z - Z_c)}{m_{31}(X - X_c) + m_{32}(Y - Y_c) + m_{33}(Z - Z_c)}\right] \tag{7.2}$$

The collinearity equations are derived under the condition that the camera centre, image point and object point all lie on a straight line. Further, the collinearity equations do not cater for camera lens distortion. In the above equations, the m_{ij} represent the elements of a 3 x 3 orthogonal rotation matrix which are the direction cosines and are derived in terms of the three rotation angles ϕ (tilt), τ (azimuth) and σ (roll). λ_x, λ_y are the horizontal and vertical scaling factors respectively. The solution of equations 7.1 and 7.2 requires at least six surveyed ground control points and the calibration of the camera to obtain the parameters such as focal length and image centre. The calibration of the camera is a complex task requiring the use of non-linear optimisation methods [Zhang, 1998].

For the purpose of this investigation, a simplified rectification method was adopted requiring the use of only two surveyed ground control points and a simple calibration procedure. Section 7.2.2 presents a discussion on the accuracy of this method

7.2.1 Simplified rectification approach

This section describes the procedure used in this investigation for the rectification of pixel coordinates to a world coordinate system. The method used is described in two sections namely, range calculation and position calculation.

Range Calculation

In the range calculation, the camera is calibrated whereby known control points are used to determine the vertical angle of view. The vertical angle of view represents the number of degrees per pixel in the field of vision of the camera in the vertical (y-direction) direction of the image plane. With this information, the actual ground distance between a point on a vehicle and the camera in terms of the world coordinate system can be achieved. This distance is finally used in the position calculation to determine the world coordinates (X,Y). Figure 7.6 illustrates a possible situation of a vehicle in which the range calculation is necessary to perform the rectification. In Figure 7.6, a required point (P) on the vehicle is to be transformed to world coordinates. Using this example, the derivation for the range calculation is described.

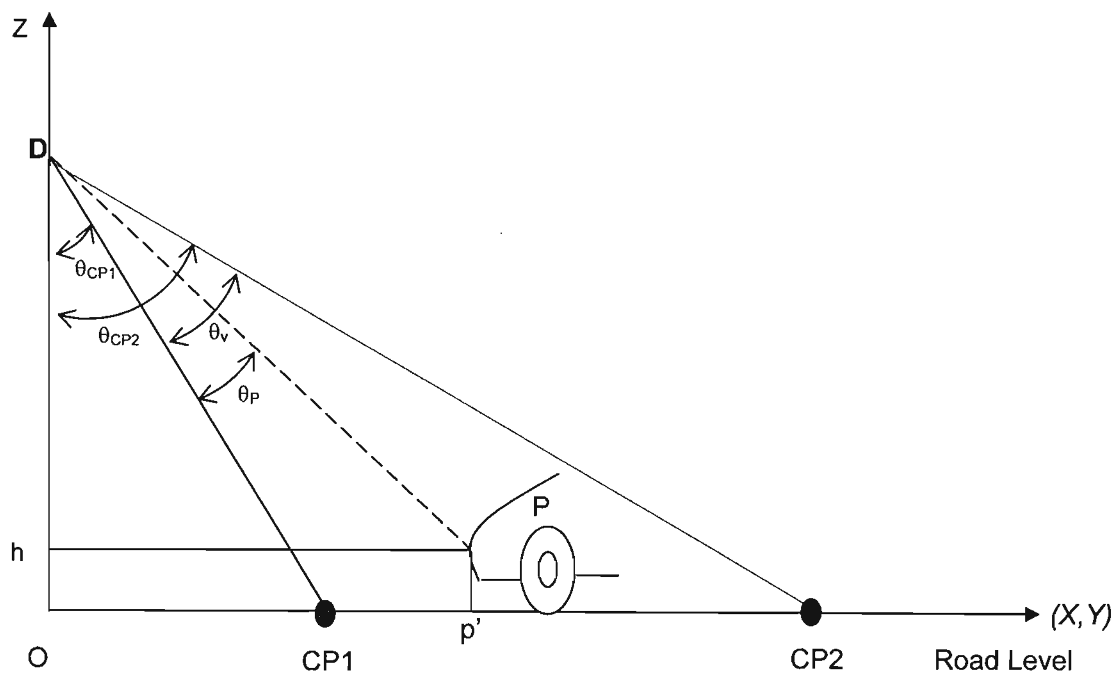


Figure 7.6 Vertical plane representing the point (P) on the vehicle to rectify

Let: D represents the known surveyed camera position at a height OD above the road level.

CP1 and CP2 represent known surveyed ground control points

Oh represent the known height of a point selected on a vehicle above road level

O is the perpendicular point below D.

P represents the point on the vehicle chosen to be rectified.

p' is the perpendicular ground projection of point P

The assumption in the derivation of the range calculation is that the x-axis of the image plane is parallel to the surface of the rpad

N.B. distance Op' = hP (follows from assumption).

The distance OCP1 is calculated as follows:

$$\overline{OCP1} = \left((X_{CP1} - X_0)^2 + (Y_{CP1} - Y_0)^2 \right)^{0.5} \quad (7.3)$$

Similarly, calculate distance $\overline{OCP2}$

Angle θ_{CP1} is calculated as follows:

$$\theta_{CP1} = \arctan\left(\frac{\overline{OCP1}}{OD} \right) \quad (7.4)$$

Similarly, calculate angle θ_{CP2}

Hence: $\theta_v = \theta_{CP2} - \theta_{CP1}$ (7.5)

The difference between the y pixel coordinates of CP1 and CP2 is given by

$$\Delta y = y_{CP1} - y_{CP2} \quad (7.6)$$

The vertical angular variation/vertical angle of view (in units of degrees/pixel) is given by:

$$\Delta V = \frac{\theta_v}{\Delta y} \quad (7.7)$$

The vertical angle between CP1 and P is:

$$\theta_P = \Delta V \times (y_{CP1} - y_P) \quad (7.8)$$

The distance hP can be calculated:

$$\overline{hP} = \overline{hD} \times \tan(\theta_P + \theta_{CP1}) \quad (7.9)$$

With distance hP calculated, the X and Y ground coordinates of point P can be calculated. This is demonstrated in the following section (position calculation).

Position Calculation

The position calculation is used to determine the world coordinates of the road user. This procedure uses the information (distance information - hP) from the range calculation. Further, the horizontal angle of view (similar to vertical angle of view) is determined. This gives the field of view in the x direction of the image plane. Figure

7.7 represents the point P as discussed in the range calculation of which the world coordinates are required. Using this example, the derivation for the range calculation is shown.

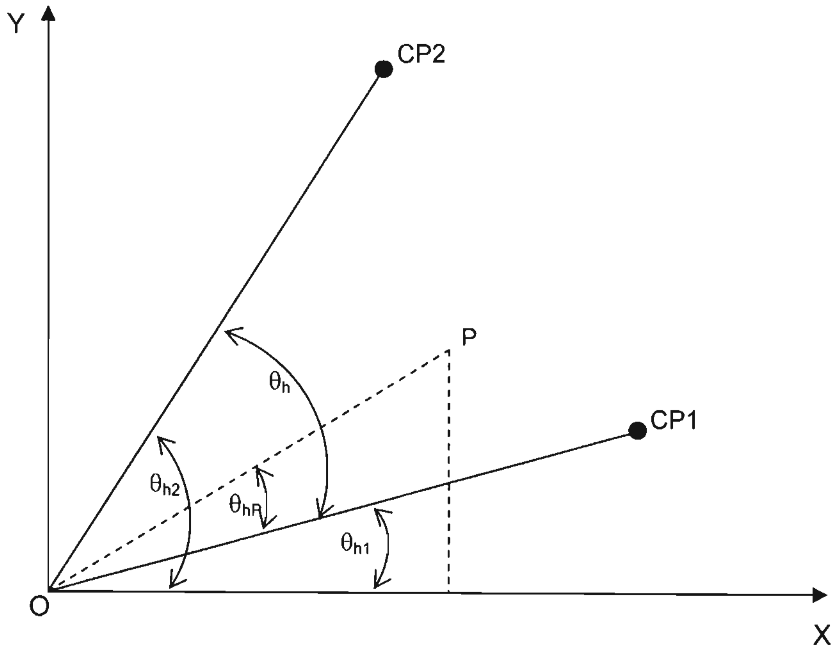


Figure 7.7 Plan view representing world coordinate system

$$\theta_{h1} = \arctan\left(\frac{Y_{CP1}}{X_{CP1}}\right) \tag{7.10}$$

Similarly calculate θ_{h2}

Hence $\theta_h = \theta_{h2} - \theta_{h1}$ (7.11)

The difference between the x pixel coordinates of CP1 and CP2 is given by

$$\Delta x = x_{CP1} - x_{CP2} \tag{7.12}$$

The horizontal angular variation (in units of degrees/pixel) is given by:

$$\Delta H = \frac{\theta_h}{\Delta x} \tag{7.13}$$

The horizontal angle between CP1 and P is:

$$\theta_{hP} = \Delta H \times (x_{CP1} - x_P) \tag{7.14}$$

Therefore, the X and Y ground coordinates are given by:

$$X_p = \overline{hP} \times \cos(\theta_{h1} + \theta_{hP}) \tag{7.15}$$

$$Y_p = \overline{hP} \times \sin(\theta_{h1} + \theta_{hP}) \tag{7.16}$$

7.2.2 Assumptions and Limitations

The simplified rectification approach adopted does not cater for camera lens distortions. In place of the collinearity equations used by Holland et al [1997], to determine the rotation angles ϕ (tilt), τ (azimuth), and σ (roll), this procedure assumes σ to be zero and the x-axis of the image plane to be parallel to the road surface. Patel [2002] adopted a similar approach and validated this method. In order that the image plane is perpendicular to the road surface, the camera was setup such that any object in view of the camera has the same y-pixel coordinate for any rotation of the camera about the y-axis of the image plane (or z-axis of the world coordinate system). Further, it is assumed that the road surface is level. However, the variations in the road surface can be accounted for if the heights of these variations are known. A major source of is incorrect height specification for the points being rectified. Hence the selection of a point to be rectified requires accurate known heights above the road level to be used in the range calculation. Figure 7.8 represents a typical situation in which rectification of a point on a vehicle is required. This is used to illustrate the errors obtained due to incorrect height selection.

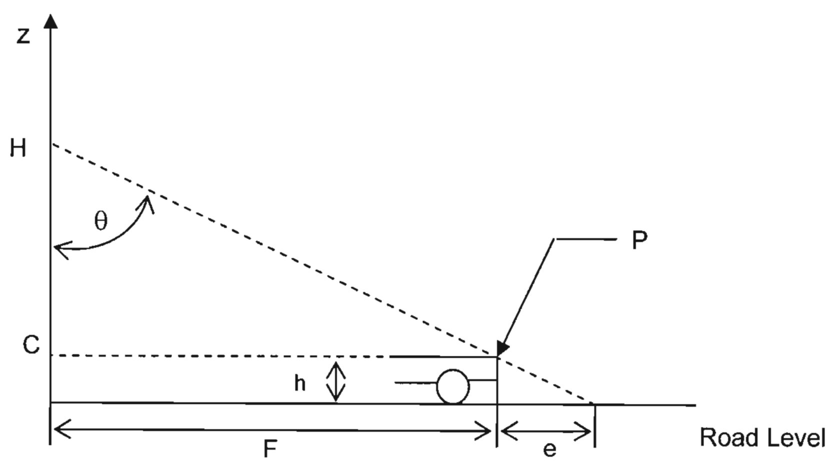


Figure 7.8. Vertical plane representing a vehicle

Assume point P is the required point on a vehicle to be rectified. The actual distance required in the position calculation is distance F. This distance F is calculated using the known height (h) of point P above the road level. If h was assumed to be zero, the distance obtained would be (F+e). The magnitude of the error, e depends on the following:

- the height of the camera above road level
- the error in the height of h
- the angle θ, which is related to the distance from the camera.

Tables 7.1, 7.2 and 7.3 illustrate the error due to incorrect height selection. In these tables, the camera height above road level is 10, 12 and 16 metres. Assume that the true height of the point on the vehicle is 0,5 metres above ground level (for example height of the bumper on the vehicle) also the vehicle distance from the camera is chosen to be 40 metres (this is a typical distance obtained from the site investigation).

Table 7.1 Errors for incorrect height selection (camera height = 10m, θ = 76 degrees)

Height CH (m) (m)	Assumed height (h) (m)	Error (e) (m)
9.50	0	2.00
9.70	0.2	1.20
9.90	0.4	0.40

Table 7.2 Errors for incorrect height selection (camera height = 12m, θ = 73 degrees)

Height CH (m) (m)	Assumed height (h) (m)	Error (e) (m)
11.50	0	1.67
11.70	0.2	1.00
11.90	0.4	0.33

Table 7.3 Errors for incorrect height selection (camera height = 16m, θ = 68 degrees)

Height CH (m) (m)	Assumed height (h) (m)	Error (e) (m)
15.50	0	1.25
15.70	0.2	0.75
15.90	0.4	0.25

From the Tables 7.1, 7.2 and 7.3, it is evident that the height of the camera (H), angle (θ) and height (*h*) influences the error in the distance. As the height of the camera increases, the error *e* decreases and the closer *h* is to the true height, the error *e* again decreases. The error e can be further reduced if the distance (F) of the point to rectify is closer to the camera. As discussed earlier, the height variations in the road level influences the error, but, this can be accounted for if the variations are known.

Due to these limitations, it is important to choose a suitable vantage point for the camera in order to minimise the error (e). However, it is not always possible to achieve this because it can require the construction of a tower to house the camera. The construction of such towers involves the permission from various authorities, which are often reluctant when the tower is to be located close to intersections in urban areas. In this investigation, the camera was located on buildings, which were close to the intersection. For two of the intersections, the camera was located at a height of 12,5 meters above road level and at the third intersection; the camera was 16,5 meters above road level.

7.3 Velocity calculation

Using the simplified rectification procedure to obtain the ground (X,Y) coordinates of the road users, the velocity vectors for the road users can be obtained. Each image contains ground coordinates at equally spaced time intervals. Therefore, the velocity vectors can be calculated at each point in time using these coordinates. Figure 7.9 shows a possible path for a road user.

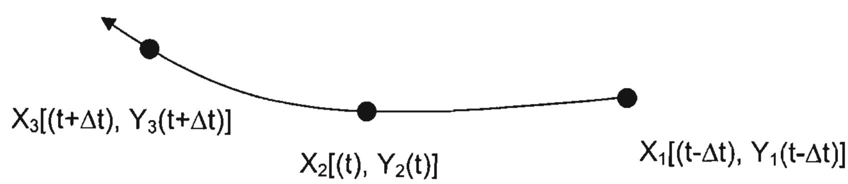


Figure 7.9 Representation of possible path for a road user

In Figure 7.9, the road user is shown a times (t-Δt), (t), (t+Δt). In order to estimate the velocity vector a time (t), the road users position at times (t-Δt) and (t+Δt) are used. The velocity vector is thus estimated using the centered difference approximation to the time derivative of position. For this application, the magnitude (speed of the road users) of the velocity vector is required and is estimated as follows:

$$V(t) = \frac{\sqrt{(X_3 - X_1)^2 + (Y_3 - Y_1)^2}}{2\Delta t} \quad (6.17)$$

For turning vehicles, the speed is estimated using the straight-line distance between successive points. This method can be used if the distances between the points are small - i.e. the time interval between successive frames is such as to allow the curved path of the turning vehicles to be estimated using straight lines. Figure 7.10 illustrates this concept. In this investigation, every fifth frame was used since the speeds of turning vehicles are low (typically less than 30km/h).

Figure 7.10 Path of a turning vehicle showing the points for tracking

From Figure 7.10, it can be seen that if the points are closely, spaced, then the distance between successive points can be estimated using the straight-line distance, without doing calculations to obtain the radius of curvature between successive points and then calculating the distance.

Consider the example shown in Figure 7.11. Figure 7.11 represents a pedestrian-vehicle interaction. This example illustrates the difference in speed estimation using the straight-line distance between successive points and the 'true distance'.

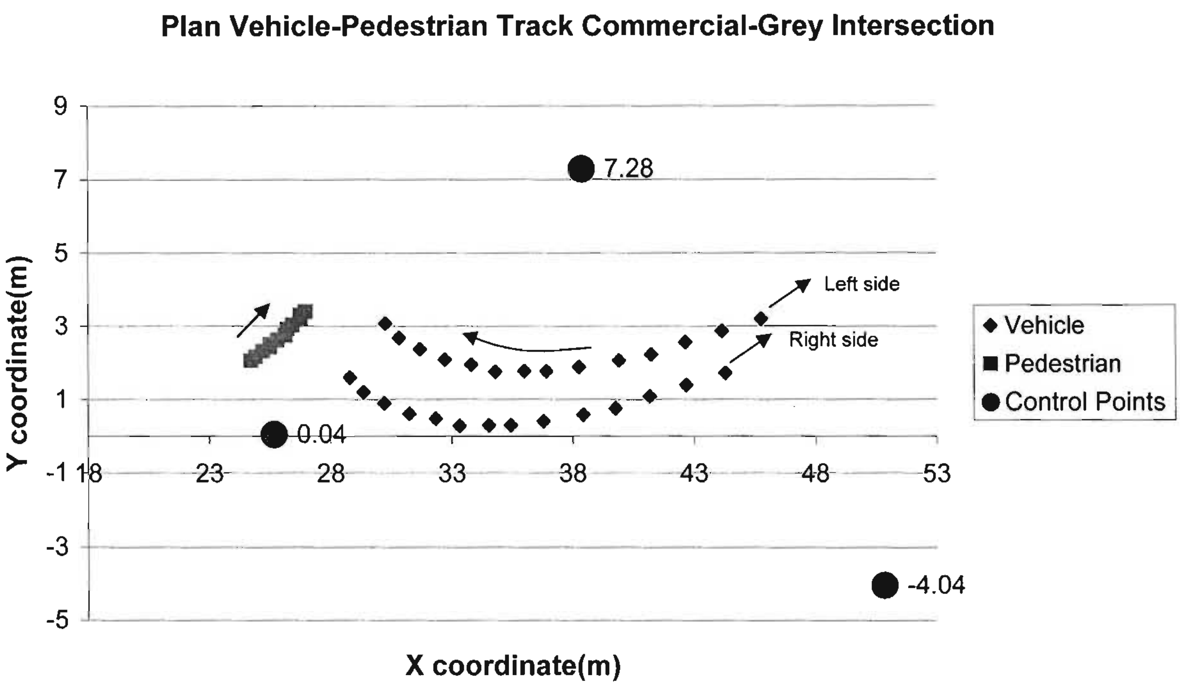


Figure 7.11 Vehicle-pedestrian interaction plot

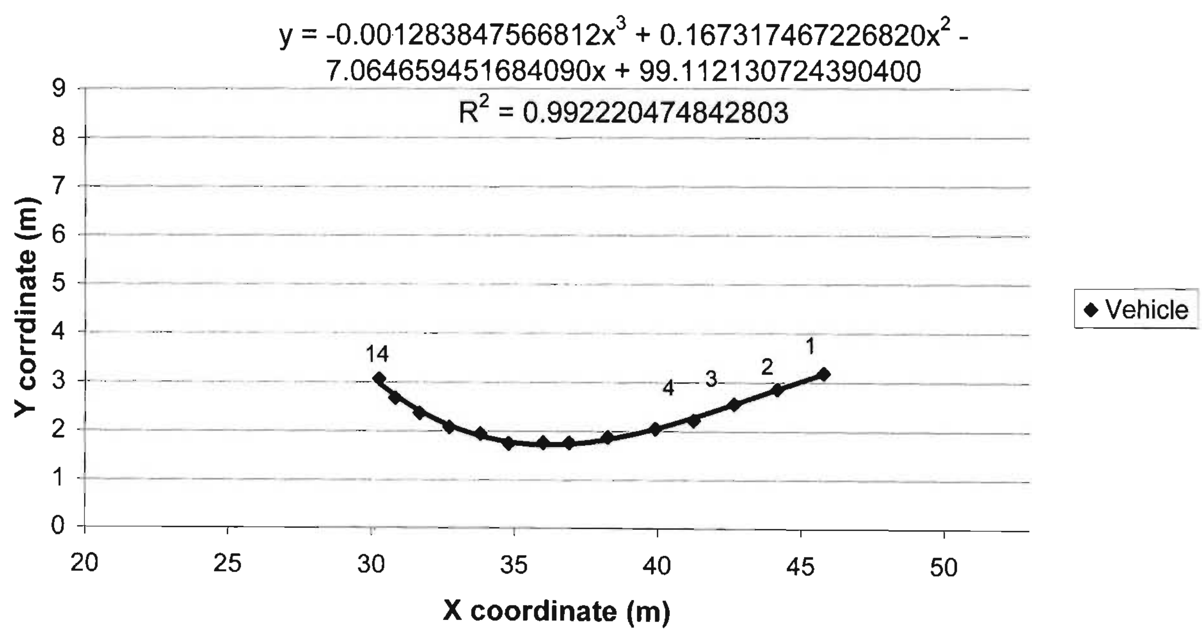


Figure 7.12 Path of the vehicle using a cubic function

The path of the vehicle is approximated using a cubic function as shown in Figure 7.12. In order to obtain the 'true distance', the distance between successive points is subdivided into smaller intervals and the sum of these intervals represents the 'true distance'. Table 7.4 shows the speed obtained from the straight-line distance and the speed obtained using the 'true distance' that is estimated using a cubic function for the path of the vehicle. Each successive pair of x-coordinates was divided into intervals of four. The cubic function was then used to estimate the distance between each division. Appendix D.1 contains a complete listing of the calculations. Table 7.4 also shows the radius of curvature obtained for each point of the vehicles trajectory. This is obtained by calculating the radius of curvature at each coordinate point of the vehicle - refer to Appendix D.1 for a derivation of the calculation.

Table 7.4 Various methods for obtaining speed

Point	Speed (m/s)	Straight-line method (m/s)	Radius of curvature (m)
1			58.71
2	7.942	7.948	193.25
3	7.429	7.459	173.88
4	6.964	6.964	62.04
5	7.549	7.515	38.10
6	7.549	7.540	25.41
7	5.659	5.657	19.91
8	5.308	5.304	17.43
9	5.517	5.513	15.16
10	5.264	5.259	13.94
11	5.473	5.417	13.15
12	4.977	4.957	12.88
13	3.831	3.970	12.98
14			13.22

From Table 7.4 it is evident that the estimated speed using the straight-line method does not vary significantly from the true speed. The maximum variation from the true speed is approximately 3,5 per-cent.

7.4 Digital image processing methods

As discussed in Section 6.1, the computer program developed tracks points selected on the road users in a conflict event. In order to achieve this, the use of digital image processing was necessary. The tracking of object features from one image to the next requires the use of image processing methods. Initially, it was decided to manually track the road users whereby each frame would be loaded and the pixel of the required point would be obtained using the pointer mouse device, using commercial software. This task of manually extracting pixel data is time consuming, as each frame has to be loaded into a software programme (for example *ImageJ*) to manually extract the pixels (points of the road users) required. Note that each image requires the extraction of two points. The next step in this task would require that the points selected to be saved in a text file and used by Microsoft Excel (spread sheet program) to perform the rectification, velocity calculation and plot of the road users trajectories. Considering that a typical interaction would be a minimum of three seconds, and that every fifth frame would be processed, the total number of frames to be processed would be fifteen thus leaving thirty points to be extracted. This task becomes time consuming and laborious. Therefore, it was decided to use image-processing methods, to automatically track objects given a sequence of frames by the development of a computer program.

The method adopted in this investigation for the tracking of objects from frame to frame is known as cross correlation. Developers of machine-vision systems initially employed the cross correlation method for pattern matching. These systems are required to accurately locate reference patterns, which may appear different from one product to the next [Wagner, 2000]. For a number of years, these developers used mathematical correlation algorithms to perform pattern matching. With images, a computer correlates matrices of pixels to perform the pattern matching. Assume two images A and B exist and the location of an object in terms of pixel coordinates in A is given by x_A, y_A. Given that the object has moved, the aim is to find the object position in image B.

7.5 Traffic conflict tracking software

7.5.1 Introduction

The tracking software was developed in order to automate the process of image processing. Various programming languages were considered for the development of the software. The choice of the programming language was made on the basis of available image processing toolkits. Various programming languages were available to perform the image processing and these include: Microsoft Visual Basic, Microsoft Visual C++, Interactive Data Language (IDL) and Matlab. Of the above-mentioned programming languages, IDL and Matlab were equipped with image processing toolkits. This, of course enables rapid development of the software. It was finally decided to use Matlab, as it is equipped with a wide range of image processing functions.

7.5.2 Computer program and algorithm description

The aim of the software is to take a sequence of frames and to automatically track road users and produce plots of the trajectories, speeds and time to collision graphs. The following flowchart explains the algorithm - refer to Figure 7.13 (Appendix C.2 contains the program listing)

The program developed for the analysis of traffic conflicts provides a graphical user interface (GUI) window when the program is executed. Upon execution, the user selects the image file to analyse from any source medium (PC hard disk, CD drive, DVD drive, etc.). Upon selection of the image file, the user has the option to view a video of the conflict. This assists the user to identify the road users involved in the conflict and to decide on the features to track. An input GUI window is the next to appear (refer to Figure 7.14). This input window prompts the user to enter the parameters for the conflict event. These parameters include the number of frames to analyse, heights for the road users and direction of movement of the pedestrian (i.e. "up" the crosswalk or "down" the crosswalk). In addition, the location (i.e. the intersection) is required in order to plot the trajectories of the road users.

