THE IMPACTS OF NEIGHBOURHOOD TRAFFIC MANAGEMENT

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Basil David Daniel

Department of Civil and Natural Resources Engineering

University Of Canterbury

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ABSTRACT

A major traffic-related problem faced by residents is speeding, which not only causes safety concerns, but also noise issues. Traffic calming is a much favoured traffic management tool employed by road controlling authorities to primarily reduce vehicle speed, hence improve community liveability.

This research aimed to investigate the impacts of traffic calming on speed, safety and traffic noise. The objectives included developing models for the prediction of speed and noise on traffic-calmed streets, and providing guidance for good design practices.

Speeds of individual vehicles as they approached and crossed traffic calming devices were observed in order to identify the behaviour of individual drivers. Results indicated that the speed hump and the raised angled slow point produced the largest speed reductions and least variation in speeds, while mid-block narrowings had no significant speed changes. Inter-device speed was found to be mainly controlled by the separation between devices.

85th percentile speeds at distances from calming devices were 40 – 45 km/h for vertical deflections and 45 – 55 km/h for horizontal deflections. Speeds on approach to speed humps were found to be influenced by the distance available on the approaches, while operating speed at the speed humps were partly influenced by the hump width relative to the road width.

There was evidence of safety benefits of traffic calming overall, despite mid-block crashes increasing post-calming. However, there was no association between the traffic calming and the crashes, which appeared to probably be due to other factors, human factors in particular.

Noise levels produced by light vehicles across speed humps were in fact lower than on a flat section of road, given their respective mean speeds. At a reference speed of 25 km/h, noise levels produced over the 100 mm hump were 3.6 dBA higher than those produced by the 75 mm hump.

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GLOSSARY OF TERMS

The following explains some of the technical terms that are mentioned in this document. These terms are common terminology used in transportation engineering, acoustics and statistics, though some may be specifically used for this research only.

Term	*Description*
85^{th} percentile speed	The speed which 85% of the vehicles travel at or below.
AADT	Annual Average Daily Traffic, which is the total yearly volume of traffic on both directions divided by the number of days in a year.
AC	Asphaltic Concrete, which is a composite material made up of aggregates and asphalt that is used for construction of road surfaces, airport runways and parking lots.
ANOVA	Acronym for "analysis of variance".
Advisory speed	The recommended maximum speed at which a section of roadway should be negotiated for comfort and safety.
Angled slow point	A road narrowing with its travel path deflected at an angle.
Approach length	The distance between a traffic calming device from a street entry or bend.
Approach speed	The highest observed 85^{th} percentile speed on the approach to an isolated traffic calming device or the first device used in a series.
Arterial road	A high-capacity road that delivers traffic between urban centres. May simply be referred to as **arterial**.

Term	*Description*
Austroads	The association of Australian and New Zealand road transport and traffic authorities.
Background noise	Noise other than those produced by traffic. Sometimes called **residual noise**.
CAS	Crash Analysis System, which is an integrated computer system that provides tools to collect, map, query, and report on road crash and related data. It contains data from all traffic crashes reported by police.
Carriageway	The portion of road that is dedicated to the use of vehicles.
Channel	The drain that directly receives surface runoff from the pavement.
Chip seal	A thin layer of binder sprayed onto a pavement surface with a layer of aggregate incorporated and which is impervious to water. Also called **spray seal.**
Collector road	A road that delivers traffic from local streets to arterials. May simply be referred to as **collector**.
Crash	An event involving one or more road vehicles that results in personal physical injury and/or damage to property. Also called **accident** or **collision**.
Crash rate	The ratio of number of crashes to a common denominator, such as period of time, or vehicle-kilometres travelled.
Cut-through	The act of driving through a street for the intention of using it as a short-cut or avoiding congested streets. Also called **short-cutting** and **rat running**.

