Vehicle Travel Speeds and The Incidence of Fatal Pedestrian Collisions

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Volume I

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Abstract

The aim of this study by the NHMRC Road Accident Research unit was to estimate the likely effect on pedestrian fatalities of a reduction in vehicle travelling speed. Results were based on detailed investigations of 176 fatal pedestrian collisions in the Adelaide area between 1983 and 1991. Estimates were developed for a range of speed reduction scenarios. The study found that a reduction of 5 km/h in vehicle travelling speeds in the Adelaide area could be expected to result in a reduction of 30% of the incidence of fatal pedestrian collisions. Under this scenario 10% of the collisions would have been avoided altogether. Volume 1 of this report contains detailed findings for each speed reduction scenario along with a description of the method used and supporting references. Volume ll contains the details of all 176 cases.

Keywords

Pedestrian, Speed, Collision, Impact, Speed reduction, Fatality, Vehicle.

NOTES:

(1) FORS Research reports are disseminated in the interests of information exchange.
(2) The views expressed are those of the author(s) and do not necessarily represent those of the Commonwealth Government
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  (b) reports of research conducted by other organisations on behalf of the FORS are published in the CR series
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This is the second edition of this report incorporating errata from the first edition.

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PREFACE

This volume is the first of two volumes that make up the report, Vehicle Travel Speeds and The Incidence of Fatal Pedestrian Collisions, prepared by the NHMRC Road Accident Research Unit for the Federal Office of Road Safety. It contains details of the study in which 176 case studies of fatal pedestrian collisions, which occurred in the Adelaide metropolitan area between 1983 and 1991, were analysed to estimate the likely effects of a reduction in travelling speed, of the accident involved vehicles, on the outcome of those collisions.

Volume II contains the case details of all 176 accidents. Only a limited number of copies of this volume have been printed. Enquiries should be directed to:

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NOTATIONS

α	Percentage increase factor for base reaction time.
a	Distance from start of skid marks to point of impact (m).
b	Distance from end of skid marks to point of impact (m).
g	Acceleration due to gravity (m/s^2).
L	Percentage of kinetic energy remaining immediately prior to wheels locking.
$m_{motorcycle}$	Mass of motorcycle (kg).
m_{rider}	Mass of rider (kg).
$m_{pedestrian}$	Mass of pedestrian (kg).
s_r	Reaction distance (m).†
s_{nr}	Hypothetical reaction distance (m).
s_d	Sighted distance (m).†
s_{nd}	Hypothetical sighted distance (m).
s_m	Motorcycle stopping distance (m).
s_c	Vehicle stopping distance (m).
s_p	Pedestrian projection distance (m).
SL	Speed limit in place at collision location (km/h).†
t_0	Beginning of crash sequence.
t_b	Base reaction time (s).
t_r	Reaction time (s).
t_l	Time elapsed before wheels lock up on braking (s).
μ_w	Coefficient of friction for locked wheels braking on wet bitumen for cars.
μ_d	Coefficient of friction for locked wheels braking on dry bitumen for cars.
μ_c	Coefficient of friction for a car under braking with no wheels locked.
μ_b	Coefficient of friction for a motorcycle under braking with locked wheels on bitumen.
μ_s	Coefficient of friction for a motorcycle sliding on its side over a bitumen surface.
μ_m	Coefficient of friction for a motorcycle under braking without locked wheels.
μ_p	Coefficient of friction for a pedestrian sliding on bitumen.
v_0	Travelling speed (m/s).†
v_i	Impact speed (m/s).†
$\vec{v}_m$	Velocity vector for motorcycle after impact (m/s).
$\vec{v}_i$	Velocity vector for motorcycle and rider before impact (m/s).
$\vec{v}_r$	Velocity vector for rider after impact (m/s).
$\vec{v}_p$	Velocity vector for pedestrian after impact (m/s).
$v_{\max}$	Maximum impact speed from projection distance (m/s).
$v_{\min}$	Minimum impact speed from projection distance (m/s).
v_{mean}	Mean impact speed from projection distance (m/s).

† Symbols superscripted with an * (eg s_r^*) refer to the value which is calculated when the travelling speed of a case is substituted by an hypothetical travelling speed.

EXECUTIVE SUMMARY

The likely effect of reduced travel speeds on the incidence of fatal pedestrian collisions is estimated in this report.

A reduction of 5 km/h in vehicle travelling speeds in the Adelaide area could be expected to result in a reduction of 30 percent of the incidence of fatal pedestrian collisions. In 10 percent of the cases the collision with the pedestrian(s) would have been avoided altogether. In areas in which the speed limit is now 60 km/h, about 32 percent of fatal pedestrian collisions would be prevented. By comparison, reducing all speeds to the current legal limit at each crash site would have reduced fatal pedestrian collisions by 12 percent overall, and by 13 percent in areas with a speed limit of 60 km/h.

A 5 km/h reduction in travelling speed is one of 26 speed reduction scenarios which were considered in this study. The results for eight of these 26 scenarios are presented in the body of the report, with the remainder in an appendix. Among these eight scenarios, the greatest predicted reduction in pedestrian fatalities was 75 percent, for a 20 km/h reduction in travelling speeds in what are now 60 km/h speed limit areas. The smallest reduction was 4 percent, for a reduction of 5 km/h in travelling speeds on local streets, with no change to travelling speeds on arterial roads and main traffic routes.

These estimates are based on analysis of the results of detailed investigations of 176 fatal pedestrian crashes in the Adelaide area by the NHMRC Road Accident Research Unit between 1983 and 1991. The method developed to estimate the effect of reduced travelling speed is described, and supported by references to the published literature. The denominator used to calculate the percentage reductions in fatalities includes those cases which would not be affected by a general reduction in travelling speed, such as turning vehicles or those slowing to stop at a traffic signal.

More than 85 percent of the 176 fatal pedestrian collisions occurred on non-local roads. This is why a reduction of 5 km/h in travelling speeds on local streets would have little effect on pedestrian fatalities.

Small differences in travelling speed can result in large differences in impact speed because braking distance is proportional to the square of the initial speed. For example, consider two cars travelling side by side at a given instant, one car travelling at 50 km/h and the other overtaking at 60 km/h. Suppose that a child runs onto the road at a point just beyond that at which the car travelling at 50 km/h can stop. The other car will still be travelling at 44 km/h at that point.

Similarly, small increases in travelling speed can result in large increases in impact speed and the risk of fatal injury.

1 INTRODUCTION

1.1 Aim

The aim of this investigation is to estimate the likely effect of a reduction in the travelling speed of vehicles on pedestrian fatalities.

1.2 Background

The NHMRC Road Accident Research Unit has investigated 176 fatal pedestrian collisions in the Adelaide area since 1983. This was done as part of a continuing study of mechanisms of injury to the brain in road crashes. Each case study commenced with attendance at an autopsy of a fatally injured pedestrian and continued with an examination of the vehicle involved and the scene of the collision. In most cases statements were available, or were obtained, from the driver and from any witnesses.

The main purpose of these investigations was to identify the location of any impact to the head and the part of the vehicle struck by the head, and also to estimate the relative velocity of that impact. When combined with information on the stiffness of the object struck by the head, it is possible in some cases, to estimate the magnitude and nature of the forces transmitted to the head, which are then compared with the nature and characteristics of the injury to the brain. This study is expected to increase the level of understanding of the tolerance of the brain to impact to the head and thereby to facilitate the design of safer vehicles and more effective protective helmets for vehicle users.

There is much that can be done in terms of vehicle design to reduce the severity of the injuries sustained by a pedestrian when struck by a vehicle. The senior author of this report is a member of an International Standards Organisation Working Group on Pedestrian Impact Test Devices. That Group is charged with the development of compliance tests which will be able to be used as the basis of vehicle safety standards aimed at the reduction of pedestrian injury. However the introduction of new standards for this purpose is still some years away and it is far from certain that they will receive ready acceptance. A notice of proposed rule making to minimise pedestrian head injury by specifying the impact properties of the bonnet of a car was withdrawn by the United States National Highway Traffic Safety Administration and the research team that developed the proposed rule has disbanded.

The most obvious way to reduce the severity of a collision between a pedestrian and a vehicle, regardless of the characteristics of the vehicle, is to reduce the impact speed. In this study we reviewed each of the fatal pedestrian collisions investigated by the NHMRC Road Accident Research Unit to estimate the likely effect of a reduction in travelling speed of the striking vehicle on the severity of the pedestrian's injuries.

2 LITERATURE REVIEW

A review was conducted of information in the literature on the injury outcome of a pedestrian/vehicle collision for a given impact speed and the likely consequences of reducing the travelling speeds of vehicles in terms of the frequency and severity of pedestrian injuries.

In the literature review no studies were found that contained a method for determining the outcome of reduced travelling speed. However, information relating to factors such as the driver's reaction time, calculation of impact speed, and the pedestrian's injuries in relation to impact speed was obtained. This information was then used in the reconstruction of the available cases and in the analyses of the hypothetical reduced travelling speeds.

2.1 Driver’s Reaction Time

Olson (1991) reviewed the available literature and recommended an approach to use in determining the perception response time of a driver. Much information suggests that perception response time increases slightly with age. Typical data from a publication by the American Automobile Association, Traffic Engineering and Safety Department (Olson, 1991) are shown in Figure 2.1. These data were collected from a sample of over 1,400 persons of various ages by having them step on a brake pedal in response to a light signal. The mean perception response times ranged from 0.44 seconds in the 20 year old group to 0.52 seconds in the 70 year old group. However, an exception to this general trend has been reported by Olson *et al* (1984) who found no difference between old and young subjects in the time taken to respond to a surprise encounter with a roadway obstacle. As the relative effect of age is small, no difference was allowed for on the basis of age in the present study.

On average, it was found that women tend to respond slower than men. Typical data from the American Automobile Association publication (Olson, 1991) are shown in Figure 2.2. This was a choice response time study in which the subjects had to distinguish between three signals. The average difference between the two groups was about 0.08 seconds. However there was almost complete overlap in the distributions of performance on this task for the two groups and so in the present study no difference was allowed for on the basis of sex alone.

Figure 2.1 *Brake reaction time as a function of age (Olsen , 1991).*

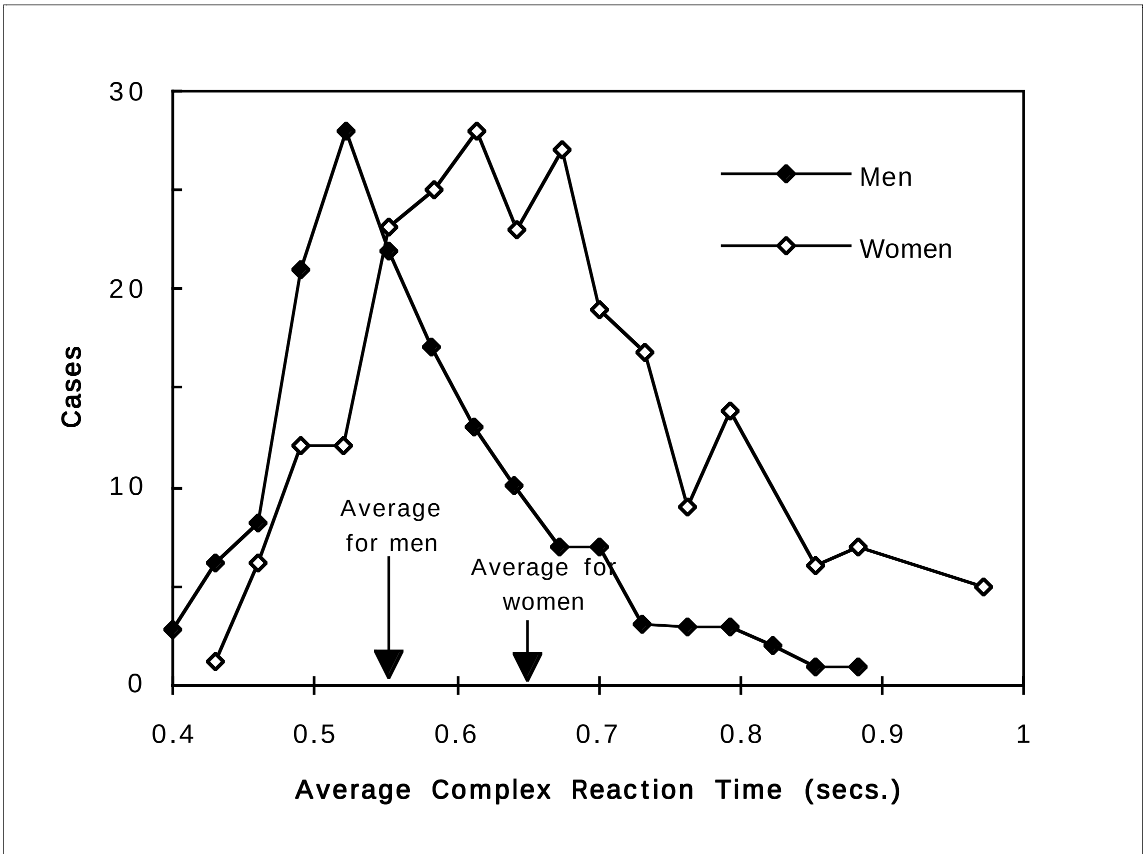


Figure 2.2 *Choice reaction time for males and females (Olsen , 1991).*

Pauwels *et al* (1992) conducted tests to determine the influence of alcohol consumption on travelling behaviour. The subjects were students between the ages of 20 and 26 years who consumed alcohol regularly. The response time of the subjects to certain simulated situations was monitored. The primary task consisted of driving a driving simulator in a filmed daily-life traffic situation. Records were taken from the accelerator, brake, steering wheel and turn indicator. The driver's reaction time was measured in response to the appearance of a visual stimulus. The results showed an increase in reaction time with increasing blood alcohol concentration (Figure 2.3).

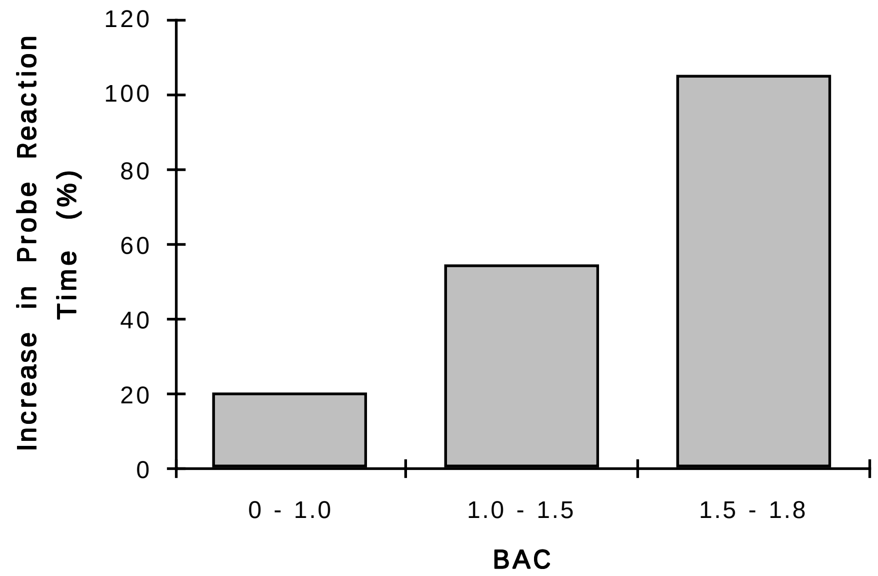


Figure 2.3 *Reaction time and blood alcohol concentration (Pauwels et al, 1992)*

Bell *et al* (1982) investigated the relative influence of heat, co-action, complexity, and sex of the subject on reaction time. The test apparatus consisted of a vertical display panel containing four white stimulus lights. Sixty four female and sixty four male subjects participated in the study. Eight subjects of each sex were randomly assigned to one cell of a factorial design. Within the cell were two levels of ambient temperature, two levels of social facilitation and two levels of task complexity. It was found that reaction time was faster for males than females, faster for the easy than for the complex task, and faster for co-acting than for individually acting subjects (Figure 2.4).

In summary, it was concluded from the review of the literature that most drivers (about 85%) begin to respond to the presence of an unexpected object in their path or an emergency situation within 1.5 seconds and so this figure was used for driver reaction time in the present study.

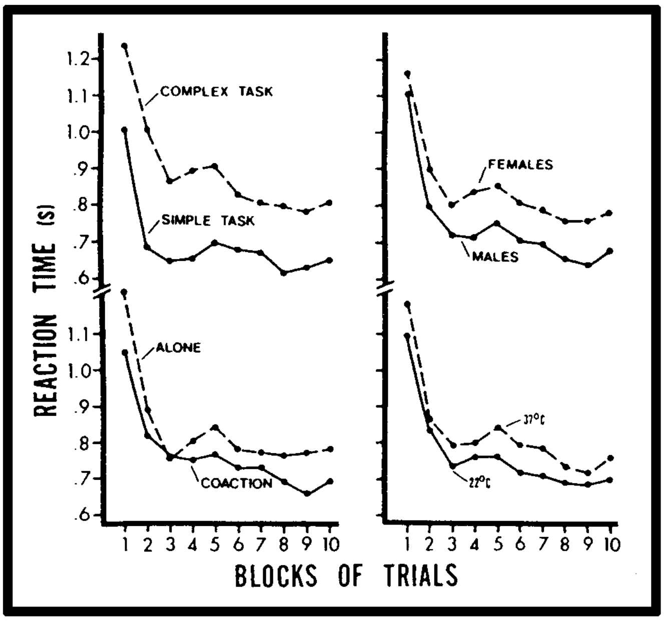
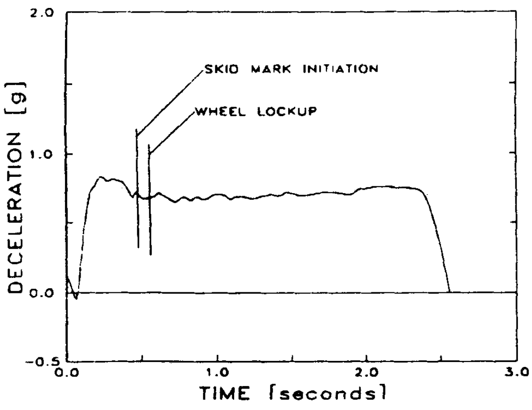


__Figure 2.4__ Reaction time as a function of task difficulty, sex of subject, social facilitation, and ambient temperature.

2.2 Speed Calculations

Keskin *et al* (1989) investigated the relationship between tyre/road friction and vehicle deceleration using the basic equation (equation 2.1) for estimating the speed lost during skidding, based on the length of the skid marks. They also recorded the actual response of the vehicle by measuring its deceleration and braking characteristics preceding and during brake application. They concluded that there is a time lag of about 0.5 seconds from when the brake pedal is initially pressed to when the wheels of the vehicle lock. (see Figure 2.5a) This means that a substantial reduction in velocity may occur before the wheels lock and produce visible skid marks. For passenger cars, typically 15% to 30% of the initial energy possessed by the vehicle is dissipated before clearly visible skid marks are produced (Figure 2.5b).



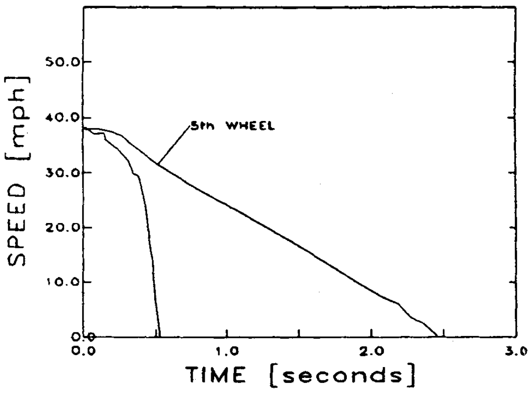


Figure 2.5a *Vehicular deceleration during emergency braking*

Figure 2.5b *Vehicle speed during emergency braking*

Warner *et al* (1983) investigated the appropriate use of friction factors in collision reconstruction, including the effect of tyre design, surface types and road conditions (wet or dry) on the effectiveness of braking. Dry pavement sliding friction decreases with increasing speed (see Figure 2.6), but at low and moderate highway speeds this is a relatively small effect. The general equation for speed calculation using skid marks is shown in equation 2.1.

$$v = \sqrt{2g\mu s} \qquad \text{..........(2.1)}$$

where

v	Travelling speed (m/s)
g	Acceleration due to gravity (9.81 m/s^2)
μ	Coefficient of friction for locked wheel braking
s	Skid mark length (m)

To determine the coefficient of friction the use of vehicle skid tests is suggested by Warner *et al*, but the results of such tests will overestimate the value of the friction coefficient because of the braking effect which occurs before the wheels lock, as noted above. Warner *et al* concluded by noting that many different roadway and tyre factors may influence the friction analysis in specific situations and engineering judgement and experience is important in assessing the interdependency of such factors and in selecting the correct friction factor.

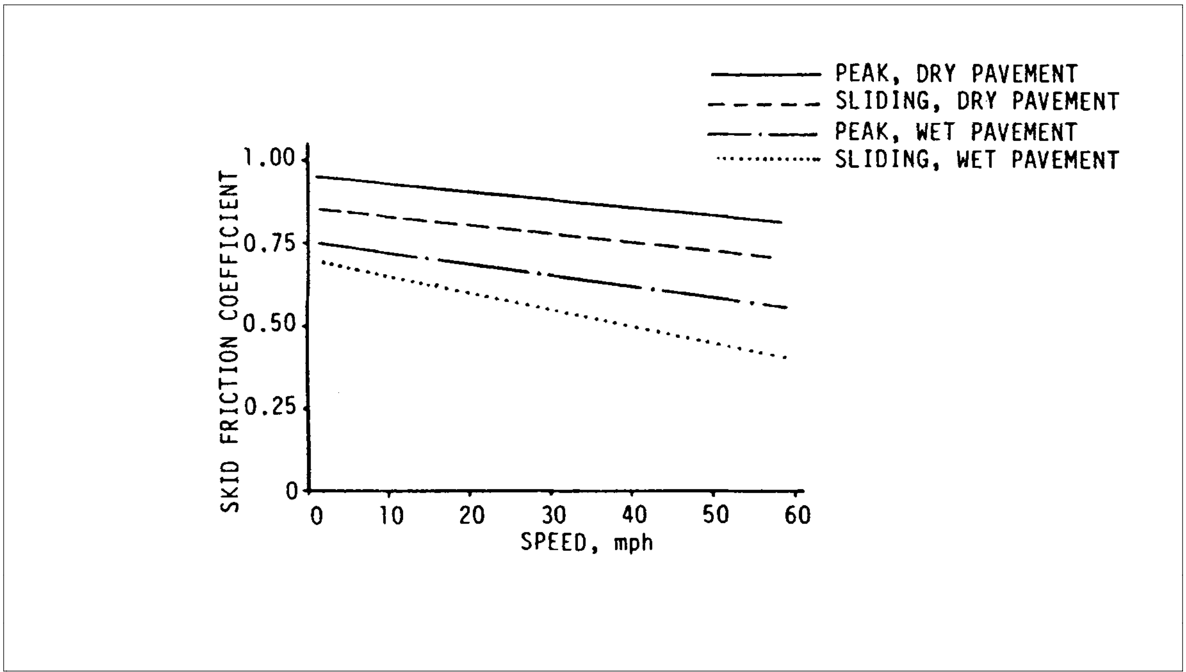


Figure 2.6 *Skid friction coefficient's dependence on speed.*

Several other studies were reviewed and results of several skid test friction factors were considered, as well as other friction factors such as that for a pedestrian sliding on a bitumen surface. Searle and Searle (1983) derived equations for the upper and lower bounds for calculating the impact speed of a vehicle by using the projection distance of the pedestrian. These equations were shown to fit well with previously collected data.

As not all factors affecting the friction coefficients of each case were known, a median value for emergency braking on bitumen was used for all cases, differentiating for wet and dry conditions, for motorcycles and other vehicles, and for locked wheel and non-locked wheel braking. Friction coefficient values, found in the literature, for sliding objects were also used. See Appendix A for more detail.

2.3 Pedestrian Injury in Relation to Impact Speed

Tharp (1974) investigated a total of 175 collisions involving pedestrians and motor vehicles which occurred in the City of Houston, Texas between June 1971, and May 1973. In addition, several years of data collected by the Houston Police was analysed for trends and compared to the information collected by the research team. A linear relationship between pedestrian injury severity (AIS) and impact speed was found. Injury severity varied considerably with "directness" of impact. With higher speed impacts the pedestrian frequently sustained fractures of the cervical spine without direct contact with that region of the body. Injuries from the pedestrian contacting the road surface or other environmental objects were less severe than those from a direct contact with the vehicle.

Glaeser (1993) investigated a total of 522 cases in which a pedestrian was struck by the front of a passenger car. A cumulative frequency of the Abbreviated Injury Score (AIS) rating for head injuries in relation to collision speed for different age groups was obtained from this investigation. It was found that AIS 5/6 head injuries occur at impact speeds above 30 km/h and are very frequent at over 50 km/h, especially among elderly persons.

Stalnaker *et al* (1986) proposed a 3-AIS summary injury score and a corresponding mortality rate. The three maximum AIS scores from any body region were ranked and the mortality rates calculated from a sample of over 7,000 injured persons.

Walz *et al* (1983) compared the distribution of impact speeds in their data with that from five other studies. The potential pedestrian injury severity was then related to the impact speed of the vehicle (see Figure 2.7). The probability of survival for a given Injury Severity Score (ISS) was then estimated from 952 cases (see Figure 2.8).

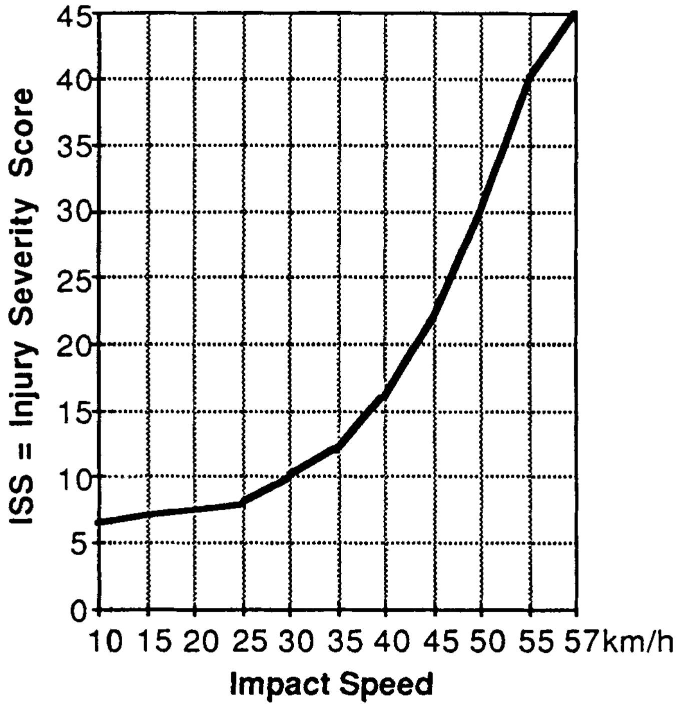


Figure 2.7 *Impact speed and injury severity (ISS)*

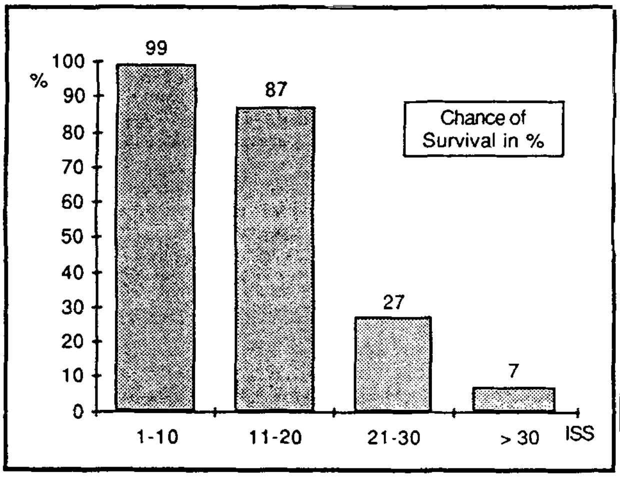


Figure 2.8 *Probability of survival as a function of ISS*

Tharp (1976) determined whether there was a relationship between impact speed and the pedestrian's age and injury severity. Data from 349 cases in which a pedestrian was struck by the front of a passenger vehicle were analysed. The results were divided into the following categories:

a) Overall injury severity was divided into the classes of non critical (overall AIS ratings of 3 and less), and critical (overall AIS of 4 or greater).

b) Impact speeds of 0-10 km/h, over 10 to 20 km/h, over 20 to 40 km/h, and over 40 km/h.

c) Age groups of 15 and younger; 16 through 50; and over 50 years of age.

The probability of sustaining critical injuries for an impact speed range and age group was found by dividing the number of cases with AIS 4 or greater by the number of cases occurring in that impact speed range and age group (see Table 2.1). It was found that the probability of critical injury was dependent on speed and age (see Figure 2.9). However, this data was found to be difficult to apply as the risk of critical injury at speeds over 40 km/h had a single value for each age group. It was thought to be unlikely, for example, that the risk of critical injury would remain at 0.3, for under 16 year olds, for all speeds over 40 km/h. So while acknowledging the role of age in the outcome of an individual vehicle-pedestrian collision, it was not taken into account in this study. The general probability for all ages observed in the sample of cases studied by Walz *et al* (1983), was considered a more appropriate model to use.

Table 2.1
Frequency of overall injury severity by impact speed and age

Impact Speed KM/HR	Overall Injury Severity	PEDESTRIAN AGE GROUP 15 and younger	16-50	Over 50	TOTAL
10 and less	Minor	41	26	20	87
	Critical	0	0	2	2
	Total	41	26	22	89
Over 10 thru 20	Minor	47	35	14	96
	Critical	1	0	2	3
	Total	48	35	16	99
Over 20 thru 40	Minor	49	22	9	80
	Critical	11	2	2	15
	Total	60	24	11	95
Over 40	Minor	11	14	5	30
	Critical	5	18	13	36
	Total	16	32	18	66
	TOTAL	165	117	67	349

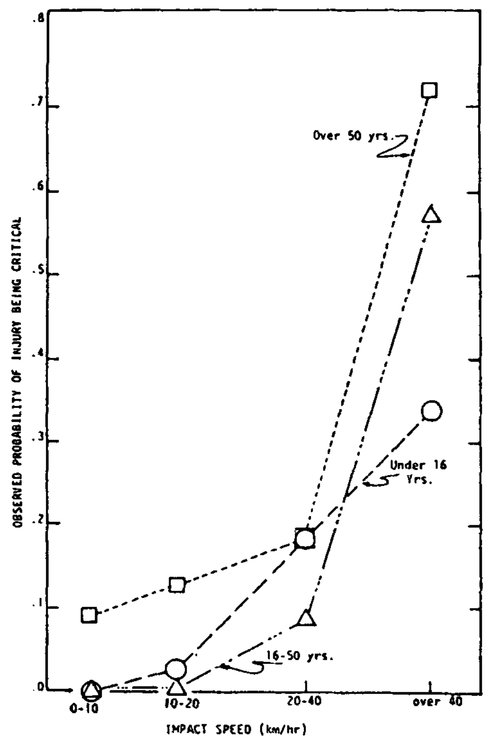


Figure 2.9 Probability of injuries being critical by impact speed and age of pedestrian

2.4 The Effect of Reduction in Travelling Speeds

Walz *et al* (1983) conducted a study investigating the effects of the reduction of the speed limit from 60 to 50 km/h in Zurich. Analysing 946 cases, they found that the number of pedestrian collisions fell by 20% with a 25% decrease in pedestrian fatalities. This reduction was attributed to the change in the speed limit, as the number of slow vehicle accidents (trucks and buses) did not change.

Through reducing the speed limit the number of victims with ISS scores of greater than 30 decreased, with the mean ISS decreasing from 28 to 20. Fractures to the pelvis and ribs were reduced by 50%. Those who were fatally injured also had fewer fatal injuries. It was shown that, whilst in 18% of the pedestrian collisions the collision speed was equal to the travelling speed of the striking vehicle, in 62% the collision speed was reduced by one-fifth.

Proctor (1991) describes the background to the treatment of accidents in urban residential areas in the UK and northern Europe. A reduction in motor traffic speed to 20 miles per hour would not only reduce the levels of pedestrian injuries sustained in collisions, but also give both parties a better chance of avoiding the collision in the first place. The chances of being killed rise dramatically with an increase in the speed of the car. The probability of a pedestrian fatality is 5% at 20 miles per hour, rising to 37% at 30 miles per hour and to 83% at 45 miles per hour.

3 CASE DATA

A sample of 176 fatal pedestrian collisions (181 fatalities) that occurred during the period from June 27, 1983 to August 25 1991, was studied to estimate the effect of a reduction in the travelling speed of the striking vehicle. Of the 176 cases, 153 were considered to have had an outcome related to the travelling speed of the vehicle involved. The other 23 cases had outcomes which did not directly involve the travelling speed of the vehicle involved for at least one of the following reasons:

(a) The vehicle was not travelling with a free velocity (eg: the vehicle was accelerating from a stop line at an intersection, the vehicle was turning at an intersection, the vehicle was doing a U-turn, etc). It was assumed that the impact speed and outcome of these collisions would have been unaffected by a general reduction in travelling speed.

(b) The collision with the pedestrian occurred off the carriageway after the driver had lost control of the vehicle.

(c) The pedestrian's intention was to commit suicide.

(d) Driver had lost consciousness before the collision with the pedestrian.

Of the 153 cases that had an outcome related to the travelling speed of the vehicle involved, 19 case files did not contain sufficient information to carry out the analyses described in the next section.

The distribution of the accidents throughout the Adelaide metropolitan area is illustrated by figure 3.1.

For a more detailed look at the characteristics of the sample, refer to Appendix B.