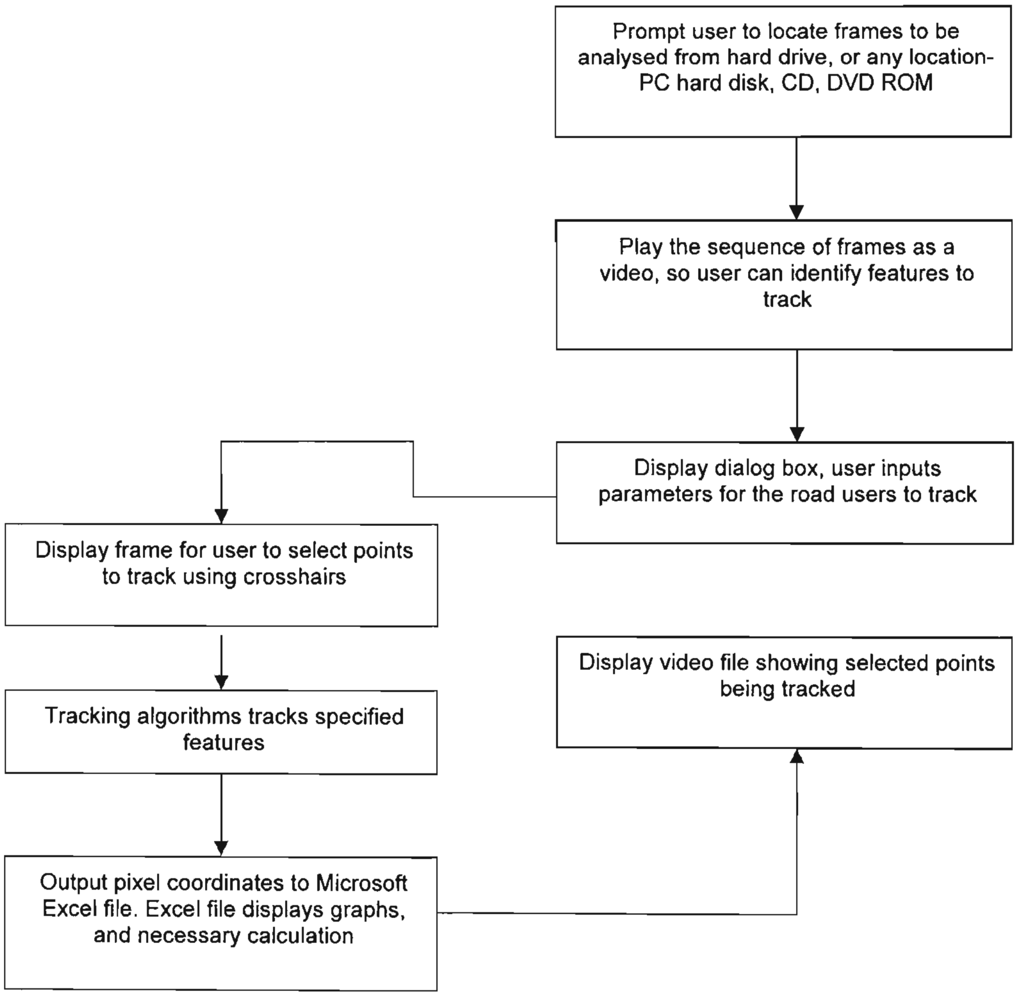


Figure 7.13 Flowchart summarising the programming structure.

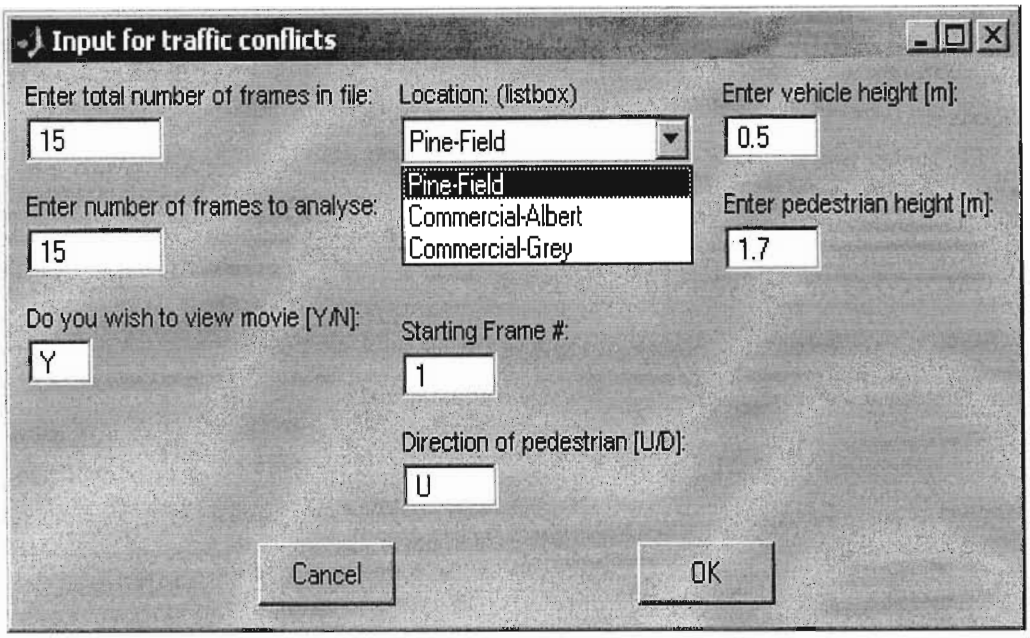


Figure 7.14 An example of the input GUI, in which parameters are provided for analysing the conflict.

In the next GUI window (refer to Figure 7.15), the image frame of the first sequence of frames to analyse is displayed. This GUI's dimensions are designed to accommodate an image of 768 pixels by 576 pixels. The user can change the window size by using the mouse pointer tool. For this GUI, the user has to select the features for the vehicle and pedestrian to track. In order that the appropriate points are selected, the user has the option to zoom in on the points and then choose the points via means of crosshairs. A message window appears together with the GUI to prompt the user in zooming in or out and using the crosshairs. Examples of the message window and the crosshairs are shown in Figures 7.16 and 7.17 respectively.

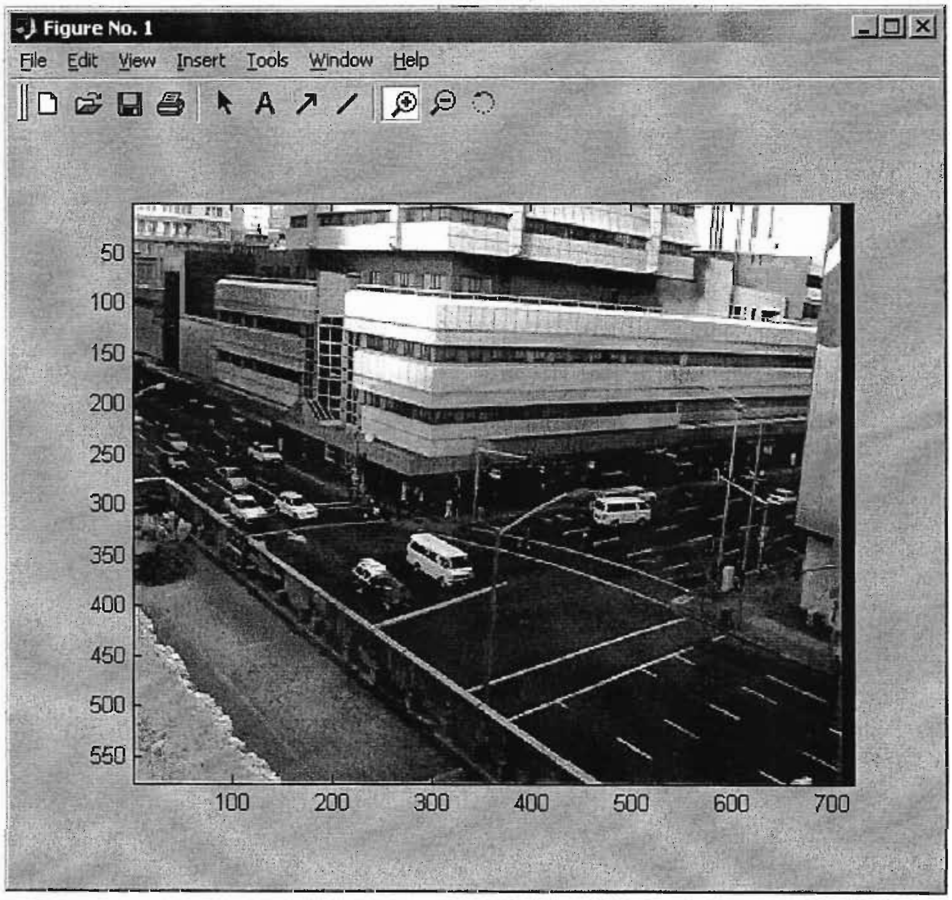


Figure 7.15 Example of the first frame in which the user has to select the road users to analyse

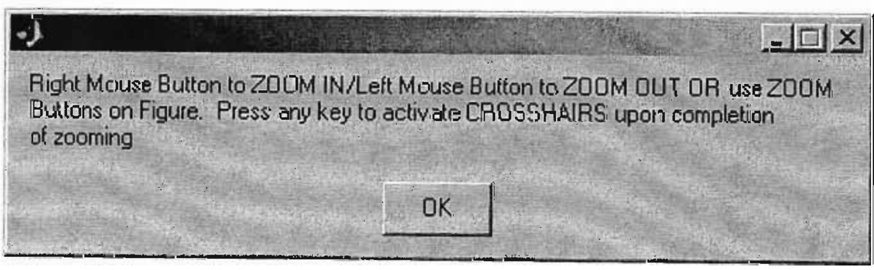


Figure 7.16 Message Box explaining the use of the zoom and crosshairs functions

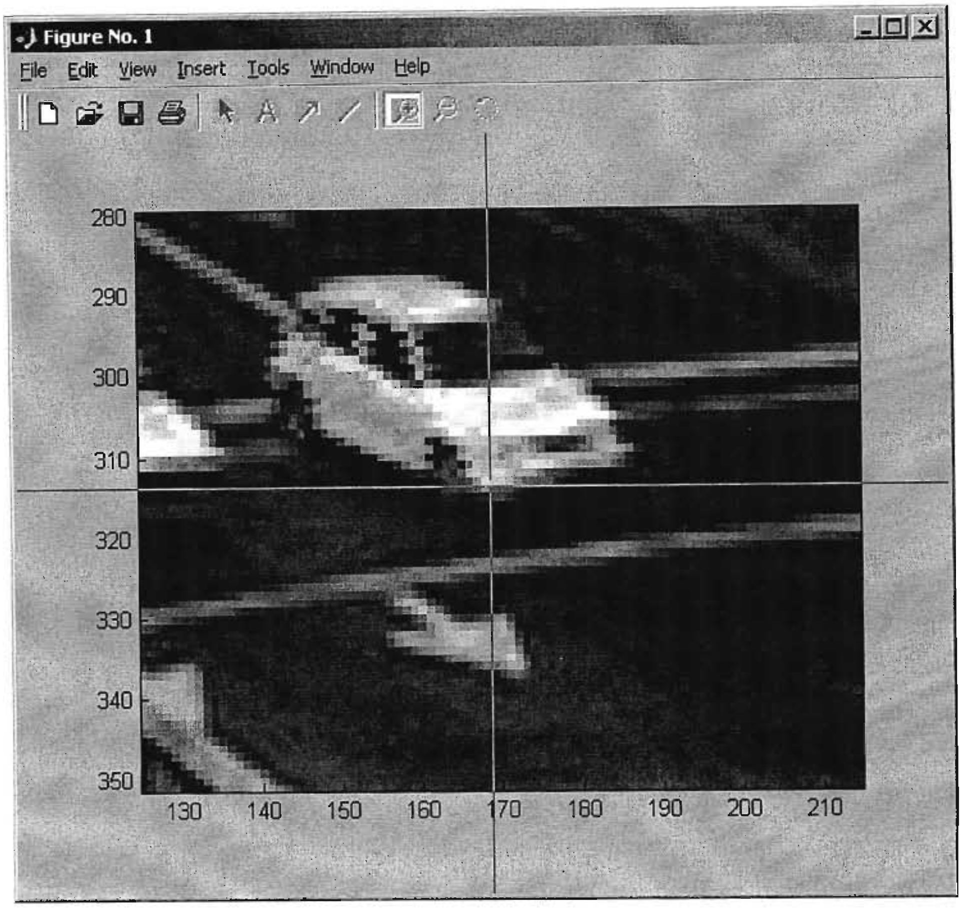


Figure 7.17 Example illustrating the use of the crosshairs to select a point on the vehicle for tracking using the zoom function.

7.6 Tracking algorithm

As discussed in Section 6.4, the tracking of object features from one image to the next involves the application of matching methods. The common matching method used is cross-correlation. However, other methods are available such as Fast Fourier Transforms (FFT) and sum of squared difference (SSD), edge detection methods, etc [Wagner, 2002]. The method selected in this study was cross-correlation. Cross-correlation is a standard method used in machine vision. In a typical machine vision application, a video camera is positioned so it can capture an image of the item to be inspected; it then sends it to the vision computer. The vision system rapidly analyses the image. For example, it might find where the item is located in the field of view and check the tolerance of its critical dimensions. This process is repeated for each item that moves into position in front of the video camera [Wagner, 200]. Unlike manual inspection, the vision system always applies the same rules objectively. In machine-vision, matrices of pixels are correlated between two images to find a "match" [Wagner, 2000]. One matrix holds grey-scale values that represent the target pattern. The other matrix contains the grey-scale values acquired from a test image (the unknown signal). Each grey-scale value corresponds to a pixel in an acquired image, and the values represent light intensities from white to black. Unfortunately, because grey-scale correlation algorithms use pixel intensities, they have difficulty in coping with changes in the appearance of features in images [Wagner, 2002]. Traditional correlation software adequately locates patterns under ideal conditions, but it cannot tolerate variations of scale, angle, focus, and contrast in acquired images [Wagner, 2000]. Day-to-day variations in materials and processing can produce precisely those variations [Wagner, 2000].

In this investigation, cross correlation values are obtained for full colour images, with each pixel represented by a RGB (red, green and blue) value. For the correlation, each pixel is treated as a vector comprising three components. The formulation of the cross correlation method is presented in Appendix C.3. The following is an illustration of the tracking algorithm demonstrating the correlation method.

Assume two images exist, *A* and *B* each with of a resolution of 15 x 15 pixels and both representing a 24-bit colour depth. Let *A* represent an image with a road user at time t and B represent the road user at time $t+\Delta t$. Let the point that is to be tracked be at cell 40 in image *A*, given by coordinates x_A, y_A. In order to perform the tracking, a template from image *A* needs to be matched with image *B*. For this a region of interest (ROI) is defined as the template, say an area of 5 x 5 pixels selected around point x_A, y_A (shaded area) which is to be matched in the next image - as shown in Figure 7.18

1	13	25	37	49	61	73	85	97	109	121	133
2	14	26	38	50	62	74	86	98	110	122	134
3	15	27	39	51	63	75	87	99	111	123	135
4	16	28		52	64	76	88	100	112	124	136
5	17	29	41	53	65	77	89	101	113	125	137
6	18	30	42	54	66	78	90	102	114	126	138
7	19	31	43	55	67	79	91	103	115	127	139
8	20	32	44	56	68	80	92	104	116	128	140
9	21	33	45	57	69	81	93	105	117	129	141
10	22	34	46	58	70	82	94	106	118	130	142
11	23	35	47	59	71	83	95	107	119	131	143
12	24	36	48	60	72	84	96	108	120	132	144

x_A

y_A

Figure 7.18 Image *A* representing the region of interest around the selected point to track

Now for a small Δt the road user would have not moved by more than a few pixels. The Δt is the key for the success of the tracking, which is influenced by the speed of the road users. Higher speeds require Δt to be correspondingly small. Note that the frame rate in this investigation is 25fps. Therefore the smallest time interval between frames would be 1/25 seconds. For this investigation, every fifth frame is chosen representing a Δt of 0,2 seconds.

Suppose that the point to be tracked moves from cell 40 (x_A, y_A) in image A to cell 92 (x_B, y_B) in image B - see Figure 7.19.

1	13	25	37	49	61	73	85	97	109	121	133	
2	14	26	38	50	62	74	86	98	110	122	134	
3	15	27	39	51	63	75	87	99	111	123	135	
4	16	28	40	52	64	76	88	100	112	124	136	x_A
5	17	29	41	53	65	77	89	101	113	125	137	
6	18	30	42	54	66	78	90	102	114	126	138	
7	19	31	43	55	67	79	91	103	115	127	139	
8	20	32	44	56	68	80	92	104	116	128	140	X_B
9	21	33	45	57	69	81	93	105	117	129	141	
10	22	34	46	58	70	82	94	106	118	130	142	
11	23	35	47	59	71	83	95	107	119	131	143	
12	24	36	48	60	72	84	96	108	120	132	144	
			y_A				X_B					

Figure 7.19 Image B illustrating the original location of the road user and the location at time *t+Δt*

In order to find the location of the tracking point in image B, the template for A is shifted over image B. Cross correlation coefficients are calculated between the template and the target image B, with the maximum correlation representing a match and thus the required point in image B. The search for the maximum correlation can be reduced if the approximate direction of the road user is known. For example, motor vehicles in this investigation include turning vehicles. Thus the direction of the vehicles is known to a high degree of certainty. The vehicles could not move backwards, they could however, stop and turn within certain limitations of the roadway. Additionally, vehicles turning often have a lower speed and therefore the search region could be confined to a specific area size. A typical search region known as the search strategy area (SSA) is illustrated in Figure 7.20.

1	13	25	37	49	61	73	85	97	109	121	133	
2	14	26	38	50	62	74	86	98	110	122	134	
3	15	27	39	51	63	75	87	99	111	123	135	
4	16	28		52	64	76	88	100	112	124	136	x_A
5	17	29	41	53	65	77	89	101	113	125	137	
6	18	30	42	54	66	78	90	102	114	126	138	
7	19	31	43	55	67	79	91	103	115	127	139	
8	20	32	44	56	68	80	92	104	116	128	140	X_B
9	21	33	45	57	69	81	93	105	117	129	141	
10	22	34	46	58	70	82	94	106	118	130	142	
11	23	35	47	59	71	83	95	107	119	131	143	
12	24	36	48	60	72	84	96	108	120	132	144	
			y_A				y_B					

Figure 7.20 Image B illustrating the search strategy area

Pedestrian movements on the other hand can be 'sudden' as pedestrians have the ability to stop, increase speed and change direction almost instantaneously. This of course influences the accuracy of the tracking for pedestrians. Further, at pedestrian crossings, pedestrians often walk in groups or with other pedestrians in close proximity. The tracking of a specific pedestrian in a group is difficult due to the "influence" of other pedestrians. For the tracking of a single pedestrian in a group of pedestrians, distinctive features were identified, for example colour of clothing (that is different from the rest of the group), and hence, these features of the pedestrians were used in the pattern matching. In the case of single pedestrian movements with no other pedestrians in close proximity, the tracking was easier and virtually any point on the pedestrian could be selected. Accounting for the movement of the pedestrian, the search strategy area (SSA) was such as to cater for these sudden movements (i.e. a SSA was defined in front as well as behind the pedestrian).

Figures 7.21 and 7.22 illustrate the output from the computer program that produces a plot of the paths of the road users:

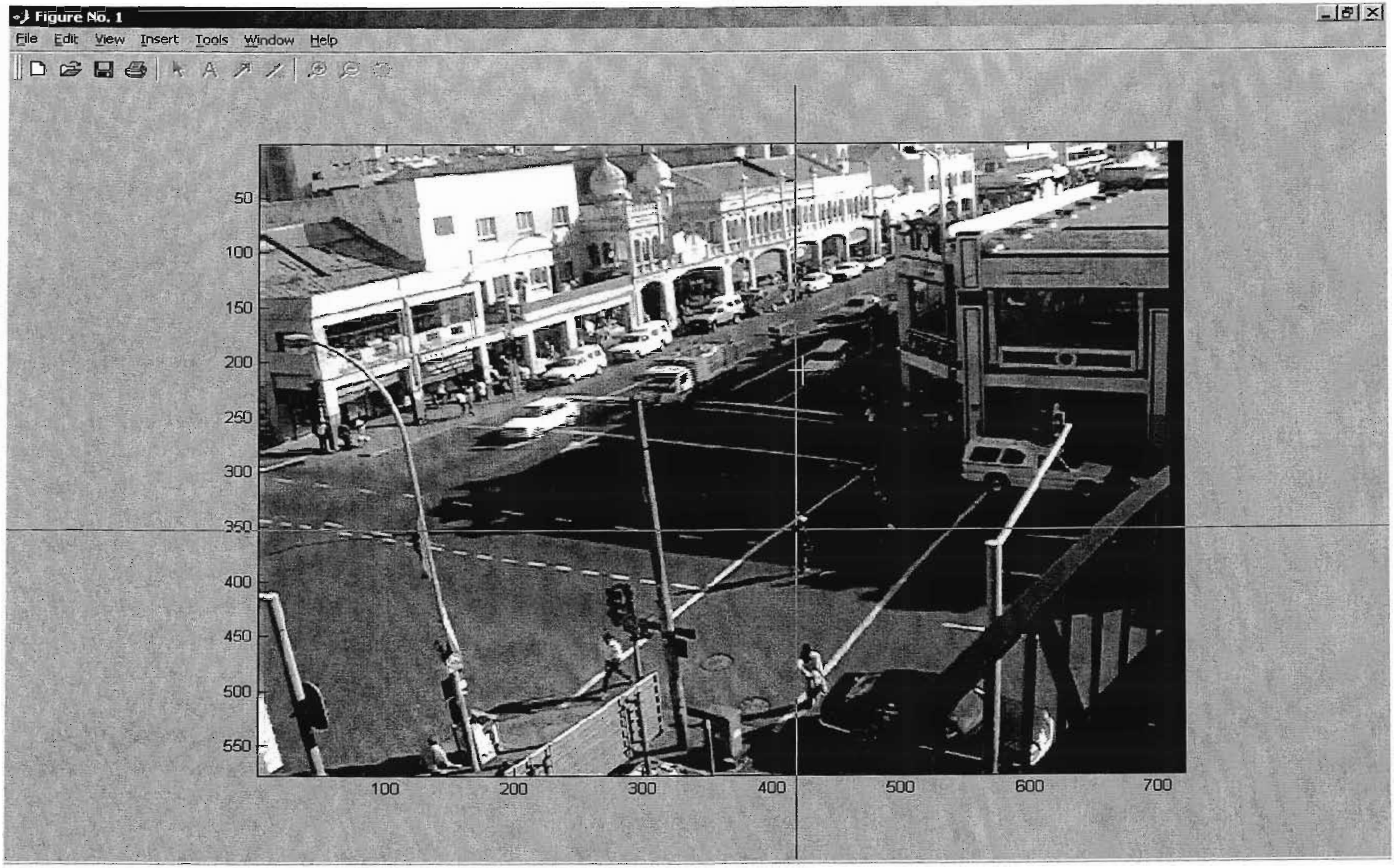


Figure 7.21 Crosshairs used to choose points on vehicle and pedestrians using the computer program

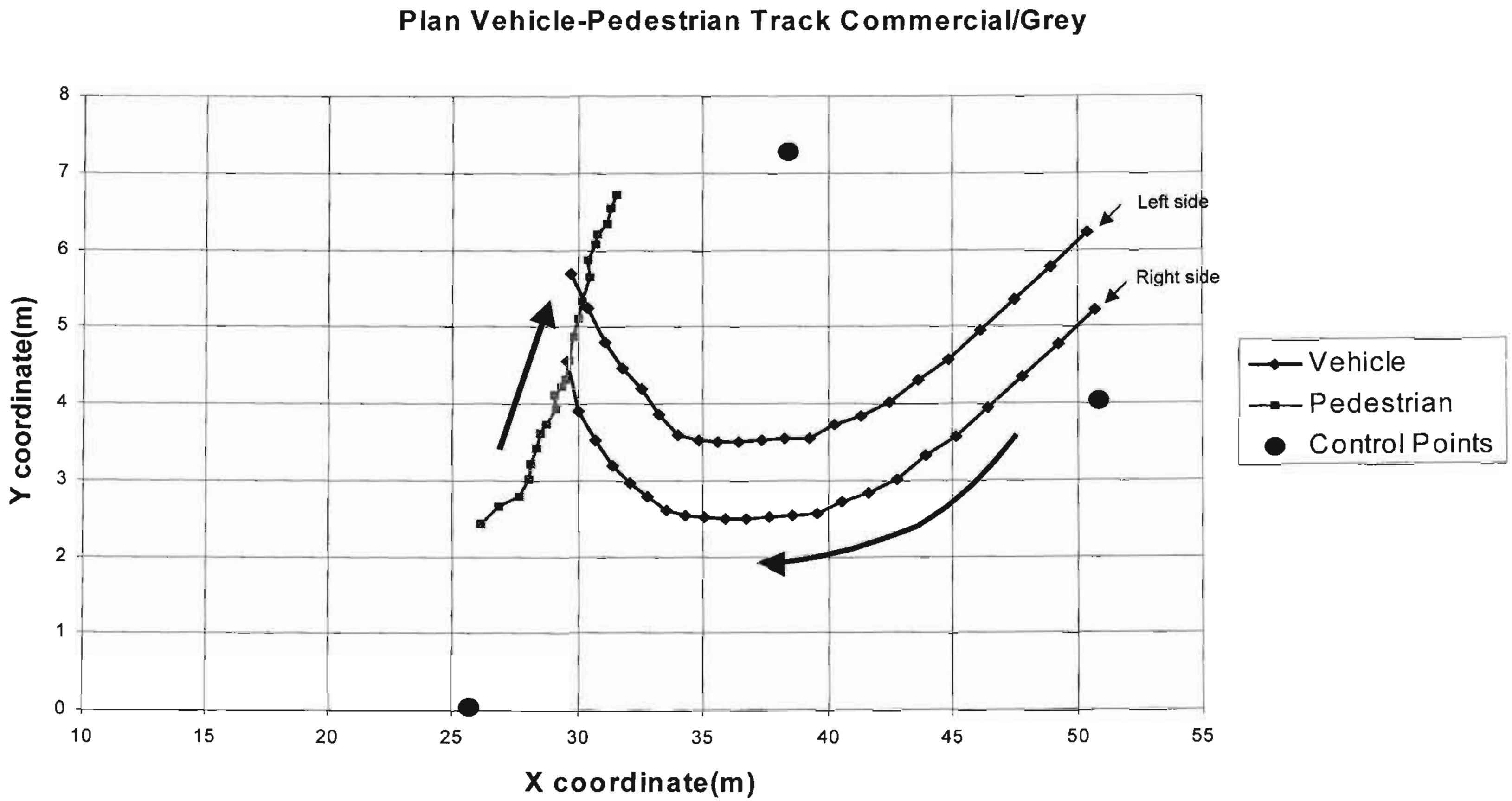


Figure 7.22 Vehicle-pedestrian tracks from computer program

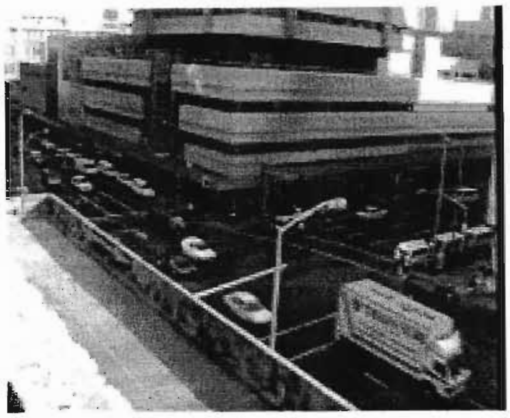
7.7 Effect of image quality on tracking algorithm

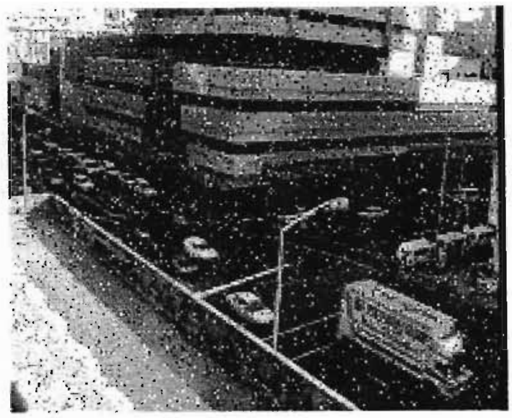
Image quality is important for object tracking because this governs the accuracy of the tracking algorithm in locating the point of interest in subsequent frames. Electronic noise is a component affecting image quality. All digital images have electronic noise, which is a random distribution of spots (pixels) at various regions in an image that affects the image quality. Digital images are prone to a variety of types of noise. There are several ways that noise can be introduced into an image and is dependent on the way the image is created. A digital camera was used to acquire the images for this investigation and hence the major source of noise arose from the mechanism in the camera for acquiring the images. In this case, the mechanism is the charged couple device (CCD) that introduces noise into the images. Further, noise is also introduced due to electronic transmission of data. In this investigation, the transfer of data between the camera and personal computer introduces a source of noise.