Term	*Description*
DUSL	Abbreviation for "default urban speed limit".
Device	An individual engineering treatment introduced in a street carriageway.
Device operating speed	The observed 85th percentile speed of vehicles negotiating a traffic calming device. May also be simply referred to as **operating speed**.
Entrance treatment	Visual and physical alterations at the entry to a street to mark a change in speed environment. Employs textured surface and carriageway narrowing, among others. Also called **threshold treatment** and **gateway treatment**.
Farside lane	The travel lane that is furthest from the observation point.
Fatal crashes	Crashes where at least one person is killed.
Flush	Binder at same level as top of sealing chips.
Heavy vehicle	A two-axle vehicle with the minimum axle spacing greater than 3.2 m, or a three- or more-axle vehicle with at least two axle groups. Weighs more than 3.5 tonnes.
Horizontal deflections	Traffic calming devices that create lateral shifts and constrictions in the roadway to slow down vehicles.
Idling engine noise	Noise produced by stationary vehicles with engines left running.
Impeded segment	The section of road that is restrained by a traffic calming device.
Injury crashes	Crashes where at least one person is injured or killed. Also referred to as **casualty crashes**.

Term	*Description*
Inter-device speed	The highest observed 85th percentile speed between consecutive traffic calming devices.
Intersection crashes	Crashes occurring where two or more streets intersect. Includes crashes that occur within 30 m from the intersection.
LATM	Local Area Traffic Management, which is an area-wide traffic calming scheme involving a cluster of streets.
LIDAR	Acronym for “light detection and ranging”.
Light vehicles	All vehicles other than those defined as heavy vehicles. Includes cars, vans, sports utility vehicles (SUV), and multi-purpose vehicles (MPV), with or without a trailer on tow.
Local roads	All roads other than State Highways.
Local streets	Roads that provide access to homes to those who enter and leave, and to those who deliver and collect. Also referred to as **residential streets** and **local access roads**. Not to be confused with “local roads”.
Mean speed	The time mean speed, which is the summation of vehicle speeds at a specific location divided by the number of vehicles observed.
Mid-block	The section of road (or “link”) between two intersections (or “nodes”).
Mid-block crashes	Crashes occurring at mid-block or all other crashes apart from intersection crashes.

Term	*Description*
Minor injuries	Non-serious injuries that may cause some discomfort or pain, and which may require first aid. Also referred to as **slight injuries**.
Multiple devices	Two or more traffic calming devices used in a series. Also called **sequential devices**.
NZTA	New Zealand Transport Agency, the government agency for funding land transport.
Narrowing	A constricted roadway segment formed by kerb extensions or traffic islands at mid-block. Also known as **choker** or **bulbous kerb**.
Nearside lane	The travel lane that is closest to the kervside observation point.
Neckdown	A narrowing at the entry to a street, formed by kerb extensions or traffic islands.
Neighbourhood	Portion of a suburb or other urban area, defined by geographical boundaries (natural and man-made) and having common community services.
Noise differential	The difference between the noise level observed when a vehicle is in motion and the idling engine noise.
Non-injury crashes	Crashes where no one is injured or killed, and may involve damage to property only.
OGPA	Abbreviation for "open graded porous asphalt", which is an asphalt mix designed with large voids that allow rapid draining of surface water.

Term	*Description*
Off-peak period	The periods that have low demand volumes during the day.
Pavement	That portion of a road designed for the support of, and to form the running surface for, vehicular traffic.
Peak period	The periods that have high demand volumes during the day.
RCA	Road Controlling Authorities, which are responsible for managing roads under their jurisdiction. Typically these are either city/district councils (for local roads) or NZTA (for State Highways).
RTN	Abbreviation for “road traffic noise”.
Ramp	An inclined plane incorporated in the design of vertical deflections to provide smoother transition of vehicles from the pavement to the device, and vice versa.
Regression	A statistical technique used to develop a mathematical relationship between two or more variables. Same as **statistical regression** or **regression analysis**.
Roadway	Any one part of the width of a road that is dedicated to the use of vehicles. Traditionally, this is from kerb to kerb.
S-curve	Short for **Sigmoid curve**, it is a curve having an “S” shape.
SPB	Abbreviation for “statistical pass-by”, a method originally designed for measuring tyre-road noise.
Serious injuries	Injuries requiring medical attention or admission to hospital.