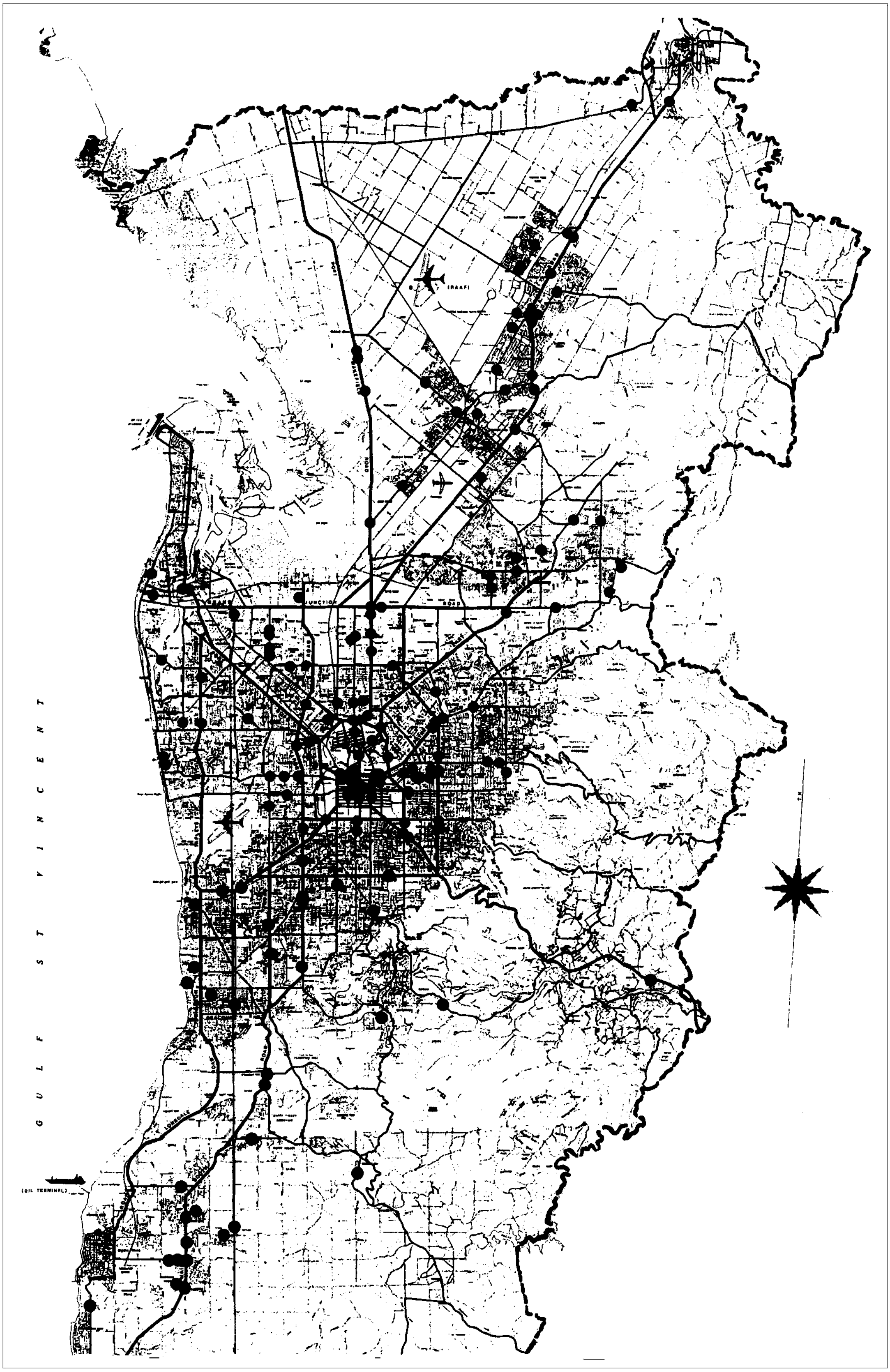


Figure 3.1 *The distribution of accidents throughout the Adelaide metropolitan area*

4 METHODS

4.1 Determining the Travelling and Impact Speeds of Each Case

The first step in the analyses was to determine the travelling speed and impact speed of each case. To do this, standard accident reconstruction techniques were employed. These techniques included reference to skid marks, pedestrian projection distances and momentum transfer. When physical evidence was insufficient to give an exact value for travelling and impact speeds, driver and witness estimates were considered, but wherever possible, these estimates were substantiated by other available evidence. Appendix A contains detailed descriptions of the calculations used.

In many cases the driver stated that no evasive action was taken to avoid collision due to the fact the pedestrian was not seen before the collision or the driver did not realise there was a danger of a collision. Seventy per cent of these cases occurred at night. The impact speed in these cases was equal to the travelling speed of the vehicle.

In the other cases, the driver attempted some evasive action. Sometimes clear skid marks were available to determine the speed before braking. Using physical laws, the speeds at different points in the collision sequence were calculated.

By choosing the most appropriate analysis for each case, the impact speed of the case vehicle was expressed mathematically, in terms of the travelling speed. Once this relationship was known, hypothetical impact speeds were calculated for different travelling speed scenarios.

4.2 Assumptions Made to Estimate the Outcome of Reduced Travelling Speeds

The following assumptions were made in the analyses of each case with hypothetically reduced travelling speeds:

1) The exposure of pedestrians to the potential of these collisions remains unchanged in the analysis. This means that in the hypothetical collision (with the travelling speed reduced), at the instant the driver recognises the potential for a collision, the topography of the accident scene is the same as in the case accident.

2) The pedestrian involved in the collision would remain unable to take any action to avoid the collision. It could be argued that in some cases, reducing the travelling speed of the vehicle may have given the pedestrian time to get out of the path of the oncoming vehicle. However, to take account of this requires that we know at which point the pedestrian recognised the danger and potential for a collision (if they did at all). Assuming that there is nothing the pedestrian could have done to avoid the collision will also produce a more conservative estimate of the benefits of the speed reduction.

3) For cases where no evasive action was taken because the driver was not aware of the potential for a collision the impact speed was equal to the travelling speed. In a reduced travelling speed scenario, this condition is maintained.

4) For the purpose of analysing cases where some evasive action was attempted, the beginning of the crash sequence for each of the accident cases was taken to be the instant that the driver recognised the potential for a collision (time, t_0). In the hypothetical scenarios, the impact point and the location of the vehicle at time, t_0 remain the same as in the actual case.

4.2.1 Location of The Vehicle at Time, t_0

Determining the initial location of the vehicle at time, t_0 relies on knowing the travelling speed of the vehicle, reaction time of the driver and the point at which braking commenced.

For cases where clear skid marks were left by the vehicle, there is good physical evidence of the location where the brakes were applied (taking account of the time lapse from the application of the brakes to the appearance of the skid marks). The location of the vehicle at time, t_0 was found by adding the distance the vehicle travelled during the driver's reaction time, the distance it travelled from when the brakes were applied to the appearance of skid marks, and the skid mark length before impact (see Figure 4.1 and Appendix A).

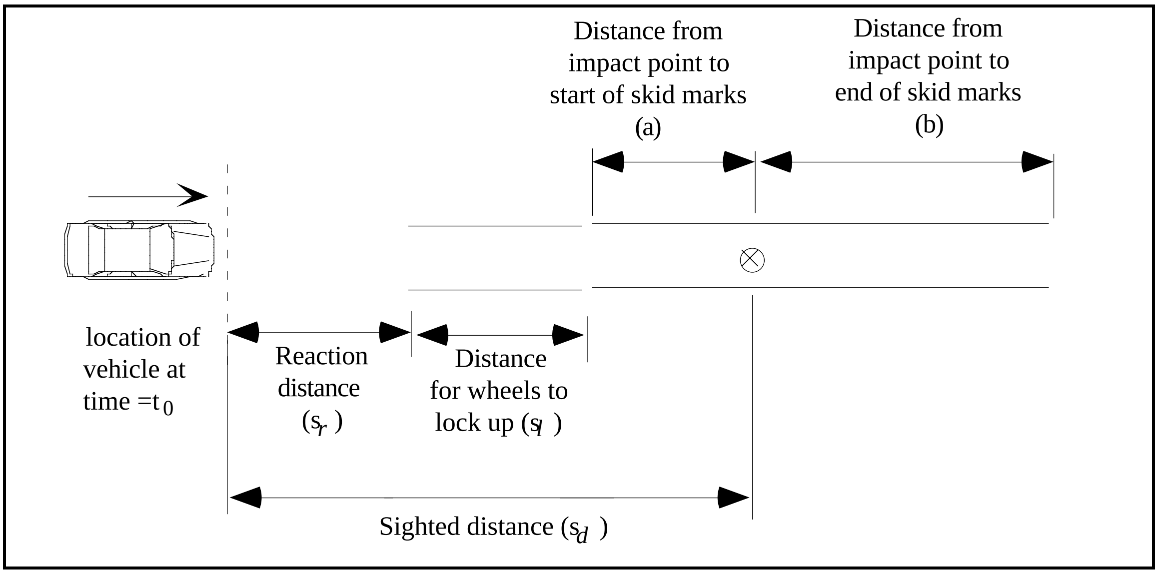


Figure 4.1 *Important dimensions of an accident scene, where clear skid marks have been left.*

For cases where the stopping distance was known but no skid marks were left, the location of the vehicle at time, t_0 was found by adding the distance the vehicle travelled during reaction time to the distance travelled under braking before impact (see Figure 4.2 and Appendix A).

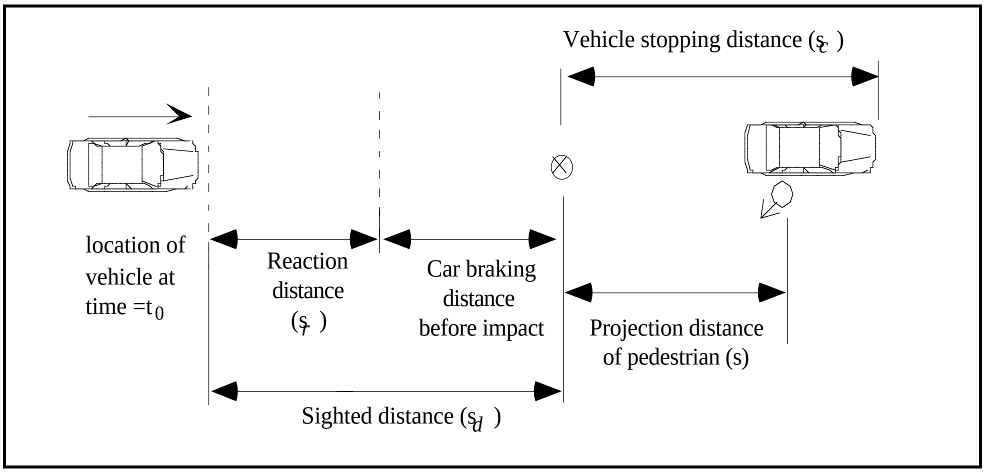


Figure 4.2 *Important dimensions of an accident scene, where the stopping distance and/or pedestrian projection distance are known.*

4.2.2 Reaction Time

The distance the vehicle travelled during the reaction time (the reaction distance) was calculated by taking the product of the travelling speed and the reaction time of the driver (see Appendix A, equation A2).

A base reaction time of 1.5 seconds (Olson, 1991) was used for the reaction time of the driver in each of the cases. Initially, several factors affecting reaction time were considered. They were age, sex, blood alcohol concentration (BAC), and complexity. However, age, sex and complexity have a minor effect on reaction time, when compared to BAC (Olson, 1991; Bell *et al* 1982), and in this study their effects were assumed to be negligible. Therefore, the only factor that was considered in modifying the driver's reaction time was the BAC.

The reaction time was assumed to increase by 20% for BAC between 0 and 0.1, 55% for BAC from 0.10 and 0.15, and 100% for BAC of 0.15 or larger (Pauwels and Helsen, 1993). The reaction time of the driver for each case was then obtained by increasing the base reaction time with the appropriate percentage according to the BAC of the driver.

4.2.3 Reduced Travelling Speed Scenarios

To calculate the effect of lowering travelling speeds on impact speeds, several travelling speed scenarios were applied to the case data. Each scenario describes modified legislated speed limits and/or modified travelling behaviour of the collision involved drivers.

Consider an arbitrary distribution of travelling speeds for a given set of vehicles as in Figure 4.3.

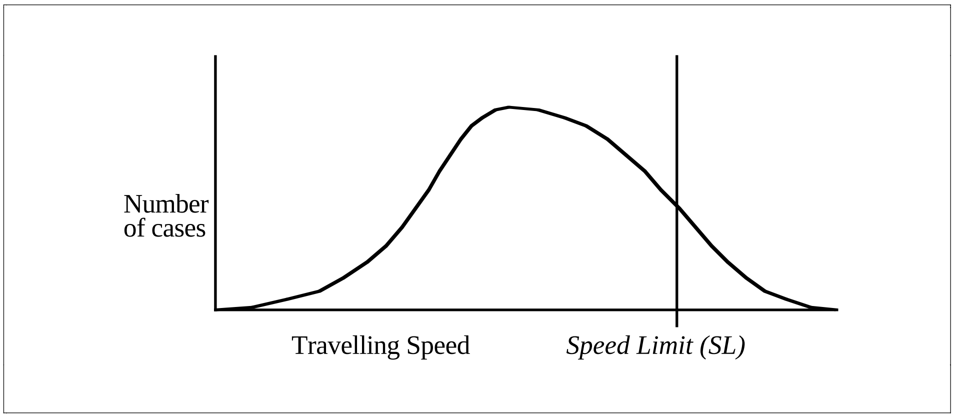


Figure 4.3 *An arbitrary distribution of travelling speeds*

The vertical line (SL) refers to the speed limit which applies to the set. How this distribution is changed, when hypothetically reducing travelling speeds of the set of vehicles, depends on the way in which travelling speeds are reduced. For example, changes in enforcement may only affect those vehicles travelling above the speed limit, whereas physical obstacles to speed, education campaigns, or speed limit changes may affect many more vehicles in the distribution.

In the analysis, five sets of scenarios are presented. The first set assumes specified lower travelling speeds of the involved vehicles. The second set assumes that all involved drivers either obeyed the prescribed speed limit along the stretch of road where the collision occurred or the fastest drivers were travelling at no more than a specified speed above the limit. The third, fourth and fifth sets of scenarios nominate lower prescribed speed limits and assume a specified resulting reduction in vehicle travelling speeds; the third scenario by hypothetically lowering all travelling speeds above the new limit, to that limit; the fourth by hypothetically lowering all travelling speeds above the limit by the same magnitude as the lowering of the limit, and the fifth by lowering all travelling speeds above the limit by the same proportion as the proportional lowering of the limit.

Scenario Set 1 - All vehicles travelling with a lower speed

In this set, the travelling speeds of all case vehicles were lowered by 5 km/h, by 10 km/h, by 10% and then by 20%. The effect of these changes on an arbitrary distribution of travelling speeds (shown in Figure 4.3) is illustrated in Figure 4.4.

In the fifth scenario of this set, the travelling speeds of the vehicles involved in collisions that occurred in local streets were reduced by 5 km/h while the speeds of all other vehicles remained the same. Some difficulty was encountered in finding a uniform definition of a local street. Two definitions were considered. The first was the strict NAASRA† delineation of roads in Adelaide as being "arterial" (class 6 or 7) and “local”. However,

† National Association of Australian State Road Authorities

this defined a conservative set of non-local roads. The other definition of local streets came from the UBD‡ Street Directory of Adelaide which is based on definitions of road types obtained from local councils in the Adelaide metropolitan area. The UBD Street Directory has therefore been used in this study to delineate between main traffic routes and local streets. The resulting set of roads contains fewer local streets than does a classification which defines all but the major arterial roads (NAASRA class 6 and 7) as local streets.

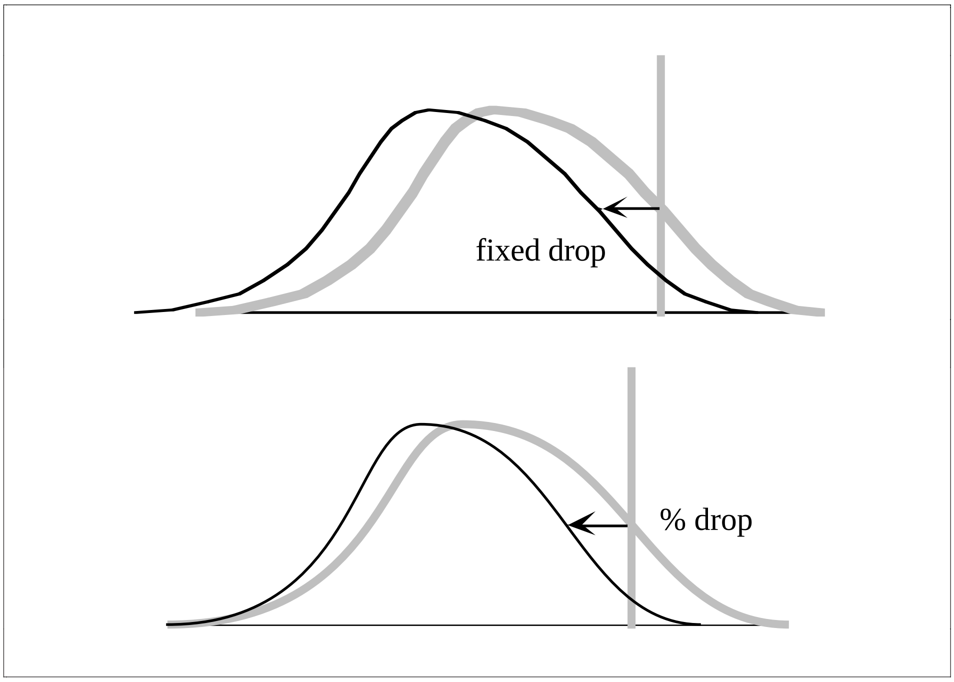


Figure 4.4 *The effect on an arbitrary speed distribution by scenarios in set 1*

Scenario Set 2 - All vehicles complying with the speed limit or within an upper tolerance of the limit

In this set, the travelling speeds of the case vehicles were reduced only if they exceeded the prescribed speed limit by a specified value (the *enforcement limit*). If the case vehicle's travelling speed exceeded this value, the travelling speed was reduced so that the hypothetical speed no longer exceeded this enforcement tolerance. The effect on the arbitrary speed distribution is shown in Figure 4.5.

‡ UBD is a division of Universal Business Press Pty Ltd.

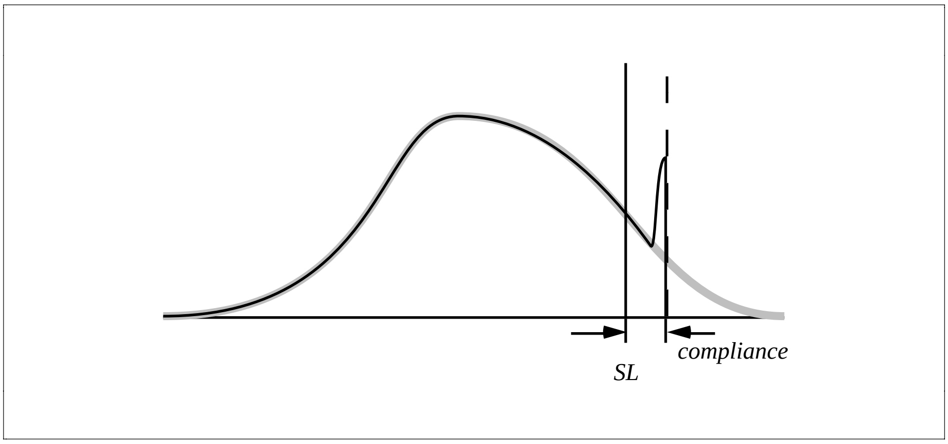


Figure 4.5 The effect on an arbitrary speed distribution of the changes described by the Scenarios in Set 2

Three enforcement tolerances were examined; 0, 5 km/h, and 10 km/h above the actual speed limit.

Scenario Set 3 - All drivers complying with a reduced speed limit

In this set (and subsequent sets), possible effects of new speed limits (denoted by SL^*) were considered. In Scenario Set 3, if the travelling speed of the case vehicle did not exceed the new speed limit, the hypothetical speed remained unchanged from the actual value. If it exceeded the new speed limit, the hypothetical travelling speed (v_0^*) was assigned the value equal to the new speed limit. Six speed limit regimes were tested in this (and subsequent) sets, with a lowering of the existing speed limits by values ranging from 5 km/h to 30 km/h. The effect on the arbitrary distribution shown in Figure 4.3 is shown in Figure 4.6.

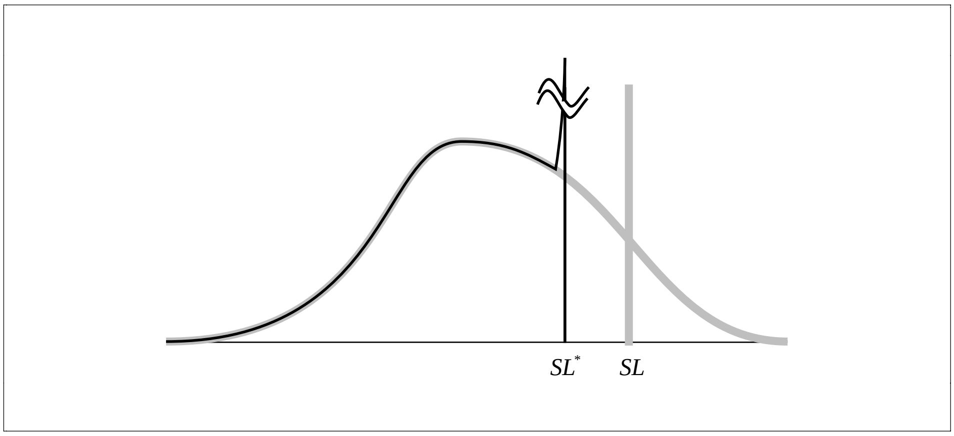


Figure 4.6 The effect on an arbitrary speed distribution by the changes described by the Scenarios in Set 3

Scenario Set 4 - Reduced speed limit with vehicles travelling with a similar level of compliance as before

Travelling speeds were affected in the following way. If the travelling speed of the case vehicle did not exceed the new speed limit, the hypothetical speed remained unchanged from the actual value. It was assumed that if a case vehicle had been travelling at, or below the posted speed limit immediately before the collision, it would do likewise in the hypothetical scenario. Therefore, if the travelling speed of the case vehicle lay between the new limit and the actual limit, the hypothetical travelling speed was reduced to the new limit. Any case vehicle which had been travelling at a speed which exceeded the posted speed limit just before the collision was assigned an hypothetical travelling speed that exceeded the new limit by the same amount (see Figure 4.7).

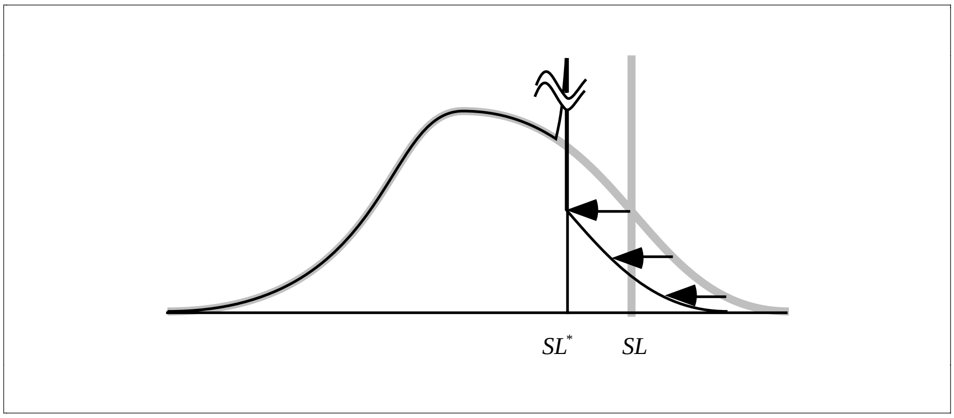


Figure 4.7 *The effect on an arbitrary speed distribution by the changes described in the scenarios in set 4*

Scenario set 5

This set of scenarios was nearly identical to set 4, with one difference. Any case vehicle exceeding the posted speed limit at the time of the collision was assigned an hypothetical travelling speed that was the product of the actual travelling speed and the new speed limit divided by the actual speed limit. For example, if the new speed limit was set at 75% of the actual limit, the hypothetical travelling speed was set at 75% of the actual travelling speed.

Summary of Scenario Sets

The Scenario Sets described above are expressed mathematically in tables 4.1 and 4.2. Each individual scenario number is also listed.

Table 4.1
Equations governing the travelling speed of cases in Scenario Sets 1 and 2.

Scenario Set	Scenario No.	Equations	Description
1	1.1	$v_0^* = v_0 - 5\ \text{km/hr}$	Uniform 5 km/hr travelling speed reduction
	1.2	$v_0^* = v_0 - 10\ \text{km/hr}$	Uniform 10 km/hr travelling speed reduction
	1.3	$v_0^* = v_0 \times 90\%$	Travel speeds reduced by 10 percent
	1.4	$v_0^* = v_0 \times 80\%$	Travel speeds reduced by 20 percent
	1.5	$v_0^* = v_0 - 5\ \text{km/hr}$ if local street	Speed limits reduced by 5 km/hr if the accident occurred in a local street
2	2.1	$v_0 < SL,\ v_0^* = v_0$ $v_0 > SL,\ v_0^* = SL$	All speeds reduced to the speed limit
	2.2	$v_0 < SL + 5\ \text{km/hr},\ v_0^* = v_0$ $v_0 > SL + 5\ \text{km/hr},\ v_0^* = SL + 5\ \text{km/hr}$	Speeds reduced to current limit plus an enforcement tolerance of 5 km/hr
	2.3	$v_0 < SL + 10\ \text{km/hr},\ v_0^* = v_0$ $v_0 > SL + 10\ \text{km/hr},\ v_0^* = SL + 10\ \text{km/hr}$	Speeds reduced to current limit plus an enforcement tolerance of 10 km/hr

Table 4.2
Equations governing the travelling speed of cases in Scenario Sets 3, 4 and 5.

Scenario Set	Scenario Number	Equations	Description
3	3.1 - 3.6	$v_0 < SL^*,\ v_0^* = v_0$ $v_0 > SL^*,\ v_0^* = SL^*$	Travelling speeds reduced to a new speed limit of SL^*
4	4.1 - 4.6	$v_0 < SL^*,\ v_0^* = v_0$ $SL^* < v_0 < SL,\ v_0^* = SL^*$ $v_0 > SL,\ v_0^* = SL^* + (v_0 - SL)$	Travelling speeds reduced to a new speed limit of SL^*, with the same magnitude of violation (those vehicles exceeding the speed limit by x km/hr, exceed the new limit by x km/hr).
5	5.1 - 5.6	$v_0 < SL^*,\ v_0^* = v_0$ $SL^* < v_0 < SL,\ v_0^* = SL^*$ $v_0 > SL,\ v_0^* = v_0 \left(SL^* / SL \right)$	Travelling speeds reduced to a new speed limit of SL^*, with the same relative violation (those vehicles exceeding the speed limit by x%, exceed the new limit by x%).

SL^* denotes an hypothetical speed limit.

4.2.4 Estimating Impact Speeds for Reduced Travelling Speeds.

Following the reduction in travelling speeds as described in the scenarios above, new impact speeds were calculated on the assumption that all other factors were identical to those in the original collision.

In cases in which the wheels of the vehicle had locked due to braking, it was assumed that the vehicles would lock their wheels again in the hypothetical reduced speed case. The hypothetical impact speed was then calculated using the reduced travelling speed and the hypothetical skid mark length before the impact point (see Appendix A). Note: the reaction distance and distance for the wheels to lock were calculated using the reduced travelling speed.

For cases where the wheels of the vehicle did not lock, the impact speed was calculated using the reduced travelling speed and the distance from when the brakes were applied to the impact point (see Appendix A).

4.3 Estimating The Outcome For Reduced Travelling Speeds

To determine the likely effect of the reduced travelling speed on the pedestrian road toll, an estimate of the probability of survival of the pedestrian at a given impact speed was used.

Walz *et al* (1983) published a graph that assigned a potential Injury Severity Score (ISS) to a given impact speed (See Figure 3.7). The graph represented the mean values of five other studies that were done on impact speed and pedestrian injury severity. The possibility of survival as a function of ISS (determined from 952 cases) was also published (Figure 3.8). Using this data, the estimated probability of survival of a pedestrian struck at a given impact speed was obtained.

Using the relationship described above, the probability of survival was calculated for each pedestrian under each scenario. In many cases, under a scenario of reduced travelling speed, the vehicle was able to stop completely before the collision took place. In these cases the probability of survival was 100%. Once the probability of survival for each pedestrian in the collision was known, the probability of the collision being non-fatal was then calculated.

In arriving at an estimation of the proportion of accidents that would have been survivable, for a given travel speed reduction scenario, there are four factors that need to be considered. The first is the number of fatal collisions that would have been avoided (including cases where an impact was avoidable), s ; the number of cases in the analysed sample, N; the total number of cases in which the vehicles travel speed was relevant to the outcome, M; and finally, the total number of fatal pedestrian collisions in the sample F.

To estimate the number of collisions that would have been survivable, consider the probability of an collision being fatal at a speed = x, as being given by $p(f_x)$†. Then for the n^{th} case, where the collision was fatal at a speed = a, the probability of it being fatal at a lower speed = b is given by,

$$p_n(f_b) = \frac{p(f_b)}{p(f_a)} \qquad \text{.......(4.1)}$$

The probability of the collision being non-fatal is,

$$1 - p_n(f_b) \qquad \text{.......(4.2)}$$

For the sample of N cases then, the hypothetical number of non-fatal accidents in the sample is given by,

$$s = \sum_{i=1}^{N} 1 - p_i(f_x) \qquad \text{.......(4.3)}$$

where x is the speed of the vehicle in case i under the scenario in consideration.

The overall proportion of collisions that might have been survivable due to the speed reductions is given by:

$$S = \frac{\frac{s}{N}M}{F} \qquad \text{.......(4.4)}$$

where

s = *number of fatal collisions that would have been avoided*

N = *the number of cases in the analysed sample*

M = *the total number of cases in which the vehicles travel speed was relevant to the outcome*

F = *the total number of fatal pedestrian collisions in the sample*

† $p(f_x)$ is only equal to the probability of a pedestrian being killed at a speed x when one pedestrian is hit by the vehicle. $p(f_x)$ has to be calculated appropriately for accidents where multiple pedestrians are involved.

5 RESULTS

Each speed related case that contained enough information was analysed with the reduced travelling speed according to the scenarios described previously. The results are presented separately for cases which occurred in 60 km/h speed zones. Other speed limit zones were not analysed separately because of the small number of cases in these zones.

A zero impact speed indicates that the collision would have been avoided under the reduced travelling speed scenario (ie had the driver been travelling at the reduced speed, he or she would have been able to stop in time.).

Pedestrians who were still struck by the vehicle but, using equations 4.1 to 4.4, were thought to have been unlikely to be fatally injured, were classed as injured survivors. These cases, taken together with the cases in which the collision would have been avoided altogether, form the group listed in the following results as "fatal collisions prevented"

Of the scenarios discussed above, several pertinent ones are discussed in detail in this section. The reader should consult Appendix B for a more detailed account of the results for other scenarios.

5.1 Uniform 5 km/h travelling speed reduction

In this scenario (scenario 1.1) the travelling speeds of all vehicles in the analysed cases were hypothetically reduced by 5 km/h. The actual and reduced travelling speed distributions are shown in Figure 5.1.

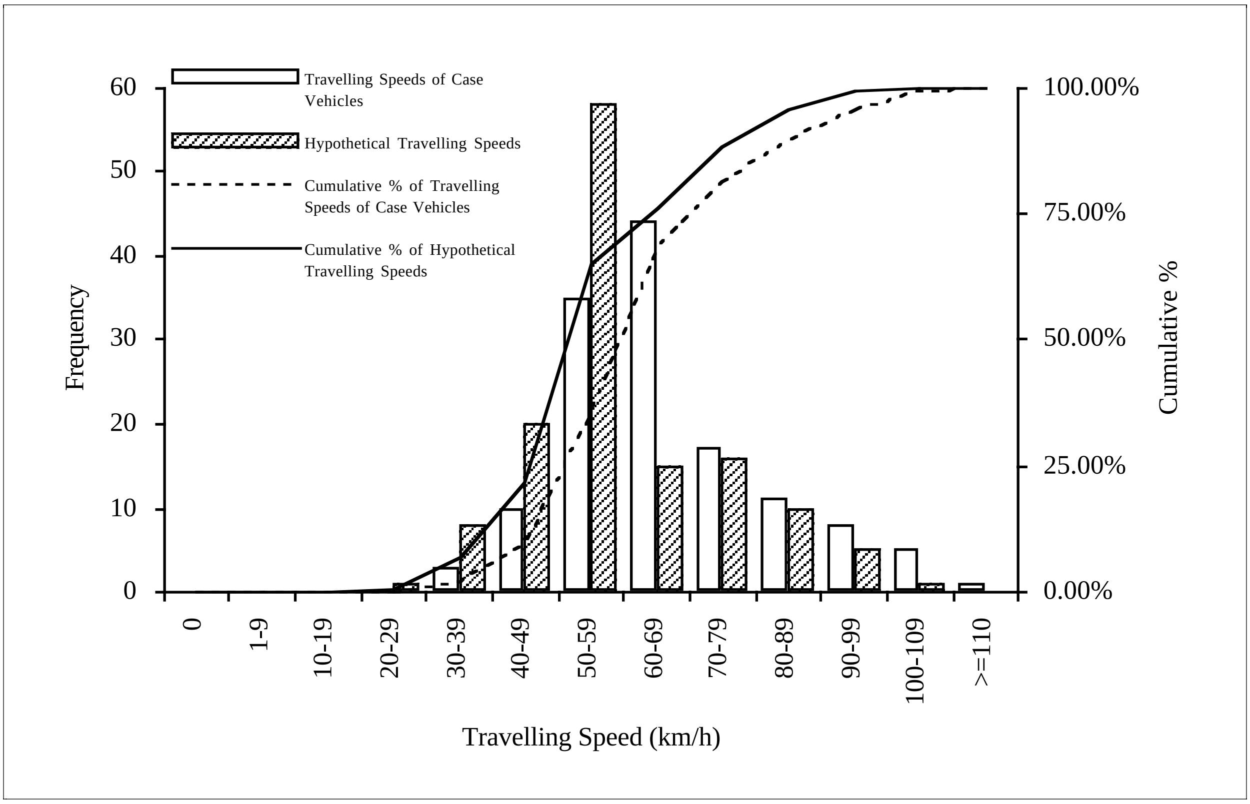


Figure 5.1 *Travelling speed distributions in scenario 1.1.*

After analysis the distribution of impact speeds shown in Figure 5.2 was obtained.