Analysis was carried out to test the accuracy of the tracking algorithm with various image qualities. In order to achieve this, various noise levels were introduced into the images. Salt and pepper noise (impulse noise) was added to the images. Statistically, the probability density function of a salt and pepper random variable z is as follows [Mathworks, 1992]:

$$p(z) = \begin{cases} P_a & \text{For } z = a \\ P_b = 1 - P_a & \text{For } z = b \\ 0 & \text{Otherwise} \end{cases}$$

Figure 7.24 illustrates images before and after the addition of salt and pepper noise (in this case the intensity is 0,02. As can be seen, the addition of noise reduces the image quality thereby making the identification of key features difficult. Thus, this can affect the accuracy of the tracking algorithm. Table 7.5 illustrates the results obtained for coordinate points before and after the addition of noise to image.





(a) (b)

Figure 7.23 Images (a) and (b) before and after the addition of noise (salt and pepper noise with density 20%)

Table 7.5 Results obtained from various noise levels

Noise Level	μ_x(m)	σ_x(m)	μ_y(m)	σ_y(m)
1	0.0220	0.0478	0.0203	0.0438

(sample size = 15)

(level 1 = 20%)

Table 7.5 represents the mean error and standard deviations for both the x and y coordinate (for a sample size of fifteen vehicle-pedestrian tracks). It can be seen that the error in the x and y coordinate are approximately 20 mm for this noise level. This is a result of an accurate template-matching algorithm. This is an extreme case and this level of noise does not affect the images in this investigation. This is used to illustrate the accuracy of obtaining coordinates and speeds. This exercise also implicitly demonstrates the accuracy of the tracking algorithm with regard to the tracking of the same point. It must the noted that in the degradation of the image quality, the original point selected for tracking is obscured due to the added noise. That being so, the aim of the algorithm is to locate this point in the subsequent frames (that are reduced in quality). The results from Table 7.5 confirm that the algorithm is able to produce a plot of the vehicle (for the reduced image quality) which is similar to the non-degraded images. The error is in the region of 20mm (for the x and y coordinates) which equates to an error of approximately five pixels. This confirms that the algorithm is tracking the "same" point (in the case of the reduced quality of images) as that for non-degraded images.

The following example (Table 7.6) illustrates the errors obtained in coordinates and speeds for an image that is affected by noise. It must be noted that the image quality is purposely degraded (by the introduction of electronic noise) to illustrate the accuracy of the calculations of coordinates and speeds.

Table 7.6 Difference between image qualities

No Noise			Noise (20%)		
X1	Y1	Speed(km/h)	X	Y	Speed(km/h)
52.95	23.16		52.95	23.16	
52.79	22.36	14.57	52.82	22.29	14.57
52.79	21.55	14.43	52.79	21.55	13.84
52.61	20.77	13.75	52.78	20.75	12.62
52.57	20.04	13.03	52.52	20.18	12.54
52.52	19.32	11.86	52.50	19.39	13.55
52.58	18.72	10.79	52.44	18.67	11.79
52.64	18.13	10.13	52.50	18.08	9.21
52.66	17.60	7.28	52.64	17.67	7.15
52.75	17.33	7.26	52.75	17.33	10.08
52.77	16.80	10.08	52.69	16.55	11.08
52.80	16.21	10.67	52.68	16.10	9.40
52.83	15.62	10.65	52.71	15.51	10.39
52.85	15.03	9.75	52.87	14.96	9.65
52.98	14.54		53.00	14.48	

From Table 7.6 it is evident that even with images that are degraded, the estimates of the coordinates and speeds are obtained with acceptable accuracy. The average speed variation is 0,87km/h.

8 RESULTS AND ANALYSIS OF EMPIRICAL TESTING

8.1 Introduction

In this chapter, the analysis of the conflict data obtained from the three intersections selected for empirical testing is presented. The analysis begins by discussing the differences between the conflicts obtained for each technique under identical traffic situations. Secondly, the level of risk is estimated using the various conflict techniques and also, the relationship between conflicts and traffic stream parameters is discussed. Thirdly, the Swedish conflict hierarchy approach is used to illustrate the relationship to traffic safety. Finally, a discussion on the usefulness of digital image processing for conflict detection is presented.

8.2 Comparison of conflict data

The conflict data collected from the three intersections studied using the Swedish, German, USA and Post encroachment time (PET) techniques are summarised in Tables 8.1 and 8.2. The conflict data for the Pine-Field and Commercial-Grey intersections was recorded using an eight-hour observation period for each intersection. A twelve-hour observation period was used for the Commercial-Albert intersection (due to the requirements for the severity hierarchy concept as described in Section 6.3). Refer to Appendix B for complete listing of all conflict data and observation periods.

The "common" and "unique" conflicts referred to in subsequent tables and discussions are defined as: -
Common conflicts are conflicts that were recorded by two or more techniques. Unique conflicts are conflicts that were recorded by only one technique.

Table 8.1 Total conflicts per intersection per technique – all severity levels

	Total conflicts per technique				Total number of "common"
Intersection	Swedish	PET	USA	German	
Commercial-Grey	151	58	38	38	186
Pine-Field	133	64	14	27	171
Commercial-Albert	86	30	18	17	117
Totals	370	152	70	82	

Table 8.2 Recorded conflicts by each technique according to severity level

	Conflicts							
	Swedish		PET		USA	German		
Intersection	Serious	Slight	Serious	Slight		Serious	Moderate	Slight
Commercial-Grey	55	96	54	4	38	1	12	25
Pine-Field	46	87	47	17	14	0	8	19
Commercial-Albert	12	74	25	5	18	1	2	14
Total	**113**	**257**	**126**	**26**	**70**	**2**	**22**	**58**

From Tables 8.1 and 8.2, it is evident that a range of conflicts result when applying the techniques under identical traffic situations. The aim of this comparative analysis is to ascertain why differences arise in conflict recording.

8.2.1 General comparison

The first step in assessing the similarities between each technique was to compare the "common" and "unique" conflicts recorded by each technique. Tables 8.3, 8.4, and 8.5 contain the data for the comparisons of "common" conflicts for each of the three intersections. Tables 8.6, 8.7 and 8.8 contain the detailed data for the "common" and "unique" conflicts recorded by each of the techniques. All conflict severities are used in all tables in this section

The information given in Tables 8.3, 8.4 and 8.5 gives an indication of the relationship between the techniques with regard to the proportion of "common" conflicts recorded by each technique. All conflict severities (slight, moderate, serious) are used in this comparison.

Table 8.3 Percentage of "common" conflicts recorded, Commercial-Grey intersection

Technique	Swedish	PET	USA	German
% of Swedish conflicts recorded by each technique	100	26	14	22
% of PET conflicts recorded by each technique	69	100	36	52
% of USA conflicts recorded by each technique	55	55	100	55
% of German conflicts recorded by each technique	87	79	55	100

Table 8.4 Percentage of "common" conflicts recorded, Pine-Field intersection

Technique	Swedish	PET	USA	German
% of Swedish conflicts recorded by each technique	100	23	4	10
% of PET conflicts recorded by each technique	48	100	8	38
% of USA conflicts recorded by each technique	36	36	100	36
% of German conflicts recorded by each technique	48	89	19	100

Table 8.5 Percentage of "common" conflicts recorded, Commercial-Albert intersection

Technique	Swedish	PET	USA	German
% of Swedish conflicts recorded by each technique	100	17	6	13
% of PET conflicts recorded by each technique	50	100	17	30
% of USA conflicts recorded by each technique	28	28	100	28
% of German conflicts recorded by each technique	65	53	29	100

From Tables 8.3, 8.4 and 8.5 it is evident that the Swedish technique has the least number of conflicts in common with the other three techniques. The German technique has the highest number of conflicts in common with the other three techniques.

Tables 8.6, 8.7 and 8.8 contain the detailed data for the "common" and "unique" conflicts recorded by each of the techniques.

Table 8.6 Commercial-Grey Intersection – "common" and "unique" conflicts recorded by each technique

	Swedish	PET	USA	German	Total conflicts per category	Percentage of total:" common" plus unique conflicts
			"Common" Conflicts			
	*	*	*	*	21	11
	*	*		*	2	1
	*	*			17	9
	*			*	10	6
		*		*	7	4
Total					**57**	**31**
			"Unique" Conflicts			
	*				101	54
		*			11	6
			*		17	9
				*	0	0
Total					**129**	**69**
Total "common" plus "unique" conflicts					**186**	**100**
Total conflicts per technique	**151**	**57**	**38**	**38**		

Table 8.7 Pine-Field Intersection – "common" and "unique" conflicts recorded by each technique

	Swedish	PET	USA	German	Total conflicts per category	Percentage of total:" common" plus unique conflicts
			"Common" Conflicts			
	*	*	*	*	5	3
	*	*		*	7	4
	*	*			19	11
	*			*	1	1
		*		*	12	7
Total					**44**	**26**
			"Unique" Conflicts			
	*				102	60
		*			14	8
			*		9	5
				*	2	1
Total					**127**	**74**
Total "common" plus "unique" conflicts					**171**	**100**
Total conflicts per technique	**133**	**64**	**14**	**27**		

Table 8.8 Commercial-Albert intersection – "common" and "unique" conflicts recorded by each technique

	Swedish	PET	USA	German	Total conflicts per category	Percentage of total:" common" plus unique conflicts
			"Common" Conflicts			
	*	*	*	*	5	4
	*	*		*	1	1
	*	*			9	8
	*			*	5	4
		*		*	3	3
Total					**23**	**20**
			"Unique" Conflicts			
	*				66	56
		*			12	10
			*		13	11
				*	3	3
Total					**94**	**80**
Total "common" plus "unique" conflicts					117	100
Total conflicts per technique	**86**	**30**	**18**	**17**		

It is important from Tables 8.6, 8.7 and 8.8 to note that:

- The Swedish technique produces the highest proportion of unique conflicts (more than fifty per-cent) at all intersections.
- The Commercial-Albert intersection has the least number of recorded conflicts although an observation period fifty per-cent larger than for the other two intersections was used.

These variations are explained as follows:

The Swedish technique records conflicts based on an observable evasive action. The severity of conflict is recorded based on the speed of the road users at the moment of evasive action and the distance to a potential point of collision at the moment of evasive action – i.e. the recording of a conflict is based on the evasive action at only a single point in time and space. The Swedish technique records an event at the first "sign" of an evasive action (initial stages of a conflict). An event in the initial stages can be recorded as serious or non-serious by the Swedish technique irrespective of whether the outcome of the event (final stages of a conflict) leads to a non-serious encounter ("large" separation between road users) or serious encounter (small separations between road users).

At the three intersections studied, conflicts between turning vehicles and pedestrians were recorded. Typically, the drivers of the vehicles would initially brake upon noticing pedestrians. This was an "early reaction" to an impending conflict; hence this event would immediately be recorded by the Swedish technique. However, other techniques such as the PET, German and USA would not record this because these events could not be defined in terms of their conflict definitions. For example:

- The German technique does not records conflicts based on "early reaction" as with the Swedish. Instead the conflict situation is qualitatively assessed based on the seriousness of the evasive action (violent swerving and or braking) and audible indicators such as screeching of tyres. None of the "unique" conflicts recorded by the Swedish technique where applicable to the German definition.
- The American technique only records vehicle-pedestrian conflicts during the Red-Man traffic signal phase and the "unique" Swedish conflicts occurred during the Green-Man traffic signal phase.
- The PET technique only records the final stages of a conflict based on the post encroachment time – the time separation between two road users arriving at the same point in space. Consequently, the final (time) separations between the

road users in the "unique" Swedish conflicts were not applicable to the PET definitions for conflicts. According to the PET technique, a conflict with a PET value of less than 1,5 seconds is recorded as serious whereas a conflict with a PET value in the range of 1,5-3 seconds is recorded as non serious. The separations between road users were greater than three seconds therefore these conflicts are not recorded by the PET technique.

It is evident from this discussion that the Swedish conflict technique is only concerned with the initial stages of a conflict and only with the actions of the road users at a single point in time and space. However, it is contended that a "true" reflection of the seriousness of an event is the final separations in both time and space between road users. This gives a "true" indication of the closeness to an accident.

For analysis purposes, the Swedish technique uses only serious conflicts i.e. slight conflicts are discarded [Hydèn, 1987]. Another, key point to note is that although the Swedish technique produces the most number of "unique" conflicts, the question arises as to what proportion of the "unique" conflicts are non-serious – i.e. what proportion of the "unique" Swedish conflicts can be discarded?

The total number of "unique" conflicts recorded by the Swedish technique at all three intersections was 269. From these 269 "unique" conflicts, 189 were non-serious and hence only eighty conflicts were recorded as serious. A high proportion of Swedish "unique" conflicts are slight conflicts, which are not used in any analysis [Hydèn, 1987]. The key point to note is that it is the operational definition that accounts for the difference in conflict recording.

The low number of conflicts recorded at the Commercial-Albert intersection in comparison with the Pine-Field and Commercial-Albert is due to the low traffic volume conditions at the Commercial-Albert intersection. The vehicular and pedestrian volume at the Commercial-Albert is some thirty-five per-cent less than the traffic volumes at the Commercial-Grey and Pine-Field intersection.

This general comparison indicates that there are significant differences in conflict recording when using the various techniques. This is because of the difference in operational definitions used by each of the techniques as discussed in Chapter 5. However a simple listing of the "common" and "unique" conflicts cannot give an adequate explanation of the conflict variation and similarities between techniques. In order to achieve this, a detailed comparison between each pair of conflict techniques is necessary. It must be noted that the conflicts in Tables 8.3, 8.4, 8.5 include all conflict severities (slight, moderate, serious). For analysis purposes, both the Swedish and PET techniques use only serious conflicts i.e. slight conflicts are discarded [Allen et al, 1978; Hydèn, 1987]. The German technique uses only moderate and serious conflicts for analysis with slight conflicts being discarded [Erke, 1984]. The aim of the detailed analysis is to:

- Explain variation in the recorded conflicts
- Establish whether similarities exist between severity ratings for each of the techniques
- Establish similarities and/or differences between qualitative and quantitative techniques.

8.2.2 Comparison of Swedish and Post Encroachment Time techniques

For the Post encroachment time technique, conflicts with a PET value in the range of 0-1,5 seconds are recorded as serious. Serious conflicts in the Swedish technique are rated on a standard Time to accident (TA)-Speed graph using both the time-to-accident (TA) value and the speed of the road users (refer to Section 4.3). All serious conflicts recorded by the Swedish technique in this investigation had a TA value of less than 1,5 seconds.

As discussed in Section 4.2.1, the PET value used for the recording of conflicts is defined as the difference in time of two road users arriving at the same point in space (conflict/collision point). Essentially this is a separation between road users. Referring to Section 4.3.1 the TA value for the Swedish technique is defined as the time remaining to accident from the instant when evasive action is taken, presupposing that the road users continued with unchanged speeds and directions.

Table 8.9 contains a summary of the "common" conflicts recorded by both the Swedish and PET techniques for all three intersections – refer to Appendix D.2 for detailed data.

Table 8.9 Summary of "common" conflicts recorded by Swedish and PET

Intersection	"Common" conflicts recorded by Swedish and PET	Number of serious conflicts recorded by Swedish	Number of serious conflicts recorded by PET	Serious conflicts recorded by both Swedish and PET	Serious conflicts recorded by Swedish but non serious by PET	Serious conflicts recorded by PET but non serious by Swedish
Commercial-Grey	40	18	20	16	2	14
Pine-Field	31	16	24	13	3	11
Commercial-Albert	15	5	13	4	1	9
Total	**86**	**39**	**57**	**33**	**6**	**34**

From Table 8.9, it is evident that a significant number of conflicts recorded as serious by the PET technique are not recorded as serious by the Swedish technique and in addition, a low percentage of the conflicts were recorded as serious by both techniques.

Comparison of total serious conflicts

The data given in Table 8.10 makes a comparison between total serious conflicts and the "common" serious conflicts recorded by both techniques. The comparison contains the combined data for all three intersections.

Table 8.10 Comparison of total serious and "common" serious conflicts

	Swedish	PET	"Common" serious conflicts recorded by both techniques
Total serious conflicts recorded by each technique at all intersections	113	125	33

The information given in Table 8.10 indicates that only thirty-three "common" serious conflicts were recorded by both techniques. The Swedish technique recorded 80 serious conflicts that were not recorded by the PET. From these eighty conflicts, the PET recorded six (Table 8.9) of these serious conflicts as slight. Therefore this leaves seventy-four conflicts that were completely missed by the PET technique. The Swedish technique missed fifty-eight serious conflicts that were recorded by the PET technique.

The reason for the Swedish technique not recording conflicts that were recorded by the PET technique is due to the fact that in these situations, the road users involved took no evasive action. The Swedish technique only records conflicts when an observable evasive action is taken. Those conflicts that were recorded by the Swedish but not by the PET occurred when the vehicle drivers in these situations came to a stop and as a result, many other pedestrians crossed the collision point thereby resulting in the vehicle driver waiting for the pedestrians to clear the collision before proceeding. Consequently, the PET values in these situations tend towards "infinity" (PET > 5s).

Serious conflicts recorded by PET as non-serious conflicts by Swedish

In the recording of identical conflicts, there is a significant difference between these two techniques, as a high proportion of serious conflicts recorded by the PET technique are recorded as non-serious by the Swedish technique.

The variation is explained as follows:

These conflict situations are typically low speed situations in the order of 15km/h for vehicles and 5 km/h for pedestrians (refer to interaction data, Appendix D.3). In the majority of these situations the road user taking evasive action was the driver and in all situations, braking was used as the evasive action. In addition, the pedestrians at these intersections often yielded and allowed the vehicle to proceed through the intersection. This situation typically occurs when only one or two pedestrians are crossing the intersection. However, when a group of pedestrians are crossing (usually in the order of ten to fifty pedestrians), the opposite occurs (i.e. the driver has no option but to yield).

For the PET technique, the pedestrians would yield and allow the vehicle to proceed through the intersections. Consequently, in these situations, the pedestrians would be in close proximity to the passing vehicle and as soon as the vehicle had passed (the collision point), the pedestrian would immediately proceed (to enter the collision point) thereby creating a PET value of less than 1,5 seconds. Therefore, these events are recorded as serious conflicts by the PET technique. In these situations although the pedestrians and vehicle drivers appear to "understand" each other, the separation between road users in both time and distance are extremely small (typically, 0,5-1,4s and 0,5-1,2m). Maintaining such small separations are not appropriate from a "safety" point of view because, any error in judgement by either road user cannot easily be recovered or corrected for with such small time and distance separations available. These situations have a high probability of resulting in a collision. However, in the Swedish version of these conflicts the severity ratings are non-serious. This is due to the fact that the Swedish technique is only concerned with the "moment" the road users take evasive (at a single point in time and space). Consequently, in these events, the vehicle drivers would initially brake upon seeing the pedestrian and as soon as the driver notices the yielding of the pedestrian the driver would continue through the intersection. The important point in the foregoing statement is that the drivers would immediately brake upon seeing the pedestrian. This behaviour by the driver is precautionary. Consequently, this is "early" reaction by the driver upon noticing the pedestrian thereby resulting in a TA value greater than 1,5 seconds. This illustrates a possible concern with the use of the Swedish technique in that a conflict situation is based on a reaction (of road users) at only a single point in time and space. Essentially, the Swedish technique illustrates the initial stages of the conflict development and is not concerned with the final stages of the conflict situation. The initial stages are described as the perception, reaction and evasive manoeuvre to a conflict situation. The final stage of the conflict development is aptly described by the PET technique, which gives the "true" closeness to a collision. The final stages represent the outcome of the event, whether or not the road users take evasive action.

Serious conflicts recorded by Swedish as non-serious conflicts by PET

In the recording of identical conflicts, there is a minor difference between these two techniques, as a low proportion of serious conflicts recorded by the Swedish technique are recorded as non-serious by the PET technique.

The variation is explained as follows:

For the conflicts recorded by the Swedish technique, the vehicle drivers taking evasive action would come to a complete stop thereby resulting in the pedestrian clearing the collision point first. After the pedestrians had cleared this point, the vehicles would then proceed through the intersection. Consequently, the vehicles would accelerate from a stop and therefore would reach the collision point at a time greater than 1,5 seconds after the pedestrian. This results in these events being recorded as non-serious by the PET technique. In these situations, the PET technique misinterprets the severity of the conflict.

Comparison between PET and TA values for common serious conflicts

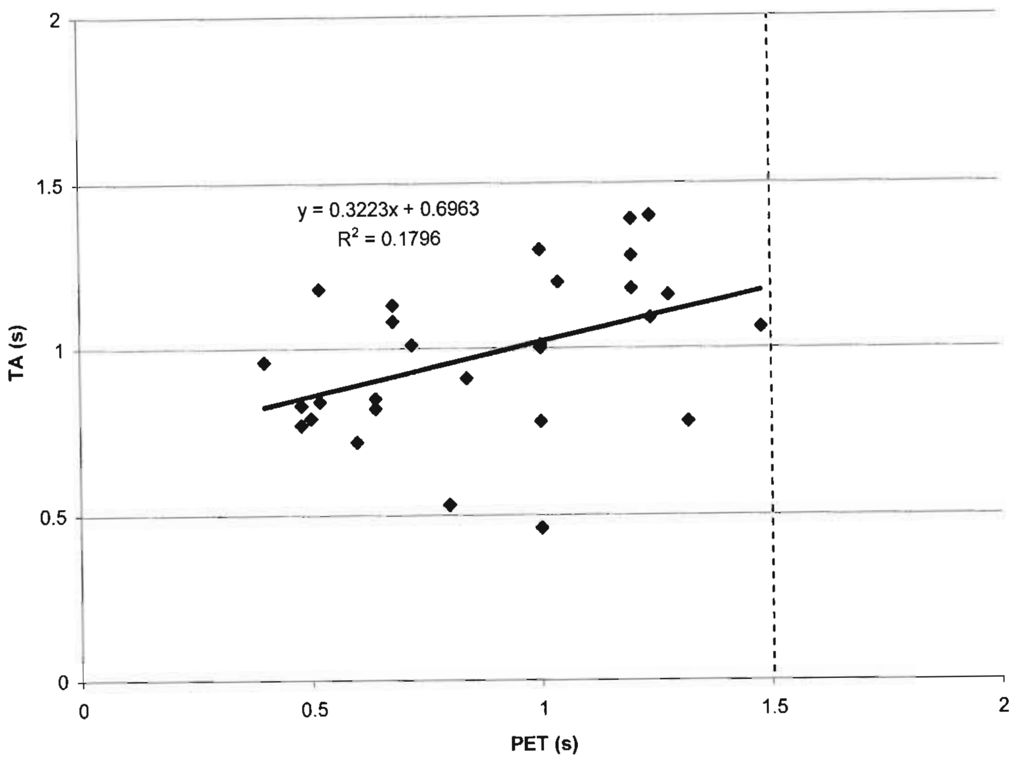


Figure 8.1 Plot of TA and PET for "common" serious conflicts

Figure 8.1 indicates a random variation between the TA and PET values for the "common" conflicts.

The following is a summary of the comparison between the Swedish and PET techniques:

- The Swedish technique cannot record dangerous traffic events that occur without evasive action.
- The Swedish technique is concerned with the initial stages of a conflict. Consequently, a conflict can be recorded as non-serious even if the final stages result in small separations between road users – noting that small separations indicate serious events.
- The Post encroachment time technique aptly describes the final stages of the conflict that is not covered by the Swedish technique.
- The PET technique can record a serious conflict as non-serious if the involved road users come to a stop and then proceed to clear the collision point.

However, if the road users come to a stop in a conflict situation and then wait for other road users (in this case pedestrians) to clear the collision point, the PET value would tend to "infinity" thereby resulting in the event not being recorded as a conflict – these situations are recorded by the Swedish technique.

Table 8.11 presents a summary of the differences in operational definition between the Swedish and PET techniques

Table 8.11 Differences in operational definition

	Evasive action	Near miss no evasive action	One road user completely stops
Swedish	*		*
PET	*	*	

The final step in comparing the Swedish and PET techniques was to ascertain what proportion of serious conflicts are not recorded due to the various flaws in the operational definitions as highlighted in the preceding discussion. In order to perform this analysis, **the number of conflicts recorded as being serious by one or more techniques (NSC**-"true number of serious conflicts") was calculated. Using the Swedish and PET techniques, the NSC is calculated as being the sum of the total serious conflict for both techniques minus the "common" serious conflicts. Table 8.12 contains the summary of the analysis for all three intersections.

Table 8.12 Quantitative summary of the flaws in operational definition

	Total serious conflicts	"Common" serious conflicts	NSC	Serious conflicts not recorded due to no evasive action	Serious conflicts not recorded due to one road user stopping	Serious conflicts not recorded due to recording of conflict in initial stages
Swedish	113	33	205	58		34
PET	125	33	205		80	

From Table 8.12, it can be inferred that the Swedish technique failed to record some thirty percent of the NSC because the road users took no evasive action and also seventeen percent due to the recording of conflicts based on only the initial stages. Therefore, the Swedish technique failed to record some forty-five percent of the NSC due to two flaws in the operational definition. The PET technique failed to record some forty percent of the NSC due to only one flaw in the operational definition.

8.2.3 Comparison of Swedish and German techniques

Table 8.13 contains a summary of the "common" conflicts recorded by both the Swedish and German techniques for all three intersections – refer to Appendix D.2 for detailed data.

Table 8.13 Summary of "common" conflicts for the Swedish and German techniques

Intersection	"Common" conflicts recorded by Swedish and German	Serious conflicts recorded by Swedish as slight by German	Serious conflicts recorded by Swedish as moderate by German	Slight conflicts recorded by Swedish as Slight by German	Serious conflicts recorded by both Swedish and German
Commercial-Grey	34	8	12	13	1
Pine-Field	13	3	6	7	0
Commercial-Albert	11	0	2	6	0
Total	**58**	**11**	**20**	**26**	**1**

Swedish serious conflicts = 32
Swedish slight = 26
German slight = 37
German moderate = 20
German serious =1

For analysis only moderate and serious conflicts are used by the German technique. The data in Table 8.13 indicates a significant difference in the "common" conflicts recorded by both techniques with regard to the severity rating. In addition, only one serious conflict was recorded by the German technique.