Term	*Description*
Single device	A single traffic calming device used with no other devices around. Also referred to as **isolated device**.
Side road crashes	Crashes occurring where a local street intersects with a side road. A side road crash is a type of intersection crash.
Sound level meter	An instrument for measuring sound levels.
Spacing	The distance between consecutive traffic calming devices.
Speed change	The drop from street speed to device operating speed.
Speed differential	The difference in the speed at a distance from a traffic calming device and the device operating speed.
Speed gun	An instrument used to measure speed and range. Also called **radar gun** or **speed meter**.
Speed hump	A raised section of pavement placed across a street to force motorists to travel at lower speeds. Has circular, parabolic or sinusoidal profiles, but may also be trapezoidal (see *speed table*). Also referred to as **road hump**, **round-top hump** or **hump**.
Speed limit	The maximum legal speed that vehicles are allowed to be driven on roads. In New Zealand, the default urban speed limit is 50 km/h, while the rural speed limit is 100 km/h or lower.
Speed profile	The observed or estimated changes in vehicle speed along a road. Usually displayed as a speed versus distance plot.

Term	*Description*
Speed table	A variant of the speed hump, having a trapezoidal profile. Also referred to as **flat-top hump**, **plateau**, **platform** or **table**.
Speed variance	A measure of how far vehicle speeds are spread out from the mean speed at a given road or section of road. Also referred to as **variation in speed**.
Standard deviation	A measure of variation from the mean value. It is the square root of variance.
Standard error	The standard deviation of the sampling distribution of a statistic.
Street speed	The 85^{th} percentile speed observed on a street.
Street-end crashes	Crashes occurring where a local street intersects with a collector or arterial. A street-end crash is a type of intersection crash.
Target speed	The speed that is expected to be achieved through the implementation of speed control measures. Also referred to as **desired speed**.
Textured surface	A pavement using interlocking paving blocks, i.e. blocks of material cut into regular shape and size. Also referred to as **textured pavement**.
Traffic calming	A form of traffic management that involves changes in street alignment, installation of barriers, and other physical measures to reduce traffic speeds and/or cut-through volumes, in the interest of street safety, liveability, and other public purposes.

Term	*Description*
Traffic management	The use of traffic engineering techniques to control the flow of vehicles.
Traffic volume	The number of vehicles passing a point during a known period of time. Sometimes referred to as **traffic flow**.
Travel lane	That portion of a carriageway assigned to moving traffic and does not include areas dedicated to kerbside parking. Also referred to as **travel path**.
Treatment	A general term which covers all types of physical actions (including devices) to manage traffic and/or adapt the street environment at the local level.
Unimpeded segment	The section of road that is not restrained by a traffic calming device.
Vertical deflections	Traffic calming devices that feature raised segments to slow down vehicles.
Watts profile hump	A speed hump with a specific circular profile designed to slow vehicles down.
Zone of influence	The area over which a traffic calming device produces a noticeable speed-reducing effect. It can be estimated from speed profiles, and is basically the distance between the point where speed starts to reduce and the point which corresponds with the device operating speed.

1 Introduction

Managing speed in neighbourhoods is a challenging task as there are many factors to be considered in the design and implementation of traffic calming measures, such as finance, practicability, and community response. A lot of work has been done in the past to evaluate the effectiveness of these measures and to ensure good practices. The results of this research add to that pool of knowledge, and in particular, it adds information regarding the behaviour of drivers in New Zealand when confronted with traffic calming devices.

1.1 Background to the research

Speeding has been identified as one of the major contributors to road deaths in New Zealand with 32% of fatal crashes being attributed to excessive speeds for the years 2008 to 2010. Speeding alone contributed to 15% of these crashes, while speeding associated with alcohol or drug intake accounted for 17%. On urban roads, speeding contributed to 31% of road fatalities (Ministry of Transport, 2011a).

The problem of speeding is widespread on urban roads. In 2011, 59% of car drivers were found to have exceeded the urban speed limit of 50 km/h. This was reflected by the high 85^{th} percentile and mean speeds of 57 km/h and 52 km/h, which happen to be the lowest observed values for several decades in New Zealand (Ministry of Transport, 2011b).

The drop in urban speed levels over the last few decades may be attributed to road safety strategies that included the implementation of speed control measures and tougher enforcement of speed limits.

Empirical studies commonly associate speeding with crashes, especially more severe crashes, and it is frequently suggested that crash frequency and severity can be significantly lowered by simply reducing speeds. One way of achieving this is through behaviour modification. The most common approach of changing driver behaviour in residential zones is through traffic calming (Shinar, 2007).