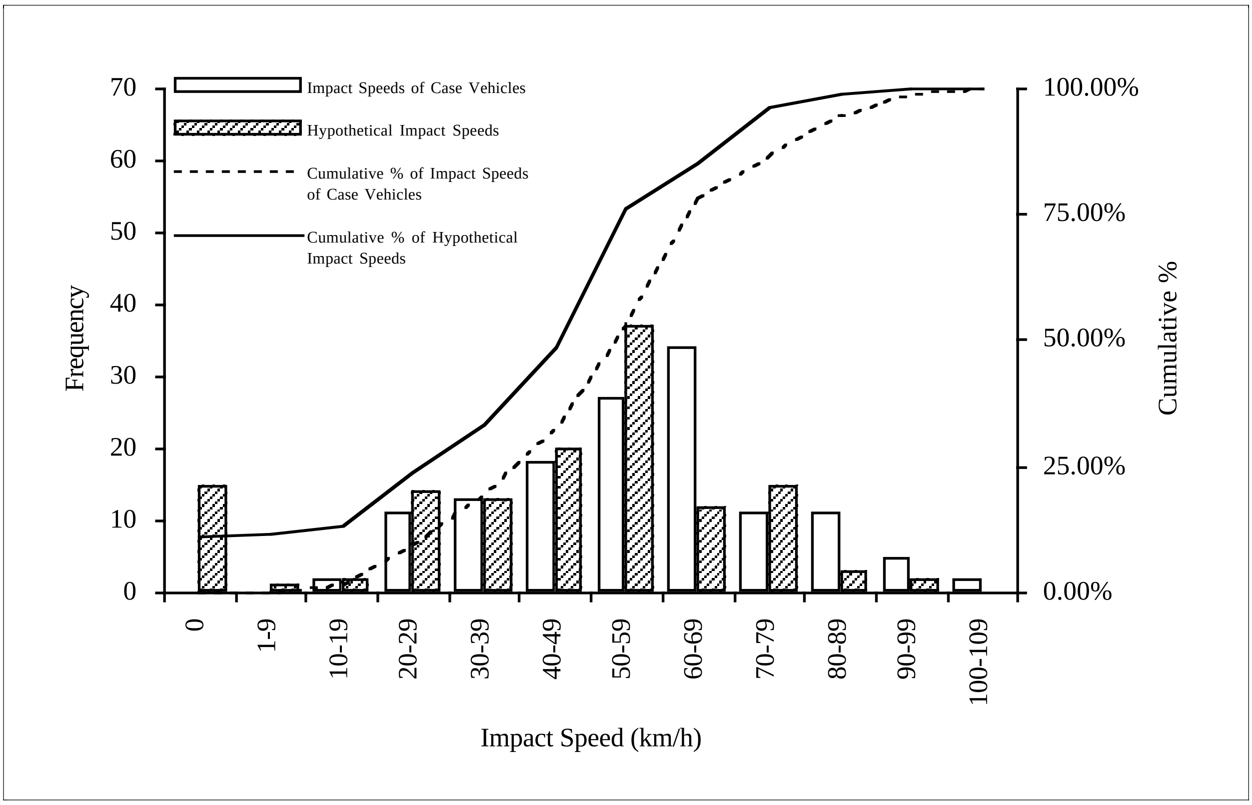


Figure 5.2 *Impact speed distributions in scenario 1.1.*

Using equations 4.1 to 4.4, the following estimates were obtained (Table 5.1):

Table 5.1
Percentages of the entire sample that were fatal collisions prevented or collisions avoided in scenario 1.1

	60 km/h zones	All speed zones
% Fatal collisions prevented*	32%	30%
% Collisions avoided	10%	10%

* Note: "Fatal collisions prevented" includes "Collisions avoided"

5.2 Uniform 10 km/h travelling speed reduction

In scenario 1.2 the travelling speeds of all vehicles in the analysed cases were hypothetically reduced by 10 km/h. The travelling speed distributions are shown in Figure 5.3.

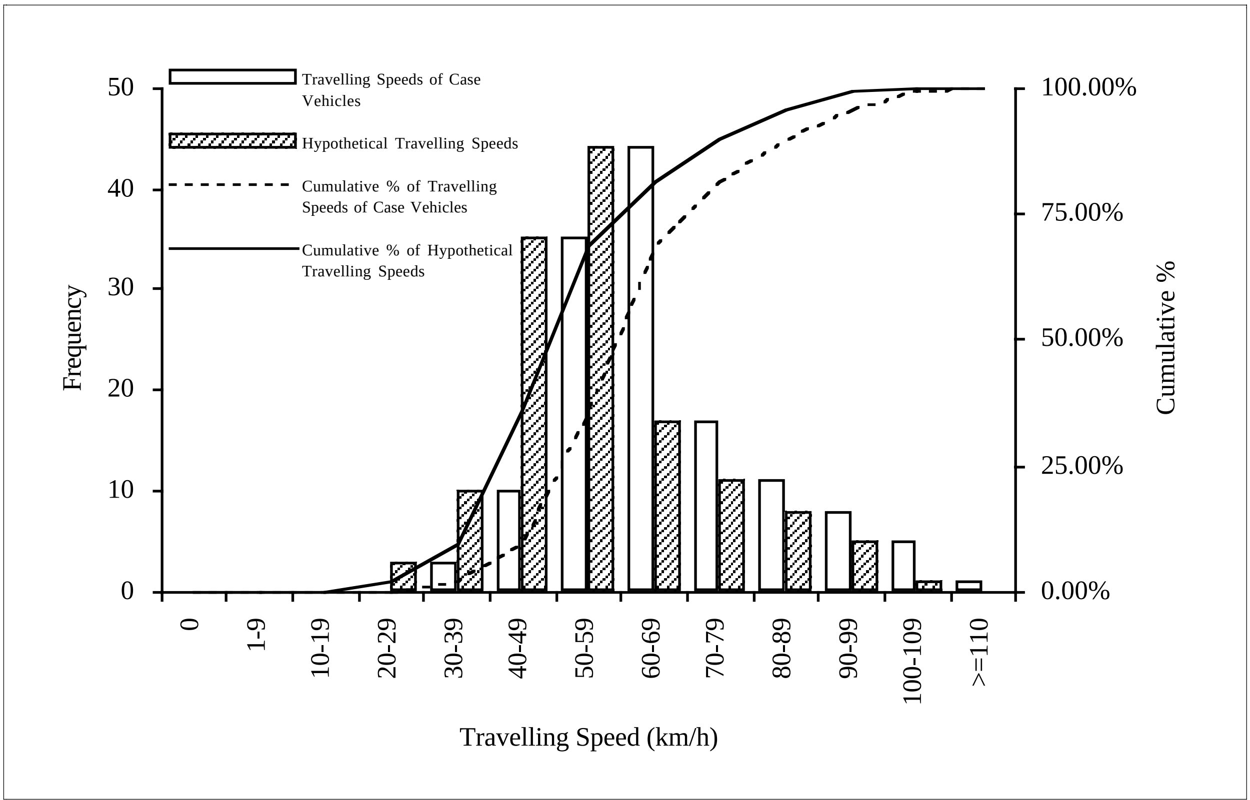


Figure 5.3 *Travelling speed distributions in scenario 1.2.*

After analysis the distribution of impact speeds shown in Figure 5.4 was obtained.

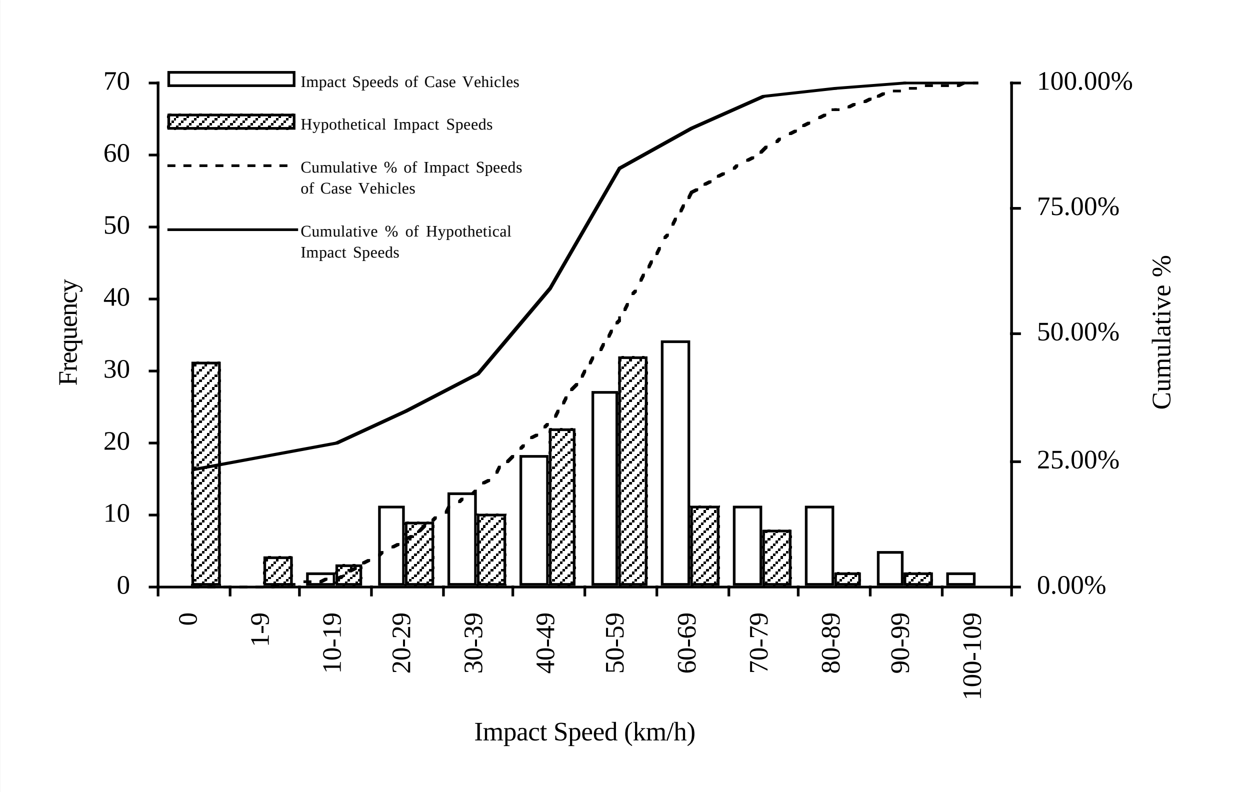


Figure 5.4 *Impact speed distributions in scenario 1.2.*

Using equations 4.1 to 4.4, the following estimates were obtained (Table 5.2):

Table 5.2
Percentages of the entire sample that were fatal collisions prevented or collisions avoided in scenario 1.2.

	60 km/h zones	All speed zones
% Fatal collisions prevented*	48%	45%
% Collisions avoided	22%	20%

* Note: "Fatal collisions prevented" includes "Collisions avoided"

5.3 Speeds reduced to the relevant speed limit plus an enforcement tolerance of 10 km/h

In this scenario (scenario 2.3), the travelling speeds of the collision involved vehicles were hypothetically reduced to the relevant limit plus 10 km/h, if they had exceeded that value. In other words, all vehicles were made to comply with an enforcement tolerance of +10 km/h. The travelling speed distributions are shown in Figure 5.5.

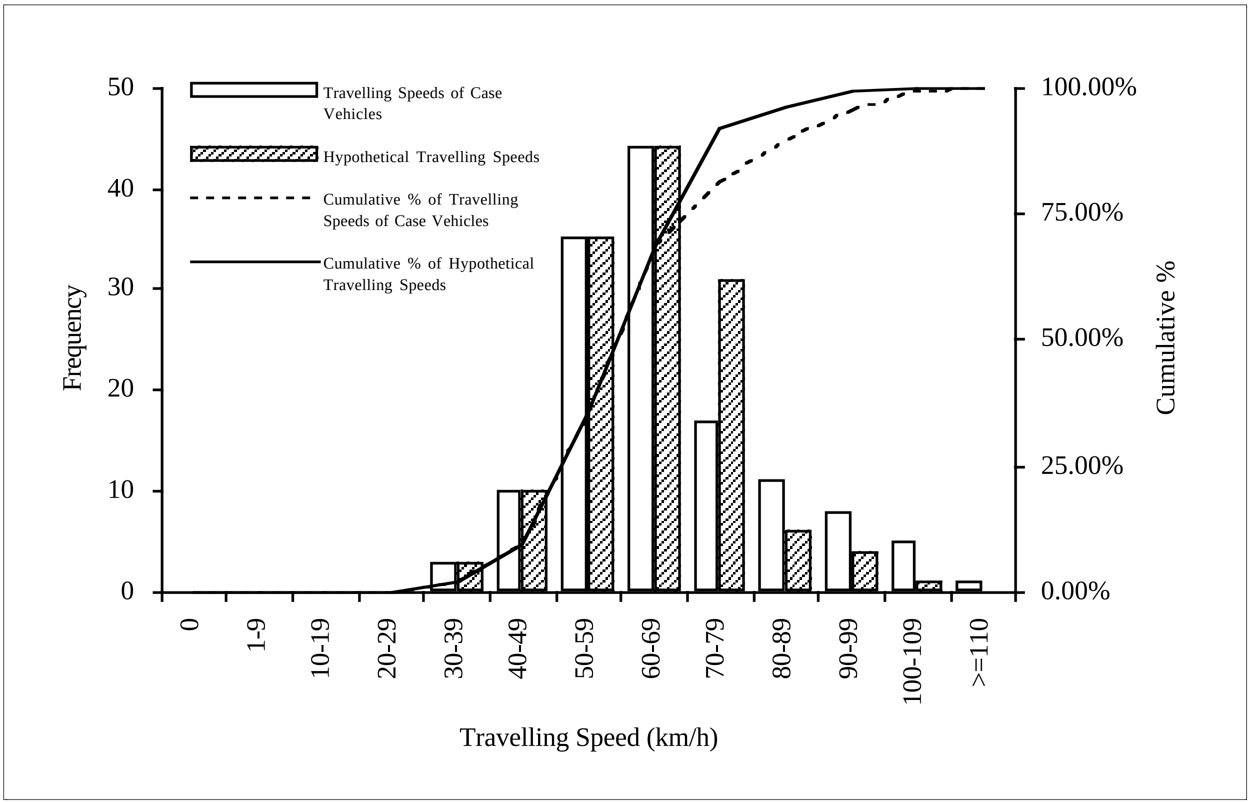


Figure 5.5 *Travelling speed distributions in scenario 2.3.*

After analysis the distribution of impact speeds shown in Figure 5.6 was obtained.

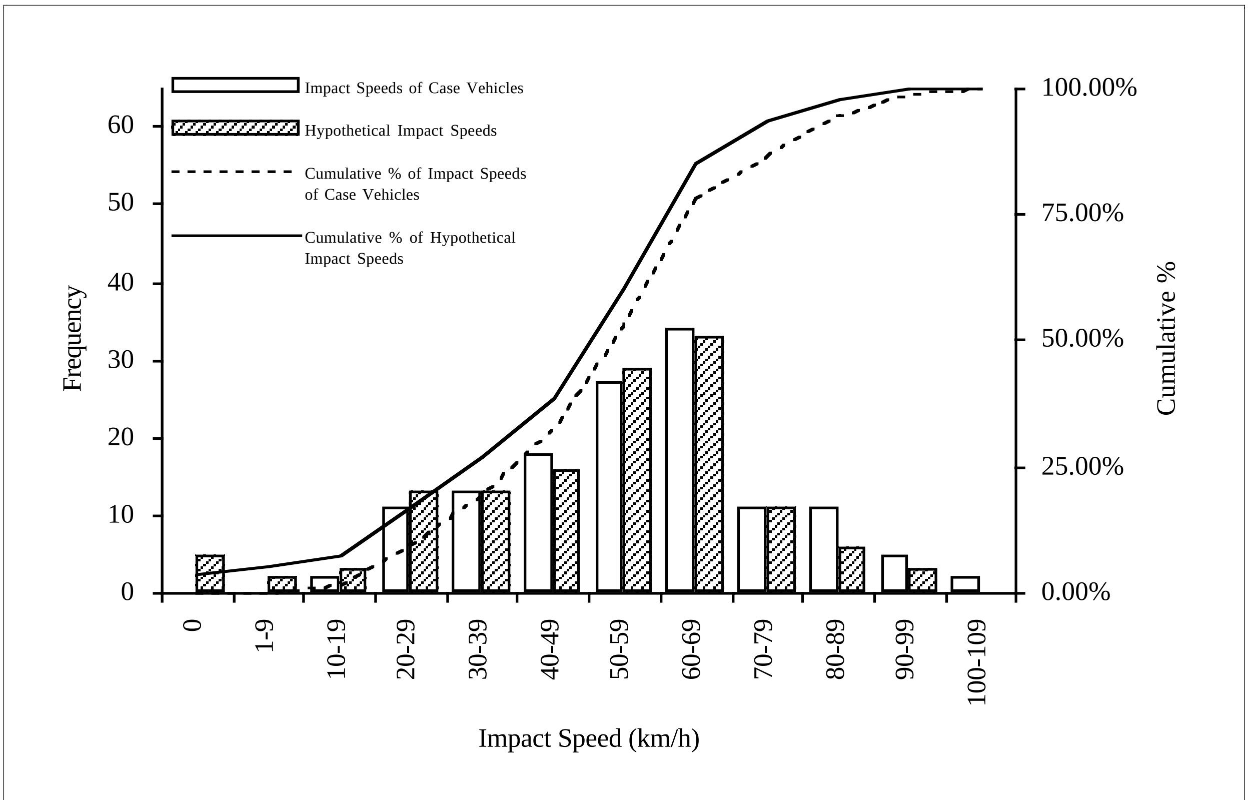


Figure 5.6 *Impact speed distributions in scenario 2.3.*

Using equations 4.1 to 4.4, the following estimates were obtained (Table 5.3):

Table 5.3
Percentages of the entire sample that were fatal collisions prevented or collisions avoided in scenario 2.3

	60 km/h zones	All speed zones
% Fatal collisions prevented*	8%	7%
% Collisions avoided	4%	3%

* Note: "Fatal collisions prevented" includes "Collisions avoided"

5.4 All speeds reduced to the relevant speed limit, with no enforcement tolerance

In this scenario (scenario 2.1), the travelling speeds of the collision involved vehicles were hypothetically reduced to the applicable speed limit if they had a travelling speed which exceeded that value. The travelling speed distributions are shown in Figure 5.7.

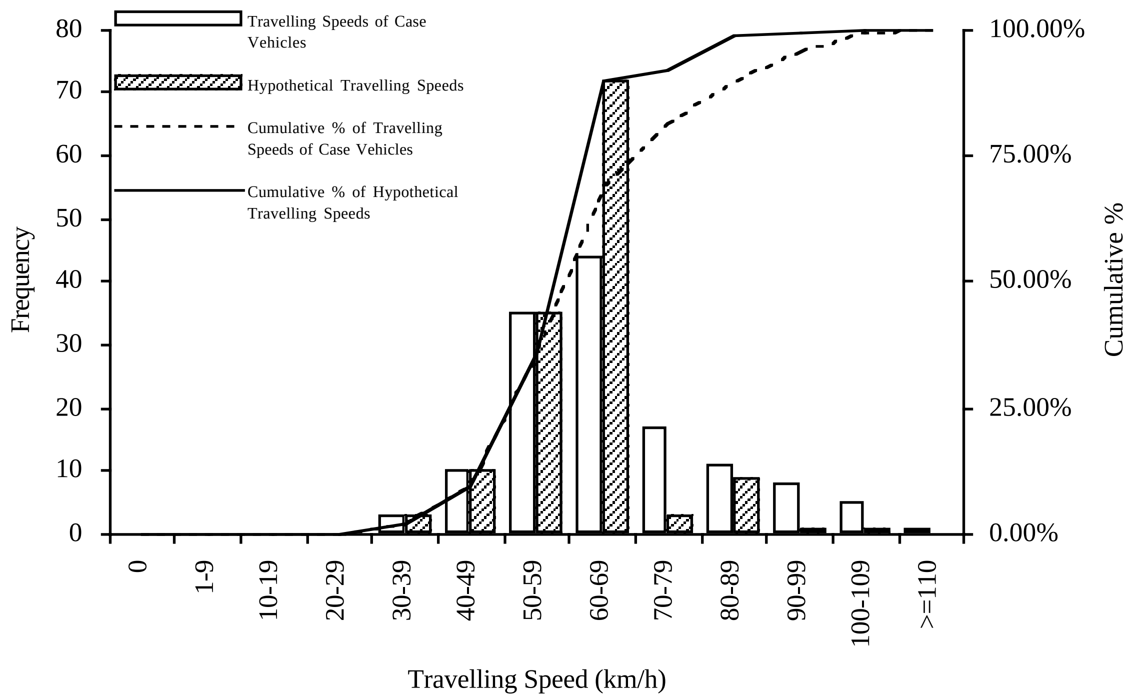


Figure 5.7 *Travelling speed distributions in scenario 2.1.*

After analysis the distribution of impact speeds shown in Figure 5.8 was obtained.

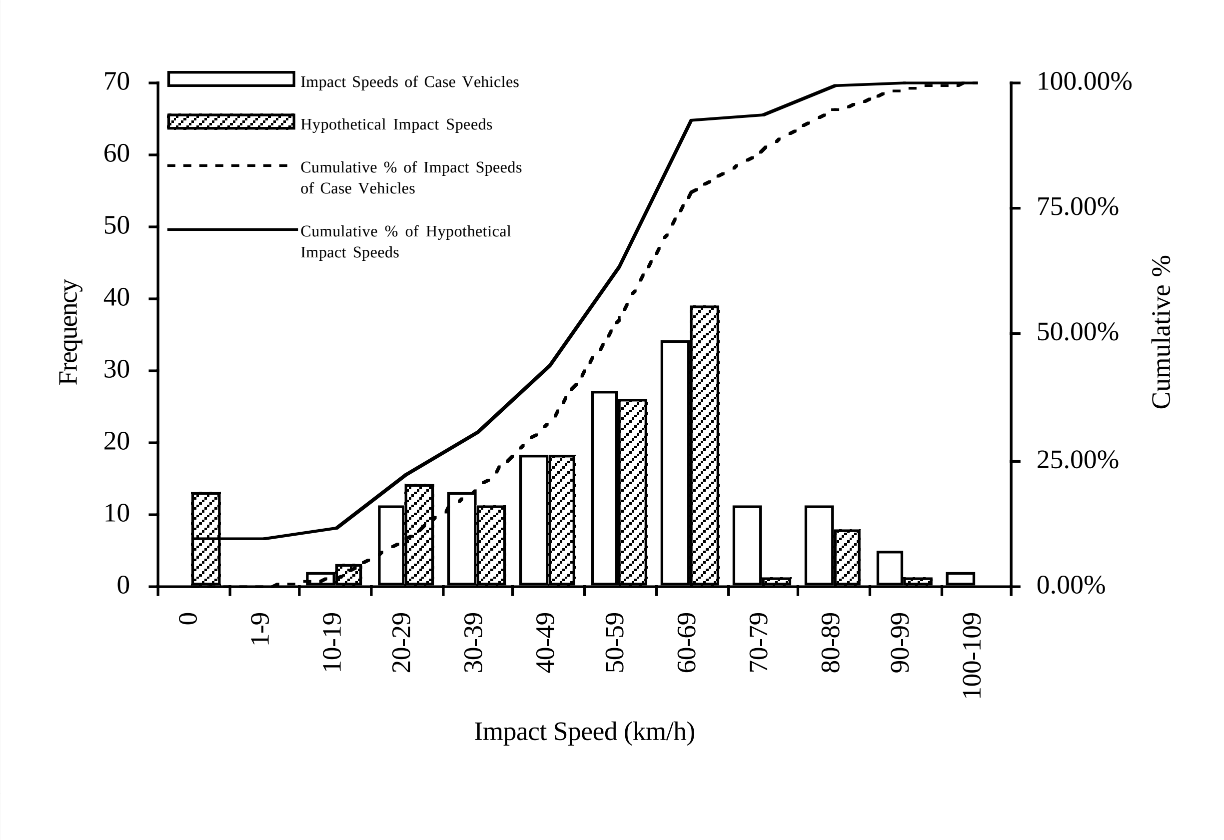


Figure 5.8 *Impact speed distributions in scenario 2.1*

Using equations 4.1 to 4.4, the following estimates were obtained (Table 5.4).

Table 5.4
Percentages of the entire sample that were fatal collisions prevented or collisions avoided in scenario 2.1

	60 km/h zones	All speed zones
% Fatal collisions prevented*	13%	12%
% Collisions avoided	10%	8%

* Note: "Fatal collisions prevented" includes "Collisions avoided"

5.5 Speed limits reduced by 5 km/h with the same level of violation

In this scenario (scenario 4.1), vehicles which were exceeding the prescribed speed limit at the time of the collision were made to exceed the lower limit by the same value. Those drivers who were complying with the prescribed speed limit at the time of the collision had this condition maintained in the scenario. The travelling speed distributions are shown in Figure 5.9.

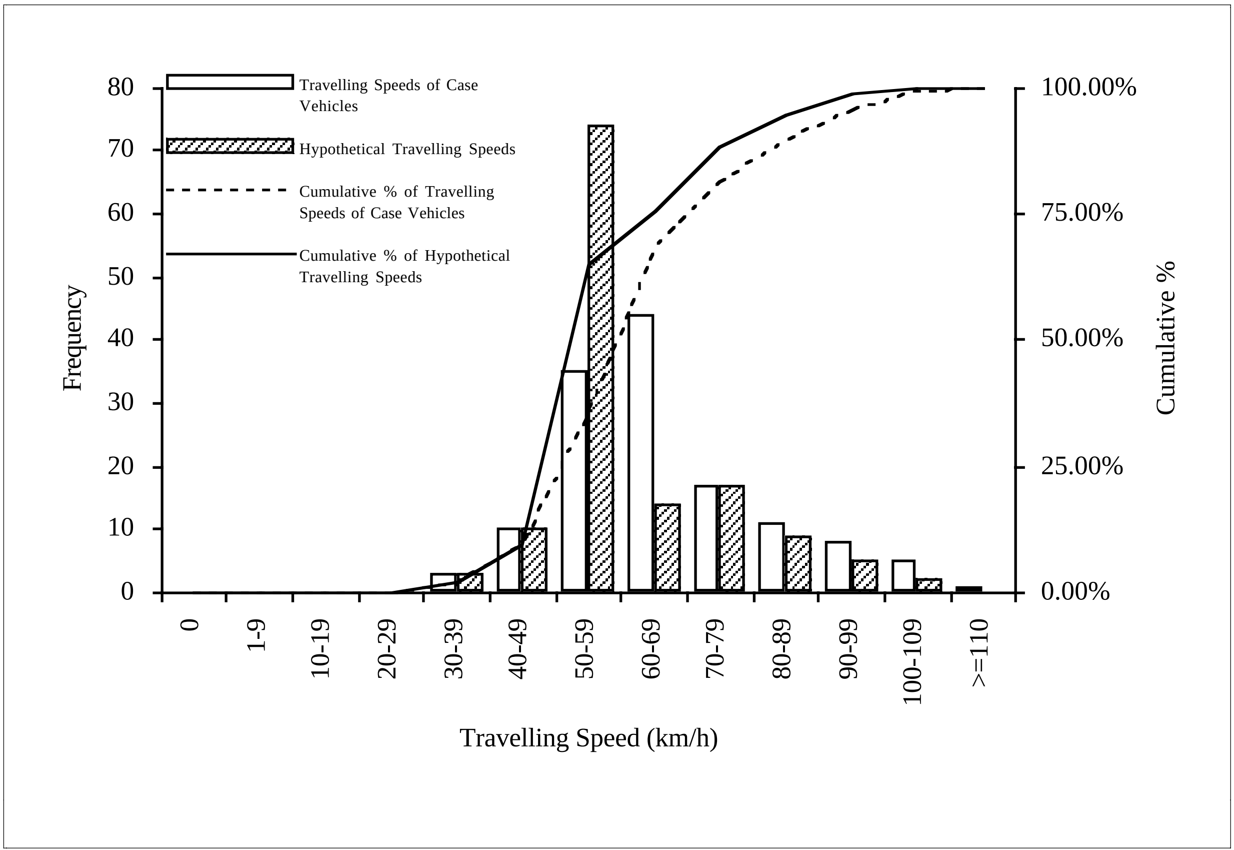


Figure 5.9 *Travelling speed distributions in scenario 4.1*

After analysis the distribution of impact speeds shown in Figure 5.10 was obtained

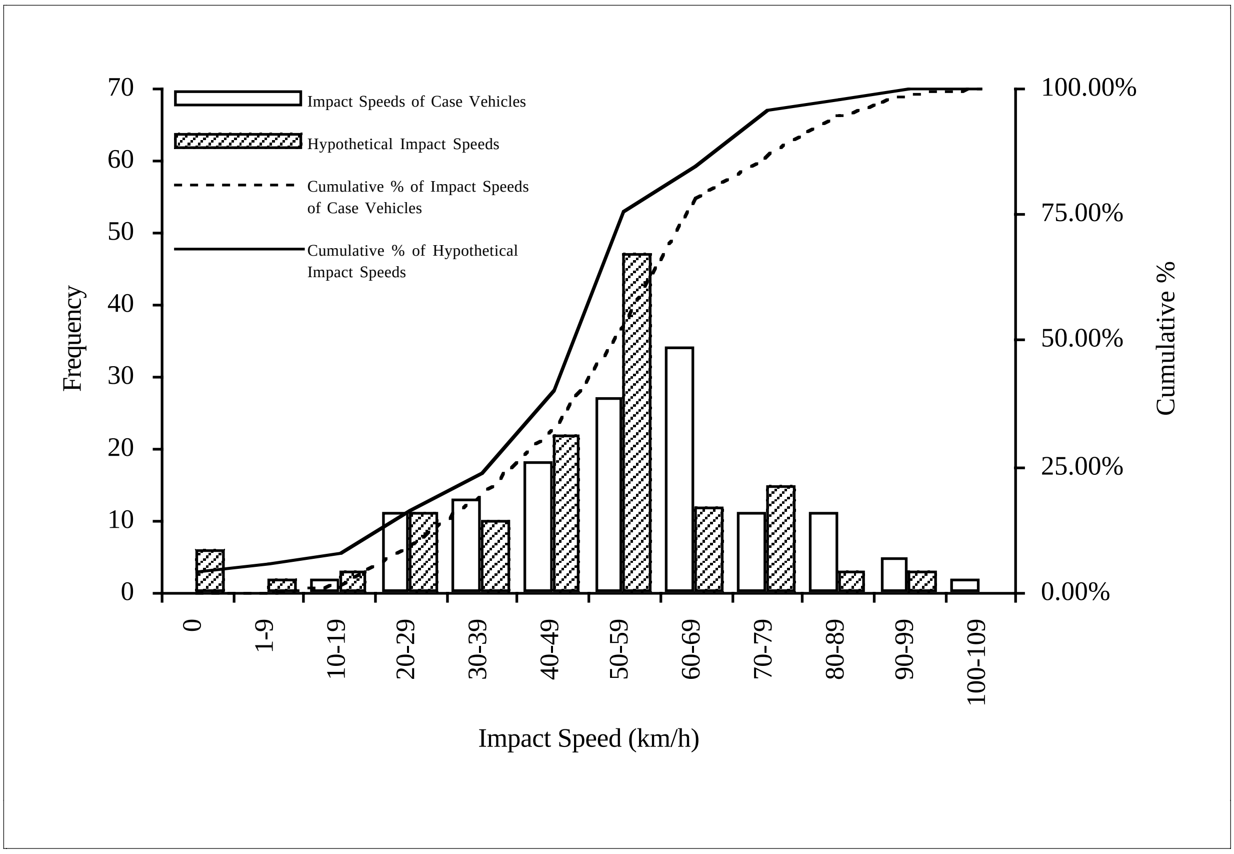


Figure 5.10 *Impact speed distributions in scenario 4.1.*

Using equations 4.1 to 4.4, the following estimates were obtained (Table 5.5):

Table 5.5
Percentages of the entire sample that were fatal collisions prevented or collisions avoided in scenario 4.1.

	60 km/h zones	All speed zones
% Fatal collisions prevented*	14%	13%
% Collisions avoided	4%	4%

* Note: "Fatal collisions prevented" includes "Collisions avoided"

5.6 Speed limits reduced by 10 km/h with the same level of violation

In this scenario (scenario 4.2), vehicles which were exceeding the prescribed speed limit at the time of the collision were made to exceed the lower limit by the same value. Those drivers who were complying with the prescribed speed limit at the time of the collision had this condition maintained in the scenario. The travelling speed distributions are shown in Figure 5.11.

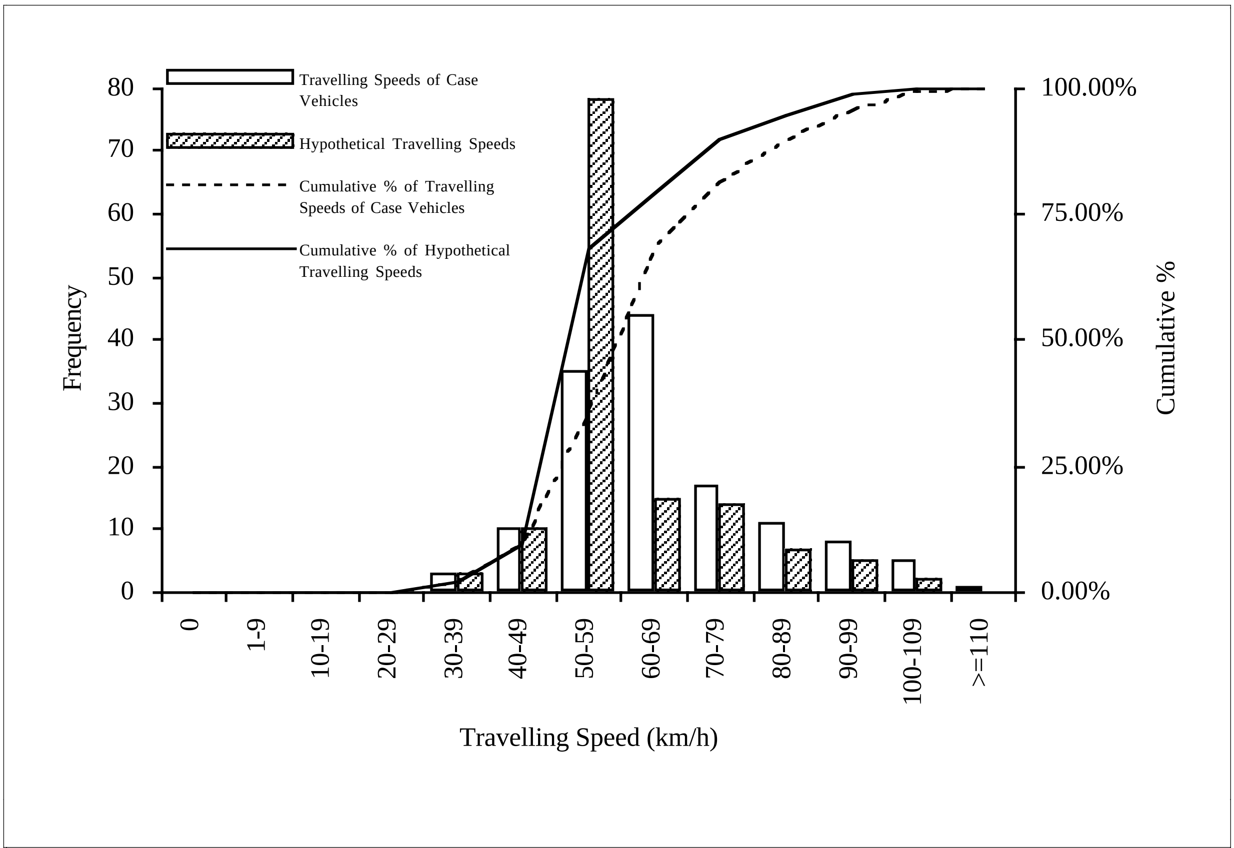


Figure 5.11 *Travelling speed distributions in scenario 4.2.*

After analysis the distribution of impact speeds shown in Figure 5.12 was obtained.