Both techniques adopt a similar approach to conflict recording in that an observable evasive action is used in identifying conflicts. However, qualitative descriptions are used by the German technique to record conflicts while the Swedish technique uses quantitative measures.

Analysing the operational definitions of serious conflicts discussed in Section 3.4.3 illustrates the "difficulty" in obtaining serious conflicts when using the German technique. The definitions of serious conflicts are as follows:

- Emergency braking or violent swerve to avoid a collision resulting in a very near miss situation or a minor collision
- Emergency action followed by collision

These definitions represent accident situations in many instances and as discussed in Section 2.2 accidents are rare and random events. Consequently, the German definition of serious conflicts describes accidents and as a result, serious conflicts are very nearly as rare an occurrence as accidents therefore resulting in extremely low number of serious conflicts.

The next step was to compare the German conflicts with the TA values recorded by the Swedish technique. Figure 8.2 is an illustration of the range of TA values for the "common" German conflicts. Appendix D.2 contains a detailed listing of the German conflicts and TA values.

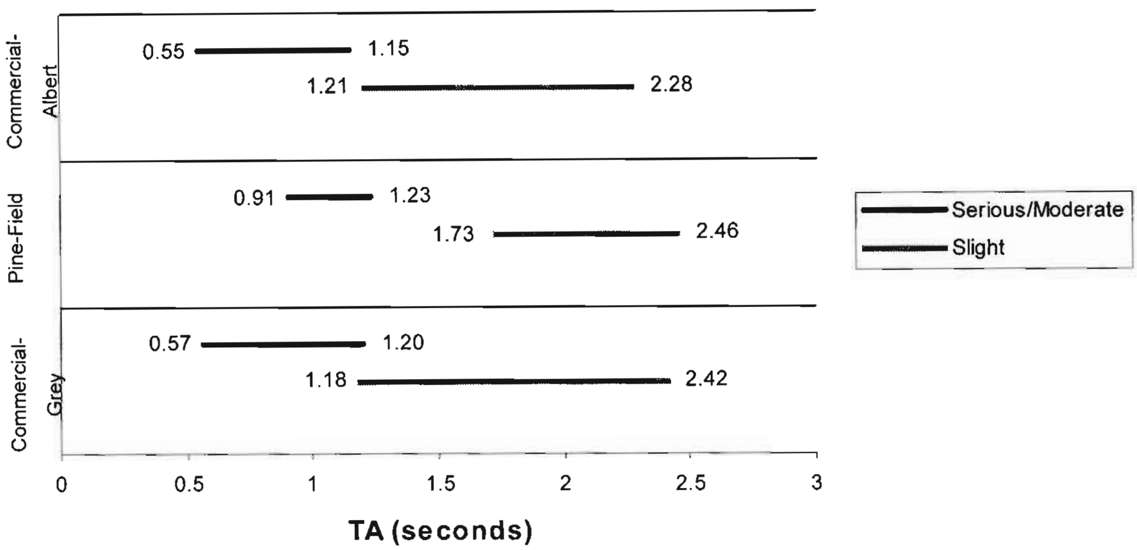


Figure 8.2 Range of TA values for the "common" German conflicts

All conflicts (twenty) recorded by the German technique as moderate were recorded as serious by the Swedish technique. In these conflict situations, the average TA value was 0,95 seconds. This value indicates that the German definition of moderate conflicts is actually serious. The definition of a moderate conflict is:

- Rapid deceleration, lane change or stopping to avoid a collision resulting in a near miss situation (no time for steady controlled manoeuvre)

It is contended that the above definition describes a potentially dangerous situation which ought to be described as a serious conflict. In this investigation, a TA value of less than 1,5 seconds represents serious conflicts according to the Swedish technique (refer to Section 8.2.2). The average TA value of 0,95 seconds for the German moderate conflicts illustrates a dangerous situation. A histogram of the TA values for the "common" German moderate conflicts is given in Figure 8.3. From Figure 8.3

twelve of the total (20) German moderate conflicts have a TA value in the range of 0,89 to 1,06 seconds.

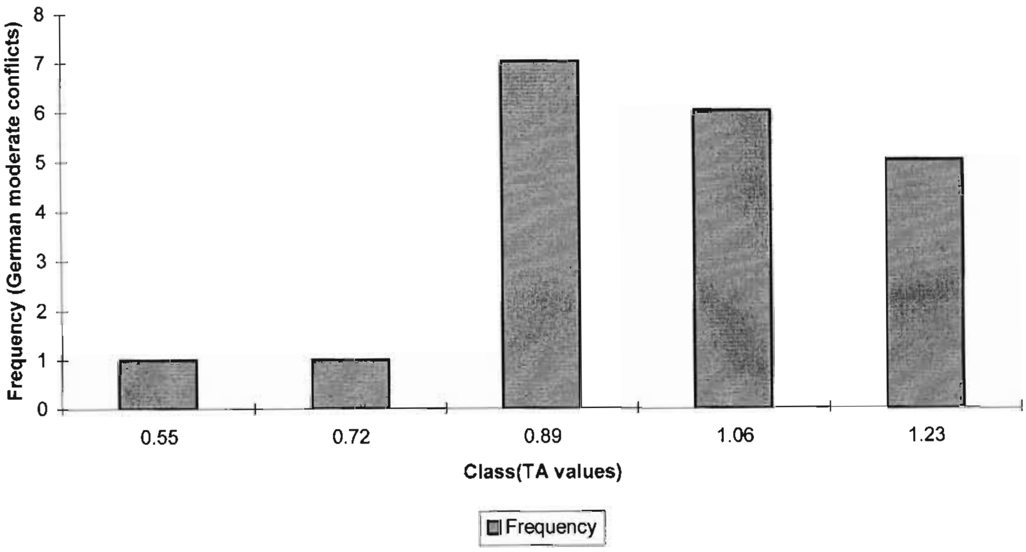


Figure 8.3 Histogram of German moderate conflicts according to the range of TA values

For comparison, the average TA value for slight conflicts was 1,72 seconds. All conflicts recorded as slight by the Swedish technique were also recorded as slight by the German technique. The German definition of a slight conflict is:

- Controlled braking or lane changing to avoid a collision but with ample time for manoeuvring safely

Figure 8.4 is a histogram of the TA values for the "common" German slight conflicts. From Figure 8.4, twenty-nine of the total (37) German slight conflicts have a TA value in the range of 1,44 to 2,05 seconds.

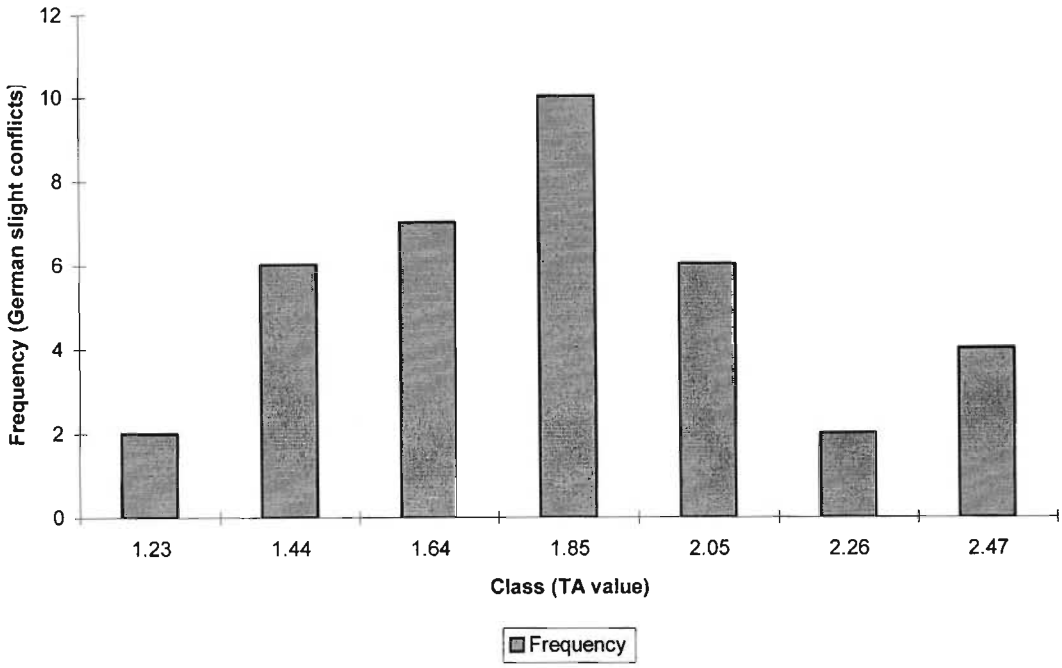


Figure 8.4 Histogram of German slight conflicts according to the range of TA values

The qualitative descriptions provided by the German technique for the various severity categories describe very serious traffic situations – situations that result in accidents (serious conflict) and situations that result in very near collisions (moderate conflicts). This was confirmed in the comparison between the German conflicts and the TA values. All moderate German conflicts, and a high proportion of slight conflicts (approximately 80%) are included under the Swedish serious threshold level of 1,5 seconds for serious conflicts.

The low number of conflicts recorded by the German technique in this investigation is due to the operational definition which describes very serious traffic situations.

8.2.4 Comparison of German and Post Encroachment Time techniques

Table 8.14 contains a summary of the "common" conflicts recorded by both the PET and German techniques at the three intersections studied – refer to Appendix D.2 for detailed data.

Table 8.14 Summary of "common" conflicts for the PET and German techniques

Intersection	"Common" conflicts recorded by both PET and German	Serious conflicts recorded by PET as slight by German	Serious conflicts recorded by PET as moderate by German	Slight conflicts recorded by PET as Slight by German	Serious conflicts recorded by both PET and German
Commercial-Grey	29	18	7	2	1
Pine-Field	24	9	8	5	0
Commercial-Albert	9	7	0	1	1
Total	**62**	**34**	**15**	**8**	**2**

PET serious conflicts = 52
PET slight conflicts = 11
German serious = 2
German moderate = 18
German slight = 42

Both techniques have different approaches to conflict recording in that the PET uses quantitative measures whereas the German technique uses qualitative descriptions. In addition, the German technique requires an observable evasive action to record conflicts whereas the PET does not.

The low number of German serious conflicts recorded is due to the operational definition as discussed in Section 8.2.3.

Figure 8.5 illustrates the range of PET values for the "common" German conflicts

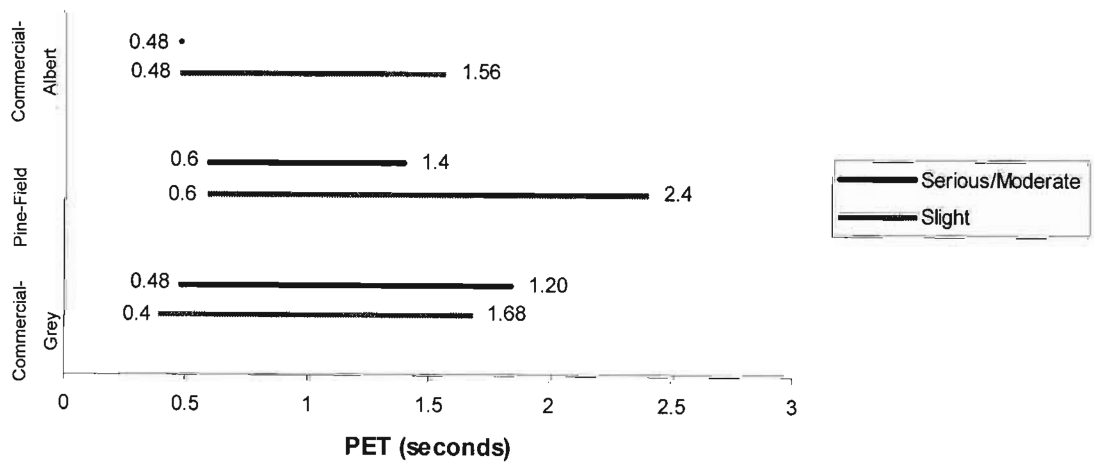


Figure 8.5 Range of PET values for the "common" German conflicts

From Figure 8.5 it is evident that there is no clear distinction between the PET values for slight and serious/moderate German conflicts and it appears that the PET values for slight and moderate/serious have similar magnitudes. The reason for the slight German conflicts being rated as serious by the PET technique is explained as follows:

The German technique uses visual and audible evidence to qualitatively record conflicts. In addition an evasive action is required. The German definition of moderate and serious conflicts are "stringent" – i.e. must have violent swerving, braking or screeching of tyres to record serious conflicts and in many of these situations, the evasive action was controlled braking which defines German slight conflicts. The German technique as compared with the Swedish is not concerned with the final separations between road users and hence can fail to record dangerous events. The final separation between road users is a "true" measure of the closeness to an accident that is aptly covered by the PET technique.

In the comparison between the PET serious conflicts and German moderate conflicts it was found that the average PET value for the moderate German conflicts is 0,9 seconds. This illustrates the previous concept as discussed in the comparison between the Swedish and German moderate conflicts - i.e. The German definition of moderate conflicts is similar to the Swedish and PET definitions for serious conflicts. However, these conflicts are "more" serious in nature in that the average TA and PET values for moderate conflicts are 0,95 and 0,90 seconds respectively. These time-based measures are approximately 0,58 seconds below the threshold level of 1,5 seconds for both the Swedish and PET techniques. A histogram of the PET values for the "common" German moderate conflicts is given in Figure 8.6.

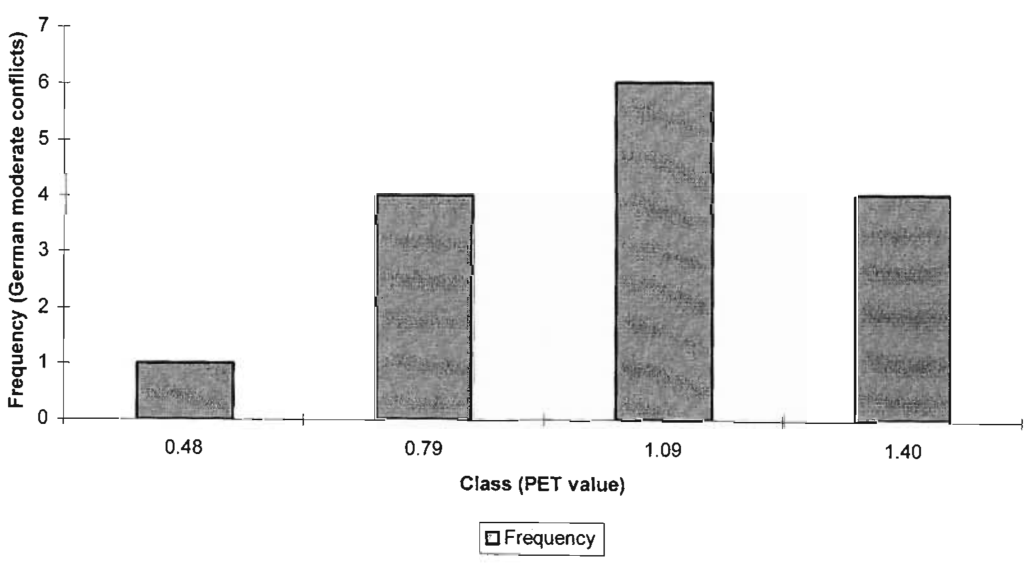


Figure 8.6 Histogram of German moderate according to the range of PET values

From Figure 8.6, sixty-eight per cent of the German moderate conflicts have PET values in the range of 0,79 to 1,09 seconds.

8.2.5 Discussion on Swedish, PET and German comparison

In Sections 8.2.2 and 8.2.3 the similarities and differences between the Swedish, PET and German techniques are discussed and it is shown that the difference in recorded conflicts is due to the operational definitions of each of the techniques. These definitions specify the types of traffic events that must be recorded as conflicts. Since each technique has different operational definitions, it can be expected that differences in conflict recording arise. Table 8.15 presents a comparison between the total serious/moderate conflicts for each technique and the **number of conflicts recorded as being serious by one or more of the three techniques (NSC** – "true number of serious conflicts"**)**. An example for the calculation of the number of conflicts recorded as being serious by one or more techniques (NSC) is as follows:

The Swedish technique recorded twelve serious conflicts at the Commercial-Grey intersections; however, it "failed" to record twenty-one of the serious conflicts recorded by the PET and one of the serious/moderate conflicts recorded by the German technique. Therefore this gives a total of thirty-four serious conflicts that should have been recorded.

Table 8.15 Comparison of serious conflicts and the number of serious conflicts recorded by one or more techniques (NSC)

	Total serious/moderate conflicts			NSC
Intersection	Swedish	PET	German	
Commercial-Grey	55 (59%)	54 (58%)	13 (14%)	93
Pine-Field	46 (58%)	47 (59%)	8 (10%)	80
Commercial-Albert	12 (35%)	25 (74%)	3 (9%)	34

The data given in Table 8.15 indicates a large proportion of NSC is not recorded by all three techniques. In addition, the quantitative techniques (Swedish and PET) record the largest proportion of the NSC. Depending on the use of the conflicts for analysis, the NSC can be significant or insignificant. For example, when calculating the risk, the

NSC should produce the "true" level of risk when compared with the individual conflict techniques. If the aim was to rank intersections according to the level of risk for remedial measures than the individual conflict techniques would produce a similar ranking order as would the NSC. The only difference would be in the magnitude of risk.

If the objective was to use conflicts to predict the number of accidents, this would be significant as the NSC would produce a "more" accurate prediction of accidents than the conflict techniques. Accidents are predicted from conflicts using the ratio of accidents to conflicts [Hydèn, 1987, Brown, 1994]. The prediction of accidents from conflicts is based on the use of accident data. As discussed in Section 2.2 accident data suffers from a range of drawbacks (unreliability, rare and random, accuracy and underreporting). Therefore it must be noted that the prediction of accidents is dependent on the quality of accident data (accidents cannot be accurately predicted using unreliable accident data).

Statistically, the conflict techniques can be tested to assess which technique would produce the highest proportion of NSC for a given conflict survey. The following test statistic is used (assuming that the data follows the *t* distribution):

$$T = \frac{\overline{X} - \mu}{s / \sqrt{n}} \sim t(n-1)$$

where $\overline{X}$ is the sample mean

n is the sample size (n=3, three intersections)

s is the standard deviation of the sample mean

The data from Table 8.15 was used to carry out the statistical test (hypotheses testing) at the 95 % confidence level of significance. A sample calculation is shown in which a null hypothesis (H_o) for the Swedish technique is tested against other hypotheses (H_1):

H_o = 0.5 (50%) vs H_1 > 0.5 (50%)

Reject H_o if $t > t_{3;0,95} = 2,535$

$$t = (0.506 - 0.5)/(0.133/\sqrt{3})$$
$$= 0.083 < 2,535$$

Ho cannot be rejected. It can be concluded that the Swedish technique would not record more than fifty per-cent of the NSC

Similarly various null hypotheses are chosen in order to find the maximum and minimum proportion (percentage) of NSC that each technique would record and is as follows:

- 32% < Swedish < 50%
- 50% < PET < 60%
- 7% < German < 11%

This statistical test indicates that the PET technique is the best suited for conflict recording because it has the highest proportion of the NSC. This is to be expected because this technique caters for "all" conflict situations (conflicts with or without evasive action). However, it must be noted that only vehicle-pedestrians conflicts are recorded and also, the high proportion of NSC recorded by the PET technique gives an indication of the road user behaviour at these intersections. At these intersections, it was noted that it is a common occurrence for pedestrians and vehicles to pass each other in close proximity (as discussed in Section 8.2.2) therefore resulting in a high number of PET serious conflicts. However, at other intersections, road users may not prefer to pass each other in close proximity and consequently, a low proportion of PET conflicts could be recorded. Therefore the proportion of NSC that is recorded by each technique is a function of the operational definition, which is also dependent partly on road user behaviour. It must be stated that if the operational definition is comprehensive (i.e. the definition caters for "all" situations- situations with or without evasive action) then road user behaviour cannot be considered as a variable in the recording of conflicts Therefore, the variation in conflict recording can be entirely attributed to the comprehensiveness of the operational definition. No single conflict technique is capable of recording all dangerous traffic situations.

Using the data from the three intersections, the number of conflicts not recorded due to flaws in the operational definition is given in Tables 8.16

Table 8.16 Summary of serious conflicts and the NSC

	Total serious/moderate conflicts	Percentage of conflicts not recorded due to operational definition	NSC
Swedish	113	45	207
PET	126	39	207
German	24	88	207

The values in parentheses are the percentages of the NSC

Table 8.17 contains the detailed description of the information given in Table 8.16

Table 8.17 Detailed data of the serious conflicts and the NSC

	Total serious/ moderate conflicts	Serious conflicts recorded by PET as non serious by	Serious conflicts recorded by Swedish as non serious by	Serious/moderate conflicts recorded by German as non serious by	Swedish serious conflicts that were missed by	PET serious conflicts that were missed by	German serious/moderate conflicts that were missed by	Total occurring conflicts
Swedish	113	36	-	0	-	55	3	207
PET	126	-	3	1	71	-	6	207
German	24	34	11	-	72	66	-	207

From Table 8.17 it is evident that the operational definition is the reason as to why conflict techniques do not record certain conflict situations

8.2.6 Comparison with the American technique

The American technique records the least number of conflicts when compared to the Swedish, German and PET techniques (refer to Tables 8.1 and 8.2). In addition, the American technique is the only technique not to use a severity scale for conflict recording. Consequently, direct comparisons cannot be made with the Swedish, German and PET techniques.

The American definition for pedestrian conflicts is such that conflicts are only recorded when the vehicle driver has right of way. Referring to Section 3.3.4 a pedestrian conflict is defined as follows:

Occurs when a pedestrian (the road user causing the conflict) crosses in front of a vehicle that has the right-of-way, thus creating a possible collision situation. Situations in which the pedestrian has right-of-way, *such as WALK phases (green man phase) are not considered as conflicts.*

At the intersections studied in this investigation, interactions occur with turning vehicles and pedestrians during the "Green-Man" traffic signal phase. Consequently, conflicts can only be recorded using the American definition (for vehicle-pedestrian conflicts) during the "Red-Man" traffic signal phase. The low number of conflicts recorded by the American technique illustrates that a minority of the pedestrians walk during the "Red-Man" phase. The minority of pedestrians creates fewer chances for interactions to occur with vehicles. Table 8.18 contains the percentages of the "common" Swedish, PET and German and American conflicts.

Table 8.18 Comparison with American technique

	Swedish	PET	German
Percentage of "common" USA conflicts recorded by each technique	8.4	21	38

The percentages given in Table 8.18 indicate that a low proportion of American conflicts are recorded by each of the techniques with the exception for the German technique. It can be expected that the German technique recorded the most number of conflicts that are common to the American technique. This is due to the fact that both techniques adopt a similar approach to conflict recording in that they both use visual and audible evidence to qualitatively record conflicts. The Swedish technique records the least number of conflicts that are common to the American technique. This can be expected since the American technique does not require road users to take evasive action, which is a prerequisite for the Swedish technique.

Due to the definition of pedestrian conflicts in the American techniques (right-of-way given to vehicle driver), the American technique is not suited for recording vehicle-pedestrian conflicts.

Except for vehicle-pedestrian conflicts it can be expected that the American definition would record the most number of conflicts when compared to any other technique due to the following:

- A severity scale is not used resulting in "all" conflicts (slight, moderate, serious) to be recorded and used in the analysis
- The definition is such that for a conflict to be recorded it suffices that the actions of one road user endangers the other of being involved in a conflict irrespective of whether the endangered road users are aware of the situation or take evasive action.

8.3 Estimating risk using conflicts and traffic parameters

The aim of this section is to provide a brief analysis of using risk models. The basic models using only traffic flow data are calibrated. The models are based on the data obtained from the conflict studies and are merely used to illustrate an alternative approach to estimating the level of risk. In addition, these models illustrate the difference between the conflict techniques with regard to the relationship of conflicts and traffic stream parameters.

8.3.1 Linear Models

Linear models typically use traffic flow data, (in this case pedestrian and vehicles volumes) to establish a relationship between conflicts. These models provide an estimate of the expected conflict rate at similar locations (intersections). This rate is used to rank intersections according the level of risk in cases where accident data are unavailable or insufficient (for statistical purposes) and also to check the effectiveness of remedial measures. The advantage of using these models is that short-term observations (i.e. conflict recording) give an estimate of the level of risk at intersections without waiting for accidents to occur. An example of this model type is an assumed linear relationship between the conflict rate and the square root of the product of the conflicting manoeuvres. Spicer, Wheeler and Older [1980], and Salman and Al-Maita [1995] found that the total number of conflicts is proportional to the square root of the product of the conflicting volumes.

The following conflict models were devised in this study based on the total number of serious conflicts and pedestrian and vehicle volumes recorded at all three intersections. The following conflict-volume relationships were established:

Swedish

$C_S = 10.60PV - 1.08$ (R = 0.57) (8.1)

American

$C_A = 6.74PV - 0.76$ (R = 0.6) (8.2)

Post Encroachment Time

$C_{PET} = 6.10PV + 1.41$ (R = 0.35) (8.3) where

C_i is the hourly conflict rate

PV is the square root of the product of the hourly conflicting manoeuvres (pedestrian and vehicle volumes)

The correlation coefficients obtained were 0,57; 0,6 and 0,35 using conflict data from the Swedish, American and PET techniques respectively. Figures 8.7, 8.8 and 8.9 represent the plots of the conflict-volume relationships for each technique. The German technique had no correlation and was discarded from further study. Admittedly, the sample size is small and as stated earlier, the models are only a guide to illustrate the type of relationship between conflicts and traffic flow data and the estimates of conflict rates. Many researchers (Spicer, Wheeler and Older [1980], and Salman and Al-Maita [1995], Sayed and Zein [1999]) using the conflict volume relationship have quoted high correlation coefficients. However, these correlation coefficients were obtained using the total conflict types at intersections. Hence, no exclusive relationship between specific conflict types such as the left-turning vehicle-pedestrian was established. Research performed by Massound and Senevirante [1991] established relationships for turning vehicles and pedestrians. These models are more sophisticated and did not make use of square root of the product of the conflicting manoeuvres but instead used variables such as time to cross the intersection along with the green phase time for pedestrians and volume data.

The models developed in this investigation indicate that the conflict rate increases with increasing interacting volumes. As the volumes increase, it is expected that the interaction rate between vehicles and pedestrians increases thus creating more chances for the occurrence of conflicts. The usefulness of these models is that they provide engineers with the facility to estimate the level of risk using traffic stream parameters. Therefore, for a given number of intersections, they can be ranked in terms of level of risk using easily measurable traffic flow parameters.