Traffic calming has been widely used in New Zealand to enhance safety on local streets. It is a form of traffic management that involves physical alterations to the street in order to slow down vehicles and discourage cut-through traffic. It also creates safe and pleasant street environments for walking, cycling, playing and other communal activities.

While there have been efforts to monitor the performance of traffic calming in New Zealand, not many in-depth studies have been conducted and the findings published. Publications on traffic calming experience in New Zealand are relatively scarce compared to neighbouring Australia and countries with a long history of traffic calming, such as the Netherlands, Germany, Denmark, Britain and the United States.

This research, while making up for the aforesaid shortage, also served to offer a better understanding of the application and performance of traffic calming devices, and to provide guidance for good practices in the design of speed control measures.

1.2 Research objectives

The aim of this research was to investigate the impacts of traffic calming on speed, safety and traffic noise. To achieve this purpose, the following objectives were drawn up:

(a) To produce speed profiles of various traffic calming devices for the assessment of drivers' speed choice and performance of traffic calming devices.

(b) To determine the speed-reducing effect and the extent of zones of influence produced by traffic calming devices.

(c) To examine the variation of speeds at traffic calming devices.

(d) To study the influence of device width on device operating speed.

(e) To develop models for the prediction of speed on the approach to devices and between consecutive devices.

(f) To assess the impact of the implementation of traffic calming measures on crash rates.

(g) To investigate the effect of speed humps on light vehicle noise emissions.

(h) To develop models for the prediction of noise levels produced by light vehicles across speed humps.

1.3 Thesis Outline

This thesis is a documentation of work that included reviewing past literature, designing research methods, analysing raw data, improving on methods for conducting data collection and analysis, making new discoveries, and turning findings into significant contributions to the state of the art. It is presented in five main chapters:

Chapter Two extensively covers literature on various topics relevant to this research, such as driver speed choice, the influence of speed on road crashes, justification for the need to lower residential speed limits, how safer streets can be achieved through behavioural changes, the benefits and issues of traffic calming, and previous research carried out on the estimation of speed and noise.

Chapter Three details the procedures applied in conducting this research. It identifies study locations, describes the methods and instruments used for obtaining speed, crash and noise data, depicts the experimental set ups for data collection, and explains comparative and statistical analyses performed in this research.

Chapter Four comprehensively reports the outcomes of studies carried out to determine the effects of traffic calming devices on drivers' choice of speed on impeded and unimpeded segments of traffic-calmed streets, evaluating the performance of these devices in terms of speed reduction, investigating the effects on safety and the environment, developing methods for the estimation of speeds and noise levels on traffic calmed streets, and providing guidance for good practice.

Chapter Five discusses the findings, makes comparisons with previous work, and discusses some of the constraints encountered during the course of this research.

Chapter Six summarises the key findings of this research, highlights the contributions of this research in the field of neighbourhood traffic management, and offers suggestions for future research.

2 Literature Review

2.1 Introduction

A study by Appleyard et al. (1976) found that San Francisco residents were more bothered by traffic than by crime, where 42 percent felt their street was quite or very dangerous because of traffic, whereas only 16 percent felt it was dangerous because of crime.

Residents' fear of traffic and their call for safer streets are further justified with reports from Australia stating that 42 percent of all casualty crashes occurred on residential streets and their intersections with the arterial system, and that the casualty crash rate on residential streets was more than 50 percent higher than on arterials (Harper, 1970; cited in Brindle, 1995).

Speeding is defined as speed that is too fast for conditions or in excess of the posted speed limit. Despite lower traffic volumes, local streets and collectors in America have speeding fatality rates almost triple that of interstate highways and these numbers make up 47% of the total speeding-related crashes (FHWA, 2000).

Traffic will still remain a threat to residents unless speeding is curbed. A study disclosed that approximately two-thirds of all crashes in which people are killed or injured happen on roads with a speed limit of 30 mph (48 km/h) or less (RoSPA, 1996).