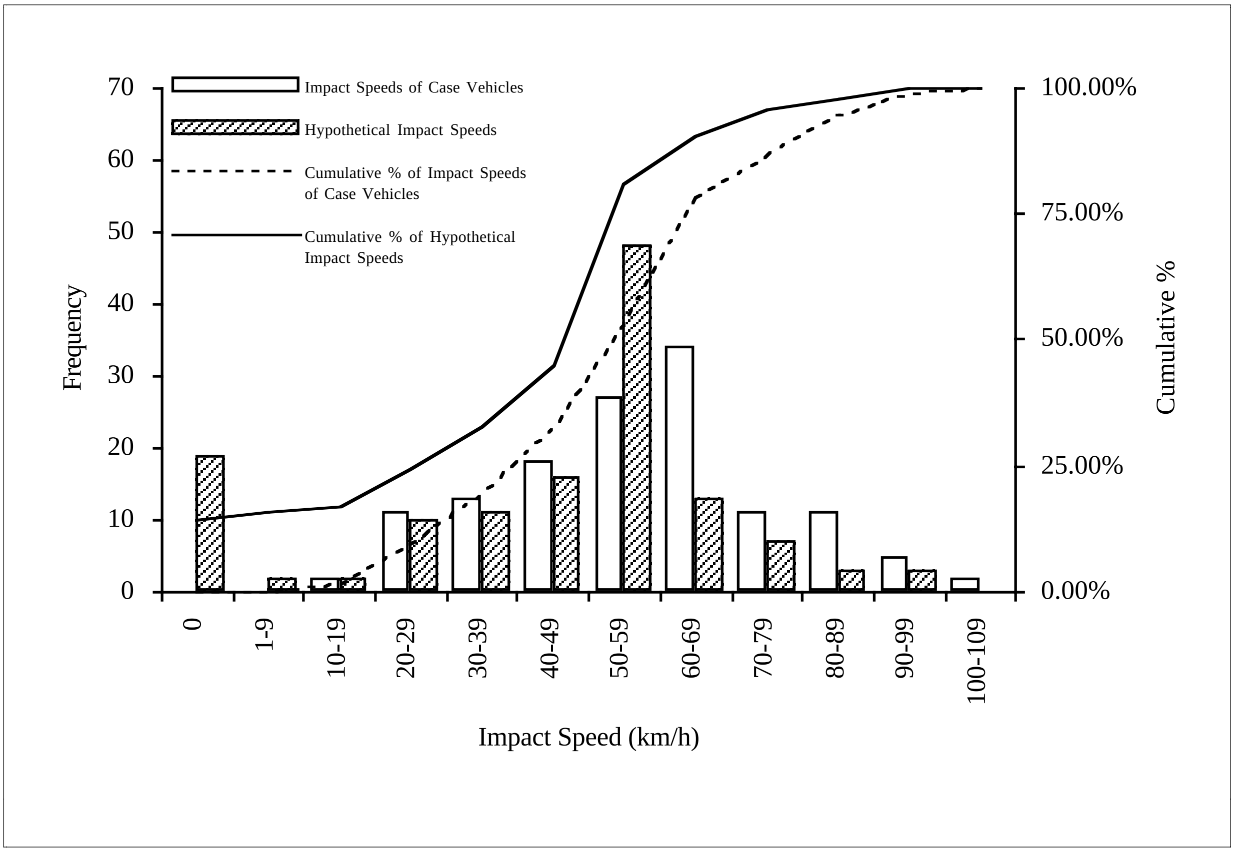


Figure 5.12 *Impact speed distributions in scenario 4.2.*

Using equations 4.1 to 4.4, the following estimates were obtained (Table 5.6):

Table 5.6
Percentages of the entire sample that were fatal collisions prevented or collisions avoided in scenario 4.2.

	60 km/h zones	All speed zones
% Fatal collisions prevented*	27%	30%
% Collisions avoided	12%	13%

* Note: "Fatal collisions prevented" includes "Collisions avoided"

5.7 Speed limits reduced by 20 km/h with the same level of violation

In this scenario (scenario 4.4), vehicles which were exceeding the prescribed speed limit at the time of the collision were made to exceed the lower limit by the same value. Those drivers who were complying with the prescribed speed limit at the time of the collision had this condition maintained in the scenario. The travelling speed distributions are shown in Figure 5.13.

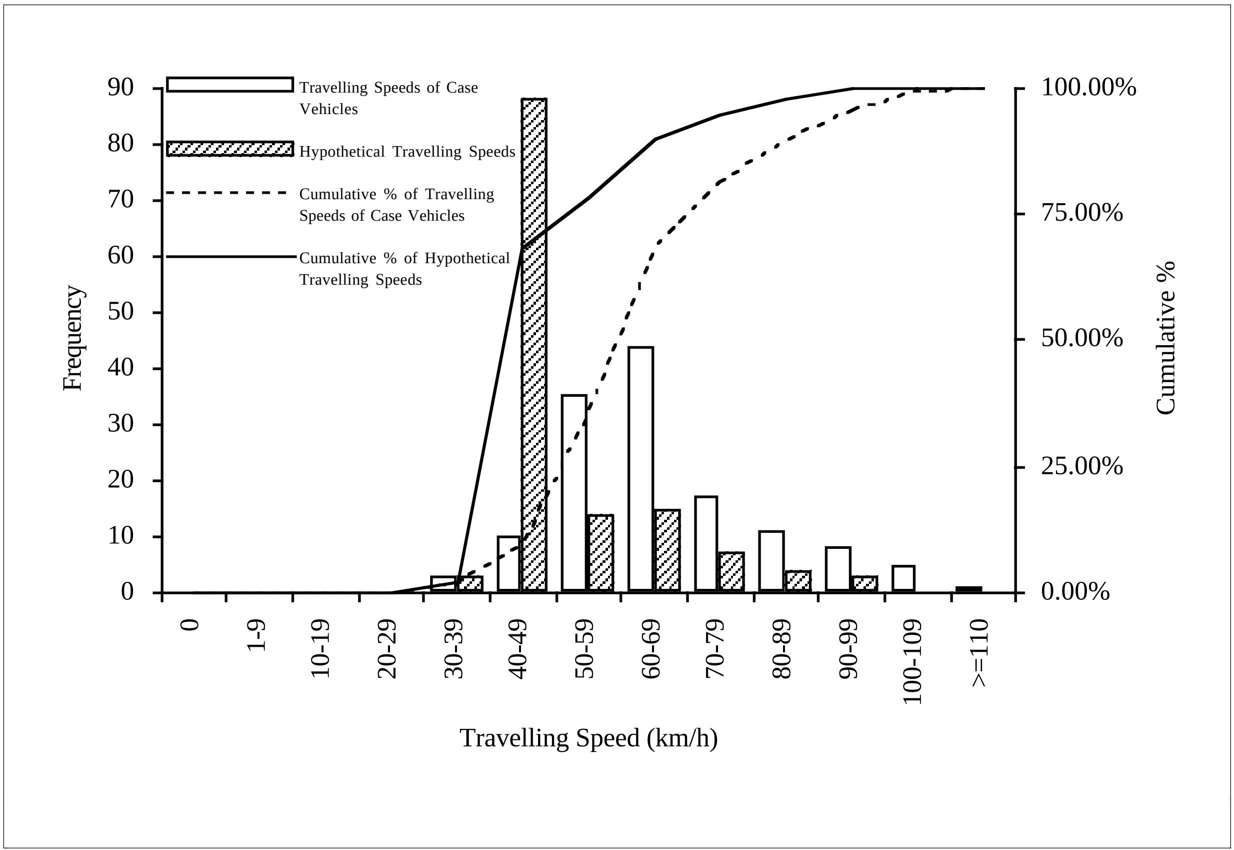


Figure 5.13 *Travelling speed distributions in scenario 4.4.*

After analysis the distribution of impact speeds shown in Figure 5.14 was obtained:

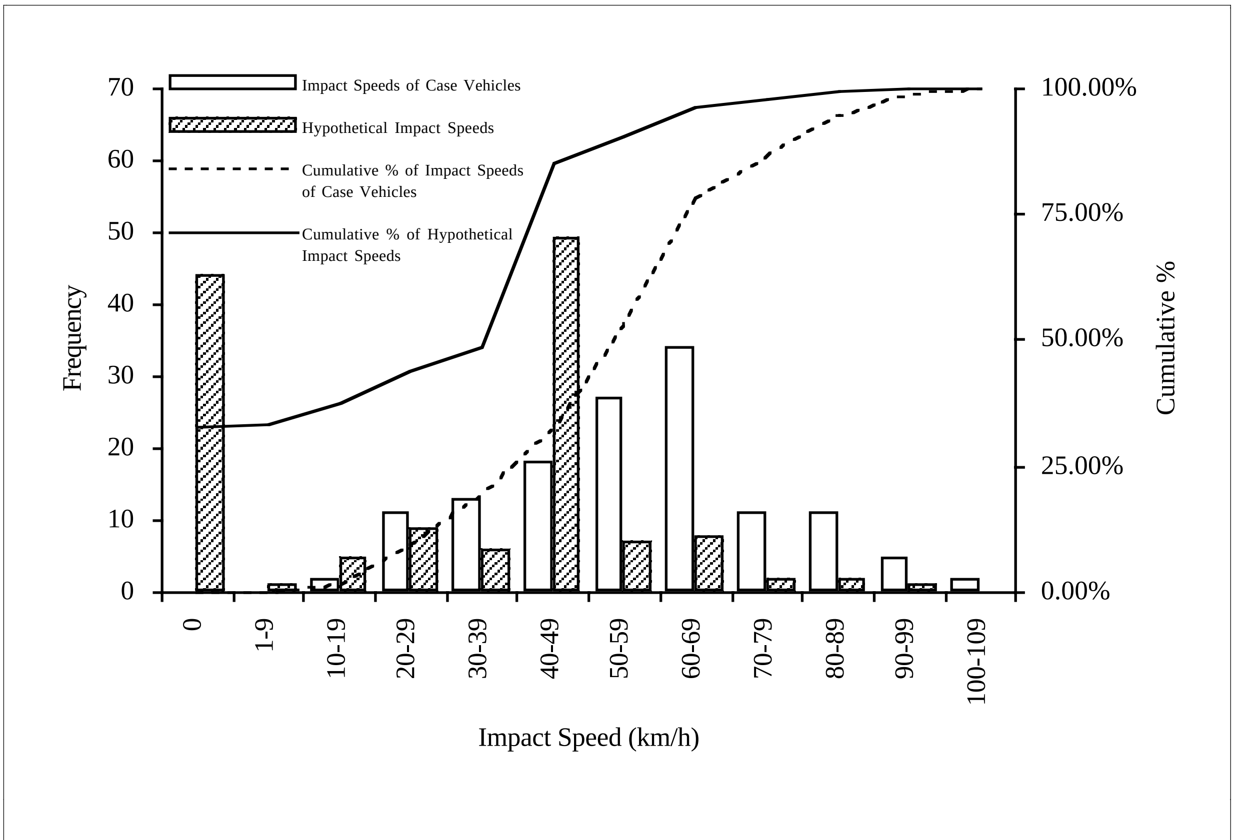


Figure 5.14 *Impact speed distributions in scenario 4.4.*

Using equations 4.1 to 4.4, the following estimates were obtained (Table 5.7):

Table 5.7
Percentages of the entire sample that were fatal collisions prevented or collisions avoided in scenario 4.4.

	60 km/h zones	All speed zones
% Fatal collisions prevented*	64%	58%
% Collisions avoided	31%	29%

* Note: "Fatal collisions prevented" includes "Collisions avoided"

5.8 Travelling speed reduced by 5 km/h if the collision occurred in a local street

In this scenario (scenario 1.5), vehicles which were travelling in a local street at the time of the collision had their travelling speeds set 5 km/h lower than the speed that they were travelling at the time of the collision. The travelling speed distributions are shown in Figure 5.15.

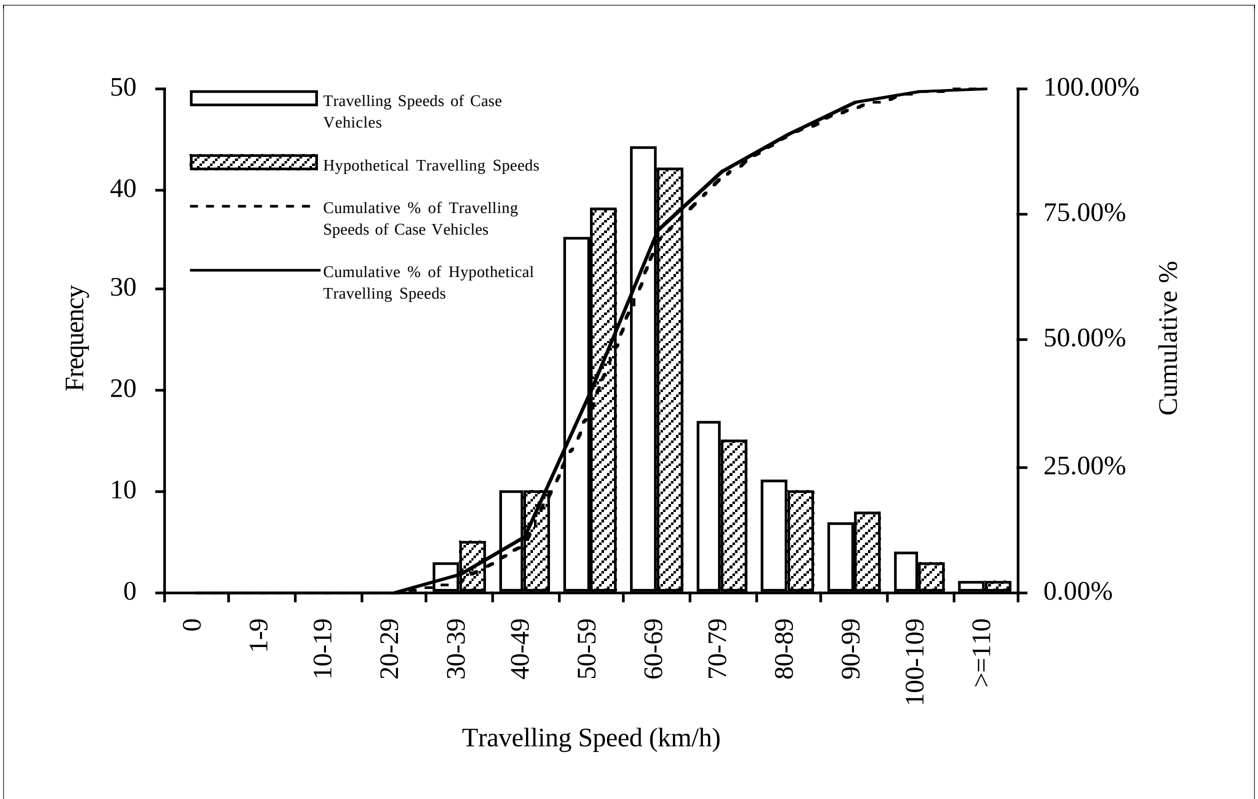


Figure 5.15 *Travelling speed distributions in scenario 1.5.*

After analysis the distribution of impact speeds shown in Figure 5.16 was obtained:

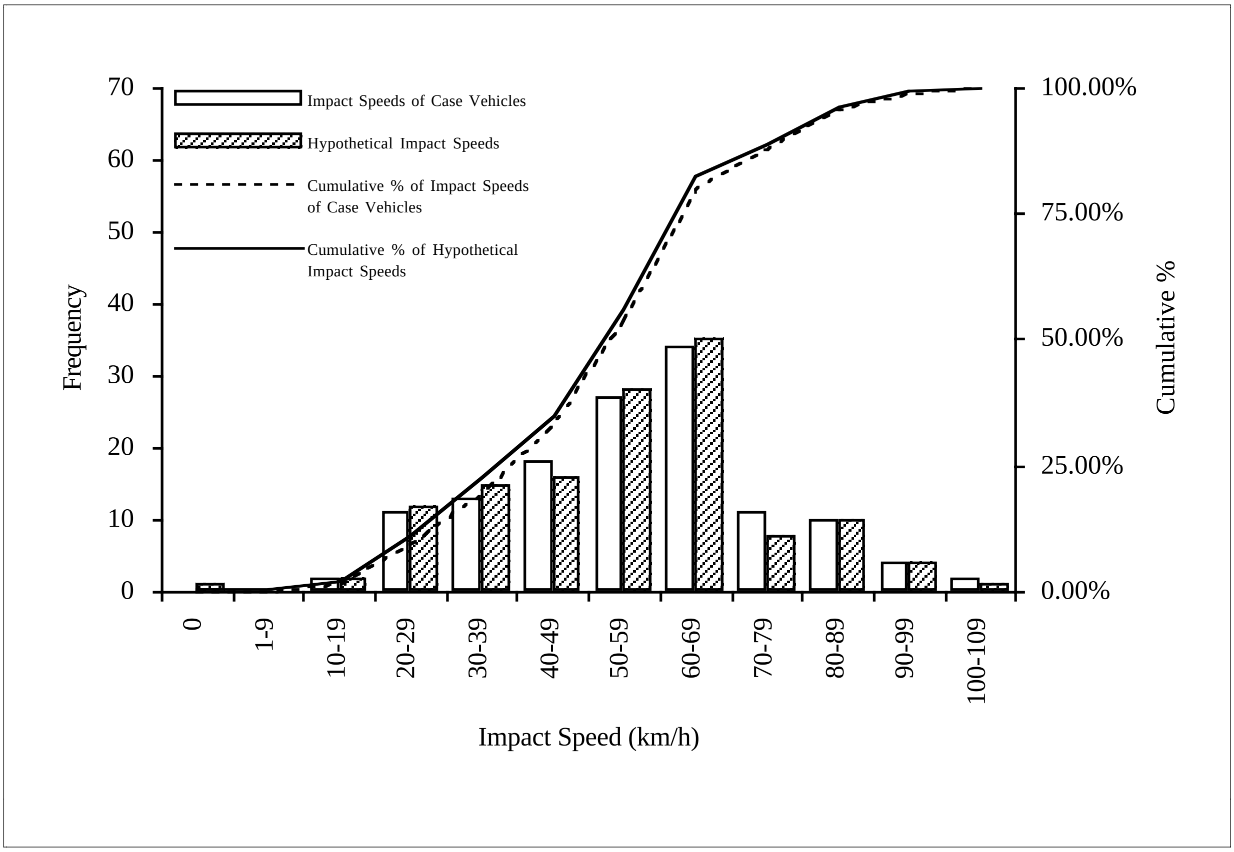


Figure 5.16 *Impact speed distributions in scenario 1.5.*

Using equations 4.1 to 4.4, the following estimates were obtained (Table 5.8):

Table 5.8
Percentages of the entire sample that were fatal collisions prevented or collisions avoided in scenario 1.5.

	60 km/h zones	All speed zones
% Fatal collisions prevented*	4%	4%
% Collisions avoided	1%	1%

* Note: "Fatal collisions prevented" includes "Collisions avoided"

It should be noted that only 15% of the fatal pedestrian collisions occurred on local streets.

5.9 Summary of results

Figure 5.17 summarises the above scenarios for those collisions that occurred in 60 km/h zones. Figure 5.18 compares the results for all speed zones.

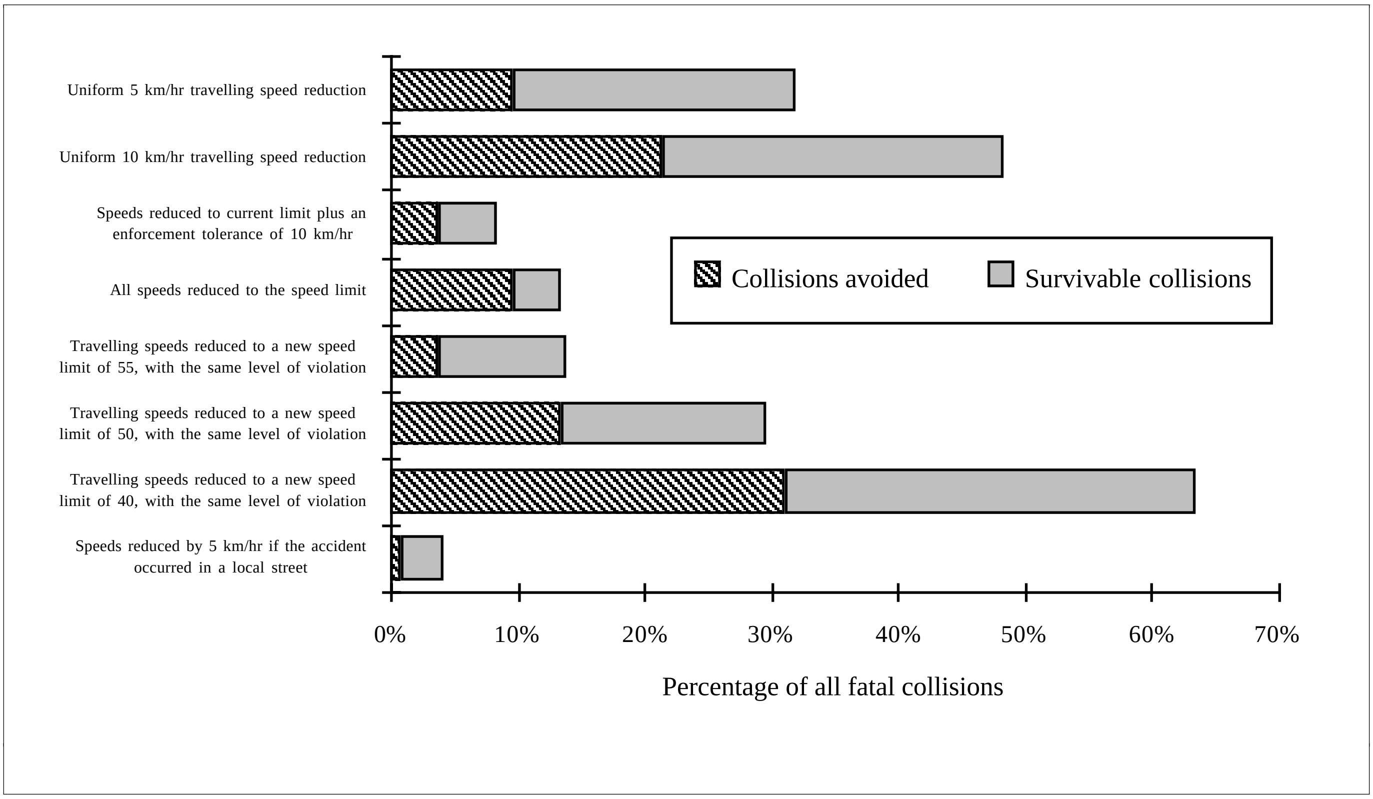


Figure 5.17 *Fatality reductions for reduced travelling speeds in 60 km/h zones.*

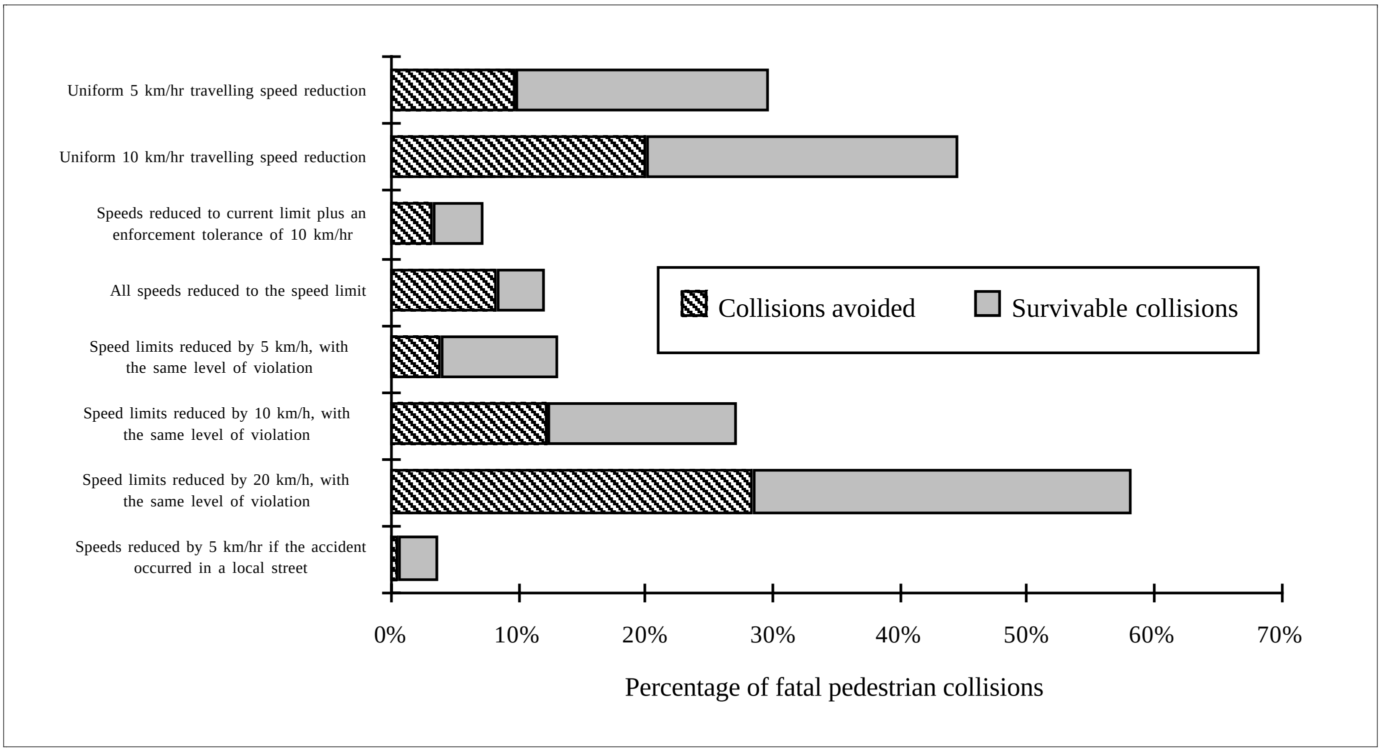


Figure 5.18 *Fatality reductions for reduced travelling speeds in all speed zones.*

In Scenario Sets 3, 4 and 5 the effects of different speed limit levels were compared under the three different compliance regimes. In Set 3, perfect compliance with the limit is assumed and, as such, can also be interpreted as the maximum speed allowed in the sample set of cases. Combining the results from Scenario Set 3 with the results from

Scenario Set 2, a comparison of the proportions of the cases which were survivable or avoidable altogether, was obtained, for different maximum speeds allowed. This is shown in Figure 5.19.

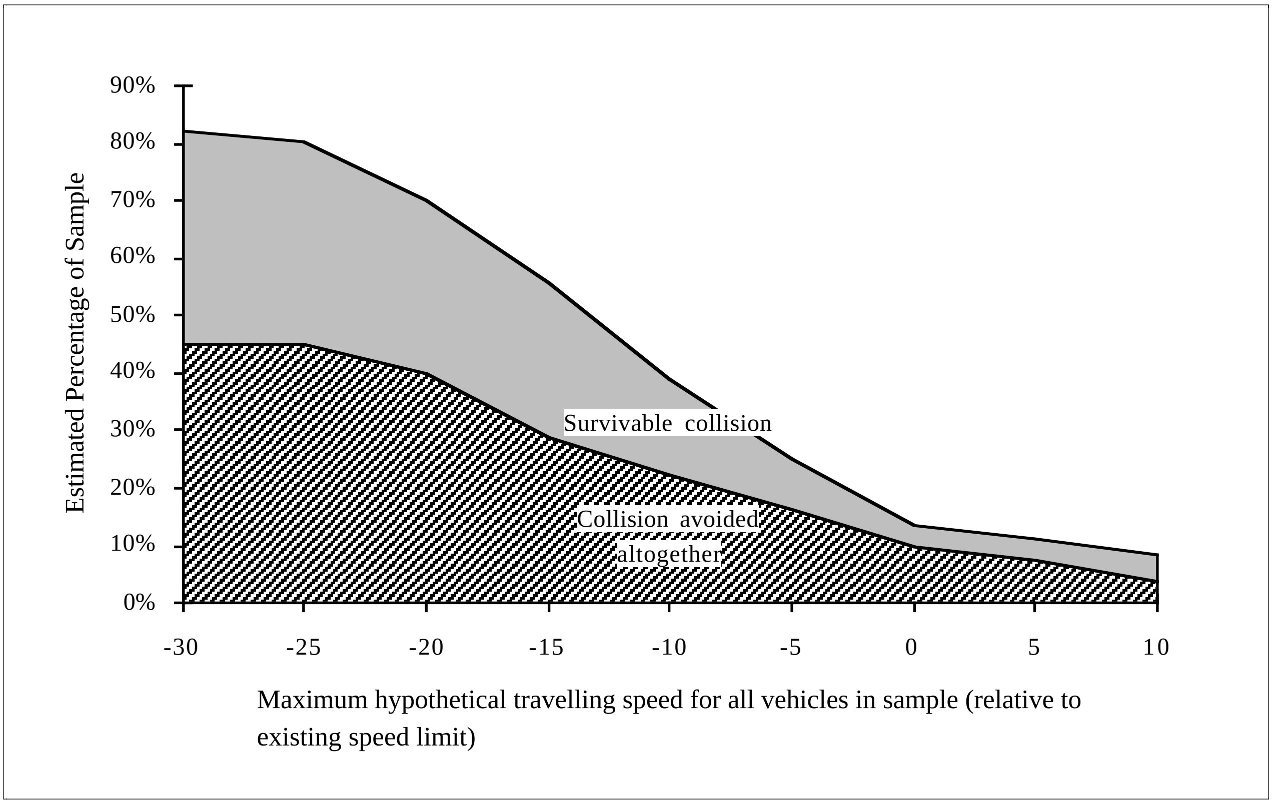


Figure 5.19 *The proportion of non-impacts and survivors as a function of the maximum speed allowed in the scenario.*

6 DISCUSSION

The results of this study show that small reductions in travelling speed translate into large reductions in impact speed in pedestrian collisions, often to the extent of preventing the collision altogether. This is because when avoiding action was attempted by a driver, in virtually every case, it involved emergency braking, and stopping distance under braking is proportional to the square of the initial speed. Figure 6.1 shows the relationship between initial speed and stopping distance, based on the data presented in Section 4. The curves relating speed to distance are preceded in each case by a horizontal straight section which represents the distance covered during the driver's reaction time, with the vehicle proceeding straight ahead at the initial travelling speed. Once braking commences, the speed of the vehicle decreases with distance travelled in the manner shown, quite slowly at first and then decreasing more and more rapidly. It can be seen in Figure 6.1 that, from an initial speed of 80 km/h, the vehicle travels about 45 metres during the first 10 km/h decrease in speed, whereas the vehicle travels less than one metre during the last 10 km/h of speed reduction before the vehicle stops.

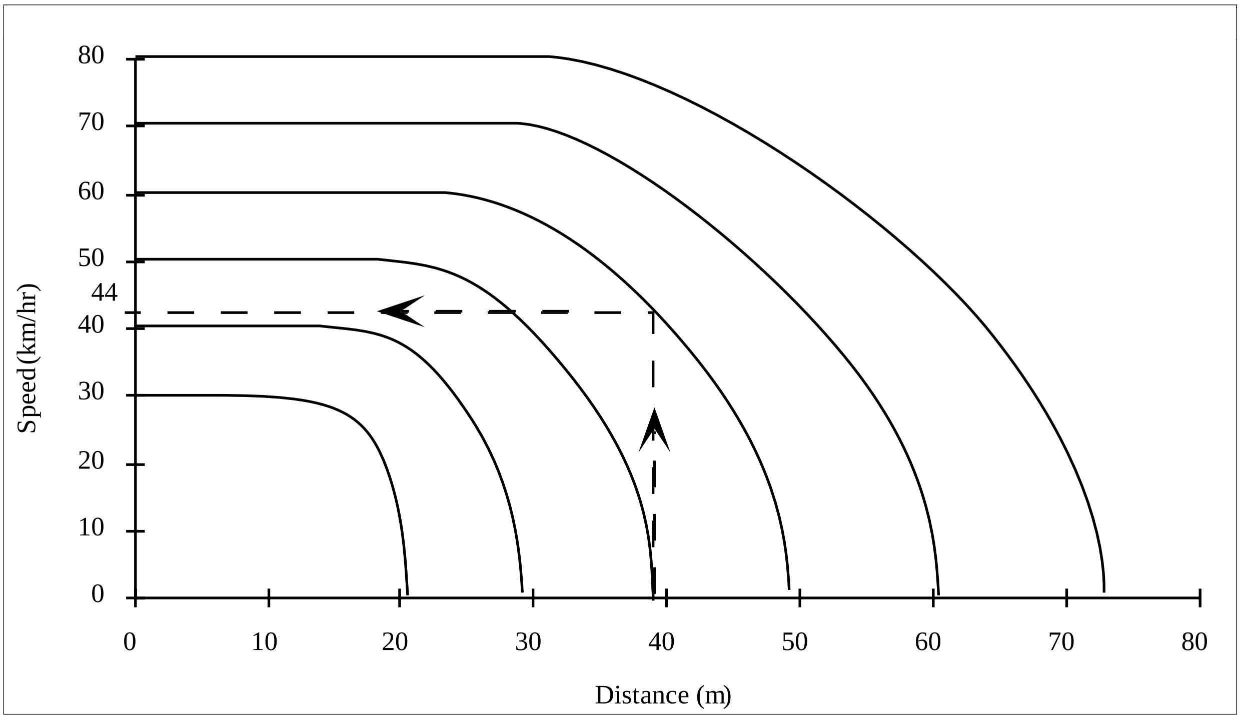


Figure 6.1 *Speed versus distance for emergency braking from time =* t_0

The effect on impact speed of a difference in travelling speeds of 50 and 60 km/h can be seen in the following example, which is indicated by the intercept lines in Figure 6.1. Consider two cars travelling side by side at a given instant, one car travelling at 50 km/h and the other overtaking at 60 km/h. Suppose that a child runs onto the road at a point just beyond that at which the car travelling at 50 km/h can stop. The other car will still be travelling at 44 km/h at that point, a collision speed at which a pedestrian has more than a 50 percent probability of being fatally injured.