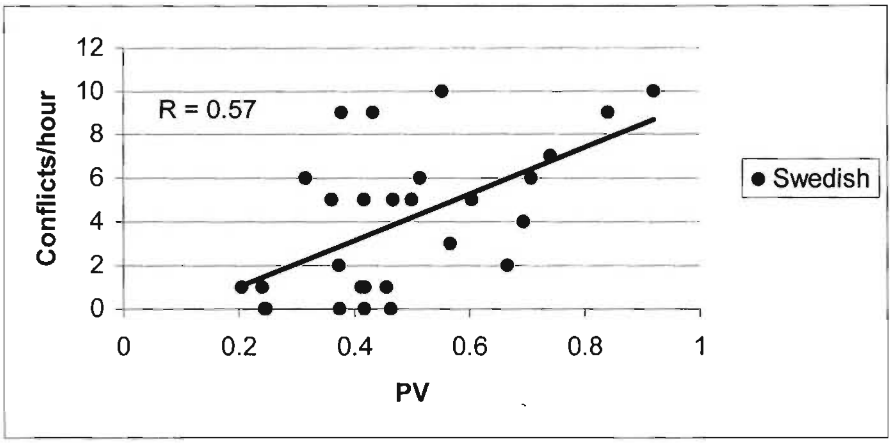


Figure 8.7 Conflict-volume relationship for Swedish technique

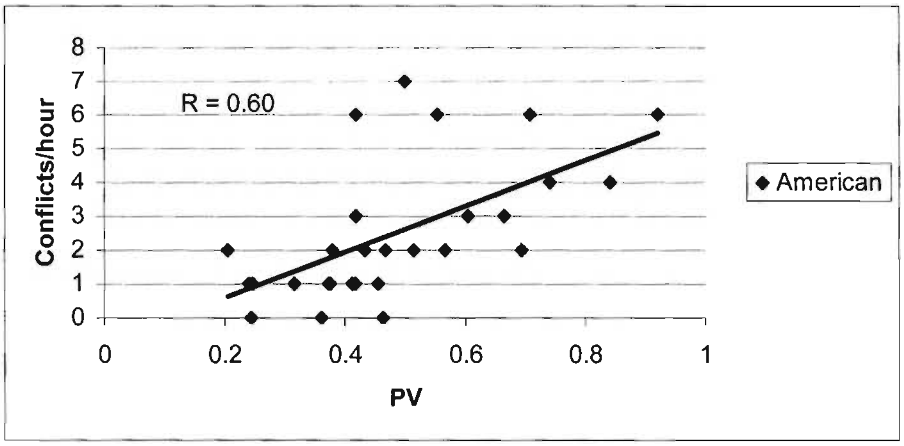


Figure 8.8 Conflict-volume relationship for American technique

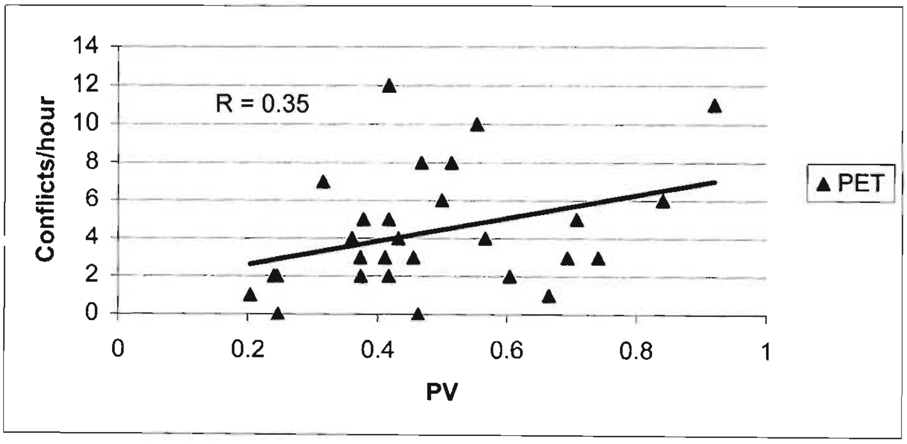


Figure 8.9 Conflict-volume relationship for PET technique

An alternative approach to rank sites by risk is to use the ratio between conflicts of the traffic flow data:

$$Risk_1 = conflicts/(Vp.Vv)^{0.5} \quad (8.4)$$

where

Vp is the hourly pedestrian volume

Vv is the hourly vehicle volume

Table 8.19 Estimated risk for each intersection and for each conflict technique

Intersection	Accident-Risk (Conflicts/(Vp.Vv)$^{0.5}$)x 10^{-4}		
	Swedish	PET	USA
Pine-Field	139	141	39
Commercial-Grey	103	97	73
Commercial-Albert	19	34	26

Equation 8.4 gives the level of risk for both vehicle drivers and pedestrians simultaneously. However, the individual risk per road user can be calculated as follows:

$$Risk_i = total\ conflicts/total\ traffic\ volume_i$$

Where i is the road user type, for example pedestrian or vehicle driver. For this risk calculation total serious conflicts (per technique) and total road user traffic volumes were used.

Table 8.20 Pedestrian Risk

Intersection	Risk (x 10^{-4})		
	Swedish	PET	USA
Pine-Field	82	73	25
Commercial-Grey	57	53	39
Commercial-Albert	8.2	17	12

Table 8.21 Vehicle Driver Risk

Intersection	Risk (x 10^{-4})		
	Swedish	PET	USA
Pine-Field	190	195	58
Commercial-Grey	175	169	121
Commercial-Albert	87	180	130

The information given in Tables 8.20 and 8.21 indicates the level of risk experienced by pedestrians and vehicle drivers. The risk is given in units of conflicts per road user. Typically, a value of 82×10^{-4} (Table 8.20) indicates that one in 122 pedestrians are involved in a serious conflict. At all intersections, the vehicle driver is at a higher level of risk than the pedestrian risk. This is to be expected because the pedestrian volume is some three times the vehicular volume at the Commercial-Grey and Pine-Field intersections while it is some ten times the vehicular volume at the Commercial-Albert intersection.

A further step in estimating the level of risk at intersections is to use accident prediction models. An accident prediction model developed by Gårder [1989] (as discussed in Section 2.5.1) was used to perform this analysis. This model was selected because it was developed specifically for the prediction of accidents between turning vehicles and pedestrians. Table 8.22 and Table 8.23 provide the ranking of the three intersections according to Gårder's [1989] accident model and accident data respectively.

Table 8.22 Ranking sites according to predicted accident rate for Gårder [1989] model

Intersection	Predicted Accidents (accidents/day) $\times 10^{-4}$
Commercial-Grey	5.6
Pine-Field	3.7
Commercial-Albert	2.1

Table 8.23 Ranking intersections by accident data for vehicle-pedestrian accidents [Durban City Engineers, Traffic Studies Department]

Intersection	Accident Counts					Average* Accidents/year
	1997	1998	1999	2000	2001	
Commercial-Grey	6	5	6	3	8	5.6
Pine-Field	3	4	2	6	5	4
Commercial-Albert	1	2	0	8	7	3.6

*Only slight, serious and fatal accidents are considered

A summary of the various risk estimates is presented in Tables 8.24 and 8.25

Table 8.24 Comparison of risk estimates

Intersection	**Average accidents per year**	**Predicted accidents per day X 10^{-4} (Garder, 1989)**	**Risk** (Conflicts/$(Vp.Vv)^{0.5}$)x 10^{-4})			**Pedestrian Risk** (conflicts/pedestrian) x10^{-4}			**Vehicle Driver Risk** (conflicts/pedestrian) x10^{-4}			**Conflicts (per eight hour obserbation)**		
			Swedish	PET	USA	Swedish	PET	USA	Swedish	PET	USA	Swedish	PET	USA
Pine-Field	4	3.7	139	141	39	82	73	25	190	195	58	133	64	14
Commercial-Grey	5.6	5.6	103	97	73	57	53	39	175	169	121	151	57	38
Commercial-Albert	3.7	2.1	19	34	26	8.2	17	12	87	180	130	43	18	12

Table 8.25 Normalised data for risk estimates

Intersection	**Average accidents per year**	**Predicted accidents per day X 10^{-4}**	**Risk (Conflicts/$(Vp.Vv)^{0.5}$)x 10^{-4})**		**Pedestrian Risk (conflicts/pedestrian) x10^{-4}**		**Vehicle Driver Risk (conflicts/pedestrian) x10^{-4}**		**Conflicts (per eight hour observation period)**	
			Swedish	PET	Swedish	PET	Swedish	PET	Swedish	PET
Pine-Field	100	100	100	100	100	100	100	100	100	100
Commercial-Grey	133	151	74	69	70	73	92	87	114	89
Commercial-Albert	88	57	14	24	10	23	46	92	32	28

Table 8.25 contains normalised information for the data given in Table 8.24. Due to the flaws inherent in the American definition, only, the Swedish and PET techniques are considered.

The data given in Tables 8.24 and 8.25 indicates the ranking of sites in terms of risk when using various risk estimates, predicted accidents and accident data. It is important to note that Pine-Field has the highest level of risk followed by Commercial-Grey and Commercial-Albert when using the various risk estimates for the Swedish and PET techniques. All methods (risk, predicted accidents and accidents counts and conflicts) rank Commercial-Albert with the least level of risk. The accident counts and predicted accidents rank Commercial-Grey with the highest level of risk followed by Pine-Field. The differences in the number of conflicts recorded by each technique accounts for the variation in the ranking of the intersections. However, as discussed in Section 8.2, various techniques produce a range of conflict counts, which is due to the differences in definitions. It is important to note that although ranges in conflicts occur, the ranking of intersections are similar. There is no concern with regard to the ranking of the Commercial-Albert intersection in that all conflict techniques, accidents and predicted accidents rank Commercial-Albert intersection with the lowest level when compared to the other two intersections. Conflict techniques although different from each other produce similar results in terms of ranking intersections according to the level of risk. A major advantage of using conflict techniques is that short-term observations give an indication of the level of risk at intersections. This can then be used to prioritise intersections for remedial measures.

8.4 Swedish severity hierarchy approach

This analysis shows the distribution of the interactions (vehicle-pedestrian conflicts) with regard to the severity of the conflicts ranging from severity levels 1-30 (as shown in Figure 8.10) with, the aim of producing the severity hierarchy for each intersection.

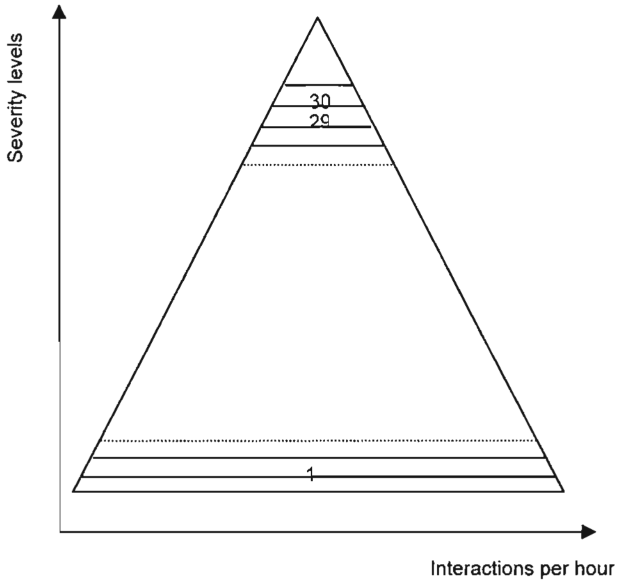


Figure 8.10 Hypothetical severity hierarchy defining various severity levels as defined by Svensson [1998].

From the conflict data obtained for the three intersections, the interactions between road users (vehicles and pedestrians) were used to determine the severity of the event with regard to the criteria proposed by the Swedish TCT and Svensson [1998]. The aim of the data collection was to collect at least 100 interactions at each intersection for the movement under investigation as outlined by Svensson [1998]. The analysis describes the interaction distribution for the intersections from a road users perspective in terms of the likelihood of being involved in an interaction with a certain severity level if exposed to the situation on n occasions.

Figure 8.11 illustrates the distribution of the interactions at the three intersections (refer to Appendix D.3 for complete listing of all interactions).

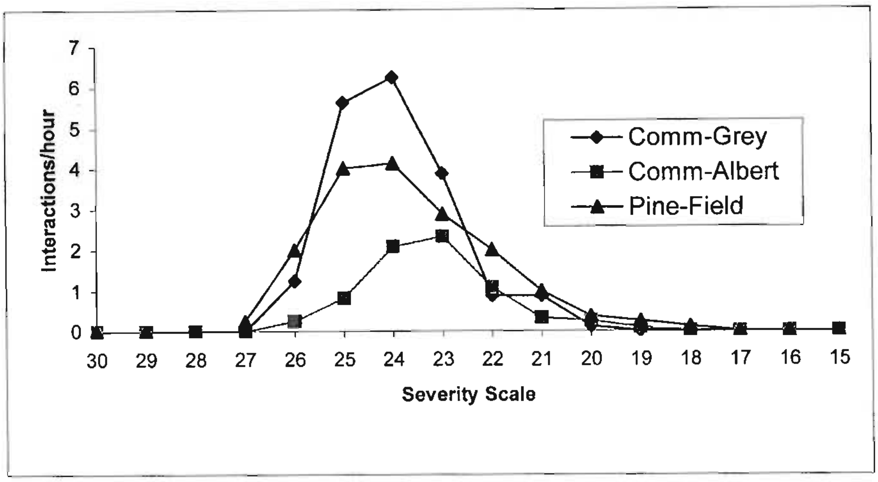


Figure 8.11 Combined graphs for the three intersections

It is can be seen from, Figure 8.11 that there are no observations for severity levels lower than ten. This can be explained as follows:

Consider an event with a severity level of 10 (refer to Figure 4.16). A driver approaching with a speed of 30km/h and a TA-value of 9 seconds would be 75 metres from the collision point and a pedestrian approaching with a speed 6km/h and a TA-value of 8,5 seconds would be 14 metres from the point of collision. This example illustrates the requirements for obtaining severity levels of ten and lower. Clearly, for the interaction under study (left-turning vehicle-pedestrian manoeuvre), it would be a rare occurrence to obtain events with severity levels of ten and less.

From Figure 8.11, it is evident that similar intersections with regard to control produce similar hierarchy shapes for the same type of manoeuvre under investigation. The "mode" (points with the highest number of interactions per hour) of all the curves is located at similar severity levels; therefore it is reasonable to assume that the curves belong to similar distributions.

The Kolmogorov-Smirnov test (KS-Test) was used to determine whether the statistical properties of two datasets differ significantly from each other. Svensson [1998] used the KS-test for testing the similarities between various hierarchies. The KS-Test has the advantage in that it makes no assumption about the distribution of the data. The interaction per hour for each intersection was tested against each other to assess whether the distributions differ significantly from each other. The Kolmogorov-Smirnov D value is the largest absolute difference between the cumulative distributions of two data sets. The D-value of two data sets is calculated and then compared with the *critical D value*. For the test, the null hypothesis states that the distributions belong to the same distribution, i.e. the distributions are identical. The procedure is to rank the data in ascending order and to calculate the cumulative frequencies for both data sets. The largest difference between the samples represents the KS D-value. The critical value is calculated using the significance level and the sample size. The null hypothesis is rejected if the D value is greater than the critical value and hence, the distributions are not identical. For this investigation, the 95% significance level is used.

The critical D value can be calculated as follows [Lindgren, 1965]:

$$Dc = \begin{cases} 1.22Y \text{ for } 90\% \text{ significance level} \\ 1.36Y \text{ for } 95\% \text{ significance level} \\ 1.63Y \text{ for } 99\% \text{ significance level} \end{cases} \quad (8.6)$$

where $Y = \sqrt{\frac{n1 \times n2}{n1 + n2}}$ with n1 and n2 the number of data points in the two samples

Table 8.26 Kolmogorov-Smirnov Test results

Intersection	D	Critical D	Accept/Reject
PF-CG	0.3	2.63	Accept
PF-CA	0.3	2.87	Accept
CG-CA	0.3	2.52	Accept

PF – Pine-Field
CG – Commercial-Grey
CA – Commercial-Albert

According to the KS-Test (Table 8.26), the distributions are similar. Therefore, the assumption that similar intersections with regard to control, layout and design produce similar hierarchy shapes when studying the same manoeuvre holds true for this investigation. Svensson [1998] concluded similar results when comparing the similarities of hierarchy shapes at similar intersections. However, Svensson [1998] noted that there could be differences between the distributions, due to factors such as traffic flows, details of the design and signal control of the intersections.

The KS-Test, confirms that the distributions of the conflict severities of the three intersections are similar. However the interaction patterns, i.e. the interactions per unit time, vary between intersections. The "mode" of the Commercial-Grey curve is greater than that of Pine-Field and Commercial-Albert curves. The traffic volumes at these intersections account for the difference in the number of interactions recorded. On average, the pedestrian and vehicular traffic volumes at the Commercial-Grey intersection are some thirty per-cent greater than the Pine-Field intersection and some seventy per-cent greater than the Commercial-Albert intersection.

8.4.1 Shapes of the severity hierarchy

The interactions per hour (vehicle-pedestrians conflicts) at various severity levels obtained from the conflict survey at the three intersections are given in Table 8.27 (refer to Appendix D.3 for complete listing of analysis). The data given in Table 8.27 is given in terms of interactions per hundred hours per severity level.

Table 8.27 Interactions per hundred hours per severity level at the three intersections.

	Interaction frequency per severity level Interactions per hundred hours		
Severity Level	Pine-Field	Commercial-Albert	Commercial-Grey
27	25	8	-
26	200	25	125
25	400	83	563
24	412	208	625
23	287	233	388
22	200	108	88
21	100	33	88
20	38	25	13
19	25	8	-
18	13	-	-

Figure 8.12 is an illustration of the severity hierarchies produced from the interaction data (Table 8.27). The severity hierarchy is a "distribution" of the interactions per hour at each severity level

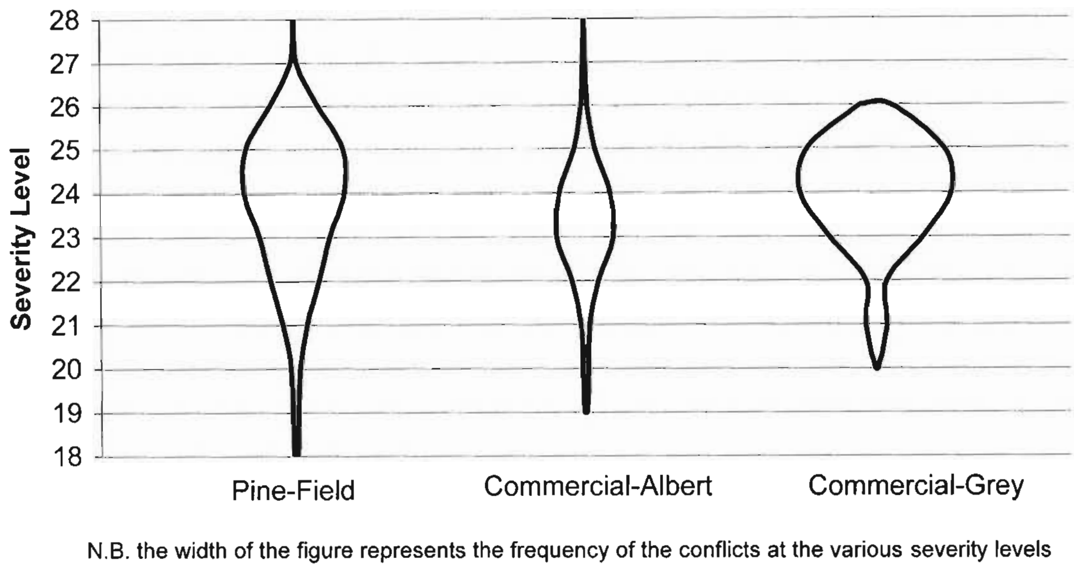


Figure 8.12 Severity hierarchies for the three intersections

The severity hierarchies developed for the three intersections reveal information of the traffic safety situation at these intersections. What these shapes mean and their relation to the safety situation (risk) is discussed as follows.

The "mode" (points with the highest number of interactions per hour) of the hierarchy describes the "normal road user behaviour" at the intersections for the specific manoeuvre under investigation. For the Pine-Field intersection, the "mode" is located at severity levels twenty-four and twenty-five. In the Swedish conflict technique, severity levels twenty-five and greater represent serious conflicts. Hence, the "mode" of this hierarchy is located at the serious level indicating that the road users are at a high level of risk at this intersection and there exists a high potential that once there is an interaction, the outcome could be severe. The highest severity level for Pine-Field is twenty-seven with a frequency of twenty-five per hundred hours. At the same time, severity levels twenty-four and twenty-five have the highest interactions per hundred hours - 412 and 400 respectively. The severe to non-severe interaction ratio at this site is 0,58 thus representing a potentially dangerous site for the left turning vehicle-pedestrian manoeuvre.

The "mode" of the Commercial-Albert hierarchy is located predominantly over levels twenty-three and twenty-four and with a significant amount of interactions also located at level twenty-two. The "normal behaviour" at this intersection is not serious, because the "mode" is located below the serious level (level twenty-five) and the severe to non-severe interaction ratio at this site is 0,19. The highest severity level at this intersection is level twenty-six with a frequency of eight interactions per hundred hours.

At the Commercial-Grey intersection, the "mode" of the hierarchy is distributed between levels twenty-five, twenty-four and twenty-three with severity level twenty-five having the largest frequency of interactions. The highest severity level for this intersection is level twenty-six with a frequency of 125 interactions per hundred hours. The severe to non-severe ratio is 0,57. Again, this represents a dangerous location for road users to be involved in an interaction.

The risk experienced by each road users (pedestrians and vehicle drivers) at each severity level can be calculated using the ratio of the number of interactions at each severity level to the traffic volume. Table 8.28 contains the risk estimate for both pedestrians and drivers at each severity level.

Table 8.28 Risk estimate at each severity level

Severity Level	Pedestrian risk X 10^{-4} Pine-Field	Vehicle risk X 10^{-4} Pine-Field	Pedestrian risk X 10^{-4} Commercial-Albert	Vehicle risk X 10^{-4} Commercial-Albert	Pedestrian risk X 10^{-4} Commercial-Grey	Vehicle risk X 10^{-4} Commercial-Grey
27	3.6	8.3	0.7	7	-	
26	29	66	2	22	10	32
25	57	133	7	72	47	143
24	59	137	17	180	52	159
23	41	96	19	202	32	99
22	29	66	9	94	7	22
21	14	33	3	29	7	22
20	5	12	2	22	1	3
19	3.6	8	0.7	7	-	
18	1.8	4	-		-	

The data given in Table 8.28 indicates that the vehicle drivers are at a higher level of risk compared with pedestrians. At the Pine-Field and Commercial-Grey intersections, the level of risk experienced by vehicle drivers is approximately three times the risk experienced by the pedestrians. However, at the Commercial-Albert intersection, the level of risk experienced by the vehicle drivers is approximately ten times the pedestrian risk. This is due to the ratio of the pedestrian and vehicle volumes as discussed in risk estimation given in Tables 8.20 and 8.21. Considering only the serious events (i.e. levels twenty-five and greater), the intersections of Pine-Field and Commercial-Grey have the highest level of risk followed lastly by Commercial-Albert.

The severity hierarchy is constructed based on the number of interactions (conflicts) per unit time per severity level. The severity of the events is a function of the speeds and time to accident (TA) values of the road users. Knowing that the intersections are similar in layout and control and that the hierarchies are similar (KS-Test), the question arises as to whether the seriousness of the events could be governed entirely by speed. The TA value decreases with increasing severity level and the interactions in this investigation indicates that the speed increases with increasing severity level. If the severity of the conflict is governed entirely by speed, then it would be reasonable to assume that the distance at which vehicle drivers perform the evasive action would be similar at each intersection. Table 8.29, contains the average speeds for the interactions at each severity level at the moment the vehicle drivers take evasive action (refer to Appendix D.3 for complete listing of interactions).

Table 8.29 Average speeds for vehicles at the moment of evasive action for various severity levels at the three intersections (km/h)

Intersection	Severity level						
	27	26	25	24	23	22	21
Pine-Field	23.01	19.27	15.94	17.62	14.53	13.71	10.42
Commercial-Albert	-	17.25	16.90	15.89	13.05	13.07	12.82
Commercial-Grey	-	19.93	15.30	13.57	10.95	10.74	9.31

Figure 8.13 represents a plot of the relationship between speed and severity levels for each of the intersections as given in Table 8.29. From Figure 8.13, it can be seen that the severity levels decrease with decreasing speeds. With the exception of the Pine-Field intersection, severity level twenty-five and twenty-four do not follow this trend but are closely related. However, the remainder of the severity levels adhere to this concept. At similar intersections, (with regard to control, layout, etc) it would be reasonable to assume that the severity of events at these locations is a function of the speed of the road users and as discussed in Section 8.4, the frequency of the events are a function of the conflicting volumes.

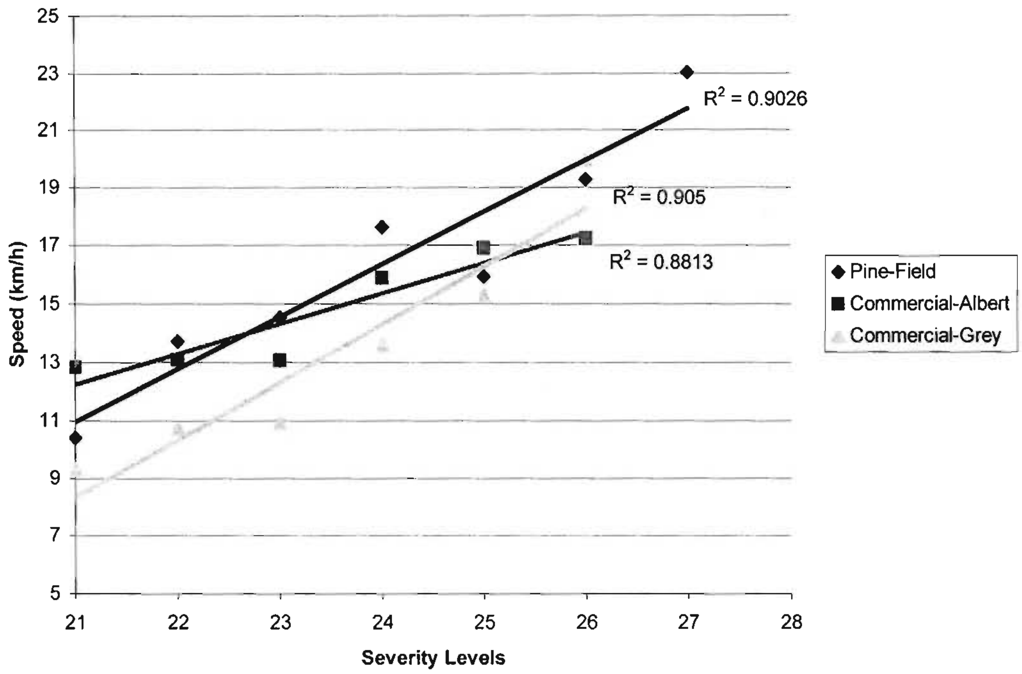


Figure 8.13 Speed-severity plots for all three intersections

The Commercial-Albert intersection sample size is small and is ignored. However, for the Commercial-Grey and Pine-Field intersections, the drivers take evasive action at a distance of 4m to 7m from the potential point of collision (refer to Appendix D.4 for calculations). Therefore, at these intersections, there exists a range (distance range) between which drivers seem to interpret an event as a possible serious encounter thereby requiring some sort of evasive action.