Engwicht (1992) defines a relationship between the speed of traffic and the attitude of motorists towards pedestrians, which is, fast flowing traffic reinforces the drivers' perception that the street is their territory. Tranter and Doyle (1996) argue that traffic is denying children the freedom to play on residential streets because parents are not allowing them to, for fear of traffic danger associated with the dominance of motorised traffic. Fortunately, new design philosophies (such as traffic calming) have led to a revolution in the way residential streets are perceived, one such perception being that streets are not for the sole use of cars.

2.2 Speed, safety and the driver

Speeding in residential areas can be partly attributed to a driver's perception of safe speed. For roads with lower speed limits, drivers' perceptions of safe speed are commonly higher than the legal speed, despite drivers being aware of the speed limit (Shinar, 2007).

In New Zealand and many parts of the world, the general speed limit for urban traffic areas including residential precincts is set at 50 km/h. This seems high for local streets, considering that these streets do not serve high traffic volumes or speeds, and are accorded the lowest design standard. The primary function of local streets is to provide access to homes to those who enter or leave, and those who deliver and collect. Through traffic is not encouraged but that alone is not enough to deter some motorists from using these streets as shortcuts.

2.2.1 The association between speed and road safety

Speed is fundamentally associated with road safety. Speed has been found to be a major causative factor in about 10% of all crashes and 30% of fatal crashes (TRB, 1998). In New Zealand, speeding was a factor in 32% of fatal crashes, 16% of serious injury crashes and 12% of minor injury crashes for the years 2008 to 2010 (Ministry of Transport, 2011a).

The effects of speed on road safety can be simply explained through the laws of physics related to speed in the "driver-vehicle" relationship. Moving vehicles accumulate kinetic energy, which increases with the square of speed. During a collision, the impact speed determines the amount of energy to be dissipated and, subsequently, the likelihood of injury. The force imparted on an occupant during a collision with an impact speed of 30 km/h is about 20 times the driver's weight (1,500 kg). At 50 km/h, the force is equivalent to a three-storey fall, while at 100 km/h, it is akin to a 13-storey fall (Sergerie, 2008).

Stopping sight distance, which is the sum of reaction and braking distances, also increases with speed. This means that a vehicle moving at a higher speed is more likely to collide with an obstacle in its path.

Figure 2.1 shows that a longer distance is required for a vehicle (modern, with good brakes and tyres) to stop if it is moving at a higher speed and on a wet road. The figure also demonstrates that the likelihood of a vehicle colliding with a person 45 m ahead in its path and the resultant impact speed increase at a higher speed and in wet conditions.