In the present study we have estimated that a uniform reduction of 10 km/h in travelling speeds in 60 km/h speed limit zones would reduce the number of fatal pedestrian cases by 48 percent, including the elimination of the collision altogether in 22 percent of the cases (Table 5.2).

Reducing the urban area speed limit from 60 to 50 km/h would not be expected to have as great an effect as a uniform reduction of 10 km/h in travelling speed because, for example, it would have relatively little effect on vehicles which were already travelling at less than 50 km/h. In estimating the likely effect of such a change in the urban area speed limit, we have assumed that the level of non-compliance would be similar to that for the existing 60 km/h speed limit (see Section 6.6), and that there would be no change at all to speeds below 50 km/h.

With the stated assumptions, we have estimated that 12 percent of the collisions would not have occurred and in an additional 15 percent of cases the pedestrian would not have been fatally injured, leading to an overall reduction of 27 percent in fatal pedestrian collisions. These percentages are remarkably similar to the changes which were observed when the urban area speed limit was reduced in this way in the city of Zurich, in Switzerland.

In Zurich, the urban area speed limit was lowered from 60 to 50 km/h in 1980 in response to a reduction in the open road speed limit (following political pressure from the Green movement to reduce pollution levels from cars to save the forests). In the year after the change in the urban speed limit there was a reduction of 16 percent in pedestrian accidents and a reduction of 25 percent in pedestrian fatalities (Walz *et al*, 1983). (The authors of this study observed that, because of those who "don't believe in the influence of driving speed on impact speed" or who "just don't care at all", "it must be proven in every country that the laws of Isaac Newton are true".)

The estimated effect on pedestrian fatalities of reducing the urban area speed limit from 60 to 50 km/h is similar overall to that which would be expected from a uniform 5 km/h reduction in travelling speeds. The former change would be slightly more effective in preventing collisions but have less effect on the severity of those collisions which would still occur, as measured by the number of cases in which the injuries would be expected to no longer result in a fatality.

The probable results from 100 percent compliance with the existing 60 km/h speed limit were considered (Table 5.4). A reduction in fatal pedestrian collisions of 13 percent could be expected to result, with a reduction of 8 percent if speeds were reduced to within a 10 km/h tolerance of the posted limit (Table 5.3). Thus, the results indicate that even a 5 km/h uniform reduction in travel speeds would have a much greater safety impact than elimination of all speeding offences against the current limit.

The effect of reducing travelling speeds by 5 km/h in local streets was investigated because that was the average speed reduction which occurred in the trial of a 40 km/h speed limit in part of the City of Unley, South Australia (Local Area Speed Limit Trial Working Party, 1993). There has also been much discussion of the possible introduction of a 40 km/h limit on local streets. We found that a 5 km/h uniform reduction in travelling speed on local streets would result in a reduction of only 4 percent in total urban pedestrian fatalities and one percent in fatal pedestrian collisions (Table 5.8).

Reductions in travelling speeds on local streets would have relatively little effect on the frequency of fatal pedestrian collisions because five out of six of these collisions occur on arterial roads or main traffic routes. Consequently, even a small reduction of travelling speeds on arterial roads can be expected to be accompanied by a significant reduction in pedestrian collisions and an even greater reduction in fatalities.

In any consideration of the likely effect of changes to urban area speed limits it is relevant to note that the urban area speed limit throughout most of Australia was 30 mph, or 50 km/h, up to about 30 years ago. The limit was then increased to 35 mph, or 56 km/h, because “vehicles, as well as roads, were now far superior in comparison to the standards existing in 1937 when the 30 mph limit was introduced” (in NSW) ("Road Safety Milestones", NRMA, 1988). With metrication, the urban speed limit was increased again, to 60 km/h. This speed was chosen, rather than 55 km/h, because the fashion of the day decreed that speed limits should be expressed in units of 10 km/h. Advisory speeds were expressed on signs in numbers ending with 5, such as 45 or 55 km/h, so that they would not be “confused” with speed limits.

It is often argued that speed limits should appear to be reasonable to the driver and that the best way to achieve this is to set the limit at or close to the 85th percentile speed of the traffic. The concept of a “reasonable” speed is often presented as though such a speed is a phenomenon which is immutable for a particular road. However, the lower urban speed limits in most other highly developed countries show that speed limits can be, and are, used successfully to achieve what the term suggests, to limit speed, often well below what the 85th percentile speed of today's Australian drivers would suggest is “reasonable”.

There are clearly many factors that a given driver will take into account when deciding what speed is “reasonable”. They can range from the physical characteristics of the road and immediate road environment, to weather and traffic conditions, and ambient lighting, through to the driver's assessment, however well founded or misguided, of his or her own driving ability and the performance characteristics of their vehicle, together with convention - how most people drive in the circumstances - and legislation (the posted limit). By comparison, it is difficult for any driver to relate their travelling speed to the risk of being involved in a crash, except at unusually high speeds. Fortunately, the average driver has a very low risk of being involved in a collision, particularly one in which a pedestrian is killed, for example. However, this means that the risk of fatally injuring a pedestrian is not a factor which can readily be taken into account by a driver in deciding what is a "reasonable" speed at which to travel on a particular road.

Any consideration of reduced travelling speeds should include an assessment of the costs, as well as the benefits which, as this study has shown, can reasonably be expected to be very large in terms of reduced economic losses from death and injury. Savings would also accrue from reduced fuel consumption and reduced property damage. A reduction in the speed limit on arterial roads would increase travel times but the increase would be considerably less than a simple calculation of distance and maximum travel speed would indicate. This is because urban traffic flow in a city such as Adelaide is regulated mainly by traffic signals and the time spent stationary at a signal is unlikely to change, assuming that computer control of linked signals is adjusted to allow for the lower maximum travelling speed. The task of drivers trying to cross arterial roads would be made much easier, and therefore safer, by a reduction in travelling speeds on those roads and the severity of any resulting collision would be greatly reduced. Even a small reduction in travelling speeds on arterial roads can be expected to result in a large increase in the safety of all road users, not only pedestrians, and an improvement in the amenity of many, including some motorists, while also resulting in some decrease in mobility when measured in terms of travelling time.

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APPENDIX A
CALCULATIONS USED IN THE ANALYSES

Calculations of Reaction Time and Distance

In these calculations it was assumed that sex, age and task complexity are negligible factors in determining the *Reaction Time* of a driver (Olson 1991;Bell *et al* 1982).

Constants: 1. Base Reaction Time, t_b = 1.5 seconds

Table A1 Percentage Increase Factors for reaction time related to BAC (after Pauwels *et al* 1993).

BAC Level	Increase in Reaction Time
0<BAC<0.10	α_1 = 20%
0.10 ≤BAC<0.15	α_2 = 55%
≥0.15	α_3 = 100%

Procedure: 1. Depending on the BAC of the driver ,the *Base Reaction Time* was increased by the percentage α_1, α_2, or α_3 (in Table A1) to find the *Reaction Time* of the Driver, as in Equation A1

$$t_r = t_b(1+\alpha) \qquad \text{..........(A1)}$$

2. To calculate the *Reaction Distance*, Equation A2 was used

$$s_r = v_0 t_r \qquad \text{..........(A2)}$$

Travelling and Impact Speed Calculations

Calculation Type 1 was appropriate when driver took no evasive action. Requires driver or witness estimate of the *Travelling Speed.* (Used in conjunction with Calculation type 3.1)

Procedure: 1. *Impact Speed = Travelling Speed* $v_i = v_0$

2. *New Impact Speed = New Travelling Speed* $v_i^* = v_0^*$

Calculation Type 2.1 was appropriate when skid marks where left by the vehicle and if the vehicle stopped at the end of the skid marks.

Assumptions: 1. Coefficient of friction is the same for any number of wheels locked.

Constants:

1. Coefficient of friction for locked wheel braking in wet conditions, $\mu_w = 0.52$

   Coefficient of friction for locked wheel braking in dry conditions, $\mu_d = 0.72$

   (Warner *et al*, 1988)
2. Percentage of kinetic energy remaining immediately prior to wheels locking L =80%. (Reed and Keskin, 1989)
3. Time elapsed before wheels lock up on braking t_l= 0.5 secs. (Reed and Keskin, 1989)

Procedure

1. The *Travelling Speed* of the vehicle was calculated using Equation A3,

$$v_0 = \sqrt{\frac{1}{L}2g\mu(b-a)} \qquad \text{..........(A3)}$$

where a is negative if the skid marks start before the impact point, and with appropriate μ (ie wet or dry).

2. The *Impact Speed* was then calculated using Equation A4,

$$v_i = \sqrt{2g\mu b} \qquad \text{..........(A4)}$$

with appropriate μ.

3. The *Sighted Distance* (ie: the distance that the case vehicle was from the impact point when the driver realised that a collision was going to occur) was calculated using Equation A5.

$$s_d = \underbrace{v_0 t_r}_{\text{Reaction Distance}} + \underbrace{\frac{1+\sqrt{L}}{2} v_0 t_l}_{\text{Distance for Wheels to Lock}} - a \qquad \text{..........(A5)}$$

The *Reaction Distance* was the distance travelled by the vehicle in the time it takes for the driver to react and apply the brakes. The *Distance for Wheels to Lock* was the distance that the vehicle travelled from the application of the brakes to when the wheels locked and produced visible skid marks. These distances were added to the distance from the start of the skid marks to the impact point to give the *Sighted Distance*.

4. The *Hypothetical Impact Speed* was calculated from the *Hypothetical Travelling Speed* by using Equation A6.

$$v_i^* = \sqrt{Lv_0^{*2} - 2g\mu s_{nd}} \qquad \text{..........(A6)}$$

where

$$s_{nd} = s_d - \left(s_{nr} + \frac{1+\sqrt{L}}{2} v_0^* t_l \right) \qquad \text{..........(A7)}$$

The *Hypothetical Impact Speed* was calculated using the distance from where the wheels would hypothetically have locked to the point of impact. This distance was found by subtracting the *Hypothetical Reaction Distance* from the *Sighted Distance* and the *Hypothetical Distance for the Wheels to Lock.* No impact would have occurred if the vehicle travelling with the *Hypothetical Travelling Speed* stopped before the point of impact.

Calculation Type 2.2 was appropriate where skid marks were left by the vehicle, but the vehicle did not stop at the end of the skid marks. It required a driver or witness estimate of the vehicle's *Travelling Speed*. The calculation was cross checked with Calculation type 2.1 for consistency and with any witness statement of final speed.

Assumptions:

1. The vehicle was travelling at the speed estimated by the driver or witness.
2. The vehicle did not stop at the end of the skid marks

Procedure:

1. The estimate of the vehicle's *Travelling Speed* was taken from the statement obtained from the driver and/or witness. If two estimates were completely different the case was looked at further to decide which estimate of *Travelling Speed* was more likely to have been correct.

2. The *Impact Speed* was calculated by starting with the *Travelling Speed* and the length of the skid marks before the impact and then calculating the speed lost using Equation A8,

$$v_i = \sqrt{Lv_0{}^2 - 2g\mu(a-b)} \qquad \text{..........(A8)}$$

where a is negative if the skid marks start before the impact point, and with appropriate μ (ie wet or dry).

3. The *Sighted Distance* was calculated using Equation A5

4. The *Hypothetical Impact Speed* was calculated from the *Hypothetical Travelling Speed* by using Equation A6 and A7.

Calculation Type 2.3 was appropriate when a motorcycle was the collision involved vehicle, and its sliding distance and/or skid mark length were known.

Assumptions:

1. The equation for calculating speed from skid marks for cars was used for motorcycles that are braking or sliding along the road surface, but with a different Coefficient of friction.

2. The percentage kinetic energy loss and the time elapsed before the wheels locked up on braking for a motorcycle was assumed to be the same as for a car.

Constants

1. Coefficient of friction for a motorcycle under braking with locked wheels, μ_b = 0.65.

2. Coefficient of friction for a motorcycle sliding on its side over a bitumen surface, μ_s = 0.6.

3. Coefficient of friction for a motorcycle under braking without locked wheels, μ_m = 0.7.
(Warner *et al*, 1988; Donahoe 1991)

Procedure:

1. The motorcycle *Impact Speed* was calculated using momentum transfer for the rider, motorcycle and the pedestrian. This was done because the mass of a motorcycle is much less than a car and so the percentage of the initial momentum of the vehicle that is transferred to the pedestrian can be a significant factor in determining the speed of the motorcycle on impact. Equation A9 was used.

$$\left(m_{rider} + m_{motorcycle}\right)\vec{v}_i = m_{rider}\vec{v}_r + m_{motorcycle}\vec{v}_m + m_{pedestrian}\vec{v}_p \qquad \text{..........(A9)}$$

This equation was solved graphically by using the velocity vectors of the rider, motorcycle and pedestrian after impact. The velocity vector magnitude for the motorcycle was found using Equation A10.

$$|\vec{v}_m| = \sqrt{2g\mu_s(s_m - b) + 2g\mu_b b} \qquad \text{..........(A10)}$$

The velocity vector magnitude for the pedestrian and rider were found using the throw distance as in Calculation Type 3.1.

2. If there were skid marks before the impact point the *Travelling Speed* was calculated using Equation A11.

$$v_0 = \sqrt{\frac{v_i^{\,2} + 2g\mu_b(-a)}{L}} \qquad \text{..........(A11)}$$

where a is negative if the skid marks start before the impact point. If no skid marks were present before impact, the rider's or witness's estimate of *Travelling Speed* was taken. If the *Impact Speed* was close to the stated speed and no apparent evasive action was taken before impact the calculated *Impact Speed* was used for the *Travelling Speed.*

3. If there were skid marks before the impact, the *Sighted Distance* was calculated using Equation A5. If there were no skid marks, the *Sighted Distance* was estimated using Equation A12.

$$s_d = \underbrace{v_0 t_r}_{\text{Reaction Distance}} + \underbrace{\frac{v_0^{\,2} - v_i^{\,2}}{2g\mu_m}}_{\text{Distance to IS}} \qquad \text{..........(A12)}$$

where Distance to IS was the distance the car travelled in the time it took for the car to decelerate from the *Travelling Speed* to the *Impact Speed*.

4. If there were skid marks then the *Hypothetical Impact Speed* was calculated using Equation A6. If there were no skid marks then the *Hypothetical Impact Speed* was found using Equation A13.

$$v_i^* = \sqrt{v_0^{*2} - 2g\mu(s_d - s_{nr})} \qquad \text{..........(A13)}$$

Calculation Type 3.1 was appropriate when the *Pedestrian Projection Distance* was known and there was a driver or witness estimate of the *Travelling Speed*. This calculation was used in conjunction with Calculation Type 1 when no evasive action was taken.

Assumptions:

1. The speed of the pedestrian immediately after impact with the car was the same as the *Impact Speed* of the car.

Constants:

1. Coefficient of friction for a pedestrian sliding over bitumen $\mu_p = 0.8$.(Warner *et al*, 1988)
2. Coefficient of friction for a car under braking with no wheels locked, $\mu_c = 1.1$. (Reed and Keskin, 1989)

Procedure:

1. The maximum and minimum *Impact Speed* of the vehicle was calculated using Equations A14 and A15 (Searle and Searle, 1983), thus giving the bounds for the *Impact Speed*.

$$v_{\min} = \sqrt{\frac{2\mu gs}{1+\mu^2}} \qquad \text{..........(A14)}$$

$$v_{\max} = \sqrt{2\mu gs} \qquad \text{..........(A15)}$$

These maximum and minimum *Impact Speeds* were then averaged.

$$v_{mean} = \frac{v_{\max} + v_{\min}}{2} \qquad \text{..........(A16)}$$

2. If the *Travelling Speed* taken from the driver's or witness's estimate was between $v_{\min}$ and v_{mean}, then the *Impact Speed* was taken as the *Travelling Speed* (the assumption being that the driver braked right on impact).
   If the *Travelling Speed* estimate was greater than v_{mean} the *Impact Speed* was taken as v_{mean}.

3. The *Sighted Distance* was calculated using Equation A12

4. The *Impact Speed* was then calculated using Equation A13.

Calculation Type 3.2 was appropriate when the *Vehicle Stopping Distance* was known and there was a driver or witness estimate of the *Travelling Speed*. This type of calculation was not chosen as the preferable option for any of the cases as there were more reliable calculation options available.

Assumptions 1. The vehicle was under constant braking and braking at the same rate (ie the driver brought the car to a complete halt as soon as possible after the impact and did not move it to another position)

Constants 1. Coefficient of friction for a car under braking with no wheels locked, $\mu_c = 1.1$. (Reed and Keskin, 1989)

Procedure 1. The driver's or a witness estimate of the *Travelling Speed* was used.

2. The *Impact Speed* was calculated using Equation A17.

$$v_i = \sqrt{2g\mu_c s_c} \qquad \text{..........(A17)}$$

3. The Sighted Distance was then calculated using Equation A12.

4. The *Impact Speed* was then calculated using Equation A13.

Calculation Type 4.1 was appropriate when the only information available was the driver's or witness estimate of *Travelling Speed* and *Impact Speed.*

Assumptions 1. The car was travelling at the speed estimated by the driver or witness on impact.

2. The vehicle hit the pedestrian at the speed estimated by the driver or a witness.

Procedure 1. *Travelling Speed* was taken from the estimate given by the driver or witness

2. *Impact Speed* was taken from the estimate given by the driver or witness

3. The *Sighted Distance* was then calculated using Equation A12.

4. The *Impact Speed* was then calculated using Equation A13.

Calculation Type 4.2 was used in one case only. This case had limited information on the *Impact Speed* but the distance the driver's estimate of the *Sighted Distance* could be substantiated. From the *Sighted Distance* , the *Impact Speed* was calculated using the reaction time and the friction coefficient of a vehicle under braking (no wheels locked). The *Hypothetical Impact Speed* was calculated the same as in Calculation type 3.3.

APPENDIX B
SAMPLE CHARACTERISTICS AND EXPANDED RESULTS

SAMPLE CHARACTERISTICS

The sample data of 176 fatal pedestrian collisions were divided into 6 groups as indicated in the main report. Table B1 shows the number of cases and fatalities in each of the groups which the sample data was divided into.

Table B1
Case Groups of Sample Data

	60 km/hr Zone		All Zones including the 60 km/hr Zone	
	No. of Cases	No. of fatalities	No. of Cases	No. of fatalities
Cases analysed	118	120	134	136
Insufficient information for analysis	15	16	19	20
Vehicle manoeuvring	12	13	12	13
Off road	1	1	4	4
Driver unconscious	3	4	3	4
Self induced	4	4	4	4
Total	153	158	176	181

The 134 cases which were travel speed related and had sufficient information were then further divided by the calculation types which best analysed each case. Table B2 shows the number of cases and fatalities that used each type of calculation (also refer to Appendix A).

Table B2
The number of cases in each calculation type category.

Calculation Type	No. of Cases	No. of Fatalities	No. of Cases	No. of Fatalities
1	53	55	61	63
2.1	26	26	28	28
2.2	4	4	5	5
2.3	8	8	8	8
3.1	23	23	27	27
3.2	0	0	0	0
4.1	2	2	4	4
4.2	1	1	1	1
Total	117	19	134	136

Figure B1 shows the age distribution of the fatally injured pedestrians in the sample.

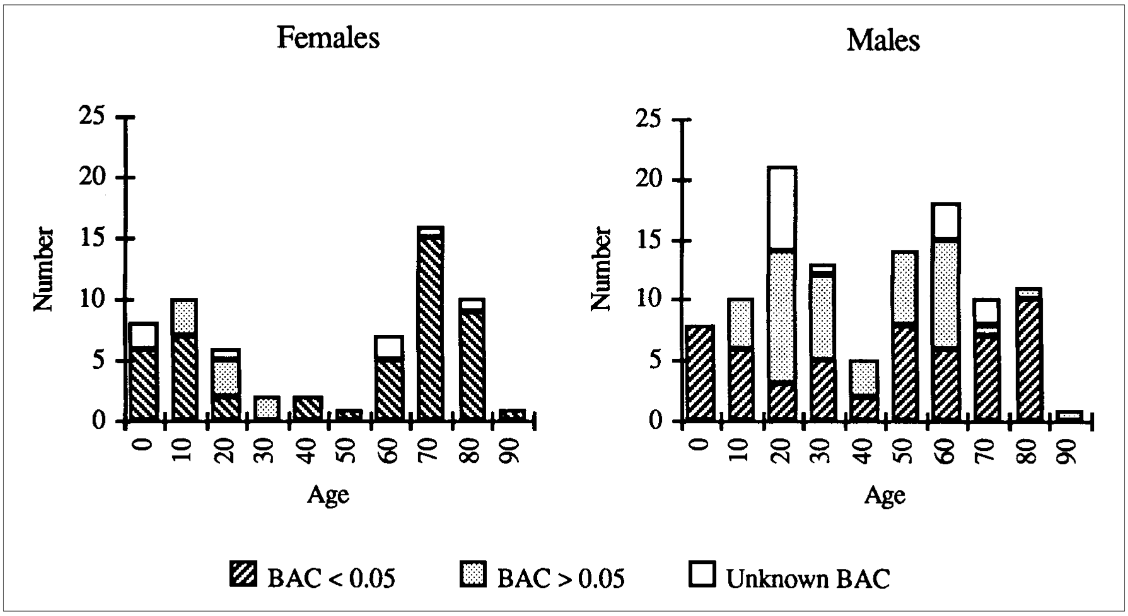

Figure B1 *Collision Victims Age Groups*

Figures B2 and B3 show the distribution of the fatally injured pedestrians in the sample by the time of day of the accident, for females and males.

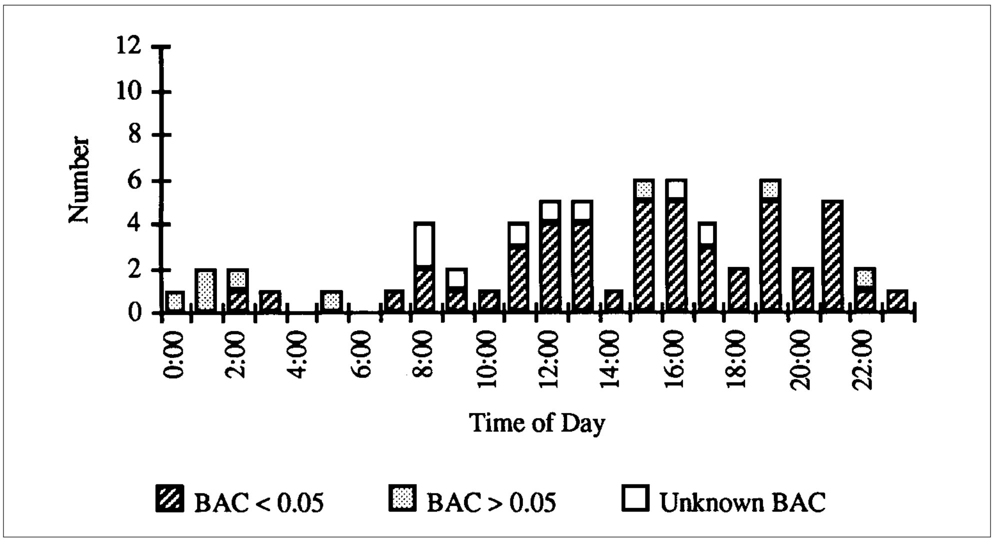

Figure B2 *Time of Collision : Females*

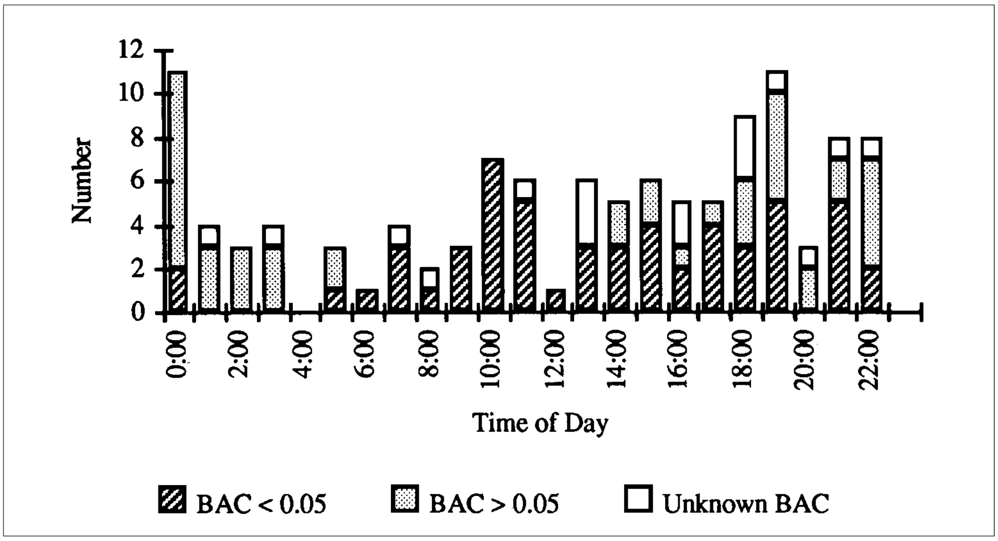

Figure B3 *Time of Collision : Males*

Figure B4 shows the distribution of fatalities in the analysed sample by day of week for females and males.

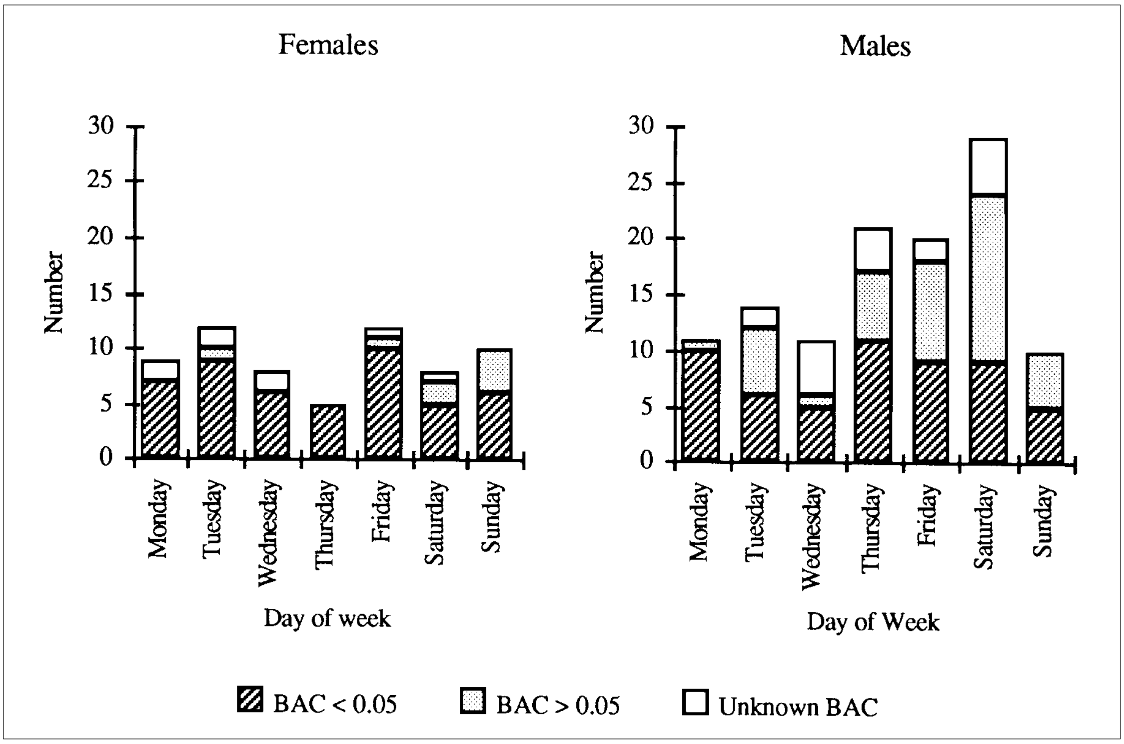

Figure B4 *Day of Collision*

Figure B5 shows the composition of the set of vehicles involved.

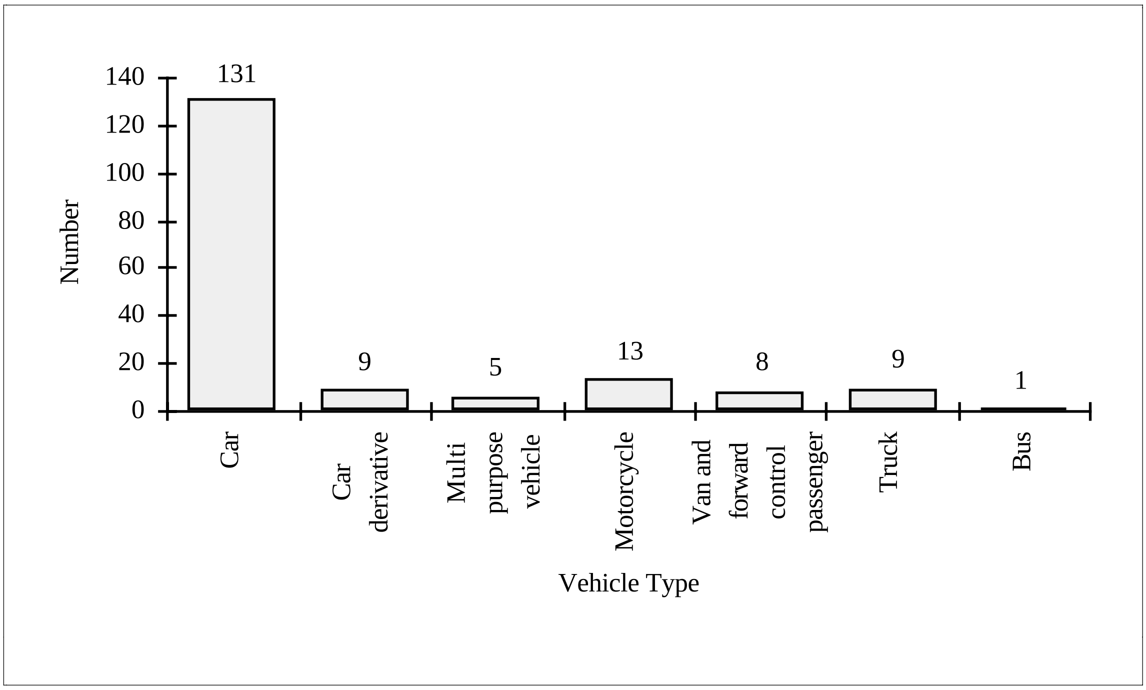

Figure B5 *Collision Vehicle Type*

Figure B6 and B7 show the distributions of travelling and impact speed respectively for the cases which were analysed.