This investigation has indicated that safety is a function of speed and traffic volumes. Chapter 2 presents the many accident models and the parameters used in defining these models. All researchers in deriving these models agreed unanimously that speed and traffic volumes are key parameters in accident modelling and traffic safety studies.

8.5 Digital imaging in conflict studies

In this investigation, the development of a computer program using digital image processing and digital imaging equipment was used for the recording and analysis of conflicts. Digital imaging provided a useful tool for the analysis of conflict situations. The use of digital imaging in this investigation has enabled:

- Large number of conflict situations to be studied
- Accurate data collection for speeds, times. In addition, trajectories of movements were obtained
- Pedestrian movements are complex; consequently, direct observation is not suitable for accurately estimating the trajectories of pedestrians. However, this was easily achieved using digital image processing.
- Digital imaging removed the subjectivity of using direct observation and hence allowed for techniques to be compared on an equal basis.

In practice, direct observation is usually used for conflict studies. The number of observers required for conflict observation depends on several factors such as size of intersection, volume of traffic, number of traffic movements etc. Typically, two conflict observers are required for observation at an intersection. In addition to the conflict observers, other observers are required to record the traffic movements. Generally a team of four observers are required. Therefore a total of six observers are required per intersection. Typically, the cost of employing a team for a single intersection is approximately R2000, 00 for traffic volume counts and R 1000,00 for conflict observers [Durban City Engineers, 2001]. Therefore, the total cost would be R 3000,00 for a conflict survey.

The main reason for not employing the use of sophisticated equipment for conflict studies is due to the high resource expenses [Hydèn, 1987, Nel, 1989]. In addition, the use of video recordings together with the employment of digital imaging for analysis of conflicts events require that the camera be mounted high above the observation area, and an un-obstructive view is required. Another disadvantage is the area covered by the camera [Hydèn, 1987]. Also, the conflict data and traffic volume data have to be abstracted when using sophisticated equipment, which is normally a maximum of four days for detailed abstraction (minimum of three days). However, with direct observation, the conflict data are available immediately after observation and a complete analysis can be achieved in two days. It must be noted however, that direct observation cannot "guarantee" the accurate, detailed and large data abstraction that can be achieved when using sophisticated equipment.

Considering these disadvantages, the use of sophisticated equipment has many advantages as discussed in the beginning of the section. It seems that the advantages outweigh the disadvantages with regard to accuracy of data collection and the elimination of the subjectivity in recording conflicts. The cost of using sophisticated equipment when compared to direct observation appears to be the deciding factor.

The cost implications of using sophisticated equipment (digital imaging) as used in this investigation are as follows:

▪	Digital video camera with *Digital Video Port*	R20 000, 00
▪	Desktop computer	R 8 000, 00
▪	Capture Card (transferring video to computer)	R 400, 00
▪	Cable for transfer between computer and video	R 300, 00
▪	Total cost	**R28 700, 00**

In addition to the equipment, a computer program as developed in this investigation is required for analysing conflicts. In general the computer program is user friendly and can be used by any person with a basic knowledge of computer hardware and software.

A typical conflict survey would require an eight-hour observation period at an intersection. Digital video recording tapes (60 minute) for eight hours cost R 400, 00 (eight tapes). The data analysis (detailed conflict abstraction and traffic volumes) requires a maximum of four days. Typically using a life span of three years for all equipment, and analysing forty intersections per year would produce a cost of approximately R 240,00 per intersection (excluding cost of videotapes). Generally videotapes can be reused upon analysis of the intersections. Even with the use of new videotapes for each intersection, the cost would be R 640, 00 per intersection. Using the sophisticated equipment would require a guard to be present (at a cost of R 200, 00). Also traffic volume abstraction would require two observers (total cost of R 600,00) and conflict abstraction requires one person to operate the software (R 600,00). Therefore, the total cost of using sophisticated equipment is R 2040,00 (some thirty per-cent less than a conventional survey).

Digital imaging is cost effective and in addition allows for accurate and large abstraction of data, which is not possible when using direct observation. Therefore, it represents a viable operational tool for conflict recording and traffic safety studies.

8.6 Summary

The empirical testing of the conflict techniques confirms the conceptual differences between these techniques. The operational definitions of the techniques illustrate the requirements and criteria for recording conflicts. Each technique has different operational definitions and therefore, differences in conflicts counts arise.

The aim of the risk analysis is to provide an estimate of the accident risk at the intersections using conflict techniques, conflict models, accident models and accident data. Ultimately, the aim is to ascertain the level of risk at these intersections thereby ranking them in terms of "danger". The basic parameters defining accidents are speeds and traffic volumes. The analysis provides estimates of the probability of being involved in dangerous situations at all three intersections using various risk estimates and the severity hierarchy concepts. Further, the frequency of conflicts at these intersections was attributed to the conflicting volumes and the seriousness of these events is shown to be dependent on the speed of the vehicles, which was obtained using the severity hierarchy concept. The conflict models confirmed the relationship between the conflict rate and the conflicting volumes: – as traffic volumes increase, the number of conflicts correspondingly increase. Lastly, the ranking of the sites according to the level of risk showed similar results when using the severity hierarchy concepts, risk measures, accident prediction model and accidents data.

Digital image processing provides (in the case of this investigation) accurate speed and distance information that cannot be acquired using direct observation. Further, pedestrian movements are difficult to accurately record using direct observation as pedestrians can change direction, increase speed or stop almost instantaneously. Considering the cost implications and the accurate and large data abstraction achievable using digital imaging, digital imaging represents a viable operational tool in place of direct observation.

9 CONCLUSIONS

9.1 Summary of investigation

In this investigation, the evaluation of pedestrian safety (left turning vehicle-pedestrian interaction) using conflict techniques at intersections was studied. The main results of the research are presented in Chapters 3 to 7.

Firstly, in Chapters 3, 4 and 5, discussions on the conflict techniques are presented. Discussions are provided on the Swedish, Post encroachment time (PET), German and American techniques. Further, the applicability of conflict techniques to pedestrians are discussed along with the concepts of the extended Swedish conflict theory (severity hierarchy).

Secondly in Chapters 6 and 7 the data collection procedures along with the observation techniques for the empirical testing are discussed. Discussions on the use of digital image processing and photogrammetry techniques (rectification) are provided. The development of the conflict analysis software in this investigation was based on the use of these techniques. Finally the accuracy of the conflict software (with regard to the tracking of the road users) was been tested by introducing noise (statistically known as impulse noise) to reduce the quality of the images.

Finally, the analysis of the data (collected for the three intersections) was performed using the conflict techniques, severity hierarchy concepts, conflict models and accident models.

9.2 Summary of findings

The following list of findings resulted from either the literature survey or from the empirical testing. The findings are discussed in the same order as the structure of this dissertation.

- There are basically two schools of thought in traffic conflict techniques. Techniques that use qualitative descriptions and techniques that use quantitative measures (time based measures) for identifying and recording conflicts.

- A further division in the school of thoughts are those techniques in which evasive action is a prerequisite and techniques in which evasive actions of road users are not a prerequisite for conflict recording.

- The PET technique can lead to over estimation of the conflict severity especially in the case when a road user accelerates towards the completion of the evasive manoeuvre. Alternatively, the opposite can occur and the road user taking evasive action can completely stop thereby resulting in the PET value tending towards 'infinity' indicating no conflict.

- No conflict technique relates the severity of the conflict with the severity of the potential accident (slight-property damage or fatal). This is important in prioritising locations in terms of danger (level of risk).

- A time-based measure (quantitative techniques – TA and PET values) represents a direct relationship to accidents in that the closer the time measures to zero; the closer is the conflict to an accident. A time measure of zero indicates an accident.

- The Swedish technique is concerned with the initial stages of a conflict.
  - Consequently, a conflict can be recorded as non-serious even if the final stages result in small separations between road users – noting that small separations indicate serious events.

- The PET technique can record a serious conflict as non-serious if:
  - The involved road users come to a stop and then proceed to clear the collision point.

- The PET technique can completely miss a conflict if:
  - The road users come to a stop in a conflict situation and then wait for other road users (in the case of this investigation- pedestrians) to clear the collision point, the PET value would tend to 'infinity' thereby resulting in the event being ignored.

- The TA and PET values for common serious conflicts recorded are comparable in that the closer both time measures are to zero, the closer is the conflict to an accident.

- In effect, the German definition of serious and moderate conflicts describes accidents and this makes the occurrence of conflicts very nearly as rare and random as accidents – therefore a low number of conflicts are recorded (approximately eleven percent of the NSC (*number of serious conflicts recorded by one or more techniques as being serious)* was recorded)

- The American definition for pedestrian conflicts is biased in that conflicts are recorded only when the vehicle driver has right-of-way. Therefore a large proportion of conflicts are not recorded (approximately 88 percent of the NSC – "true number of conflicts" are not recorded).

- The number of conflicts recorded by the Swedish, PET and German techniques differ significantly from the NSC ("true number of conflicts") that should be recorded.

- Conflicts recorded by each of the techniques cannot be used for accurately predicting the number of accidents due to the difference with the NSC

- Statistical analysis carried out in this investigation confirms that the PET technique is best suited for conflict recording because it records the highest proportion (sixty percent) of the NSC followed by the Swedish (thirty-two to fifty percent) and German (seven percent) techniques

- All conflicts techniques produce similar results in ranking of intersections according to the level of risk. These results are comparable with the accident data and no major variation exists between conflicts and accidents in terms of ranking intersections according to the level of risk.

- Results from the analysis of conflicts have indicated that the conflict rate (conflicts/hour) is related to the conflicting volumes. The conflict rate increases with increasing traffic volumes.

- The severity of the conflict is a function of speed. Higher speeds produce more severe events.

- The use of digital image processing for analysing conflicts is extremely useful because accurate information on the speeds at various points in time, distances to potential point of collision and the trajectories of the road users are obtained. This information cannot be achieved using direct observation.

- Digital imaging due to its high accuracy can be used to eliminate the subjectivity involved in conflict recording when using direct observation.

- Using the digital image processing, it was noted that the drivers take evasive action at a distance of 4m-7m from the pedestrian crossing.

9.3 Conclusions

From the above findings the following can be concluded:

- Quantitative conflict techniques represent a direct relationship to accidents and can be used as a surrogate safety measure of risk.

- No single conflict technique is capable of recording all conflict situations due to the limitations of their operational definitions.

- It is the operational definition that is the only factor in the difference between the recorded conflicts and the NSC ("true number of conflicts").

- The Qualitative techniques (German and American) are not suited for conflict recording due to the fact that some eighty-eight percent of the NSC was not recorded.

- Conflict techniques although different from each other (in definition) produce similar results in ranking intersections according to the level of risk

- Traffic volumes and the speed of the road users influence the conflict rate and conflict severity. Increase in traffic volumes lead to an increase in the conflict rate similarly, an increase in speed results in an increase in the severity of the conflict.

- The large data abstraction and accurate information available when using digital imaging together with the relatively low cost makes it viable for use as an operational tool.

9.4 Recommendations and suggestions for future work

Due to the difference in recorded conflicts for each technique and the NSC ("true" number of conflicts), conflict techniques should be used to estimate the level of risk at intersections and not the number of accidents

A significant number of conflicts that should be recorded are ignored due to the shortfalls in the operational definitions of each technique. The shortfalls inherent in each technique can be corrected if the definitions of these techniques include definitions of other techniques not incorporated in their definitions. For example the Swedish technique observes conflicts based on evasive actions. Many dangerous situations occur with no evasive action taken by the road users. These situations are not recorded by the Swedish technique but are adequately catered for in the PET definitions. The Swedish technique in addition to their definition should incorporate the PET definition with regard to "no evasive" action needed for recording dangerous situations.

No conflict technique adopts a relationship between severity of the conflict and the severity of the potential accident situation. Since this has an important bearing on prioritising locations for safety remedies, the aim would be to include the severity of the potential accident as part of conflict recording. This can be achieved by using the speed of the road users.

The use of digital image processing has proved viable for the analysis of conflicts and hence this can be used on a more regular basis to assist with traffic safety studies. The aim in this context would be the recording of intersections for a week at say eight hours a day and apply digital imaging techniques to automatically detect dangerous situations and then produce a severity hierarchy for the intersections. This stage would involve the analysis of all movements at the interactions thereby producing a total severity hierarchy for the intersections.

APPENDIX A

This appendix contains the standard table for the accident prediction model developed by Gårder [1989] as well as the predefined conflict categories for the General Motors, American and German conflict techniques discussed in Chapter 3.

A.1 Standard values for accident prediction model

Coefficients for accident prediction model for various intersections and traffic volumes [Gårder, 1989]

Intersection type	Distance from cross-walk to "curb"(m)	Existence of refuge	Street width (m)	Number of sites (intersec-tion arms)	Estimate of risk acc/100 years (exposure=1)	Correlation coefficient	Significance level (t-test)
LOW SPEED	0.0-1.9	No	<10.0	20	0.153	0.262	not significant
			10.0-15.0	4	0.000	-	not significant
			>15.0	0	-	-	not significant
		Yes	<10.0	0	-	-	not significant
			10.0-15.0	0	-	-	not significant
			>15.0	4	0.052	0.007	not significant
	2.0-10.0	No	<10.0	36	0.051	0.140	not significant
			10.0-15.0	100	0.164	0.339	0.1%
			>15.0	4	0.369	0.165	not significant
		Yes	<10.0	48	0.119	0.452	1 %
			10.0-15.0	180	0.132	0.318	0.1 %
			>15.0	16	0.105	0.247	not significant
	10.1-30.0	No	<10.0	0	-	-	not significant
			10.0-15.0	4	0.115	0.164	not significant
			>15.0	0	-	-	not significant
		Yes	<10.0	8	0.017	0.034	not significant
			10.0-15.0	8	0.083	0.201	not significant
			>15.0	0	-	-	not significant
HIGH SPEED	0.0-1.9	No	<10.0	8	0.000	-	not significant
			10.0-15.0	8	0.000	-	not significant
			>15.0	0	-	-	not significant
		Yes	<10.0	8	0.061	0.238	not significant
			10.0-15.0	28	0.144	0.171	not significant
			>15.0	12	0.000	-	not significant
	2.0-10.0	No	<10.0	72	0.451	0.221	5 %
			10.0-15.0	48	0.000	-	not significant
			>15.0	12	1.626	0.451	10 %
		Yes	<10.0	84	0.166	0.423	0.1 %
			10.0-15.0	244	0.264	0.221	0.1 %
			>15.0	140	0.467	0.292	0.1 %
	10.1-30.0	No	<10.0	4	1.415	0.055	not significant
			10.0-15.0	0	-	-	not significant
			>15.0	0	-	-	not significant
		Yes	<10.0	8	0.106	0.455	not significant
			10.0-15.0	8	0.000	-	not significant
			>15.0	4	0.000	-	not significant
SIGNALIZED	0.0-1.9	No	<10.0	0	-	-	not significant
			10.0-15.0	8	0.124	0.776	not significant
			>15.0	0	-	-	not significant
		Yes	<10.0	8	0.000	-	not significant
			10.0-15.0	40	0.140	0.278	5 %
			>15.0	60	0.124	0.391	0.1 %
	2.0-10.0	No	<10.0	4	0.180	0.254	not significant
			10.0-15.0	36	0.286	0.384	1%
			>15.0	8	0.030	0.019	not significant
		Yes	<10.0	28	0.027	0.127	not significant
			10.0-15.0	116	0.286	0.300	0.1 %
			>15.0	272	0.198	0.245	0.1 %
	10.1-30.0	No	<10.0	0	-	-	not significant
			10.0-15.0	0	-	-	not significant
			>15.0	0	-	-	not significant
		Yes	<10.0	16	0.046	0.192	not significant
			10.0-15.0	12	0.111	0.310	not significant
			>15.0	0	-	-	not significant

A.2 General Motors Conflict Categories

Twenty-four predefined conflict categories

GENERAL CONFLICTS

1. Weave
2. Left turn from wrong lane
3. Right Turn from wrong lane
4. Turn into wrong lane
5. Opposing right turn
6. Through cross traffic (left to right)
7. Through cross traffic (right to left)
8. Right-turn cross (traffic from left)
9. Right-turn cross (traffic from right)
10. Left turn cross (Traffic)

REAR-END CONFLICTS

11. Stop on amber
12. Slow for left turn
13. Slow for right turn
14. Previous traffic conflict
15. Shopping entrance (beyond intersection)
16. Slow truck
17. Congestion in intersection
18. Clear intersection
19. Stalled vehicle
20. Traffic back-up
21. Pedestrian
22. Merging beyond intersection
23. Single vehicle/pedestrian conflict
24. Weave-pedestrian conflicts

A.3 American Conflict Categories

Same Direction Conflicts:

These conflicts occur when the first vehicle slows down and / or changes direction thereby placing the following vehicle in danger of a rear end conflict. The second vehicle takes an evasive manoeuvre by braking or swerving to avoid a collision, then continues through the intersection.

There are four types of same direction conflicts:

a) Left turn, same direction conflict.
b) Right turn, same direction conflict.
c) Slow vehicle, same direction conflict.
d) Lane change conflict.

Opposing Right Turn Conflict:

This occurs when an oncoming vehicle makes a right turn across the path of a through vehicle that has right of way.

Cross Traffic Conflicts

This occurs when a vehicle from a cross street crosses the path of a vehicle (that has the right of way) on the main street.

Cross street conflicts can occur from vehicle manoeuvring to the right and / or left:

a) Cross Traffic Conflicts From The Right Cross Street Approach - Three cases: -
   1) Right turn, cross traffic from right conflict – occurs when a vehicle from the right hand cross streets makes a right turn thus endangering the vehicle on the main street.
   2) Left turn cross traffic from right conflict – occurs when a vehicle on the right hand cross street makes a left thereby endangering the vehicle on the main street.
   3) Through cross traffic from right conflict – occurs when a vehicle on the right hand cross street crosses in front of the vehicle on the main street.

b) Cross Traffic Conflicts From the Left Cross Street Approach – Three cases:-
   1) Right turn, cross traffic from left conflict – occurs when a vehicle from the left hand cross street makes a turn across the centre of the main street.
   2) left turn, cross traffic from left conflict – occurs when a vehicle from the left hand cross street makes a left turn across the vehicle on the main street.

3) Through, cross traffic from left conflict – occurs when the vehicle from the left hand cross street crosses in front of the vehicle on the main street.

Left Turn on Red (LTOR)

The conflict occurs when a LTOR vehicle makes a turn and places the vehicle (that has the right of way) on the other lane at risk.

Pedestrian Conflicts

The conflict occurs when a pedestrian (the road user causing the conflict) crosses in front of a vehicle (that has the right of way).

Secondary Conflicts

In all of the conflicts discussed above, the consequence of the action of the second vehicle was not discussed. The action (evasive manoeuvre) of the second vehicle may also may another road user in danger of a collision. This event is known as a secondary conflict. Therefore each conflict situation can have a secondary conflict but only one secondary conflict by definition for any initial conflict should be counted.

A.4 German Conflict Categories

Thirteen categories have been defined for the German TCT

1. Straight ahead conflict

This occurs when two vehicles are following each other and the leading vehicle slows down or stops resulting in the second vehicle approaching the leading vehicle with excess speed.

2. Lane changing conflict

This can happen when a vehicle changes from one lane to another and disturbs the vehicle in the next lane, resulting in the driver of the lane changing vehicle or the driver of the disturbed vehicle having to make a critical movement.

3. Right turn conflict

This can happen when a right turning vehicle obstructs a vehicle approaching from the opposite direction. Should any of the drivers of the vehicles concerned have to take an evasive action, a right turn conflict occurs.

4. U – Turn/Turn about conflict

This happens when the driver of a vehicle turns his vehicle in a lane or making a U-turn, obstructing another vehicle. A conflict occurs when the driver of the turning vehicle and/or the driver of the disturbed vehicle have to take an evasive action.

5. Exiting conflict

This happens when a vehicle exits a lane to turn left into a parking area, another street or driveway. When the driver of a following vehicle has to take an evasive action an exiting conflict occurs.

6. Joining conflict

This happens when a vehicle joins other traffic from a side street, a parking area or driveway. Should the driver of the joining vehicle and/or the driver of an oncoming vehicle have to take evasive action, a joining conflict occurs.

7. Right turn / Right turn conflict

This happens when two vehicles approaching from opposite directions simultaneously enter a crossing, both turning to the right. Should either driver or both have to take evasive action, a right turn / right turn conflict occurs.

8. Left turn / Right turn conflict

This happens when two vehicles approaching from opposite directions simultaneously enter a crossing, one turning left, the other turning right. Should either driver have to take evasive action, a left turn / right turn conflict occurs.

9. Evacuating conflict

This happens when vehicles are in an intersection whilst the traffic light that originally gave permission to enter the intersection changes from green to red to green to authorise right of way to the cross street traffic. Should any of the drivers approaching the intersection have to take an evasive action, an evacuating conflict occurs.

10. Intersection conflict

This happens when a vehicle driver ignores a red traffic light, a stop sign, or yield sign controlling an intersection and passes the intersection in front of oncoming vehicle which has right of way from the cross road. Should either driver take evasive action, an intersection conflict occurs.

11. Approach / approach conflict

This happens when the driver of a vehicle turns right into the lane of an oncoming vehicle from the opposite direction. Should one or both drivers involved take evasive action, an approach / approach conflict occurs.

12. Vehicle / pedestrian conflict

This happens when the driver of a vehicle, turning left or right or proceeding straight forward, has to swerve or brake to prevent a collision.

13. Pedestrian / vehicle conflict

This happens when a pedestrian moves in front of an oncoming vehicle forcing the driver of the vehicle to take evasive action.

APPENDIX B

This appendix contains the data from the site investigation. Traffic flow data along with the conflict data from the analysis is included.

B.1 Traffic Flow Data

Pine Street and Field Street Intersection

Date	Time	Pedestrian flow per hour	Vehicle flow per hour
4/06/2002	08H35	605	288
4/06/2002	09H36	763	286
5/06/2002	06H58	393	253
5/06/2002	07H59	586	319
6/06/2002	07H13	472	303
6/06/2002	08H16	479	271
9/07/2002	14H25	1048	306
9/07/2002	15H26	1258	383

Commercial Road and Grey Street Intersection

Date	Time	Pedestrian flow per hour	Vehicle flow per hour
13/06/2002	09h21	605	288
14/06/2002	07h16	763	286
14/06/2002	08h18	393	253
14/06/2002	13h42	586	319
14/06/2002	14h46	472	303
15/06/2002	09h42	479	271
08/07/2002	14h22	1048	306
08/07/2002	15h23	1258	383

Commercial Road and Albert Street Intersection

Date	Time	Pedestrian volume	Vehicle Volume
13/06/2002	07h57	640	90
14/06/2002	11h28	1170	149
14/06/2002	12h29	830	72
15/06/2002	08h34	1817	118
15/06/2002	10h51	1741	119
15/06/2002	11h53	2387	153
02/07/2002	07h17	663	63
02/07/2002	08h18	613	99
03/07/2002	10h04	1113	126
03/07/2002	11h06	1104	126
04/07/2002	14h41	1313	129
04/07/2002	15h42	1225	142

B.2 Conflict Data

American TCT

Pine-Field

Date	Time	Conflicts
4/06/2002	08H35	3
4/06/2002	09H36	2
5/06/2002	06H58	1
5/06/2002	07H59	2
6/06/2002	07H13	2
6/06/2002	08H16	0
9/07/2002	14H25	2
9/07/2002	15H26	2

Commercial-Grey

Date		Conflicts
13/06/2002	09h21	2
14/06/2002	07h16	7
14/06/2002	08h18	6
14/06/2002	13h42	6
14/06/2002	14h46	6
15/06/2002	09h42	4
08/07/2002	14h22	4
08/07/2002	15h23	3

Commercial-Albert

Date		Conflicts
13/06/2002	07h57	1
14/06/2002	11h28	6
14/06/2002	12h29	0
15/06/2002	08h34	0
15/06/2002	10h51	1
15/06/2002	11h53	3
02/07/2002	07h17	2
02/07/2002	08h18	1
03/07/2002	10h04	1
03/07/2002	11h06	1
04/07/2002	14h41	1
04/07/2002	15h42	1

Post Encroachment Technique (PET)

Pine-Field

Tape #	Time	PET<0.5	0.5<PET<1.0	1.0<PET<1.5	1.5<PET<2.0	2.0<PET<2.5	2.5<PET<3.0
1	08H35		3	9	2	5	
2	09H36		5	3	3	1	
3	06H58		3	4		1	
4	07H59		1	3	1		
5	07H13		4	1			2
6	08H16		1	3			
7	14H25			4	1		
8	15H26		1	2	1		

Commercial-Grey

Tape #	Time	PET<0.5	0.5<PET<1.0	1.0<PET<1.5	1.5<PET<2.0	2.0<PET<2.5	2.5<PET<3.0
1	09h21	2	1	5			
2	07h16		2	4			
3	08h18	3	4	3	1		
4	13h42	1	5	5			
5	14h46	3	1	1	2		
6	09h42	3	3		1		
7	14h22		3	3			
8	15h23		1	1			

Commercial-Albert

Tape #	Time	PET<0.5	0.5<PET<1.0	1.0<PET<1.5	1.5<PET<2.0	2.0<PET<2.5	2.5<PET<3.0
1	07h57		1	1			
2	11h28	2	1	2			
3	12h29		2				
4	08h34				1		
5	10h51		2	1		1	
6	11h53		1	1	1		
7	07h17			1			
8	08h18						
9	10h04		1	1	1		
10	11h06		2	1			
11	14h41		1	2			
12	15h42		2		1		

Swedish TCT

Pine-Field

Date	Time	Conflicts
4/06/2002	08H35	5
4/06/2002	09H36	5
5/06/2002	06H58	6
5/06/2002	07H59	9
6/06/2002	07H13	9
6/06/2002	08H16	5
9/07/2002	14H25	3
9/07/2002	15H26	4

Commercial-Grey

Date	Time	Conflicts
13/06/2002	09h21	6
14/06/2002	07h16	5
14/06/2002	08h18	10
14/06/2002	13h42	10
14/06/2002	14h46	6
15/06/2002	09h42	9
08/07/2002	14h22	7
08/07/2002	15h23	2

Commercial-Albert

Date		Conflicts
13/06/2002	07h57	1
14/06/2002	11h28	1
14/06/2002	12h29	0
15/06/2002	08h34	0
15/06/2002	10h51	1
15/06/2002	11h53	5
02/07/2002	07h17	1
02/07/2002	08h18	0
03/07/2002	10h04	0
03/07/2002	11h06	2
04/07/2002	14h41	1
04/07/2002	15h42	0

German TCT

Pine-Field

Date	Time	Conflicts		
		slight	moderate	serious
4/06/2002	08H35	7	4	
4/06/2002	09H36	5		
5/06/2002	06H58		1	
5/06/2002	07H59	3		
6/06/2002	07H13		2	
6/06/2002	08H16	1		
9/07/2002	14H25		1	
9/07/2002	15H26	3		

Commercial-Grey

Date	Time	Conflicts		
		slight	moderate	serious
13/06/2002	09h21		2	
14/06/2002	07h16	5	2	
14/06/2002	08h18	4	2	
14/06/2002	13h42	5	1	
14/06/2002	14h46	5	1	
15/06/2002	09h42	1	2	1
08/07/2002	14h22	3	1	
08/07/2002	15h23	2	1	

Commercial-Albert

Date		Conflicts		
		slight	moderate	serious
13/06/2002	07h57	1		
14/06/2002	11h28	4	1	1
14/06/2002	12h29			
15/06/2002	08h34			
15/06/2002	10h51	1		
15/06/2002	11h53	3		
02/07/2002	07h17	2		
02/07/2002	08h18	1		
03/07/2002	10h04	1		
03/07/2002	11h06	1		
04/07/2002	14h41			
04/07/2002	15h42			

B.3 Observation periods and interaction data

Intersection	Date	Time	Interactions
Pine and Field	4/06/2002	08:35-09:35	24
	4/06/2002	09:36-10:36	20
	5/06/2002	06:58-07:58	22
	5/06/2002	07:59-09:00	23
	6/06/2002	07:13-08:13	16
	6/06/2002	08:16-09:16	15
	9/07/2002	14:25-15:25	8
	9/07/2002	15:26-16:26	12
Commercial and Grey	13/06/2002	09:21-10:21	13
	14/06/2002	07:16-08:16	17
	14/06/2002	08:19-09:19	28
	14/06/2002	13:42-14:42	30
	14/06/2002	14:46-15:46	21
	15/06/2002	09:42-10:42	18
	08/07/2002	14:22-15:22	18
	08/02/2002	15:23-16:23	8
Commercial and Albert	13/06/2002	07:57-08:57	8
	14/06/2002	11:28-12:38	8
	14/06/2002	08:34-09:34	3
	15/06/2002	12:29-13:29	10
	15/06/2002	10:50-11:50	10
	15/06/2002	11:53-12:53	12
	02/07/2002	07:17-08:17	6
	02/07/2002	08:18-09:18	3
	03/07/2002	10:04-11:04	8
	03/07/2002	11:06-12:06	11
	04/07/2002	14:41-15:41	6
	04/07/2002	15:42:16:42	6

APPENDIX C

This appendix contains the technical specifications for the digital imaging equipment and software. The program listing for the conflict tracking software along with the derivation for the cross correlation coefficient is also included.