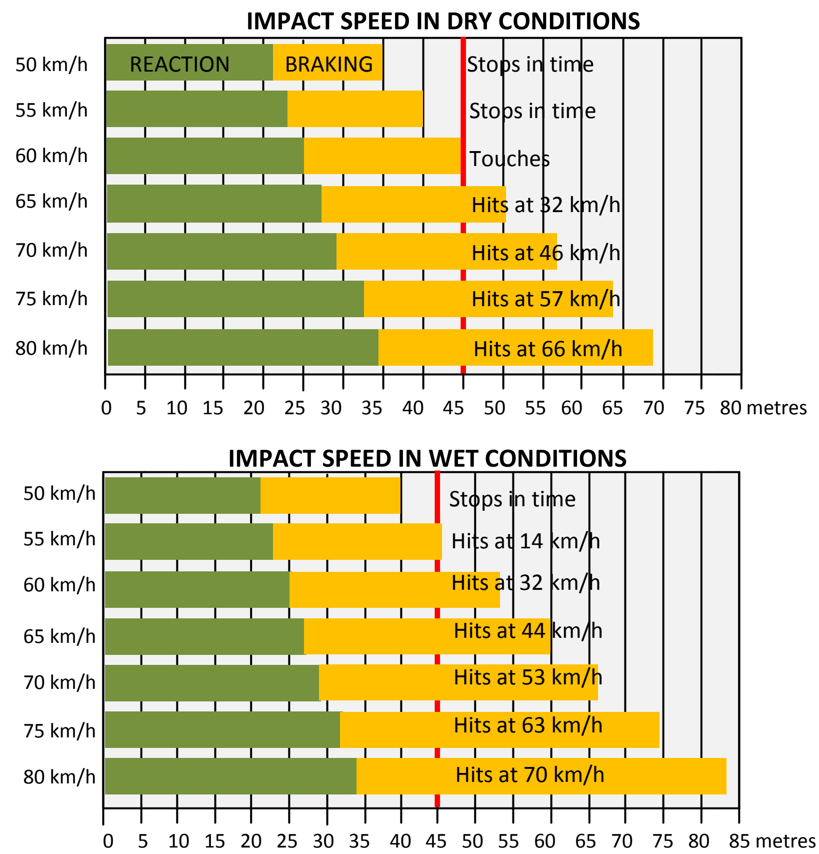

Figure 2.1 – Stopping distance at various speeds in dry and wet conditions adapted from Australian Transport Safety Bureau (2004)

Speed is also linked to the reduction of visual ability while driving. *Figure 2.2* illustrates that at a greater speed, the driver's visual field becomes narrower, hence reducing the capability of the driver to assess potential hazards and react in time when an obstacle appears from either side of this reduced field of view (OECD/ECMT, 2006).

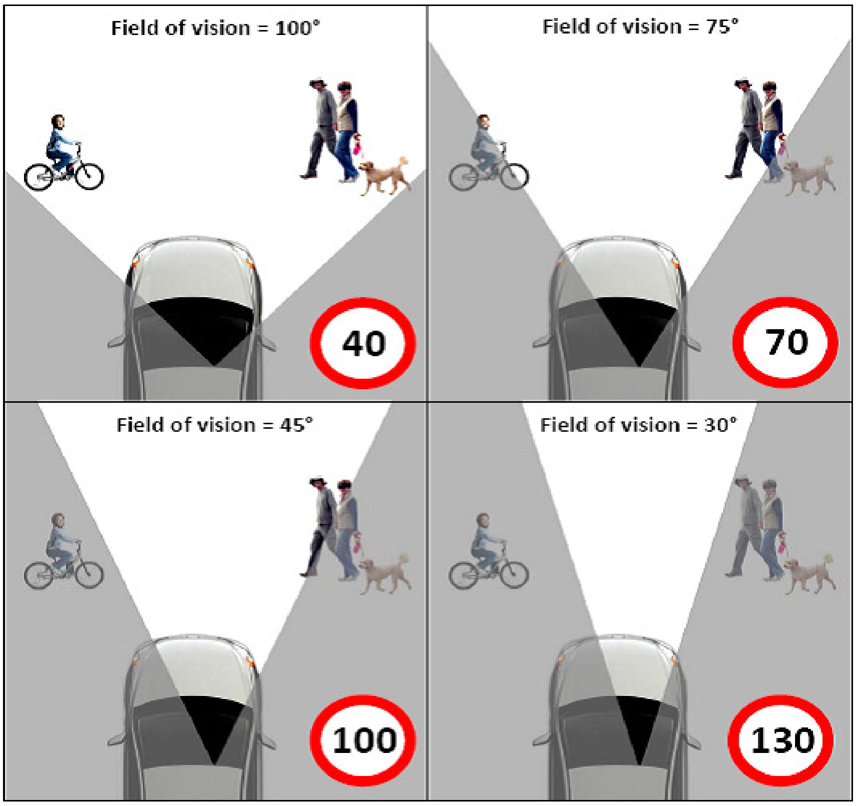

Figure 2.2 – Effect of speed on the field of vision adapted from Ministry of Transport, France (2001)

Furthermore, higher speed alters depth perception by making it more difficult for a driver to estimate distances to objects in front of them. The ability to correctly judge distances is vital for the safe execution of manoeuvres that require extra caution, such as overtaking and changing lanes. According to Marret (1994; cited in Sergerie, 2008), for each 10 km/h, a driver must be 3.75 m closer to an object in order to see it.

Researchers have attempted to correlate speed with crash frequency and severity. Though there have been varying results, one common agreement is that the number of crashes and seriousness of injury are more likely to worsen at higher speeds.

Taylor et al. (2000) concluded that a 10% increase in mean speed would result in a 21% increase in the number of crashes. Kloeden et al. (2002) found that the risk of involvement in casualty crashes is doubled for every 5 km/h increase in speed.