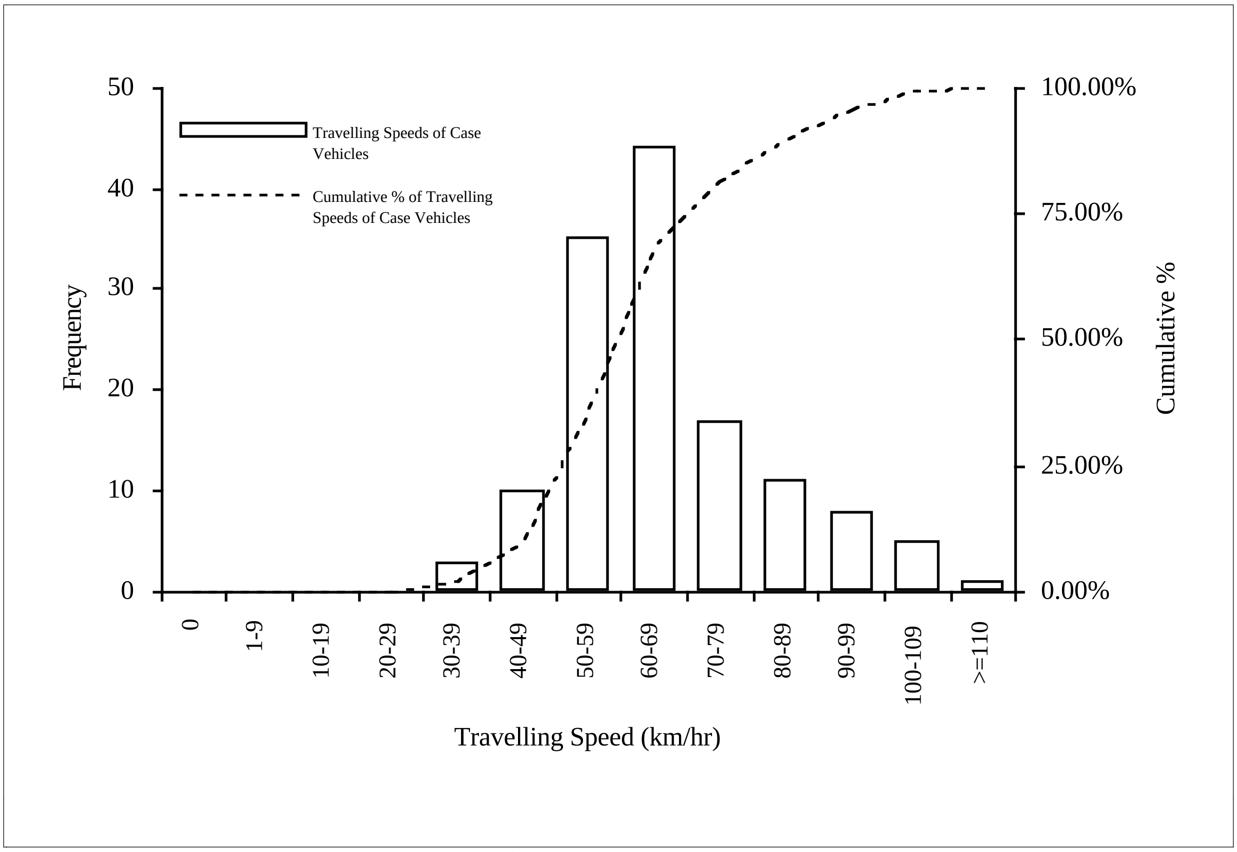

Figure B6 *The travelling speed distribution of the cases in the sample which were analysed.*

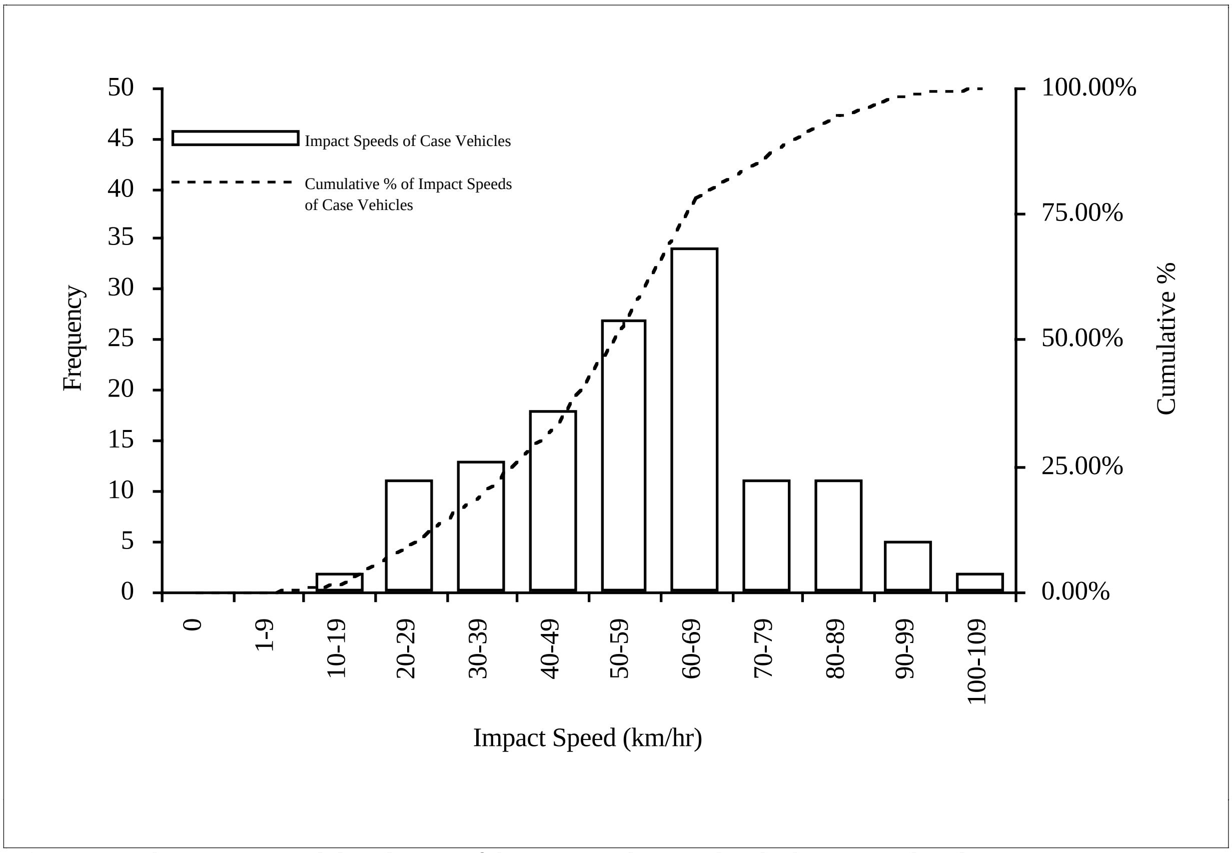

Figure B7 *The impact speed distribution of the cases in the sample which were analysed.*

EXPANDED RESULTS

In section 6, a selection of results from the different scenarios are presented. Following is a more comprehensive listing of the results. For clarity the entire set of results is presented here.

Tables B3 and B4 list the scenarios and the equations applied to the travel speed of the vehicles in the sample.

Table B3
Equations governing the travelling speed of cases in Scenario Sets 1 and 2.

Scenario Set	Scenario No.	Equations	Description
1	1.1	$v_0^* = v_0 - 5 \text{ km/hr}$	Uniform 5 km/hr travelling speed reduction
	1.2	$v_0^* = v_0 - 10 \text{ km/hr}$	Uniform 10 km/hr travelling speed reduction
	1.3	$v_0^* = v_0 \times 90\%$	Travel speeds reduced by 10 percent
	1.4	$v_0^* = v_0 \times 80\%$	Travel speeds reduced by 20 percent
	1.5	$v_0^* = v_0 - 5 \text{ km/hr}$ if local street	Speed limits reduced by 5 km/hr if the accident occurred in a local street
2	2.1	$v_0 < SL,\ v_0^* = v_0$ $v_0 > SL,\ v_0^* = SL$	All speeds reduced to the speed limit
	2.2	$v_0 < SL + 5 \text{ km/hr},\ v_0^* = v_0$ $v_0 > SL + 5 \text{ km/hr},\ v_0^* = SL + 5 \text{ km/hr}$	Speeds reduced to current limit plus an enforcement tolerance of 5 km/hr
	2.3	$v_0 < SL + 10 \text{ km/hr},\ v_0^* = v_0$ $v_0 > SL + 10 \text{ km/hr},\ v_0^* = SL + 10 \text{ km/hr}$	Speeds reduced to current limit plus an enforcement tolerance of 10 km/hr

Table B4
Equations governing the travelling speed of cases in Scenario Sets 3, 4 and 5.

Scenario Set	Scenario Number	Equations	Description
3	3.1 - 3.6	$v_0 < SL^*,\ v_0^* = v_0$ $v_0 > SL^*,\ v_0^* = SL^*$	Travelling speeds reduced to a new speed limit of SL^*
4	4.1 - 4.6	$v_0 < SL^*,\ v_0^* = v_0$ $SL^* < v_0 < SL,\ v_0^* = SL^*$ $v_0 > SL,\ v_0^* = SL^* + (v_0 - SL)$	Travelling speeds reduced to a new speed limit of SL^*, with the same magnitude of violation (those vehicles exceeding the speed limit by x km/hr, exceed the new limit by x km/hr).
5	5.1 - 5.6	$v_0 < SL^*,\ v_0^* = v_0$ $SL^* < v_0 < SL,\ v_0^* = SL^*$ $v_0 > SL,\ v_0^* = v_0 \left(SL^* / SL \right)$	Travelling speeds reduced to a new speed limit of SL^*, with the same relative violation (those vehicles exceeding the speed limit by x%, exceed the new limit by x%).

SL^* denotes an hypothetical speed limit.

The reader is referred to section 5 for a detailed description of the different scenario sets.

The results from the scenarios detailed in Tables B3 and B4 are presented below. The results from scenarios in sets 1 and 2 are shown in figure B8 and B9. These figures show the relative effects of those scenarios.

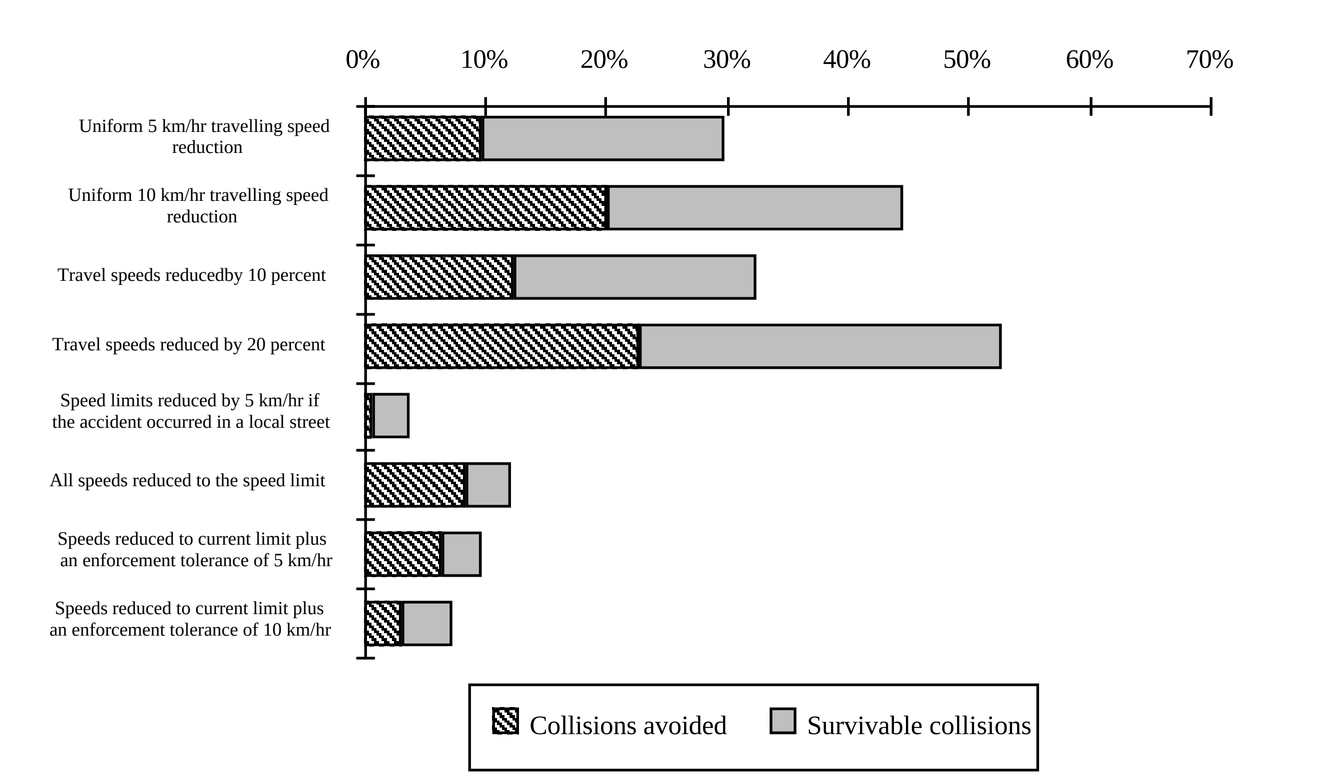

Figure B8 *The estimated number of Non Impacts and Survivors in the sample of accident involved pedestrians for scenarios in Set 1 and 2 for all speed zones.*

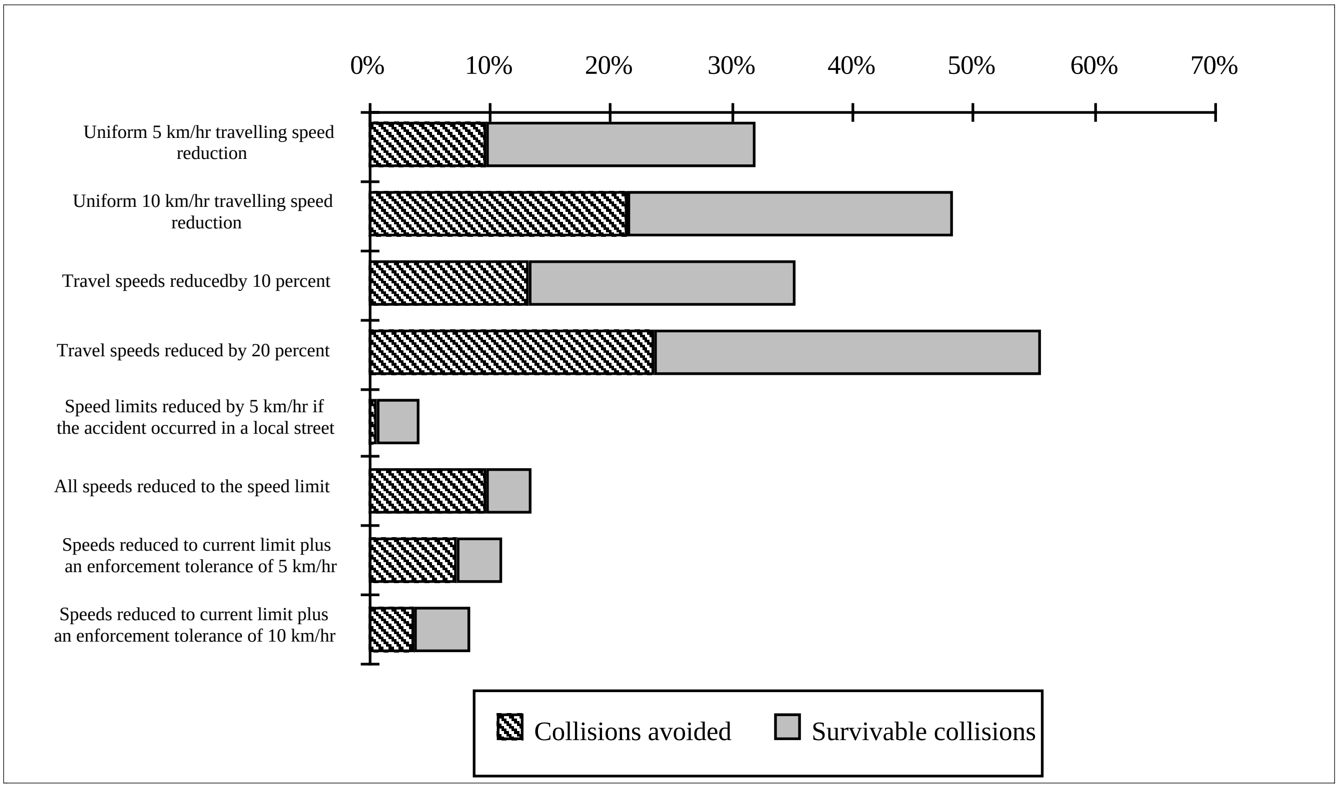

Figure B9 *The estimated number of Non Impacts and Survivors in the sample of accident involved pedestrians for scenarios in Set 1 and 2 for accidents that occurred in a 60 km/hr speed zone.*

As described in section 5 of this report, Scenarios in Sets 3, 4, and 5, nominate a new speed limit and then assume some compliance regime. In Set 3 absolute compliance is assumed. Figure B10 and B11 compare the estimates of the proportion of the sample that would have survived and those accidents where an impact would have been avoided, where an absolute compliance with different speed limits is assumed.

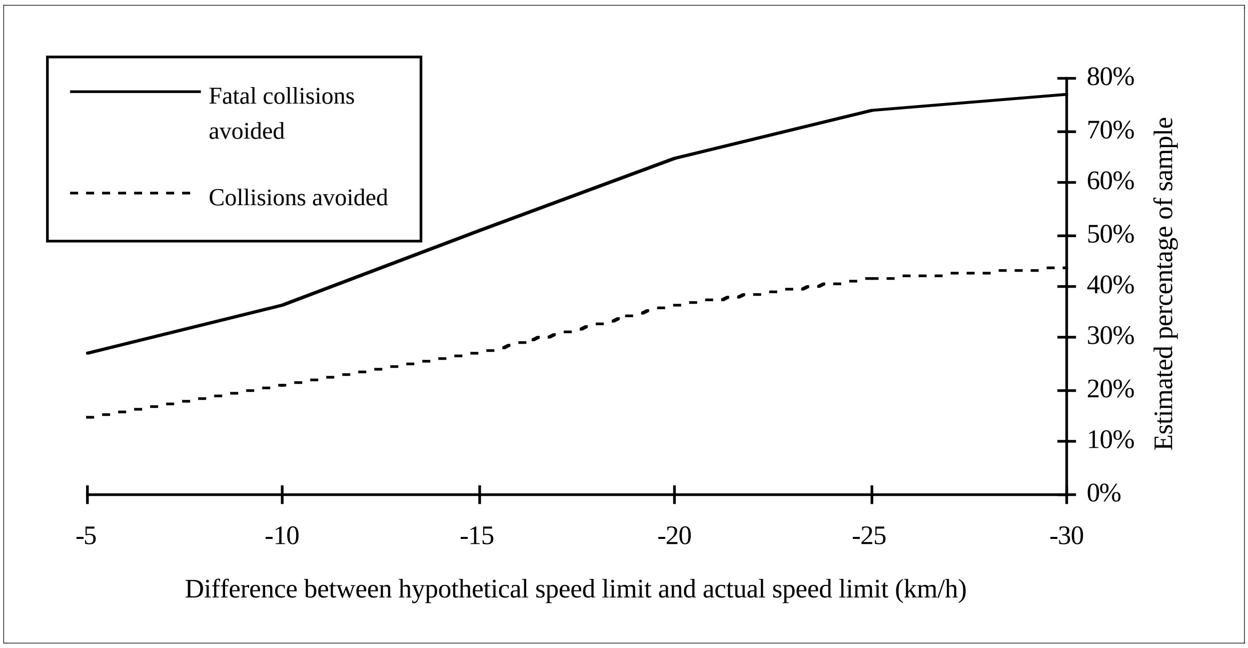

Figure B10 *The relative effects of reducing travelling speeds to an hypothetical speed limit for all accidents that occurred in all speed zone when there is absolute compliance.*

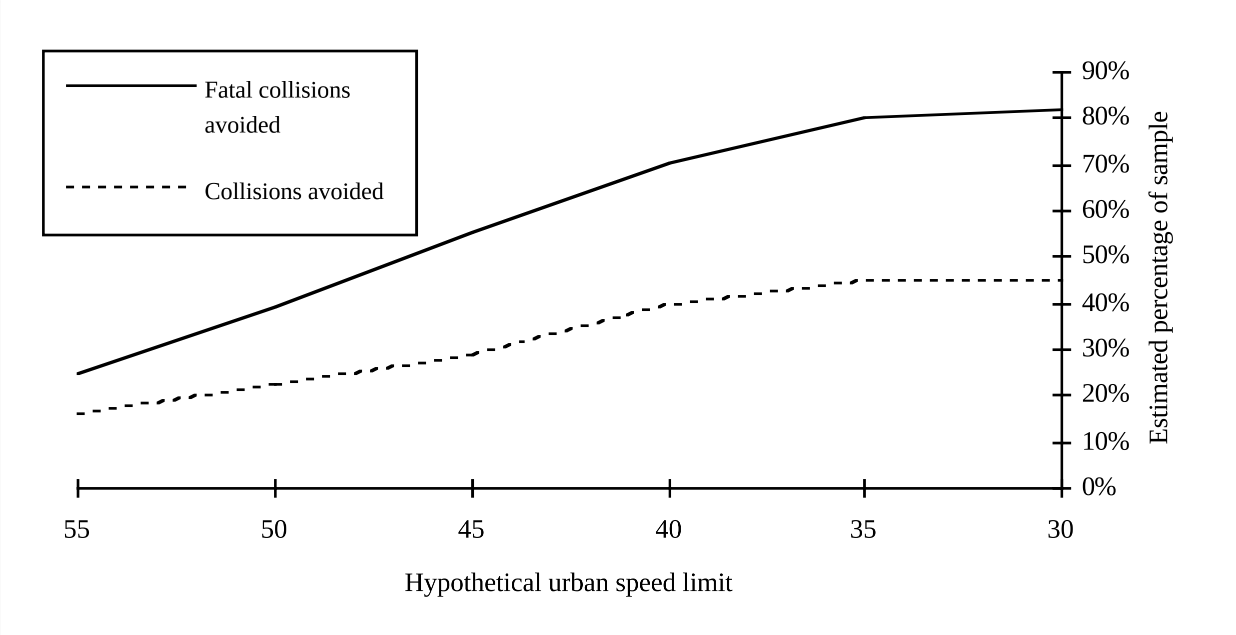

Figure B11 *The relative effects of reducing travelling speeds to an hypothetical speed limit for all accidents that occurred in a 60 km/hr speed zones when there is absolute compliance.*

In the scenarios in set 4, those vehicles that were exceeding the speed limit at the time of the accident had a speed which exceeded the hypothetical limit by the same magnitude (for example, a vehicle travelling at 67 km/hr in a 60 km/hr zone, travelled at 57 km/hr when the speed limit was set at 50 km/hr). The results of these scenarios are shown in figure B12 and B13.

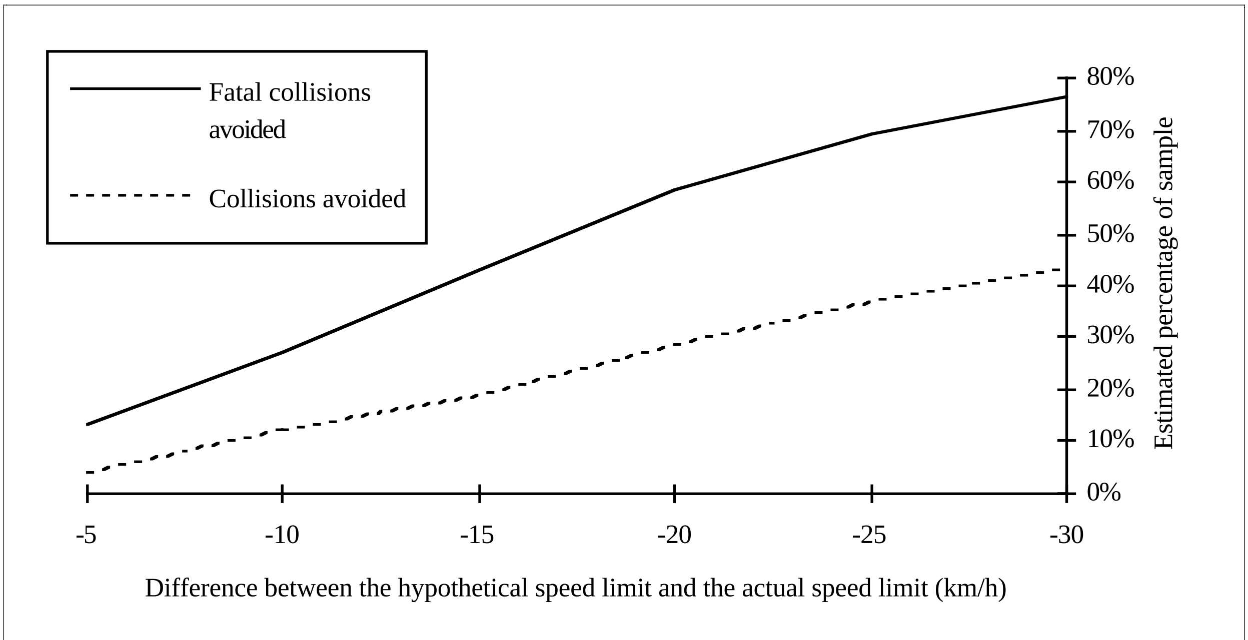

Figure B12 *The relative effects of reducing travelling speeds to a new speed limit of SL^* and assuming the same magnitude of violation as in the actual accident (for accidents that occurred in all speed zones)*

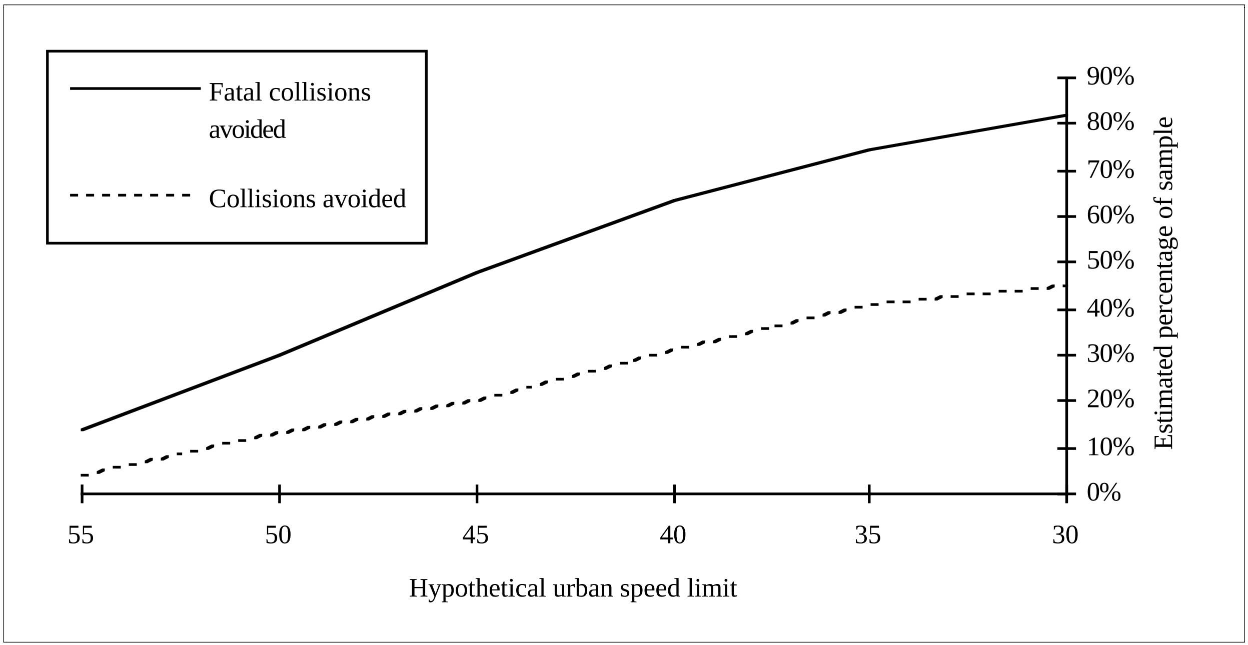

Figure B13 *The relative effects of reducing travelling speeds to a new speed limit of SL* and assuming the same magnitude of violation as in the actual accident (for accidents that occurred in 60 km/hr zones).*

In the scenarios in set 5, those vehicles that were exceeding the speed limit at the time of the accident had a speed which exceeded the hypothetical limit by the same proportion (eg A vehicle travelling at 67 km/hr in a 60 km/hr zone (= 1.117 x 60), travelled at 56 km/hr when the speed limit was set at 50 km/hr (1.117 x 50 = 55.8)). The results of these scenarios are shown in figure B14 and B15.

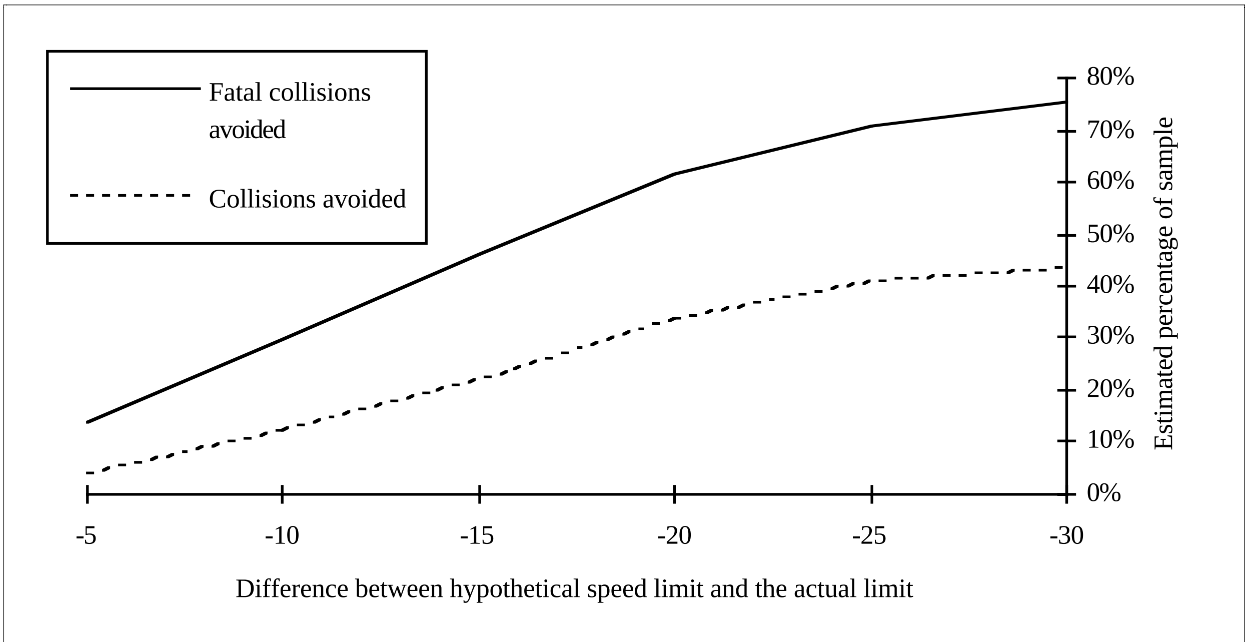

Figure B14 *The relative effects of reducing travelling speeds to a new speed limit of SL* and assuming the same proportional violation as in the actual accident (for accidents that occurred in all speed zones).*

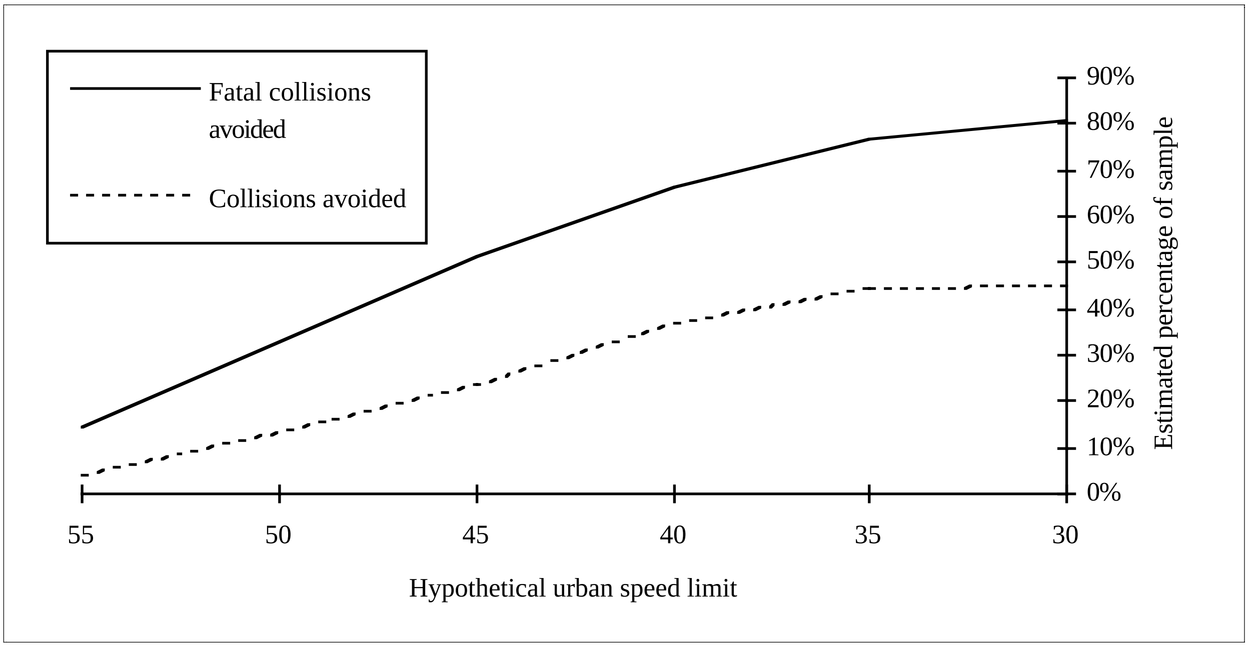

Figure B15 *The relative effects of reducing travelling speeds to a new speed limit of SL* and assuming the same proportional violation as in the actual accident (for accidents that occurred in 60 km/hr zones).*

The following sections describe how the distribution of travel and impact speeds were modified under each scenario.

Scenario Set 1

In this scenario set the travelling speeds of all the drivers were altered by an amount depending on the scenario. The results can be seen in Table B5 and figures B16 to B20.

Table B5
Results of scenario set 1

	All Speed Zones		60 km/hr Zone	
Scenario	Impacts avoided	Non fatal	Impacts avoided	Non fatal
1.1	10%	30%	10%	32%
1.2	20%	45%	22%	48%
1.3	12%	33%	13%	35%
1.4	23%	53%	24%	56%
1.5	1%	4%	1%	4%

Uniform 5 km/hr travelling speed reduction

In this scenario (scenario 1.1) the travelling speeds of all vehicles in the analysed cases were hypothetically reduced by 5 km/hr. The travelling and impact speed distributions of the analysed cases are shown in Figure B16.

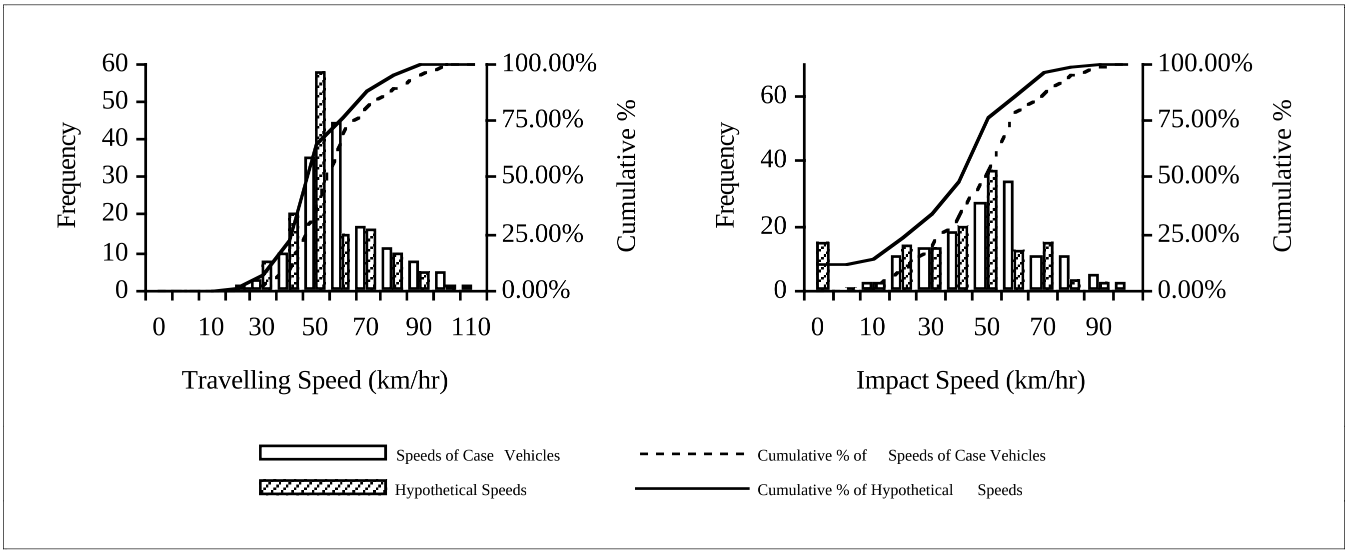

Figure B16 *Travelling and impact speed distributions of the analysed cases in scenario 1.1.*

Uniform 10 km/hr travelling speed reduction

In this scenario (scenario 1.2) the travelling speeds of all vehicles in the analysed cases were hypothetically reduced by 10 km/hr. The travelling and impact speed distributions of the analysed cases are shown in Figure B17.