C.1 Specifications for image processing

Digital Video Camera

The digital video camera used for this investigation was a Panasonic AG-EZ35E. The storage facility is a mini-DV cassette cable of recording continuous video for 63 minutes on short play and 93 minutes on long play. The camera had a digital zoom setting up to 12 with a resolution of 720 x 576 pixels. The camera had a video frame rate of 25fps. With the above specifications for the camera, a transfer rate required (by doing simple calculations, see below) between the camera and the computer would 30 megabytes per second.

Calculation for obtaining the transfer rate (in megabytes per second) between camera and personal computer:

720 horizontal resolution
X
576 vertical resolution
= *414 720 pixels per frame*
X *3 bytes per pixel (for RGB)*
= *1 244 160 bytes*
X *25 frames per second*
= *31 104 000 bytes*
/ 1 048 576 to convert to megabytes
= **29.7 megabytes per second**

Firewire Card or Capture Card

An IEEE 1394 ("FireWire" ™) interface card allows the transferring of digital video data at speeds of 100, 200, or 400 megabits per second (Mbps). With such high data speeds the full-motion video could be viewed directly on the monitor of the PC. This card is installed on a PC.

Software

Commercial software ("Moto DV" by Digital Origin) was used for the viewing, extracting and saving images from the video camera to the computer hard disk [www.digitalorigin.com].

C.2 PROGRAM LISTING

```
function track
clear all;
close all;

 [tiffile, tifpath] = uigetfile('*.tif', 'Open File:');

if (tifpath == 0)
  break
  ;
else
   prompt={'Number of frames in file:'};
  title='Input';
  answer=inputdlg(prompt,title);
  n1=str2num(char(answer(1,:)));

 pf4 = uint8(zeros(576,720,3,n1));
for frame=1:n1
   % Read each frame into the appropriate frame in memory
   [pf4(:,:,:,frame)] = imread([tifpath,tiffile],(frame));
end
 MOV = immovie(pf4);
 movie(MOV,1,12)

n1=0;
n= 0;
movi ='Y';
mo ='D';
str = 0;
ht1 = 0;
ht = 0;
prompt={'Enter total number of frames in file:',...
       'Enter number of frames to analyse:',...
       'Do you wish to view movie [Y/N]:',...
       'Location: (listbox)',...
       'Starting Frame #:',...
       'Direction of pedestrian [U/D]:',...
       'Enter vehicle height [m]:',...
       'Enter pedestrian height [m]:'};
 def={num2str(n1),num2str(n),char(movi),{'Pine-Field',...
    'Commercial-Albert','Commercial-Grey'},...
     num2str(str),char(mo),num2str(ht1),num2str(ht)};
 dlgTitle='Input for traffic conflicts';
 lineNo=[1.7 10;1.7 10; 1.7 3; 5 25; 1.7 6; 1.7 6; 1.7 6; 1.7 6];

PromptDef(1,:)=  [0,0, 0, 3, 0, 0, 0, 0];
% PromptDef(2,:) = 1 for initially disabled Quests
%     for ListBox:          1  initially disabled ListBox
%                     2  Single item selection ListBox
%                   3  Single item selection + initially disabled ListBox
PromptDef(2,:)=  [0, 0, 0, 0, 0, 0, 0, 0];
Resize = 'on';
% ListInit{N} is the initial selection for ListBox(N) - see PromptDef(1,:)
ListInit = {[2,2,3], [3] };
% answer=inpdlg(prompt,dlgTitle,lineNo,def);
AnsFlg1 = {};
[Answer, figfmen1, AnsFlg1] =inpdlg(prompt, dlgTitle, lineNo, ...
```

continued...

```
        def, PromptDef, AnsFlg1, Resize,ListInit);
% Display AnsFlg1
AnsFlg1{:}
n1= str2num(char(Answer(1,:)));
n = str2num(char(Answer(2,:)));
[movi]=sscanf(Answer{3},'%s',1);
[M_ans] = sscanf(Answer{4},'%s',1);
str = str2num(char(Answer(5,:)));
[mo]=sscanf(Answer{6},'%s',1);
ht1 = str2num(char(Answer(7,:)));
ht = str2num(char(Answer(8,:)));
if (movi == 'Y')
 pf4 = uint8(zeros(576,720,3,n));
for frame=1:n1
   % Read each frame into the appropriate frame in memory
   [pf4(:,:,:,frame)] = imread([tifpath,tiffile],(frame));
end
 MOV = immovie(pf4);
 movie(MOV,1,12)
end
  if (mo == 'D')
     ssay = 0;
      ssax = -8;
  else
      ssax = -8;
     ssay = -10;
  end
end
 pf4 = uint8(zeros(576,720,3,n));
for frame=1:n
   % Read each frame into the appropriate frame in memory
   [pf4(:,:,:,frame)] = imread([tifpath,tiffile],((frame-1)+str));

end
image(pf4(:,:,:,1));
axis image;
msgbox('Left mouse Button to zoom in/Right Button to zoom out. Press any key to activate Crosshairs')
zoom
pause
hold on
%%%% VEHICLE
button = 0;
while button~=1 % left mouse click
   hold on
   [x,y,button]=ginput(1);
hold on
plot(x,y,'r+')
end
x1 = x;
y1 = y;
zoom
pause
button = 0;
while button~=1 % left mouse click
   hold on
   [xq,yq,button]=ginput(1);
hold on
```

continued...

```
plot(xq,yq,'r+')
end
xm1 = xq;
ym1 = yq;
cx = x;
cy  = y;
px = xq;
py = yq;
hold on
trackalgo = cputime;
for fr = 1:(n-1)
xp = x1;
yp = y1;
a = (xp-5); % starting point for ROI(11x11) - first cell
b = (yp-5); % starting point for ROI(11x11) - first cell
 hold on
image(pf4(:,:,:,(fr)))
 hold on
axis image;
 hold on
plot(x1,y1,'+')
[sq,sw] = meshgrid(a:1:(a+10),b:1:(b+10)); %ROI 11x11 pixels

 i=1:1:121;
   c([i]) = [sq([i])];
   d([i]) = [sw([i])];
RGBU = impixel((pf4(:,:,:,((fr)))),c,d); %RGB values for each pixel value in ROI
RGBUT = RGBU';
sumb = sum(RGBU)./121; %mean of the sums of columns of RGBU
sumb1 = (sumb.*121).^2;
sumb2 = sumb.^2;
su = (1/464*(sum(sumb1) - sum(sumb2)))^0.5; %stanard deviation

%SEARCH STRATEGY AREA
a1=(xp-10); %SSA starting point: x pixel coordinate
b1=(yp); %SSA starting point: y pixel coordinate

[sq1,sw1] =meshgrid(a1:1:(a1+28),b1:1:(b1+15)); %SSA 29x16pixels

 i = 1:1:464; % 461 cells in SSA
   c1([i])=[sq1([i])];
   d1([i])=[sw1([i])];

   ax([i]) = c1([i]) - 5;%starting point for each ROI in SSA - x pixel
   ay([i]) = d1([i]) - 5;%starting point for each ROI in SSA - y pixel

%since SSA 29x16 - 464 points to place ROI - make  grids with center
%positioned over each cell point in the SSA
wqm = zeros(464,121); %allocate memory
wsm = zeros(464,121); %allocate memeory

for i = 1:464
      [wq,ws] =meshgrid(ax(1,i):1:(ax(1,i)+10),ay(1,i):1:(ay(1,i)+10));
  for j = 1:11
     for k = 1: 11
          num = k+((j-1)*11);
          wqv(1,num)= wq(k,j);
          wsv(1,num) = ws(k,j);
```

continued...

```
        end
  end

wqm(i,:) = wqv(1,:);
wsm(i,:) = wsv(1,:);
end

wqmT = wqm';
wsmT = wsm';

%obtain RGB values for each point in each of the
%464 ROI but display in a single matrix
 r = 1:1:56144;
   RGB3(r,:) = impixel((pf4(:,:,:,(fr+1))),wqmT(r),wsmT(r));

VMatrix = zeros(121,3); %allocate memory, VMatrix = RGB matrix for each ROI
corr = zeros(1,464); %allocate memory for the correlation array
jump = 1;
  for count = 1: 464
     if count > 1
        jump = (count-1)*121 +1;
     end

     suma = sum(RGB3(jump:count*121,:))./121;%mean of the sums of columns of RGB3
     VMatrix = RGB3(jump:count*121,:);
     VMatrixT = VMatrix';
    sumVa = suma.^2;
    sumVb = (suma.*121).^2;
    sv = (1/464*(sum(sumVb) - sum(sumVa)))^0.5; %stanard deviation

       o = 1:1:363; %121x3
       RGBV([o]) = [VMatrixT([o])];
       RGBUx([o]) =[RGBUT([o])];


    cov1 = 1/464*(RGBV*RGBUx' -(121*(sumb*suma.'))); %covariance
    [corr([count])] =  cov1/(sv*su);

end

Maxcor = max(corr); %obtain max correlation
% find position of the maximum correlation
for search = 1: 464
   if corr(search) == Maxcor
      find = search;
   end
end
%find pixel coordinates in SSA for maximum correlation
find1 =find;
xnew = c1(find);
ynew = d1(find);
[xc([fr])] =xnew;
[yc([fr])] =ynew;

xc;
yc;
x1 = xnew;
y1 = ynew;
```

continued...

```
end

%PEDESTRIAN
for fr = 1:(n-1)
xp1 = xm1;
yp1 = ym1;
ap = (xp1-2); % starting point for ROI(5x5) - first cell
bp = (yp1-2); % starting point for ROI(5x5) - first cell
 hold on
image(pf4(:,:,:,(fr)))
 hold on
axis image;
 hold on
plot(xm1,ym1,'r+')

[sqp,swp] = meshgrid(ap:1:(ap+4),bp:1:(bp+4)); %ROI 5x5 pixels

 i=1:1:25;
   cp([i]) = [sqp([i])];
   dp([i]) = [swp([i])];


RGBUp = impixel((pf4(:,:,:,((fr)))),cp,dp); %RGB values for each pixel value in ROI
RGBUTp = RGBUp';
sumbp = sum(RGBUp)./25; %mean of the sums of columns of RGBU
sumb1p = (sumbp.*25).^2;
sumb2p = sumbp.^2;
sup = (1/187*(sum(sumb1p) - sum(sumb2p)))^0.5; %stanard deviation

%SEARCH STRATEGY AREA
a1p=(xp1+ssax); %SSA starting point: x pixel coordinate
b1p=(yp1+ssay); %SSA starting point: y pixel coordinate

[sq1p,sw1p] =meshgrid(a1p:1:(a1p+16),b1p:1:(b1p+10)); %SSA 17x11pixels

 i = 1:1:187; % 187 cells in SSA
   c11p([i])=[sq1p([i])]; %vector- starting at a1-increments of 1
   d11p([i])=[sw1p([i])];

   ax1p([i]) = c11p([i]) - 2;%starting point for each ROI in SSA - x pixel
   ay1p([i]) = d11p([i]) - 2;%starting point for each ROI in SSA - y pixel

%since SSA 17x11 - 187 points to place ROI - make  grids with center positioned over
% eac cell point in the SSA
wqm1p = zeros(187,25); %save time
wsm1p = zeros(187,25);  %save time

for i = 1:187
      [wqp,wsp] =meshgrid(ax1p(1,i):1:(ax1p(1,i)+4),ay1p(1,i):1:(ay1p(1,i)+4));
  for j = 1:5
    for k = 1: 5
         num = k+((j-1)*5);
         wqvp(1,num)= wqp(k,j);
         wsvp(1,num) = wsp(k,j);
      end
  end
wqm1p(i,:) = wqvp(1,:);
wsm1p(i,:) = wsvp(1,:);
```

continued...

```
end

wqmTp = wqm1p';
wsmTp = wsm1p';

%obtain RGB values for each point in each of the 187 ROI but display in a single matrix
 r = 1:1:4675;
   RGB3p(r,:) = impixel((pf4(:,:,:,(fr+1))),wqmTp(r),wsmTp(r));

VMatrixp = zeros(25,3); %allocate memory, VMatrix = RGB matrix for each ROI

corrp = zeros(1,187); %allocate memory for the correlation array
jump = 1;
  for count = 1: 187
     if count > 1
        jump = (count-1)*25 +1;
     end

     sumap = sum(RGB3p(jump:count*25,:))./25;%mean of the sums of columns of RGB3
     VMatrixp = RGB3p(jump:count*25,:);
     VMatrixTp = VMatrixp';
    sumVap = sumap.^2;
    sumVbp = (sumap.*25).^2;
    svp = (1/187*(sum(sumVbp) - sum(sumVap)))^0.5; %stanard deviation

       o = 1:1:75; %25x3
       RGBVp([o]) = [VMatrixTp([o])];
       RGBUxp([o]) =[RGBUTp([o])];

    cov1p = 1/187*(RGBVp*RGBUxp' -(25*(sumbp*sumap.'))); %covariance
    [corrp([count])] =  cov1p/(svp*sup);

end

Maxcorp = max(corrp); %obtain max correlation

for search = 1: 187 % find position of the maximum correlation
   if corrp(search) == Maxcorp
      find1p = search;
   end
end

%find pixel coordinates in SSA for maximum correlation
findp =find1p;
xnew1 = c11p(findp);
ynew1 = d11p(findp);
[xc1([fr])] =xnew1;
[yc1([fr])] =ynew1;
xm1 = xnew1;
ym1 = ynew1;
end
cputime-trackalgo
%plot trajectories of road users
%PINE FILED
if (M_ans == 'Pine-Field')
tv = 0.0404318551296185;
th = 0.0745711705678967;
for fr = 1:(n-1)
```

continued...

```
dyp([fr]) = 403-yc([fr]);
dxp([fr]) = 568-xc([fr]);
dtv([fr]) = dyp([fr]).*tv;
dth([fr]) = dxp([fr]).*th;

Y1([fr]) = ((tan((70.956+dtv([fr]))*(pi/180)))*(16.648-ht1)) ;
Y([fr]) = Y1([fr])*sin((pi/180)*dth([fr]));
X([fr]) = Y1([fr])*cos((pi/180)*dth([fr]));

end
for fr = 1:(n-1)
dyp1([fr]) = 403-yc1([fr]);
dxp1([fr]) = 568-xc1([fr]);
dtv1([fr]) = dyp1([fr]).*tv;
dth1([fr]) = dxp1([fr]).*th;

Y1p([fr]) = ((tan((70.956+dtv1([fr]))*(pi/180)))*(16.648-ht)) ;
Yp([fr]) = Y1p([fr])*sin((pi/180)*dth1([fr]));
Xp([fr]) = Y1p([fr])*cos((pi/180)*dth1([fr]));

end
figure,plot(X,Y,'*', 48.23,0,'o', 51.15,33.18,'o',59.4,18.33,'o',Xp,Yp,'*');

%COMMERCIAL ALBERT
elseif (M_ans == 'Commercial-Albert')
tv = 0.0314513504278909;
th = 0.0765716651514905;
for fr = 1:(n-1)
dyp([fr]) = 432-yc([fr]);
dxp([fr]) = 626-xc([fr]);
dtv([fr]) = dyp([fr]).*tv;
dth([fr]) = dxp([fr]).*th;

Y1([fr]) = ((tan((69.4056+dtv([fr]))*(pi/180)))*(12.9-ht1)) ;
Y([fr]) = Y1([fr])*sin((pi/180)*dth([fr]));
X([fr]) = Y1([fr])*cos((pi/180)*dth([fr]));

end
for fr = 1:(n-1)
dyp1([fr]) = 432-yc1([fr]);
dxp1([fr]) = 626-xc1([fr]);
dtv1([fr]) = dyp1([fr]).*tv;
dth1([fr]) = dxp1([fr]).*th;

Y1p([fr]) = ((tan((69.4056+dtv1([fr]))*(pi/180)))*(12.9-ht)) ;
Yp([fr]) = Y1p([fr])*sin((pi/180)*dth1([fr]));
Xp([fr]) = Y1p([fr])*cos((pi/180)*dth1([fr]));

end
figure,plot(X,Y,'*', 34.33,0,'o', 40.18,15.73,'o',36.21,26.46,'o', Xp,Yp,'*');

%COMMERCAIL GREY
elseif (M_ans == 'Commercial-Grey')
tv = 0.0710190861367249;
th = 0.0684370897283332;
for fr = 1:(n-1)
dyp([fr]) = 408-yc([fr]);
dxp([fr]) = 345-xc([fr]);
```

continued...

```
dtv([fr]) = abs(dyp([fr]).*tv);
dth([fr]) = abs(dxp([fr]).*th);

Y1([fr]) = ((tan((64.76152+dtv([fr]))*(pi/180)))*(12.09575-ht1)) ;
Y([fr]) = Y1([fr])*sin((pi/180)*dth([fr]));
X([fr]) = Y1([fr])*cos((pi/180)*dth([fr]));

end
for fr = 1:(n-1)
dyp1([fr]) = 408-yc1([fr]);
dxp1([fr]) = 345-xc1([fr]);
dtv1([fr]) = abs(dyp1([fr]).*tv);
dth1([fr]) = abs(dxp1([fr]).*th);

Y1p([fr]) = ((tan((64.76152+dtv1([fr]))*(pi/180)))*(12.09575-ht)) ;
Yp([fr]) = Y1p([fr])*sin((pi/180)*dth1([fr]));
Xp([fr]) = Y1p([fr])*cos((pi/180)*dth1([fr]));

end
figure,plot(X,Y,'*', 25.66,0.04,'o', 38.4,7.28,'o',50.84,4.04,'o',44.05,16.18,'o', Xp,Yp,'*');
end
ped = [Xp' Yp'];
car = [X' Y'];
pedp = [xc1' yc1'];
carp = [xc' yc'];
ped1 = [px py];
car1 = [cx cy];


%output data to text files
fid = fopen('C:\Car1Xp.txt','w');
fprintf(fid,'Car - X pixel value\n\n');
fprintf(fid,'  %12.8f\n',cx);
status = fclose(fid);
fid = fopen('C:\Car1Yp.txt','w');
fprintf(fid,'Car - X pixel value\n\n');
fprintf(fid,'  %12.8f\n',cy);
status = fclose(fid);

fid = fopen('C:\CarXp.txt','w');
fprintf(fid,'Car - X pixel value\n\n');
fprintf(fid,'  %12.8f\n',xc');
status = fclose(fid);
fid = fopen('C:\CarYp.txt','w');
fprintf(fid,'Car - X pixel value\n\n');
fprintf(fid,'  %12.8f\n',yc');
status = fclose(fid);
%%%%%%%%%%5
%%%%%%%%%%
fid = fopen('C:\Ped1Xp.txt','w');
fprintf(fid,'Pedestrian - X pixel value\n\n');
fprintf(fid,'  %12.8f\n',px);
status = fclose(fid);
fid = fopen('C:\Ped1Yp.txt','w');
fprintf(fid,'Pedestrian - X pixel value\n\n');
fprintf(fid,'  %12.8f\n',py);
status = fclose(fid);
```

continued...

```
fid = fopen('C:\PedXp.txt','w');
fprintf(fid,'Pedestrian - X pixel value\n\n');
fprintf(fid,'  %12.8f\n',xc1');
status = fclose(fid);
fid = fopen('C:\PedYp.txt','w');
fprintf(fid,'Pedestrian - X pixel value\n\n');
fprintf(fid,'  %12.8f\n',yc1');
status = fclose(fid);


fid = fopen('C:\info.txt','w');
fprintf(fid,'%6d\n ',n,M_ans,mo,str,ht1,ht);
fclose(fid)
```

C.3 Cross Correlation Coefficient

Correlation is used to determine whether two ranges of data are related. A positive correlation exits when large values of one set are associated with large values of the other and a negative correlation exists when small values of one set are associated with large values of the. No correlation exists when values in both sets are unrelated (correlation near zero). The cross correlation is defined as:

$$\rho_{U,V} = \frac{Cov(X,Y)}{\sigma_X . \sigma_Y}$$

where,

$$Cov(X,Y) = \frac{1}{n}\Sigma\left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right)$$

and,

$$\sigma_X^2 = \frac{1}{n}\Sigma\left(X_i - \overline{X}\right)^2$$

$$\sigma_Y^2 = \frac{1}{n}\Sigma\left(Y_i - \overline{Y}\right)^2$$

with *n* the number of values in each data set.

However, in this study a vector cross correlation coefficient is required as matrices of pixel data are correlated noting that each pixel contains three scalar values (known as the RGB values-red, green and blue)

$$Cov(X,Y) = \frac{1}{n}\Sigma\left(\overline{X \cdot Y} - \overline{X} \cdot \overline{Y}\right)$$

$$Cov(X,Y) = \frac{1}{n}\Sigma\left(\overline{\begin{bmatrix} X_R\, X_G\, X_B \end{bmatrix} \cdot \begin{bmatrix} Y_R \\ Y_G \\ Y_B \end{bmatrix}} - \left(\begin{bmatrix} \overline{X_R\, X_G\, X_B} \end{bmatrix} \cdot \begin{bmatrix} \overline{Y_R} \\ Y_G \\ Y_B \end{bmatrix}\right)\right)$$

$$Cov(X,Y) = \frac{1}{n}\Sigma\left(\overline{X_R \cdot Y_R + X_G \cdot Y_G + X_B \cdot Y_B} - \left(\overline{X_R} \cdot \overline{Y_R} + \overline{X_G} \cdot \overline{Y_G} + \overline{X_B} \cdot \overline{Y_B}\right)\right)$$

and:

$$\sigma_X = \sqrt{\left(\frac{1}{n}\Sigma\left(\overline{(X \cdot X)} - \overline{X} \cdot \overline{X}\right)\right)}$$

$$\sigma_X = \sqrt{\frac{1}{n}\Sigma\left(\overline{X_R^{\,2} + X_G^{\,2} + X_B^{\,2}} - \left(\overline{X_R}^2 + \overline{X_G}^2 + \overline{X_B}^2\right)\right)}$$

where

$$\overline{X_R} = \frac{1}{n}\Sigma(X_R)$$

and similarly for x_G and x_B

and:

$$\sigma_Y = \sqrt{\left(\frac{1}{n}\Sigma\left(\overline{(Y \cdot Y)} - \overline{Y} \cdot \overline{Y}\right)\right)}$$

$$\sigma_Y = \sqrt{\frac{1}{n}\Sigma\left(\overline{Y_R^{\,2} + Y_G^{\,2} + Y_B^{\,2}} - \left(\overline{Y_R}^2 + \overline{Y_G}^2 + \overline{Y_B}^2\right)\right)}$$

APPENDIX D

This appendix provides the calculations used for the velocity error estimation discussed in Section 7.3 are presented. The detailed analysis for the 'severity hierarchy concept' is presented. Detailed comparison of the conflict techniques is also presented. Lastly the calculation for the distance to collision is presented.