Nilsson (1982) found that the relationship between changes in the number of crashes and changes in speed takes the following form, which is commonly known as the “Power model”:

$$\left(\frac{Crashes\ after}{Crashes\ before}\right)=\left(\frac{Speed\ after}{Speed\ before}\right)^{Exponent}$$

He proposed that the relative change in the number of injury crashes is directly proportional to the square of the relative change in speed, and rationalised that the number of severe crashes would rise at a higher rate with an increase in speed. Thus, severe injury crashes and fatal crashes were assigned larger exponent values, i.e. 3 and 4 respectively.

After some refinements to his earlier work, Nilsson (2004) produced six equations for estimating changes in the number of crashes and casualties when speed is altered. The equations are summarised in *Table 2.1* and a representation of the speed and safety relationship by way of the Power model is illustrated in *Figure 2.3*.

Table 2.1 – Summary of the Power model for change in traffic safety when speed changes from v_0 to v_1

Accidents (y)	Number of fatal accidents	$y_1 = y_0\left(\frac{v_1}{v_0}\right)^4$
	Number of fatal and serious injury accidents	$y_1 = y_0\left(\frac{v_1}{v_0}\right)^3$
	Number of all injury accidents	$y_1 = y_0\left(\frac{v_1}{v_0}\right)^2$
Injured (z)	Number of fatalities	$z_1 = y_0\left(\frac{v_1}{v_0}\right)^4 + (z_0 - y_0)\left(\frac{v_1}{v_0}\right)^8$
	Number of fatalities and seriously injured	$z_1 = y_0\left(\frac{v_1}{v_0}\right)^3 + (z_0 - y_0)\left(\frac{v_1}{v_0}\right)^6$
	Number of all injured (including fatalities)	$z_1 = y_0\left(\frac{v_1}{v_0}\right)^2 + (z_0 - y_0)\left(\frac{v_1}{v_0}\right)^4$

Key: v = speed, y = number of accidents, z = number of injuries, subscript 0 = “initial” and subscript 1 = “current”

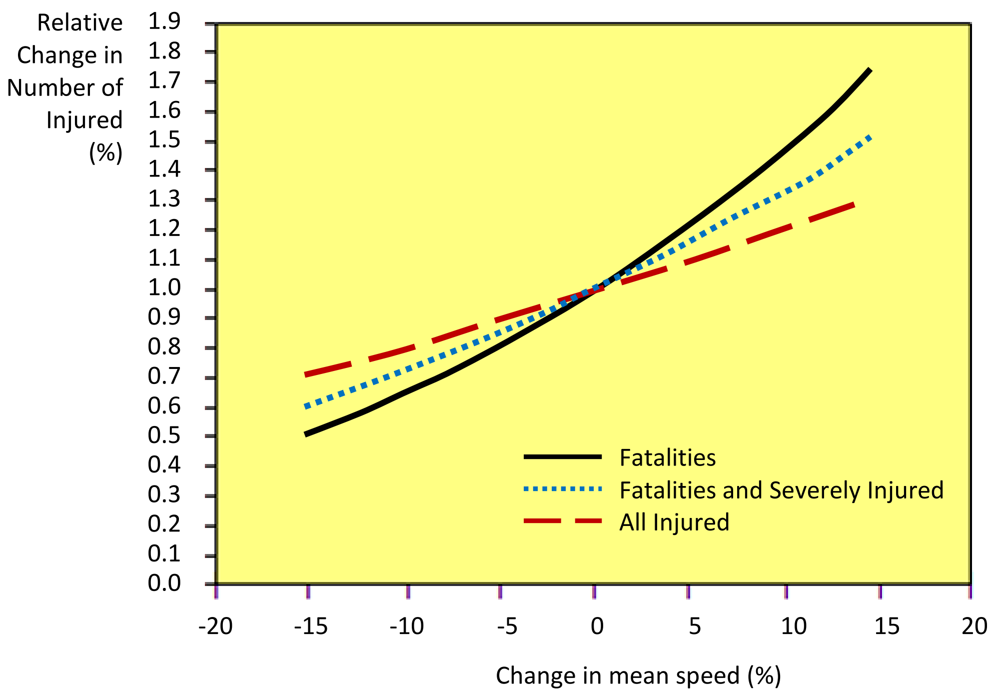

Figure 2.3 – Nilsson’s Power model reflecting the relationship between change in speed and change in the number of injured

Aarts and van Schagen (2006) in reviewing Nilsson's Power model produced estimates for the changes in crash types if the average speeds were altered by 1 km/h. Note that increases in road casualties were higher for lower speed environments, and severe crashes were more susceptible to increases in speed (see *Table 2.2*).