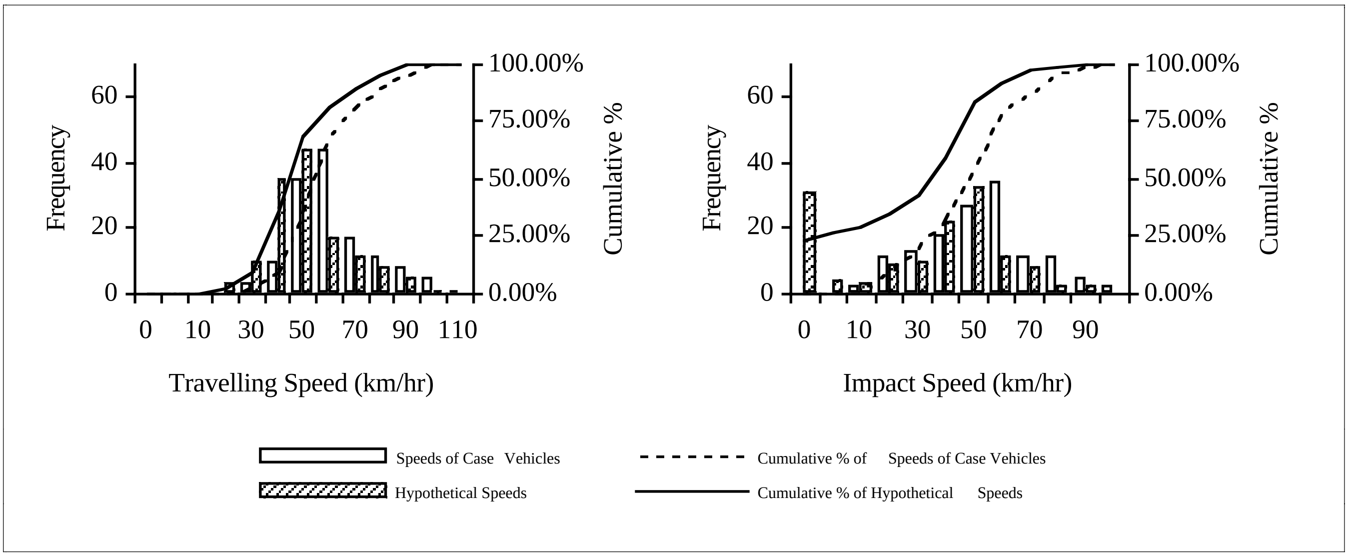

Figure B17 *Travelling and impact speed distributions of the analysed cases in scenario 1.2.*

Travel speeds reduced by 10 percent

In this scenario (scenario 1.3) the travelling speeds of all vehicles in the analysed cases were hypothetically reduced by 10 percent. The travelling and impact speed distributions of the analysed cases are shown in Figure B18.

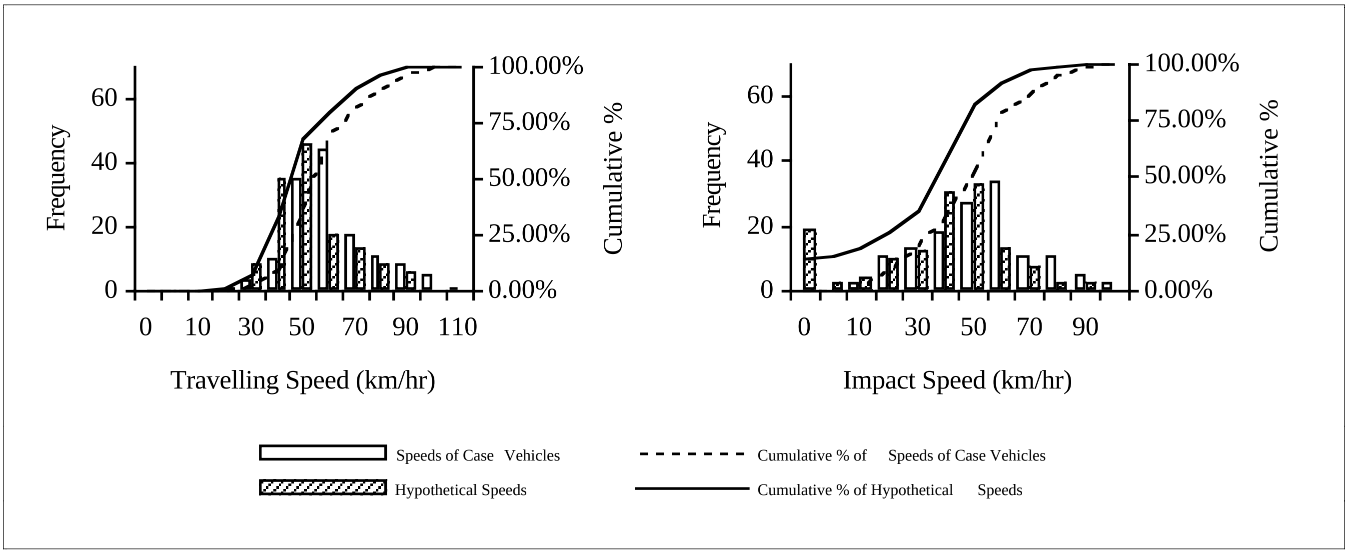

Figure B18 *Travelling and impact speed distributions of the analysed cases in scenario 1.3.*

Travel speeds reduced by 20 percent

In this scenario (scenario 1.4) the travelling speeds of all vehicles in the analysed cases were hypothetically reduced by 20 percent. The travelling and impact speed distributions of the analysed cases are shown in Figure B19.

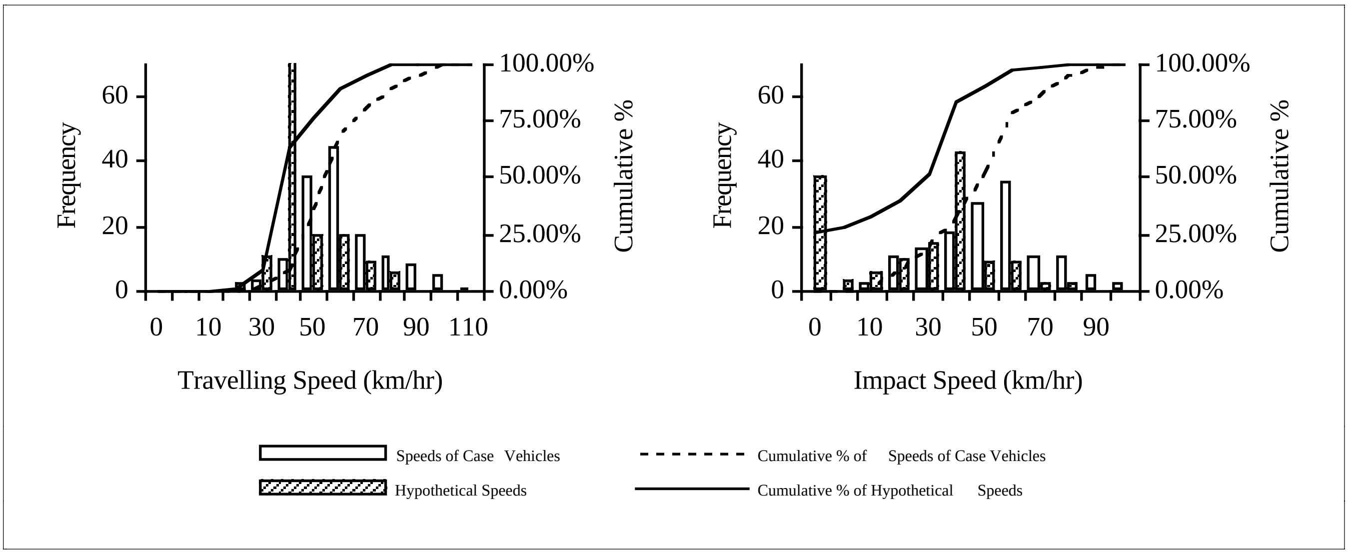

Figure B19 *Travelling and impact speed distributions of the analysed cases in scenario 1.4.*

Speed limits reduced by 5 km/hr if the accident occurred in a local street

In this scenario (scenario 1.5), vehicles which were travelling in a local street at the time of the accident had travelling speeds set 5 km/hr lower than the speed that they were travelling at the time of the accident. The travelling and impact speed distributions of the analysed cases are shown in Figure B20.

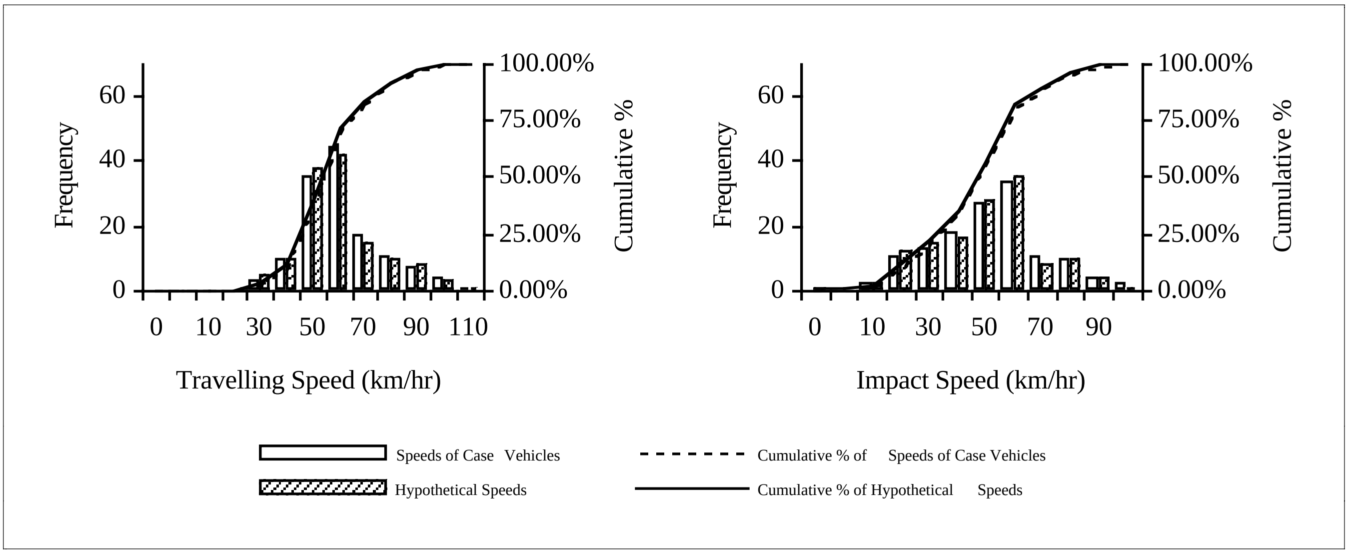

Figure B20 *Travelling and impact speed distributions of the analysed cases in scenario 1.5.*

Scenario Set 2

In this scenario set the travelling speeds of all the drivers were altered if they were exceeding a prescribed enforcement of the speed limit. The results can be seen in Table B6 and figures B21 to B23.

Table B6
Results for scenario set 2

	All Speed Zones		60 km/hr Zone	
Scenario	Impacts avoided	Non fatal	Impacts avoided	Non fatal
2.1	8%	12%	10%	13%
2.2	6%	10%	7%	11%
2.3	3%	7%	4%	8%

All speeds reduced to the speed limit

In this scenario (scenario 2.1), the travelling speeds of the accident involved vehicles were hypothetically reduced to the applicable speed limit if they had a travelling speed which exceeded that value. The travelling and impact speed distributions of the analysed cases are shown in Figure B21.

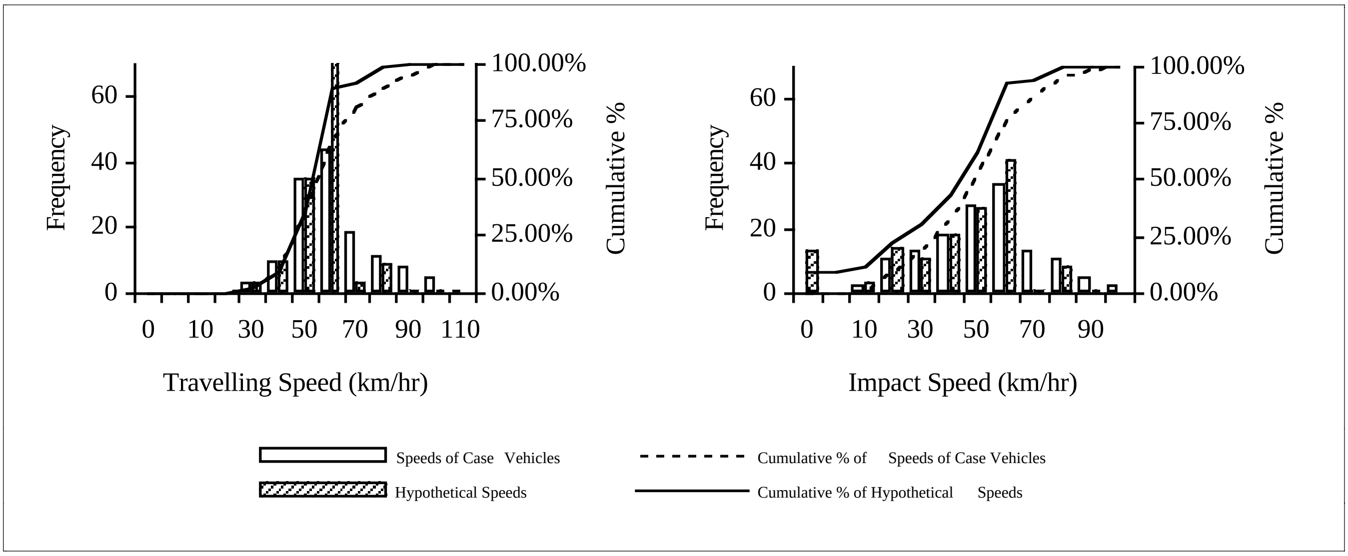

Figure B21 *Travelling and impact speed distributions of the analysed cases in scenario 2.1.*

Speeds reduced to current limit plus an enforcement tolerance of 5 km/hr

In this scenario (scenario 2.2), the travelling speeds of the accident involved vehicles were hypothetically reduced to the relevant limit plus 10 km/hr, if they exceeded that value. In other words, all vehicles were made to comply with an enforcement tolerance of +5 km/hr. The travelling and impact speed distributions of the analysed cases are shown in Figure B22.

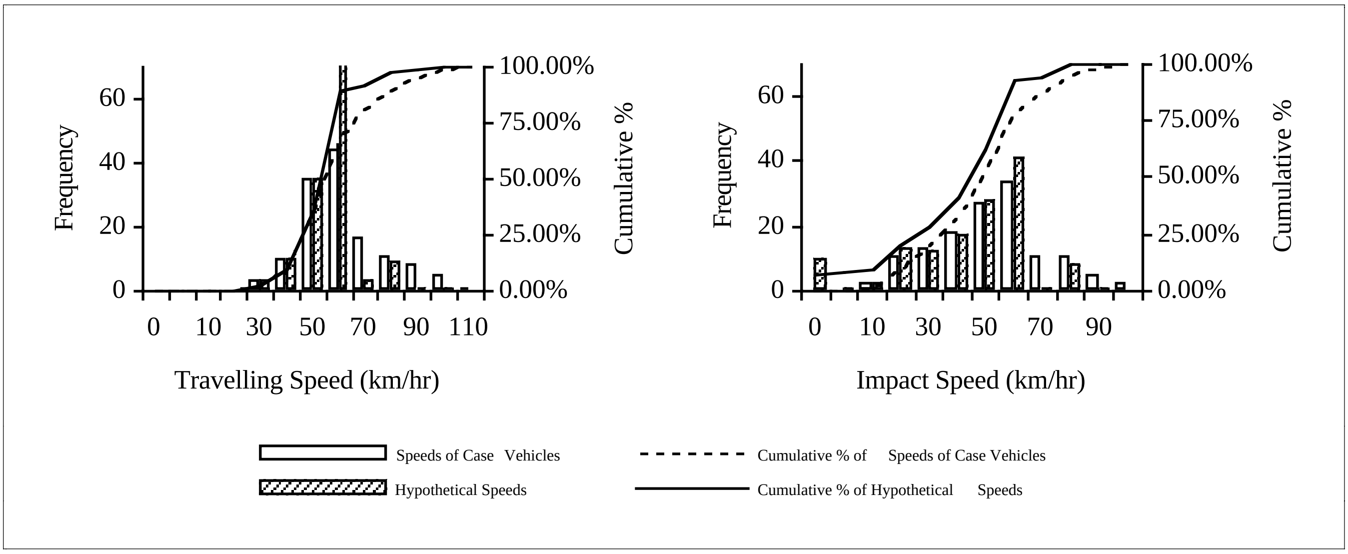

Figure B22 *Travelling and impact speed distributions of the analysed cases in scenario 2.2.*

Speeds reduced to current limit plus an enforcement tolerance of 10 km/hr

In this scenario (scenario 2.3), the travelling speeds of the accident involved vehicles were hypothetically reduced to the relevant limit plus 10 km/hr, if they exceeded that value. In other words, all vehicles were made to comply with an enforcement tolerance of +10 km/hr. The travelling and impact speed distributions of the analysed cases are shown in Figure B23.

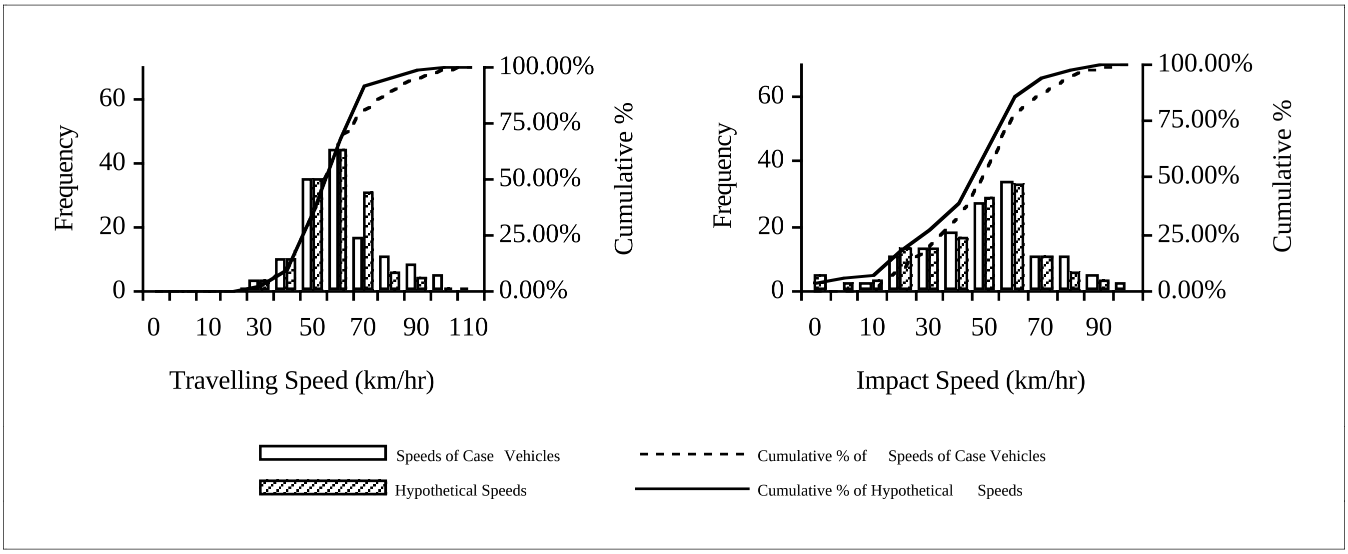

Figure B23 *Travelling and impact speed distributions of the analysed cases in scenario 2.3.*

Scenario Set 3

In this Set of Scenarios, if the travelling speeds of the involved vehicles exceeded an hypothetically reduced speed limit, their speeds were reduced to a value equal to the new limit. Otherwise, they remained unchanged. The results are shown in table B7 and the travelling and impact speed distributions of the analysed cases are shown for each scenario in figures B24 to B29.

Table B7
Results for scenario set 3

	All Speed Zones		60 km/hr Zone	
Scenario	Impacts avoided	Non fatal	Impacts avoided	Non fatal
3.1	15%	27%	16%	25%
3.2	21%	36%	22%	39%
3.3	27%	51%	29%	56%
3.4	36%	65%	40%	70%
3.5	42%	74%	45%	80%
3.6	43%	77%	45%	82%

Speeds reduced to current limit - 5 km/hr (Scenario 3.1)

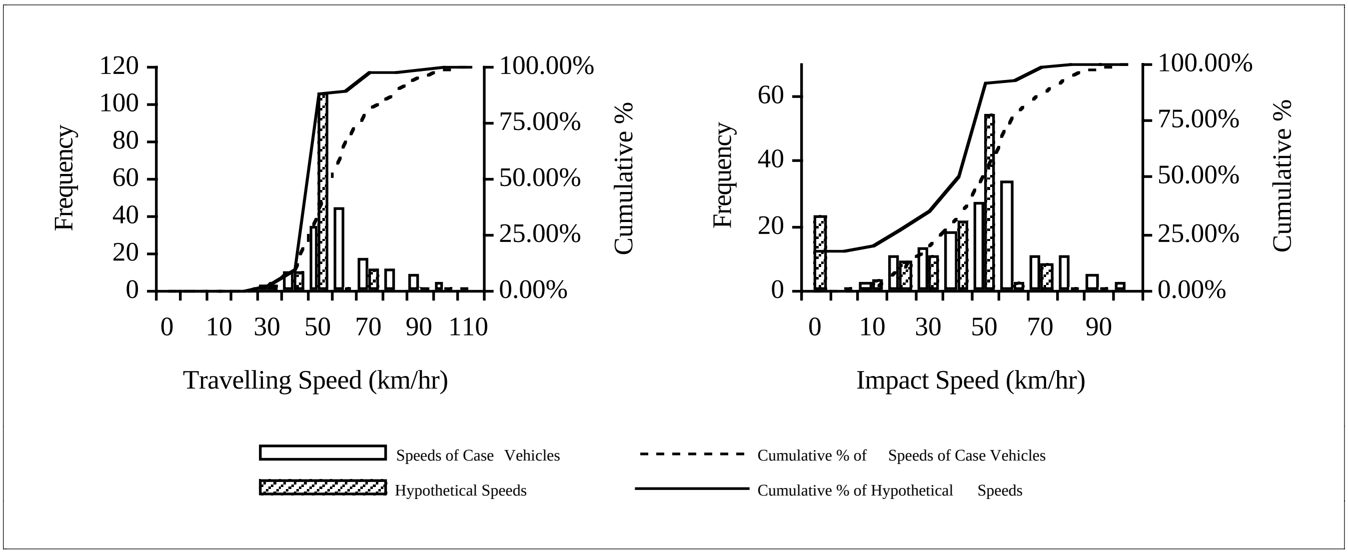

Figure B24 *Travelling and impact speed distributions of the analysed cases in scenario 3.1.*

Speeds reduced to current limit - 10 km/hr (scenario 3.2)

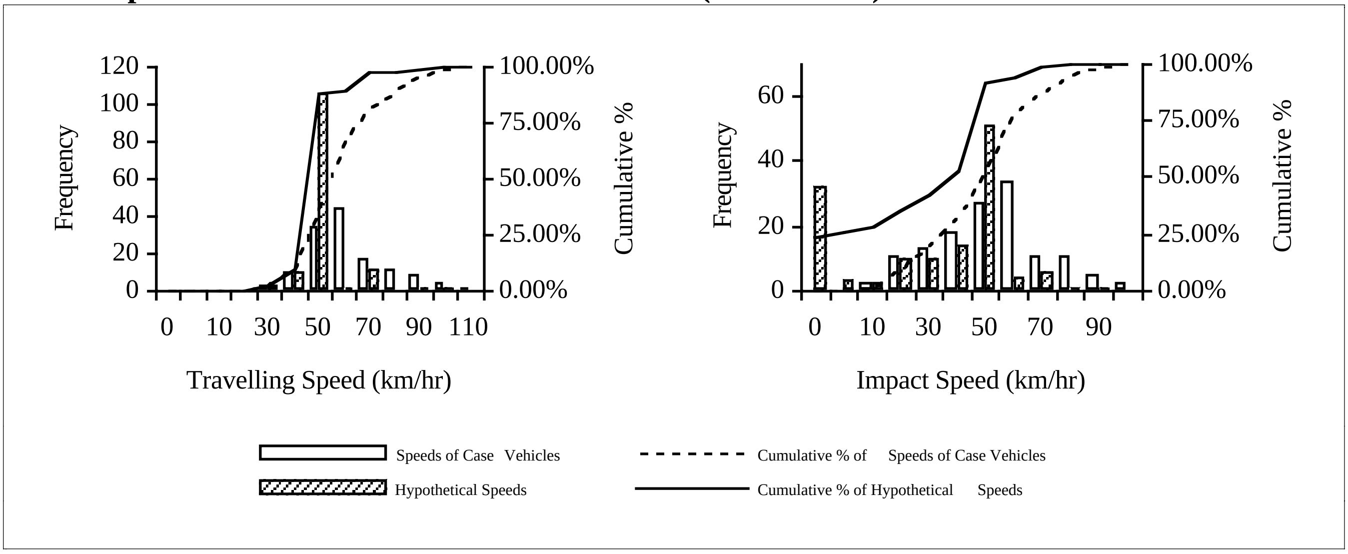

Figure B25 Travelling and impact speed distributions of the analysed cases in scenario 3.2.

Speeds reduced to current limit - 15 km/hr (Scenario 3.3)

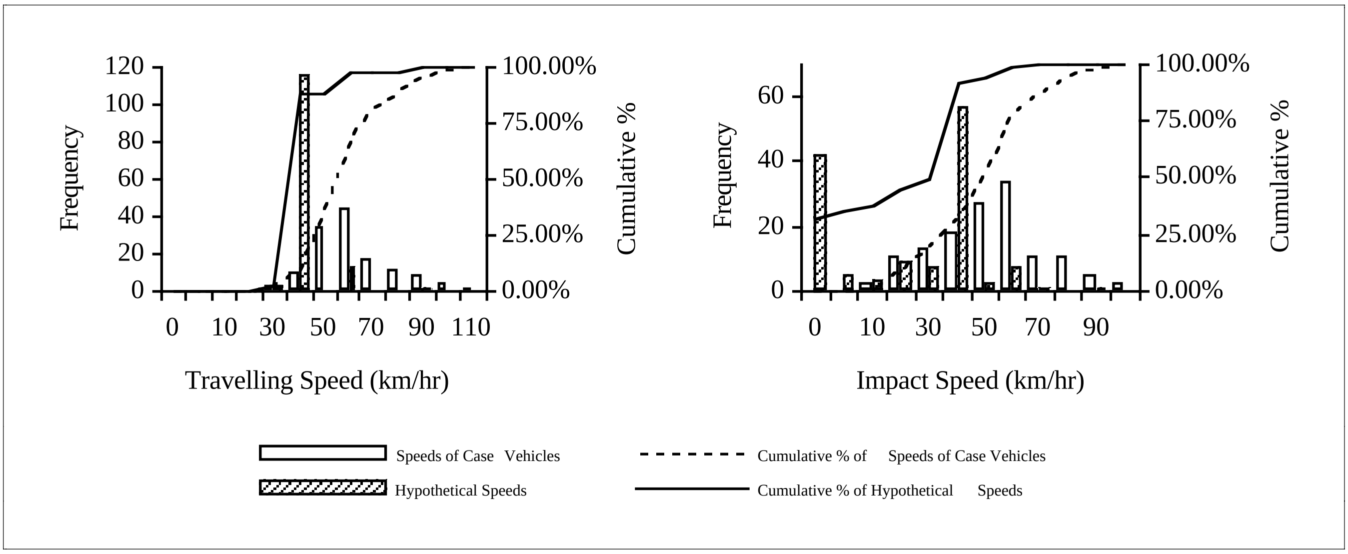

Figure B26 Travelling and impact speed distributions of the analysed cases in scenario 3.3.

Speeds reduced to current limit - 20 km/hr (Scenario 3.4)

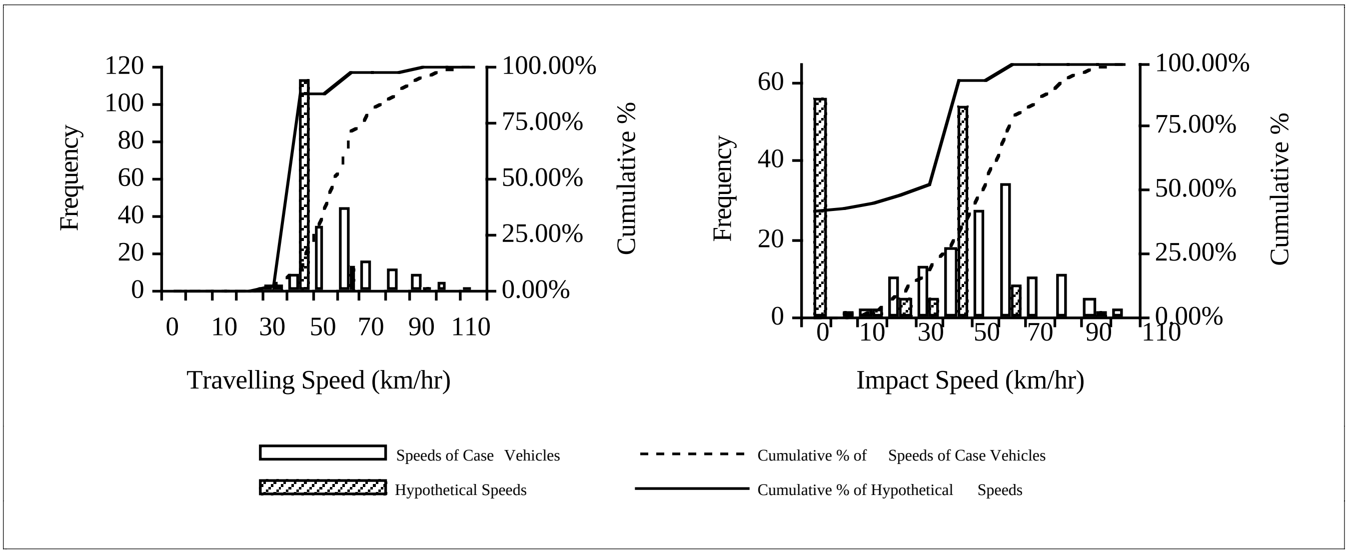

Figure B27 *Travelling and impact speed distributions of the analysed cases in scenario 3.4.*

Speeds reduced to current limit - 25 km/hr (Scenario 3.5)

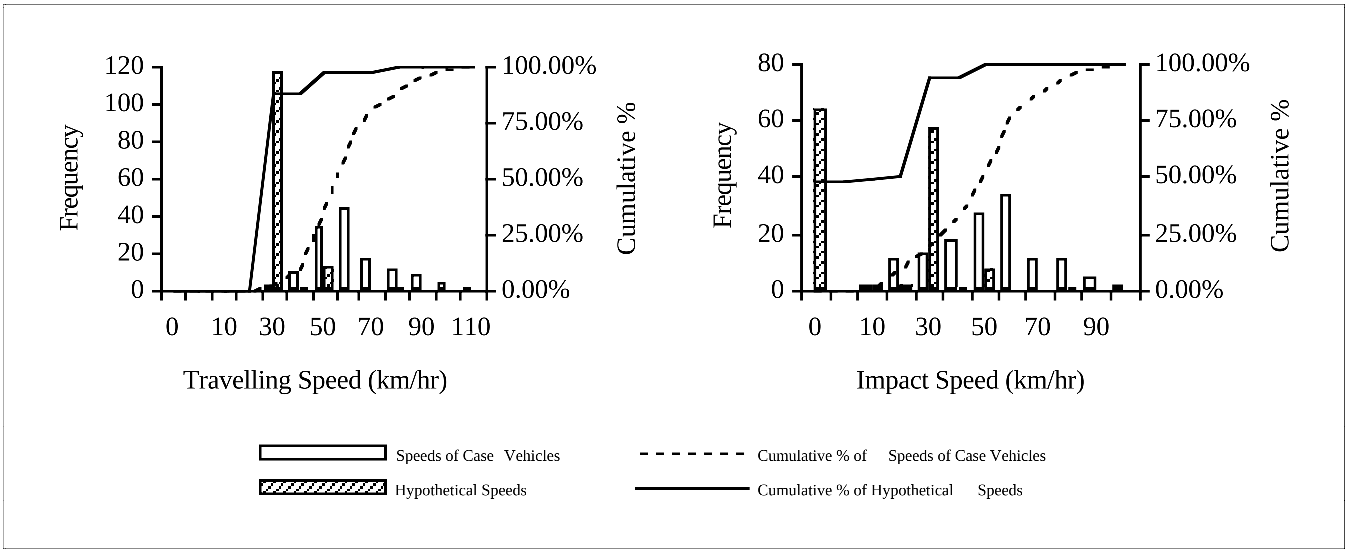

Figure B28 *Travelling and impact speed distributions of the analysed cases in scenario 3.5.*

Speeds reduced to current limit - 30 km/hr (Scenario 3.6)

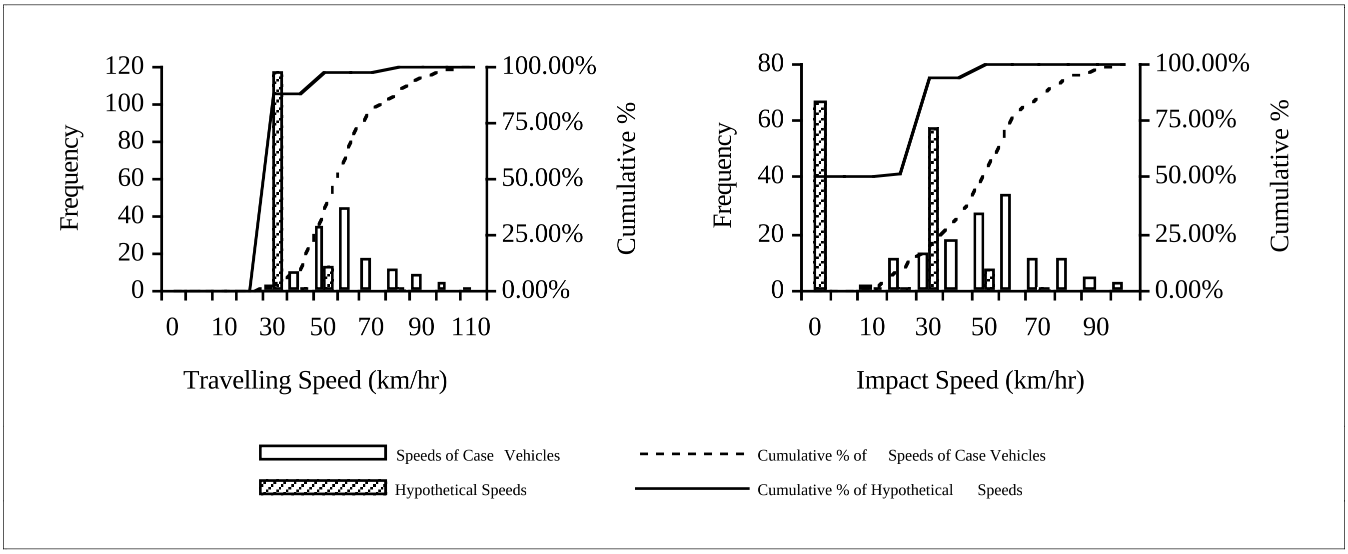

Figure B29 *Travelling and impact speed distributions of the analysed cases in scenario 3.6.*

Scenario Set 4

In this Set of Scenarios, vehicles which were exceeding the speed limit at the time of the accident were made to exceed an hypothetical limit by the same value. Those drivers who were complying with the speed limit at the time of the accident had their speeds reduced to the new limit. The results are shown in table B8 and the travelling and impact speed distributions of the analysed cases are shown in figures B30 to B35.