D.1 Velocity Calculation

Computer Program				Cubic Function – Speed Calculation			
X	Y	Speed (m/s)		X	Y	Distance (m)	Speed (m/s)
45.77	3.19			45.77	3.17		
44.15	2.86	7.947951		45.44	3.11	0.33	
42.65	2.56	7.459029		45.12	3.05	0.33	
41.24	2.22	6.963644		44.80	2.99	0.33	
39.91	2.05	7.514877		44.48	2.93	0.33	
38.25	1.88	7.539876		44.15	2.86	0.33	7.94200877
36.91	1.77	5.656582		43.85	2.80	0.31	
35.99	1.77	5.303835		43.55	2.74	0.31	
34.79	1.75	5.513099		43.25	2.68	0.31	
33.80	1.94	5.259344		42.95	2.62	0.31	
32.71	2.08	5.417194		42.65	2.56	0.31	7.429075235
31.67	2.36	4.957328		42.37	2.50	0.29	
30.82	2.67	3.969849		42.09	2.44	0.29	
30.25	3.06			41.80	2.39	0.29	
				41.52	2.33	0.29	
				41.24	2.28	0.29	6.964175467
				40.97	2.23	0.27	
				40.71	2.19	0.27	
				40.44	2.14	0.27	
				40.18	2.10	0.27	
				39.91	2.05	0.27	7.548858237
				39.58	2.00	0.33	
				39.25	1.96	0.33	
				38.92	1.91	0.33	
				38.59	1.87	0.33	
				38.25	1.84	0.33	7.549468702
				37.99	1.81	0.27	
				37.72	1.79	0.27	
				37.45	1.77	0.27	
				37.18	1.76	0.27	
				36.91	1.74	0.27	5.65926098
				36.72	1.74	0.18	
				36.54	1.73	0.18	
				36.36	1.73	0.18	
				36.18	1.73	0.18	
				35.99	1.73	0.18	5.308059215
				35.75	1.73	0.24	

continued...							
				35.51	1.74	0.24	
				35.27	1.75	0.24	
				35.03	1.77	0.24	
				34.79	1.78	0.24	5.516746337
				34.59	1.80	0.20	
				34.39	1.82	0.20	
				34.19	1.85	0.20	
				33.99	1.87	0.20	
				33.80	1.90	0.20	5.264161976
				33.58	1.94	0.22	
				33.36	1.98	0.22	
				33.14	2.02	0.22	
				32.93	2.07	0.22	
				32.71	2.12	0.22	5.472802063
				32.50	2.17	0.21	
				32.29	2.22	0.21	
				32.09	2.28	0.22	
				31.88	2.34	0.22	
				31.67	2.41	0.22	4.977155926
				31.50	2.47	0.18	
				31.33	2.53	0.18	
				31.16	2.59	0.18	
				30.99	2.66	0.18	
				30.82	2.73	0.18	3.830606957
				30.70	2.77	0.12	
				30.59	2.82	0.12	
				30.47	2.87	0.12	
				30.36	2.92	0.12	
				30.25	2.98	0.13	

Calculation for radius of curvature

The radius of curvature for each point on the path of the vehicle is calculated using the cubic function follows [Thomas & Finney, 1996]

$$\kappa(x) = \frac{|y''|}{\left[1+(y')^2\right]^{3/2}}$$

y represents the cubic function

D.2 Detailed data for comparison of techniques

Comparison between Swedish and PET technique – all intersections

Swedish	PET	Serious conflicts by both Swedish & PET	Serious conflicts recorded by only the Swedish	Serious conflicts recorded by only the PET
1.39	1.20	*		
0.46	1.00	*		
1.30	1.00	*		
1.01	1.00	*		
0.72	0.60	*		
0.84	0.52	*		
0.53	0.80	*		
0.91	0.84	*		
0.78	1.00	*		
1.06	1.48	*		
1.09	1.24	*		
1.16	1.28	*		
1.00	1.00	*		
0.93	2.28		*	
1.03	2.36		*	
1.34	1.56		*	
1.99	1.44			*
2.46	1.44			*
2.28	0.68			*
2.19	1.28			*
3.31	0.88			*
2.11	0.88			*
2.73	0.88			*
2.54	0.60			*
2.05	1.48			*
2.44	1.20			*
1.80	1.40			*
1.73	2.28			
2.23	2.32			
1.78	1.92			
1.91	1.79			

Comparison between Swedish German techniques

Intersection	Swedish TA(s)	German Slight	German Moderate	German Serious
Pine-Field	1.73	*		
	1.77	*		
	1.78	*		
	1.80	*		
	1.99	*		
	2.44	*		
	2.46	*		
	0.91		*	
	1.00		*	
	1.01		*	
	1.06		*	
	1.09		*	
	1.23		*	
Commercial-Grey	1.18	*		
	1.28	*		
	1.28	*		
	1.32	*		
	1.40	*		
	1.45	*		
	1.48	*		
	1.50	*		
	1.59	*		
	1.65	*		
	1.70	*		
	1.71	*		
	1.74	*		
	1.76	*		
	1.81	*		
	1.85	*		
	1.89	*		
	1.96	*		
	2.12	*		
	2.13	*		
	2.42	*		
	0.57		*	
	0.78		*	
	0.78		*	
	0.79		*	
	0.82		*	
	0.82		*	
	0.85		*	
	0.85		*	
	0.96		*	
	0.97		*	

continued...

	1.18		*	
	1.20		*	
	0.77			*
Commercial-Albert	1.21	*		
	1.32	*		
	1.42	*		
	1.53	*		
	1.53	*		
	1.59	*		
	1.85	*		
	1.86	*		
	2.28	*		
	0.55		*	
	1.15		*	

Comparison between PET and German techniques

	PET	German		
Intersection	(s)	Slight	Moderate	Serious
Pine-Field	0.6	*		
	0.72	*		
	1	*		
	1.16	*		
	1.2	*		
	1.2	*		
	1.28	*		
	1.36	*		
	1.44	*		
	1.6	*		
	1.92	*		
	2	*		
	2.28	*		
	2.4	*		
	0.6		*	
	0.8		*	
	0.84		*	
	0.92		*	
	1		*	
	1.16		*	
	1.28		*	
	1.4		*	
	1.56		*	
	2.68		*	

continued...

Commercial-Grey	0.4	*		
	0.48	*		
	0.5	*		
	0.52	*		
	0.64	*		
	0.64	*		
	0.68	*		
	0.72	*		
	0.8	*		
	0.8	*		
	1	*		
	1	*		
	1.04	*		
	1.12	*		
	1.2	*		
	1.2	*		
	1.32	*		
	1.36	*		
	1.64	*		
	1.68	*		
	0.48		*	
	0.5		*	
	0.6		*	
	0.64		*	
	1		*	
	1		*	
	1.24		*	
	1.84		*	
	0.56			*
Commercial-Albert	0.48	*		
	0.52	*		
	0.68	*		
	0.72	*		
	0.76	*		
	1	*		
	1	*		
	1.56	*		
	0.48			*

D.3 Interaction Analysis

The highlighted cells indicate that the pedestrian took evasive action. The 'Vehicle Speed' column represents the vehicle speed when the pedestrian took evasive action

Pine Street and Field Street Intersections

Interactions	Vehicle/Pedestrian Speed (km/h)	TA(s)	Severity	Vehicle Speed (km/h)	Dist. To collision (m)
1	10.28	0.93	25		2.64
2	19.20	1.03	25		5.50
3	14.45	1.77	24		7.10
4	7.29	2.88	21		5.84
5	20.20	1.99	24		11.19
6	9.54	2.49	22		6.59
7	14.33	2.54	22		10.13
8	15.49	2.46	22		10.60
9	14.72	3.49	20		14.25
10	14.28	1.93	23		7.66
11	11.55	2.17	23		6.95
12	10.67	2.38	22		7.06
13	20.43	1.80	24		10.24
14	15.23	2.71	22		11.45
15	4.26	2.28	22	23.20	2.69
16	15.42	1.19	25		5.08
17	15.50	2.34	23		10.09
18	8.75	0.41	26		1.00
19	13.61	2.19	23		8.29
20	4.36	0.99	25	10.99	1.20
21	21.83	1.73	24		10.50
22	16.32	2.09	23		9.48
23	10.61	2.98	21		8.77
24	13.15	2.74	22		10.00
25	10.61	1.97	23		5.80
26	13.43	1.07	25		4.00
27	4.09	0.44	26	13.79	0.50
28	14.69	2.73	22		11.15
29	15.16	0.98	25		4.13
30	4.73	4.19	19	14.58	5.50
31	10.32	1.37	24		3.93
32	14.33	1.94	23		7.74
33	16.69	1.77	24		8.18

continued...

34	26.54	0.59	27		4.33
35	21.96	0.80	26		4.88
36	17.46	2.50	22		12.12
37	3.74	3.01	19	14.51	3.13
38	3.96	2.91	21	6.49	3.20
39	10.99	1.34	24		4.08
40	3.91	3.31	20	23.41	3.60
41	12.24	1.71	24		5.82
42	4.27	2.11	23	15.83	2.50
43	14.86	1.44	24		5.94
44	8.42	1.28	24	15.42	3.00
45	8.17	2.73	23		6.20
46	15.85	2.78	22		12.25
47	8.12	3.18	21		7.18
48	4.73	9.16	8		12.03
49	4.04	2.67	21	20.39	3.00
50	3.14	4.62	18	3.93	4.03
51	5.72	1.89	23		3.00
52	14.30	3.02	21		11.98
53	14.02	2.54	22		9.88
54	4.78	1.07	25	13.43	1.42
55	16.73	1.39	25		6.45
56	11.05	0.60	26		1.85
57	10.83	1.19	25		3.58
58	7.05	1.53	24	16.07	3.00
59	19.67	1.70	24		9.31
60	18.42	2.23	23		11.39
61	6.20	0.46	26	29.51	0.80
62	21.48	1.68	24		10.02
63	14.86	1.65	24		6.81
64	10.35	1.99	23		5.73
65	12.17	0.99	25		3.34
66	13.21	2.99	21		10.98
67	22.84	1.23	25		7.82
68	19.71	1.97	24		10.78
69	21.55	1.61	24		9.61
70	15.57	1.30	25		5.61
71	14.87	1.07	25		4.43
72	14.06	1.01	25		3.94
73	6.86	1.26	24		2.39
74	19.94	0.72	26		4.00

continued...

75	20.76	1.69	24		9.75
76	17.37	2.30	23		11.09
77	20.60	1.17	25		6.68
78	16.81	2.80	22		13.05
79	16.64	1.78	24		8.20
80	25.32	1.16	26		8.18
81	15.66	2.71	22		11.78
82	3.90	3.56	20	16.77	3.86
83	22.23	1.03	26		6.34
84	23.21	1.56	25		10.06
85	18.56	1.66	24		8.55
86	4.59	1.96	23	8.45	2.50
87	16.08	2.01	23		8.97
88	4.42	1.63	23	25.28	2.00
89	3.72	0.97	25	6.67	1.00
90	14.97	1.15	25		4.78
91	16.11	2.18	23		9.76
92	9.01	3.00	21		7.52
93	13.36	0.96	25		3.57
94	23.99	0.84	26		5.58
95	19.48	0.53	27		2.86
96	12.39	0.72	26		2.48
97	1.78	0.70	25	16.70	0.35
98	17.86	0.91	26		4.50
99	11.44	1.21	25		3.85
100	17.46	1.89	24		9.16
101	9.95	1.16	25		3.21
102	17.71	1.60	24		7.86
103	13.73	2.00	23		7.63
104	6.02	0.60	26	21.06	1.00
105	5.16	0.42	26	16.18	0.61
106		2.54	22	15.24	0.00
107	17.34	1.26	25		6.06
108	10.60	1.98	23		5.82
109	15.33	2.42	22		10.30
110	19.65	1.70	24		9.26
111	14.35	1.84	24		7.33
112	17.61	1.24	25		6.07
113	11.21	1.87	23		5.82
114	16.23	1.08	25		4.87
115	14.44	2.05	23		8.24

continued...

116	19.68	1.99	24		10.89
117	14.16	2.44	22		9.59
118	23.72	0.78	26		5.12
119	6.14	2.14	23	19.38	3.65
120	21.39	0.97	26		5.76
121	18.67	1.18	25		6.11
122	17.36	1.91	24		9.22
123	20.44	1.06	26		6.01
124	21.55	1.09	25		6.55
125	5.59	1.31	24	22.40	2.03
126	11.73	1.87	23		6.08
127	17.22	1.16	25		5.53
128	18.18	1.67	24		8.43
129	19.62	1.96	23		10.70
130	16.72	1.68	24		7.81
131	26.40	2.05	24		15.05
132	24.53	1.80	24		12.24
133	20.19	2.39	23		13.43
134	17.90	1.18	25		5.86
135	21.15	1.34	25		7.86
136	12.02	1.00	25		3.33
137	17.88	1.62	24		8.03
138	17.80	1.39	25		6.89
139	15.13	2.46	22		10.35
140	16.49	1.83	24		8.37

Commercial Road and Albert Street Intersection

Interactions	Vehicle/Pedestrian Speed (km/h)	TA(s)	Severity	Vehicle Speed (km/h)	Dist. To collision (m)
1	8.02	3.44	20		7.67
2	3.28	0.55	26	14.18	0.50
3	12.06	2.10	23		7.02
4	12.11	1.96	23		6.60
5	8.28	2.32	22		5.35
6	13.15	2.43	22		8.89
7	10.43	2.02	23		5.85
8	9.33	2.24	23		5.80
9	10.06	1.82	23		5.08
10	10.06	2.05	23		5.72
11	12.48	1.88	23		6.53

continued...

12	15.74	1.59	24		6.96
13	12.01	2.03	23		6.79
14	16.43	1.30	25		5.92
15	16.79	1.86	24		8.69
16	10.04	1.48	24		4.14
17	10.16	1.83	23		5.16
18	10.64	1.97	23		5.83
19	15.31	1.61	24		6.83
20	4.36	1.24	24	7.26	1.50
21	18.68	1.94	24		10.09
22	18.71	1.58	24		8.20
23	19.05	1.72	24		9.10
24	13.70	1.58	24		6.02
25	19.15	2.13	23		11.35
26	7.64	4.45	17		9.45
27	9.74	2.20	23		5.97
28	15.59	2.04	23		8.85
29	4.96	2.12	23	19.62	2.92
30	11.35	2.70	22		8.53
31	14.75	2.21	23		9.07
32	17.50	2.42	23		11.77
33	4.76	0.93	25	10.51	1.23
34	15.35	2.53	22		10.77
35	15.79	2.55	22		11.20
36	13.24	2.69	22		9.91
37	17.32	1.90	24		9.16
38	4.76	1.21	24	25.28	1.60
39	13.93	2.25	23		8.72
40	15.63	1.32	25		5.72
41	20.31	1.15	25		6.50
42	15.57	1.99	23		8.61
43	14.77	1.69	24		6.95
44	9.10	2.62	22		6.63
45	13.08	1.55	24		5.65
46	21.36	1.53	25		9.07
47	16.87	2.16	23		10.12
48	13.87	2.13	23		8.23
49	10.03	3.49	20		9.72
50	17.28	1.37	25		6.57
51	13.01	1.21	25		4.36
52	14.33	2.98	21		11.84

continued…

53	3.67	0.43	26	16.54	0.44
54	14.77	2.44	22		10.01
55	20.07	1.85	24		10.32
56	15.67	1.65	24		7.17
57	2.84	1.48	24	15.11	1.17
58	11.74	1.53	24		4.98
59	17.02	2.63	21		12.42
60	8.01	1.99	23		4.42
61	14.02	2.69	22		10.46
62	20.62	1.79	24		10.26
63	8.36	4.35	18		10.11
64	9.25	3.02	21		7.77
65	16.82	2.32	23		10.84
66	19.06	1.69	24		8.96
67	16.42	2.00	23		9.14
68	8.13	3.06	21		6.92
69	8.35	3.33	20		7.72
70	12.99	2.14	23		7.71
71	16.06	2.00	23		8.94
72	9.46	1.79	23		4.70
73	11.43	1.95	23		6.21
74	16.36	2.46	22		11.17
75	16.26	2.61	22		11.78
76	24.40	1.47	25		9.99
77	11.17	1.56	24		4.83
78	13.65	1.49	24		5.67
79	3.01	1.42	25	16.56	1.19
80	13.53	1.32	25		4.97
81	8.70	2.28	22		5.50
82	21.02	0.85	26		4.97
83	18.21	1.70	24		8.62
84	14.36	1.83	24		7.30
85	14.37	1.67	24		6.66
86	10.10	1.97	23		5.52
87	14.08	1.98	23		7.73
88	10.71	3.07	21		9.14
89	17.44	1.60	24		7.74
90	10.88	1.98	23		5.97
91	3.74	2.12	22	13.59	2.20

Commercial Road and Grey Street Intersection

Interactions	Vehicle/Pedestrian Speed(km/h)	TA(s)	Severity	Vehicle Speed (km/h)	Dist. To collision (m)
1	15.72	1.75	24		7.63
2	11.39	0.85	25		2.70
3	15.44	1.23	25		5.29
4	11.32	1.84	23		5.80
5	17.55	1.94	24		9.44
6	12.32	1.56	24		5.34
7	10.31	1.29	24		3.68
8	9.96	1.19	25		3.30
9	10.12	1.80	23		5.08
10	13.61	1.40	24		5.28
11	12.88	1.13	25		4.03
12	21.35	1.23	25		7.28
13	15.39	1.36	25		5.83
14	7.80	2.72	21		5.89
15	12.21	3.98	19		13.50
16	4.78	0.57	26	5.12	0.76
17	15.98	1.76	24		7.83
18	12.47	1.99	23		6.90
19	11.45	1.71	24		5.44
20	14.09	3.18	21		12.43
21	16.01	1.28	25		5.68
22	14.95	1.59	24		6.59
23	8.48	1.86	23		4.38
24	4.78	2.90	21		3.86
25	21.03	0.78	26		4.56
26	6.70	1.74	23		3.24
27	4.57	1.97	23		2.50
28	15.82	0.64	26		2.83
29	8.25	2.12	23		4.86
30	24.92	0.75	26		5.18
31	12.97	1.02	25		3.69
32	7.26	1.35	24		2.73
33	11.92	1.23	25		4.07
34	8.40	1.61	24		3.76
35	4.33	0.83	25		1.00
36	8.64	1.32	24		3.16
37	10.60	1.71	24		5.03
38	12.03	1.51	24		5.03
39	16.01	1.28	25		5.68

Durban City Engineers. (2001), *Conflict study at Manning Road and Clark Road*, Durban, South Africa.

Erke, H. (1984), *The traffic conflict technique of the Federal Republic of Germany*, International calibration study of traffic conflict techniques, NATO ASI series Vol. F5, Springer-Verlag, Berlin, pp. 107-119.

FHWA. (1989), *Traffic conflict techniques for safety and operations-Engineers Guide*, Washington D.C.

Friedstrom, L. & Ingebritsen, S. (1991), *An aggregate accident model based on pooled, regional time series data*, Accident Analysis and Prevention, Vol. 23, No 5, New York, Pergamon Press, pp 363-378.

Fruin, J.J. (1973), *Pedestrian accident characteristics in a one-way grid*, Highway Research Record 436, National Research Council, Washington, D.C., pp.1-7

Gårder, P. (1989), *Konfliktsstudier i landsvägskorsningar,* Bulletin 26, Lund, Sweden

Gårder, P. (1989), *Pedestrian safety at traffic signals: A study carried out with the help of a traffic conflicts technique*, Accident Analysis and Prevention, Vol. 5, No. 21 New York, Pergamon Press, pp. 435-444.

Glauz, W.D., Bauer, K.M. & Migletz, D.J. (1985), *Expected conflict rates and their use in predicting accidents*, Transportation Research Record 1026, Transportation Research Board, Washington D.C., pp. 1-12.

Glauz, W.D. & Migletz, D.J. (1980), *Traffic conflicts techniques for use at intersections*, Transportation Research Record 770, Transportation Research Board, Washington D.C., pp. 21-29.

Glennon, J.C., Glauz, W.D., Sharp, M.C. & Thorson, B.A. (1977) *Critique of the traffic-conflict technique*, Transportation Research Record 630, Transportation Research Board, Washington, D.C., pp. 32-38.

Hauer, E. (1971), *Accidents, overtaking and speed control*, Accident Analysis and Prevention, Vol. 3, New York, Pergamon Press, pp 1-13.

Hauer, E. & Hakkert, A.S. (1988), *Extent and some implications of incomplete accident reporting*, Transportation Research Record 1185, Transportation Research Board, Washington D.C., pp. 1-10.

Hayward, J.C. (1972), *Near-miss determination through use of a scale of danger*, Highway Research Record 384, Highway Research Board, Washington D.C., pp. 24-34.

Hollan, K.T., Holman, R.A. & Lippman, T.C. (1997), *Practical use of video imagery in near shore oceanographic field studies*, IEEE Journal of oceanic engineering, Vol. 22

Hoose, N. (1991), *Computer image processing in traffic engineering*, Research Studies Press, Somerset, England.

Hydén, C. (1987), *The development of a method for traffic safety evaluation: The Swedish traffic conflict technique*, Bulletin 70, Lund Institute of Technology, Lund, Sweden.

James, H.F. (1991), *Under-reporting of road traffic accidents,* Traffic Engineering and Control, Vol. 32, pp. 573-583.

Joksch, H. C. (1975), *An empirical relation between fatal accident involvement and speed.* Accident Analysis and Prevention, Vol. 7, New York, Pergamon Press, pp 129-132.

Kruysse, H.W. & Wijlhuizen, G.J. (1992), *Why are expert not better in judging the danger of filmed traffic conflicts?*, Accident Analysis and Prevention, Vol. 24, No. 3, New York, Pergamon Press, pp. 227-235.

Lehman, G. & Reynolds, T. (1999), *The contribution of onboard recording systems to road safety and accident analysis.*
<http://www.ntsb.gov/events/symp_rec/proceedings/authors/lehmann.htm>

Lötter, S. (2001), *Course on traffic conflict measuring techniques*, South African Road Federation, Johannesburg, South Africa

Linderholm, L. (1981), *Vidareutveckling av kinflikttekniken för riskbestämning i trafiken*, Rapport No. 7025, Lund, Sweden.

Massound, J. & Seneviratne, P.N. (1991), *Applying conflict technique to pedestrian safety evaluation*, ITE Journal, March 1991, pp. 21-26.

Mathworks Publication (1992), *The student edition of MATLAB for MS-DOS personal computers*, Prentice-Hall, New Jersey.

McCullagh, P. & Nelder, J.A. (1989), *Generalised linear models,* 2nd Edition, Chapman and Hall, London.

McDonald, J W (1953), *Relation between number of accidents and traffic volume at divided-highway intersections,* Bulletin 74, 7-17 (Highway Research Board).

McShane, W.R. & Roess, R.P. (1990), *Traffic Engineering*, Prentice-Hall, New Jersey

National Department of Transport (1999), *The South African Road Safety Manual*, South Africa.

National Department of Transport (2002), *Pedestrian-Bicycle conference*, Durban, South Africa

National Cooperative Highway Research Program (NCHRP), (1980), *Application of Conflict Analysis at Intersections,* National Research Council, Washington, D.C.

Nel, P.W. (1989b), *Traffic conflict measuring techniques: a user's manual*, CSIR, Pretoria (Technical Manual DPVT/M-19).

OECD Publication (1997), *Road safety principles and models: Review of descriptive, predictive, risk and accident consequence models,* IRRD No 892483, Road Transport Research, OECD, Paris 1997. OCDE/GD(97)153.

OECD Publication (1998), *Safety of vulnerable road user*, <www.oecd.org/dsti/sti/transport/road/index.html>.

Older, S.J. and Shippey, J. (1979), *Proceedings of the second international traffic conflict technique workshop, May 1979*, Transport and Road research Laboratory, Department of the Environment Department of Transport, Berkshire (TRRL Supplementary Report 557).

Paddock, R.D. (1974), *The traffic conflicts technique: an accident prediction method*, Highway Research Record 486, Highway Research Board, Washington D.C., pp. 1-10.

Patel, S. (2001), *Application of digital imaging in measuring cross track drift of vessels entering a port*, Masters dissertation, School of Civil Engineering, University of Natal, Durban, South Africa.

Perkins, S.R. & Harris, J.I. (1968), *Traffic Conflict Characteristics-Accident Potential at Intersections*, Highway Research Record 225, Washington D.C., pp. 35-43.

Pickering D., Hall, R.D. & Grimmer, M. (1986), *Accidents at rural T-junctions*, Department of Transport, *TRRL Research Report RR65,* Crowthorne: Transport and Road Research Laboratory.

Roebuck, C.S. (1989), *Transport Development*, Course notes, University of Natal, South Africa

Satterhwaite, S. P. (1981), *A survey of research into relationships between traffic accidents and traffic volumes,* TRRL Supplementary Report 692, Crowthorne: Transport and Road Research Laboratory.

Salman, N.K., and Al-Matia, K.J. (1995), *Safety evaluation at three-leg, unsignalized intersections by traffic conflict technique*, Transportation Research Record 1485, Transportation Research Board, Washington, D.C., pp. 117-185.

Sayed, T. & Zein, S. (1999), *Traffic conflict standards for intersections*, Transportation planning and technology, Vol. 22, Issue 4, pp. 309-323.

Shbeeb, L. (2000), *Development of a traffic conflicts technique for different environments. A comparative study of pedestrian conflicts in Sweden and Jordan*, Lund Institute of Technology, Department of Technology and Traffic Engineering, Lund, Sweden.

Smeed, R. J. (1949), *Some statistical aspects of safety research*, Journal of the Royal Statistics Society, Series A, 112, Blackwell Publishers, Oxford, UK, pp 1-34.

Smeed, R. J. (1972). *The statistics of road accidents*, Proceedings of the Third International Symposium on Urban Traffic Safety, Budapest.

Solomon, D. (1964), *Accidents on main rural highways related to speed, driver and vehicle,* Bureau of Public Roads, Department of Commerce, Washington, USA.

Spicer, B.R. (1971), *A pilot study of traffic conflicts at rural dual carriage intersections*, Transport Road Research Laboratory, Laboratory Report LR 410, Crowthorne.

Spicer, B.R. (1972), *A traffic conflict study at an intersection on the Andoverford bypass*, Transport Road Research Laboratory, Laboratory Report LR 520, Crowthorne.

Spicer, B.R. (1973), A *study of traffic conflicts at six intersections*, Transport Road Research Laboratory, Laboratory Report LR 55?, Crowthorne.

Spicer, B.R., Wheeler, A.H. and Older, S.J. (1980), *Variation in vehicle conflicts at a T-junction and comparison with recorded collisions*, Department of the Environment Department of Transport TRRL Report, SR 545, Crowthorne.

Svensson, Å, (1998), *A method for analysing the traffic safety process in a safety perspective*, Lund Institute of Technology, Department of traffic planning and engineering, Lund, Sweden.

Tanner, J.C. (1953). *Accidents at rural highway junctions,* Journal of the Institution of Highway Engineers. Vol II (11), pp 56-57.

The Concise Oxford Dictionary of Current English (1990), first edited by Fowler, H.W. and Fowler, F.G. - 8th ed. / edited by R.E. Allen, Oxford, Clarendon Press.

Thomas, G.B. Jr. & Finney, R.L. (1996). *Calculus*, Ninth edition, Addison-Wesley Publishing Company, United States

UNECE Publication (1997) <http://www.unece.org/trans/roadsafe/rs3ras.html>.

Van der Horst, A.R.A. (1984), *The ICTCT calibration study at Malmo: a quantitative analysis of video recording*, TNO Institute for perception, the Netherlands.

Wagner, G. (2000), *Algorithm Choices Give Pattern Matching an Edge* <http://www.e-insite.net/tmworld/index.asp?layout=article&articleid=CA187424>.

Webster, D. C. & Mackie, A.M. (1996), *Review of traffic calming schemes in 20 mph zones*, TRL Report 215, Transport Research Laboratory, Crowthorne, Berks.

Williams, M.J. (1981), *Validity of the traffic conflict technique*, Accident Analysis and Prevention, Vol. 13, New York, Pergamon Press, pp. 133-145.

World Bank Publication (1999), *Urban Transport Safety and Security,* <http://www.worldbank.org/transport/utsr/yokohama/day2/ben_safety.pdf>.

Zegeer, C.V., Opiela, K.S. & Cynecki M.J. (1982), *Effect of pedestrian signals and signal timing on pedestrian accidents*, Transportation Research Record 847, Transportation Research Board, Washington D.C., pp. 62-72.

Zhang, Z. (1998), *A flexible new technique for camera calibration*, Microsoft Research, Microsoft Corporation, MSR-TR-98-71.
<http://research.microsoft.com/~zhang>