Table B8
Results for scenario set 4

	All Speed Zones		60 km/hr Zone	
Scenario	Impacts avoided	Non fatal	Impacts avoided	Non fatal
4.1	4%	13%	4%	14%
4.2	12%	27%	13%	30%
4.3	19%	43%	20%	48%
4.4	29%	58%	31%	64%
4.5	37%	69%	41%	75%
4.6	78%	33%	73%	30%

Speed limits reduced by 5 km/hr with the same level of violation (Scenario 4.1)

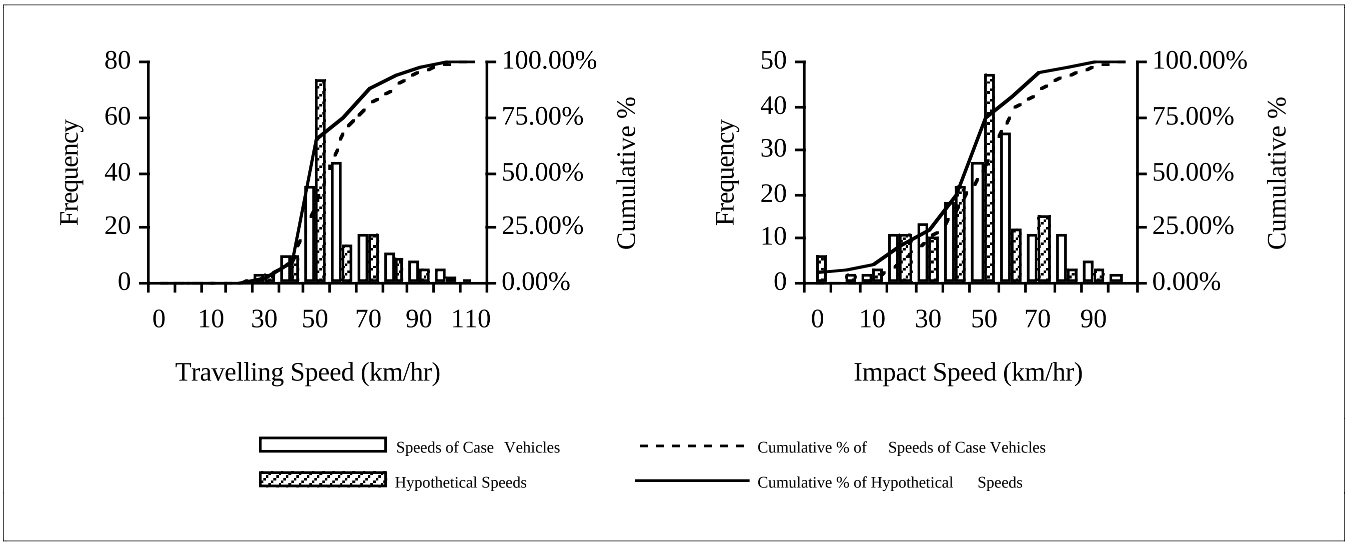

Figure B30 *Travelling and impact speed distributions of the analysed cases in scenario 4.1.*

Speed limits reduced by 10 km/hr with the same level of violation (Scenario 4.2)

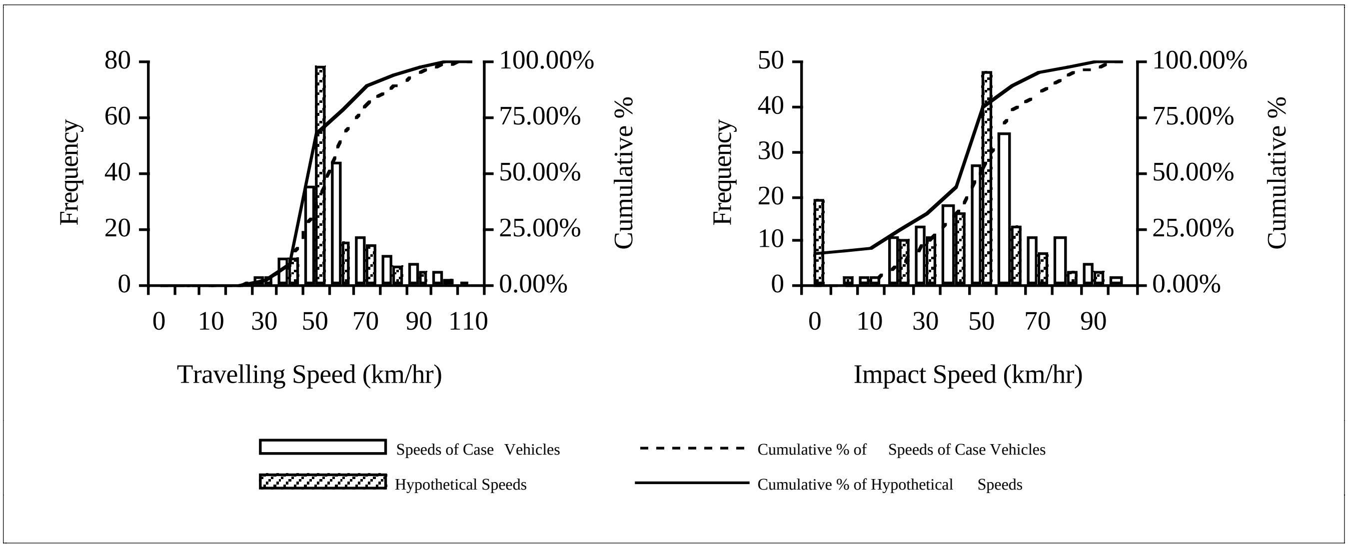

Figure B31 *Travelling and impact speed distributions of the analysed cases in scenario 4.2.*

Speed limits reduced by 15 km/hr with the same level of violation (Scenario 4.3)

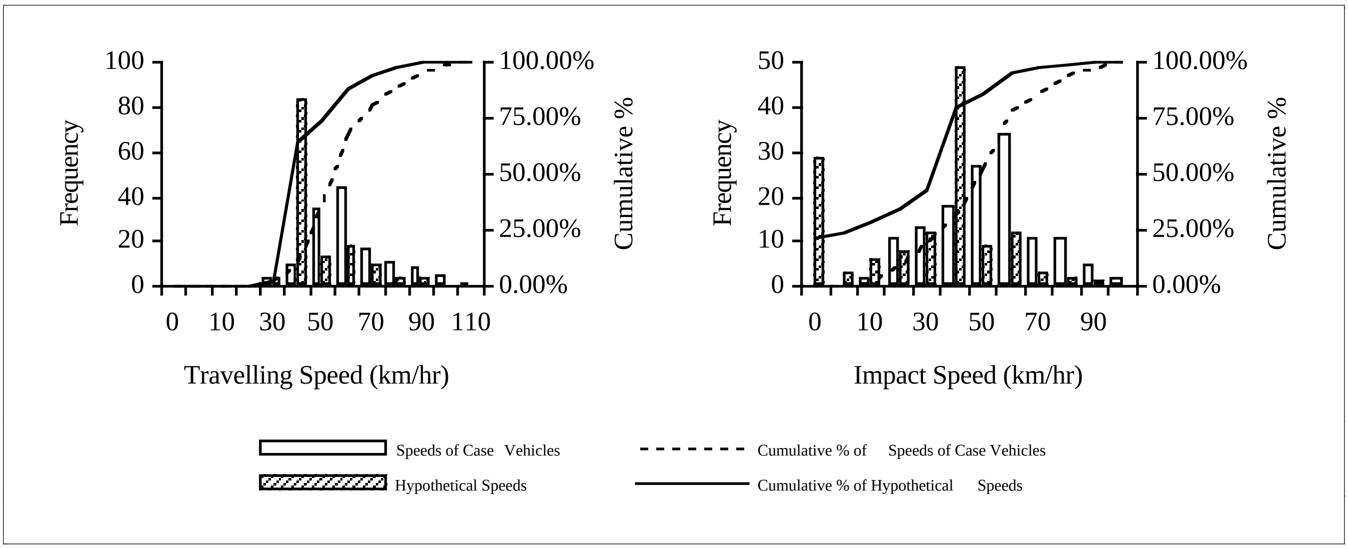

Figure B32 *Travelling and impact speed distributions of the analysed cases in scenario 4.3.*

Speed limits reduced by 20 km/hr with the same level of violation (Scenario 4.4)

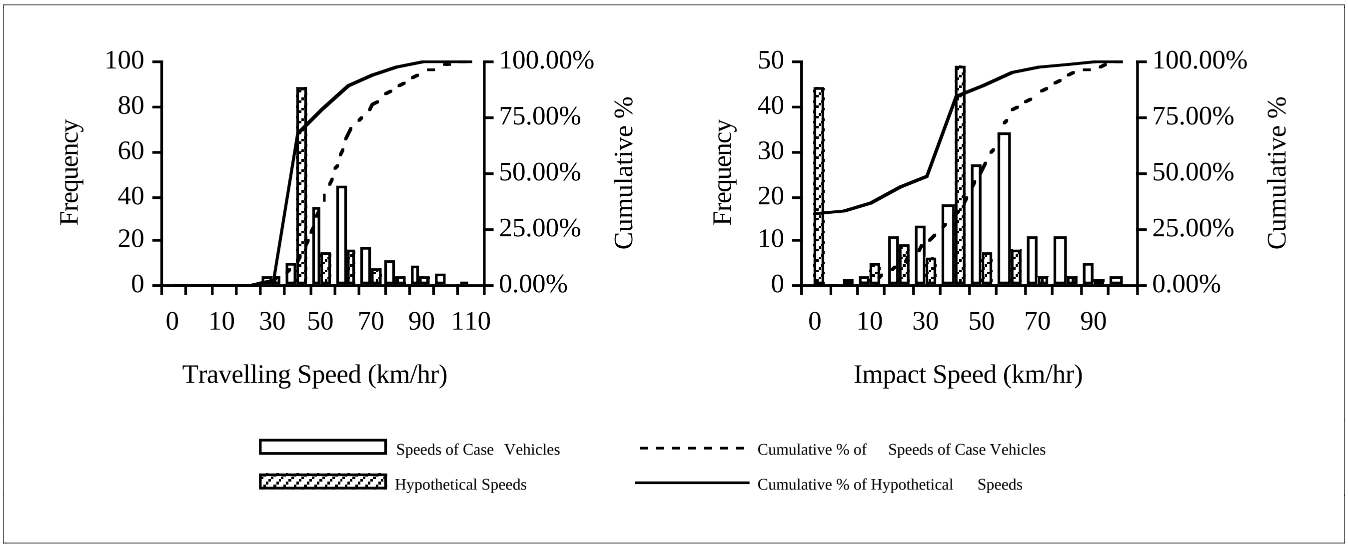

Figure B33 *Travelling and impact speed distributions of the analysed cases in scenario 4.4.*

Speed limits reduced by 25 km/hr with the same level of violation (Scenario 4.5)

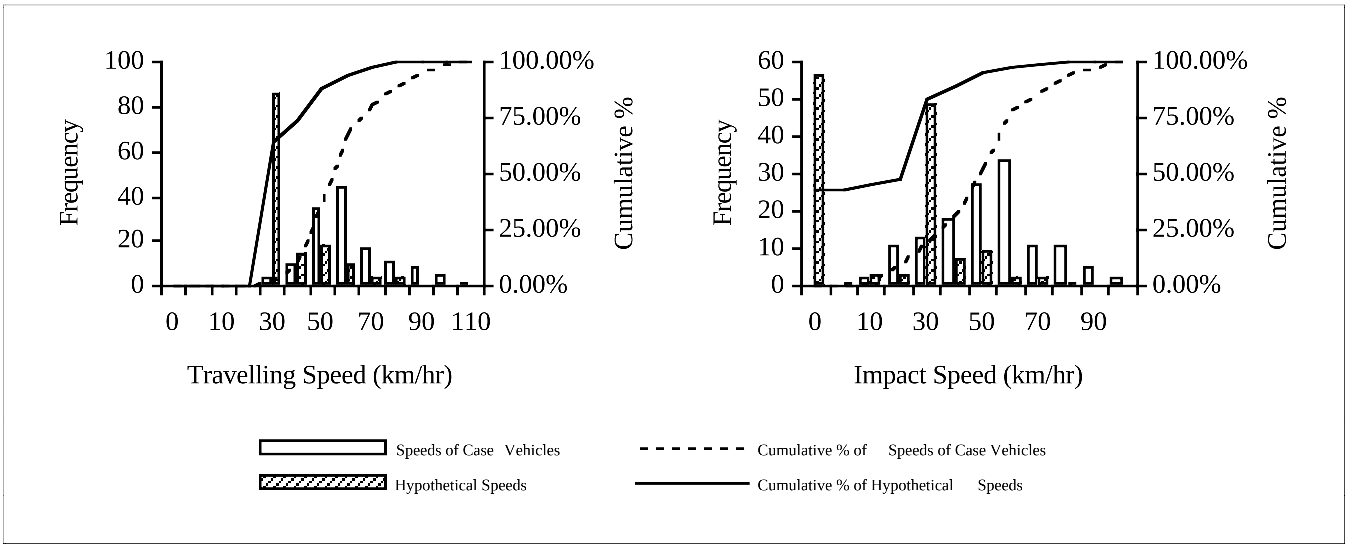

Figure B34 *Travelling and impact speed distributions of the analysed cases in scenario 4.5.*

Speed limits reduced by 30 km/hr with the same level of violation (Scenario 4.6)

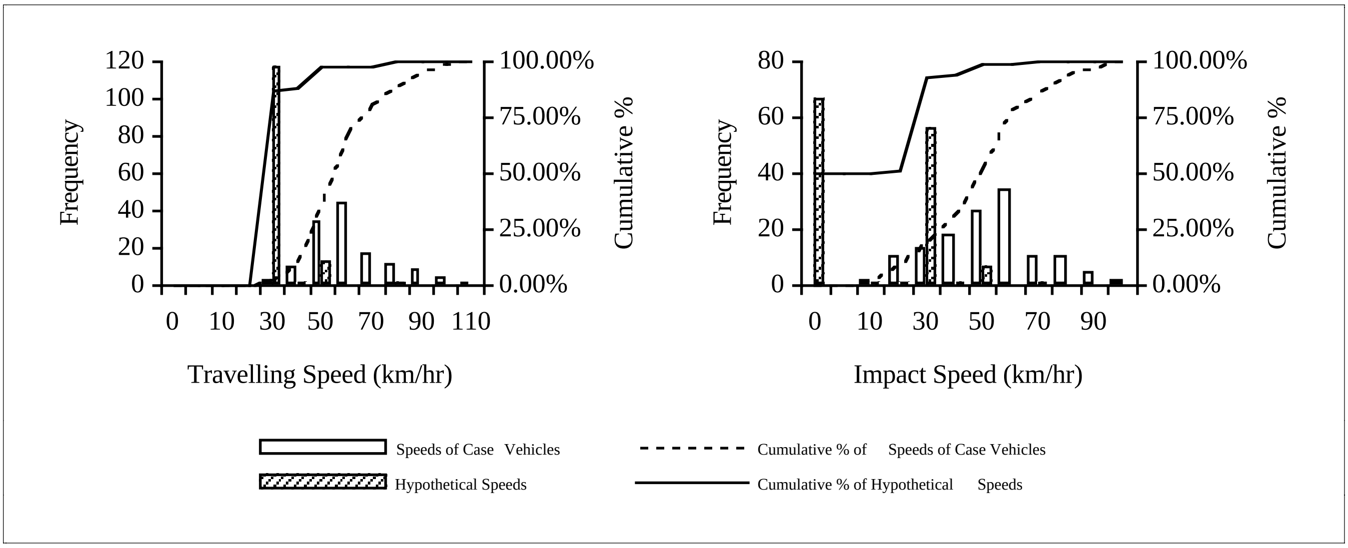

Figure B35 *Travelling and impact speed distributions of the analysed cases in scenario 4.6.*

Scenario Set 5

In this set of scenarios, vehicles which were exceeding the speed limit at the time of the accident were made to exceed the hypothetical limit by the same proportion. Those drivers who were complying with the speed limit at the time of the accident also complied with the new limit. The results are shown in table B9 and the travelling and impact speed distributions of the analysed cases are shown in figures B36 to B41.

Table B9
Results for scenario set 5

	All Speed Zones		60 km/hr Zone	
Scenario	Impacts avoided	Non fatal	Impacts avoided	Non fatal
5.1	4%	14%	4%	15%
5.2	12%	30%	13%	33%
5.3	22%	46%	24%	51%
5.4	34%	61%	37%	67%
5.5	41%	71%	45%	77%
5.6	43%	76%	45%	81%

Speed limits reduced by 5 km/hr with the same relative level of violation (scenario 5.1)

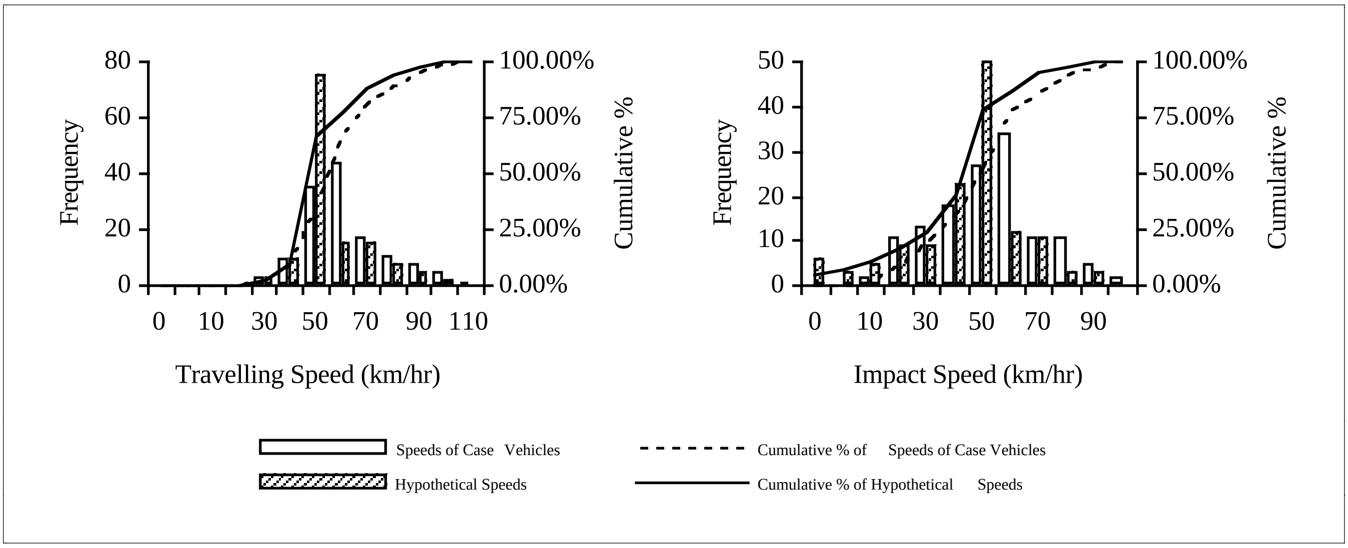

Figure B36 *Travelling and impact speed distributions of the analysed cases in scenario 5.1.*

Speed limits reduced by 10 km/hr with the same relative level of violation (scenario 5.2)

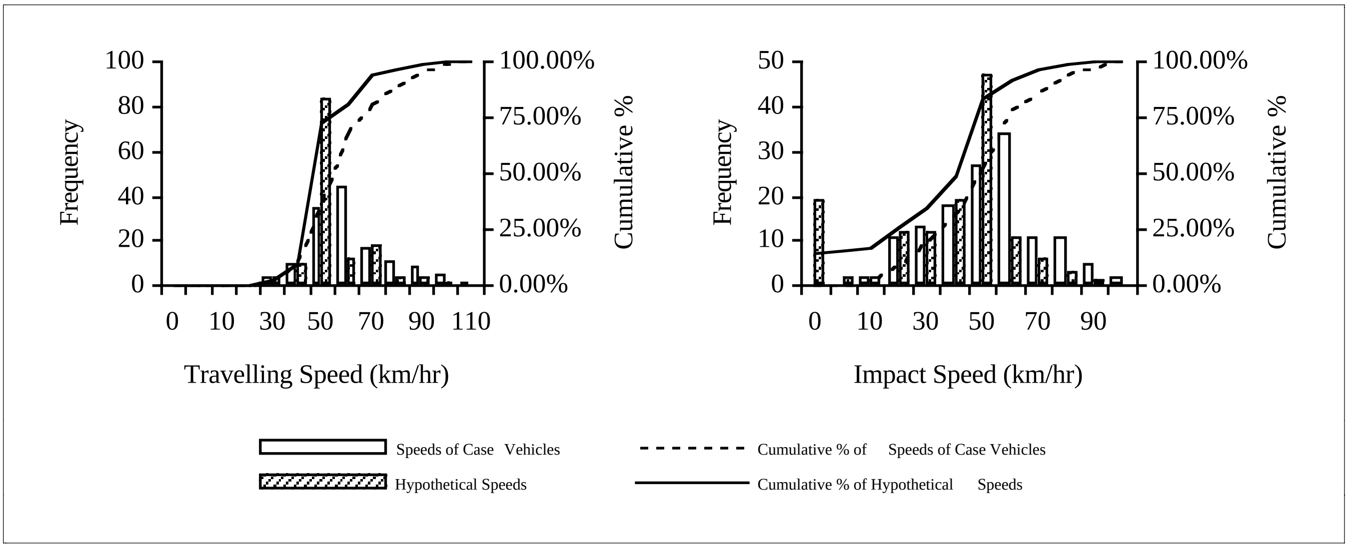

Figure B37 *Travelling and impact speed distributions of the analysed cases in scenario 5.2.*

Speed limits reduced by 15 km/hr with the same relative level of violation (scenario 5.3)

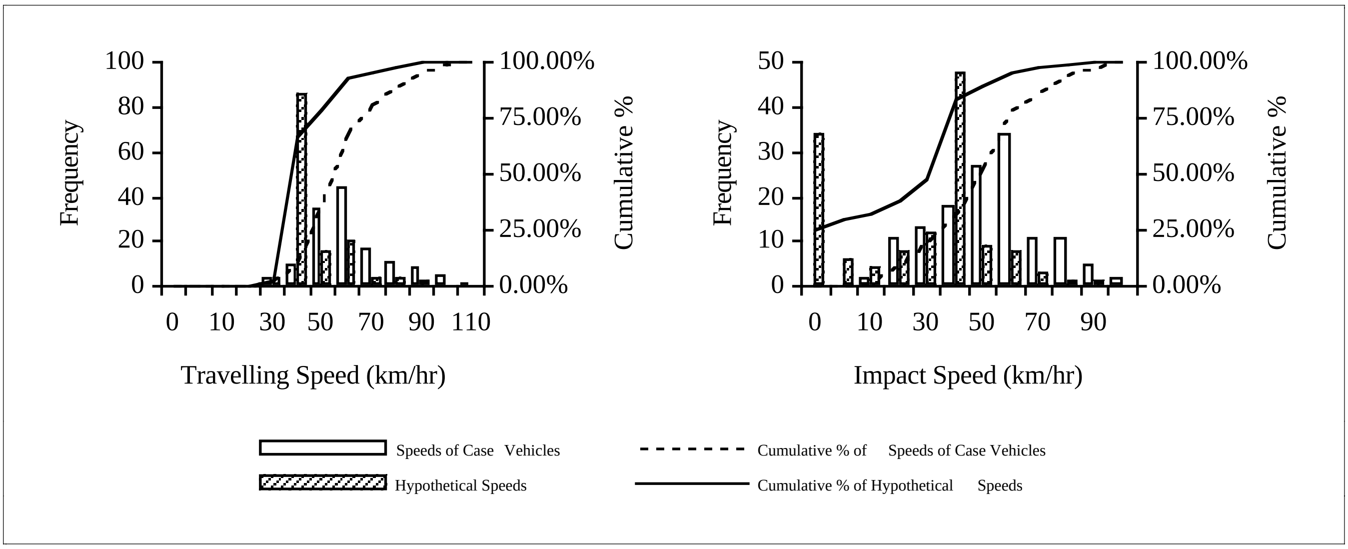

Figure B38 *Travelling and impact speed distributions of the analysed cases in scenario 5.3.*

Speed limits reduced by 20 km/hr with the same relative level of violation (scenario 5.4)

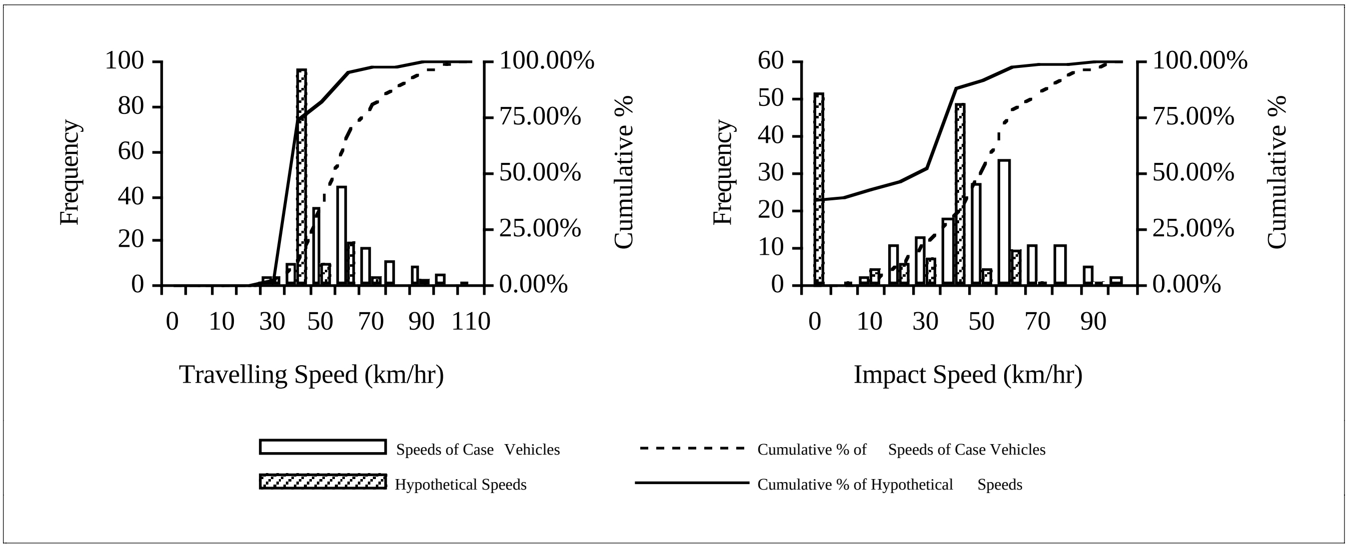

Figure B39 *Travelling and impact speed distributions of the analysed cases in scenario 5.4.*

Speed limits reduced by 25 km/hr with the same relative level of violation (scenario 5.5)

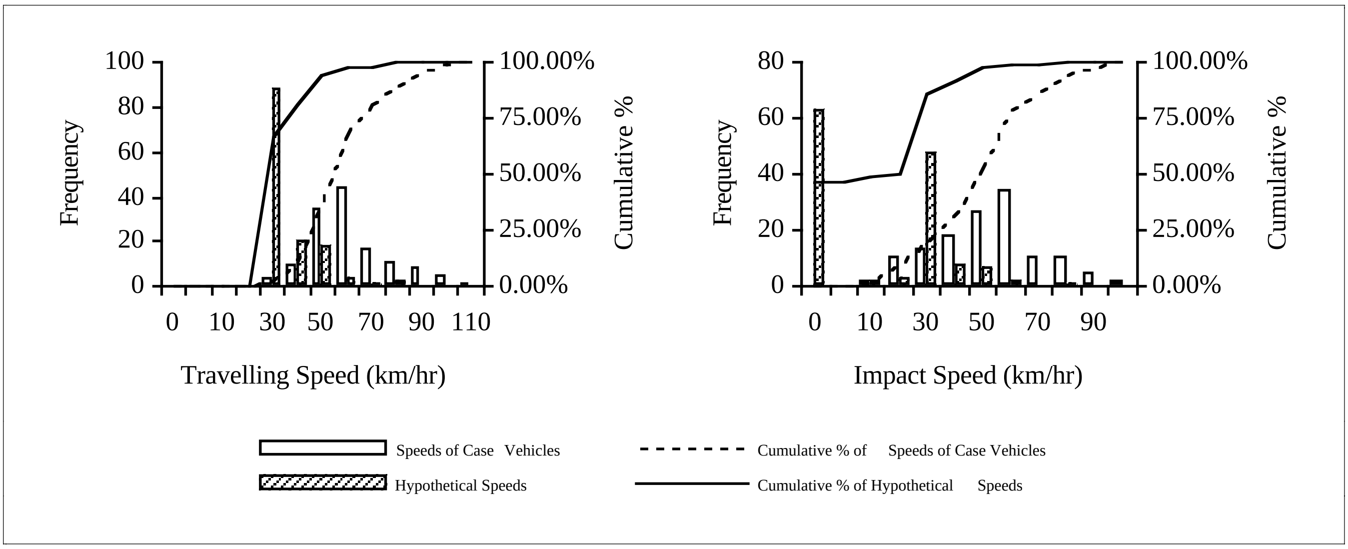

Figure B40 *Travelling and impact speed distributions of the analysed cases in scenario 5.5.*

Speed limits reduced by 30 km/hr with the same relative level of violation (scenario 5.6)

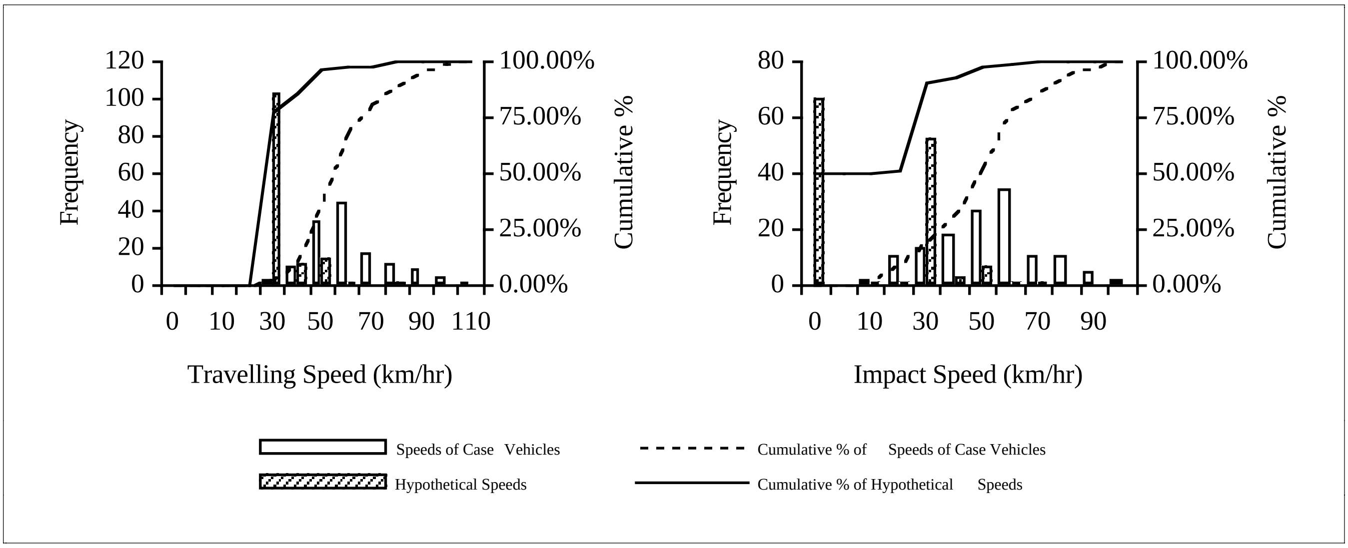

Figure B41 *Travelling and impact speed distributions of the analysed cases in scenario 5.6.*