Table 2.2 – Expected change in crashes for different speed levels when average speed changes by 1 km/h

Reference Speed (km/h)	50	70	80	90	100	120
Injury Crashes	4.0%	2.9%	2.5%	2.2%	2.0%	1.7%
Serious Injury Crashes	6.1%	4.3%	3.8%	3.4%	3.0%	2.5%
Fatal Crashes	8.2%	5.9%	5.1%	4.5%	4.1%	3.3%

Revision to the original model was done by Elvik (2009), suggesting that the type of traffic environment moderates the effect of speed on crashes. He proposed lower estimates of the exponents for the Power model than those of Nilsson's theory, and found that the exponents were much lower on urban and residential roads than on rural roads and freeways (see *Table 2.3*).

Elvik's modified Power model provides a better representation of the effect of speed on safety in different road environments. The model is also more diverse as it allows for the estimation of changes in the number of crashes and casualties across four levels of crash types (fatal, serious, slight injuries and non-injury/property damage only), as opposed to Nilsson's Power model which has three levels – one of which combines both fatal and severe injury crashes.

Table 2.3 – Exponents for Elvik's modified Power model

	Summary estimates of exponents by traffic environment					
	Rural roads/freeways		Urban/residential roads		All roads	
Accident or injury severity	**Best estimate**	**95% CI**	**Best estimate**	**95% CI**	**Best estimate**	**95% CI**
Fatal accidents	4.1	(2.9, 5.3)	2.6	(0.3, 4.9)	3.5	(2.4, 4.6)
Fatalities	4.6	(4.0, 5.2)	3.0	(-0.5, 6.5)	4.3	(3.7, 4.9)
Serious injury accidents	2.6	(-2.7, 7.9)	1.5	(0.9, 2.1)	2.0	(1.4, 2.6)
Seriously injured road users	3.5	(0.5, 5.5)	2.0	(0.8, 3.2)	3.0	(2.0, 4.0)
Slight injury accidents	1.1	(0.0, 2.2)	1.0	(0.6, 1.4)	1.0	(0.7, 1.3)
Slightly injured road users	1.4	(0.5, 2.3)	1.1	(0.9, 1.3)	1.3	(1.1, 1.5)
Injury accidents – all	1.6	(0.9, 2.3)	1.2	(0.7, 1.7)	1.5	(1.2, 1.8)
Injured road users – all	2.2	(1.8, 2.6)	1.4	(0.4, 2.4)*	2.0	(1.6, 2.4)
PDO accidents	1.5	(0.1, 2.9)	0.8	(0.1, 1.5)	1.0	(0.5, 1.5)

CI = Confidence Interval; PDO = property damage only; * Specified informally

2.2.2 Speed limits on residential streets

Speed limits are implemented principally to regulate vehicle speeds. Speed limits vary from one road category to another, with roads in the upper hierarchy and in rural settings having higher limits.

The speed limit is the maximum speed considered safe for favourable weather and visibility. It is determined from traffic studies and engineering judgement based on experience and research. While the 85th percentile speed is a major factor in deciding on the appropriate speed limit for a given road, traffic engineers also consider other factors such as adjacent land-use and developments, accident experience, roadway characteristics and pedestrian/cyclist activity.

It is believed that lower speed limits would result in lower mean speeds, and consequently, reductions in the number of crashes and road trauma. There has been a lot of research done to relate the impact of changing speed limits on safety, and the findings are mostly in agreement with this. In fact, Nilsson

(1982, 2004) produced his Power model from studying the effects of lowering and increasing speed limits on crash frequency and severity.

Elvik et al. (2004) revealed that speed limits actually have an influence on the mean speed of traffic, as shown in *Figure 2.4*. On average, the change in mean speed resulting from a change in speed limit is approximately 25% of the change in speed limit, meaning that when the speed limit is lowered by 10 km/h, the mean speed will decrease by 2.5 km/h.

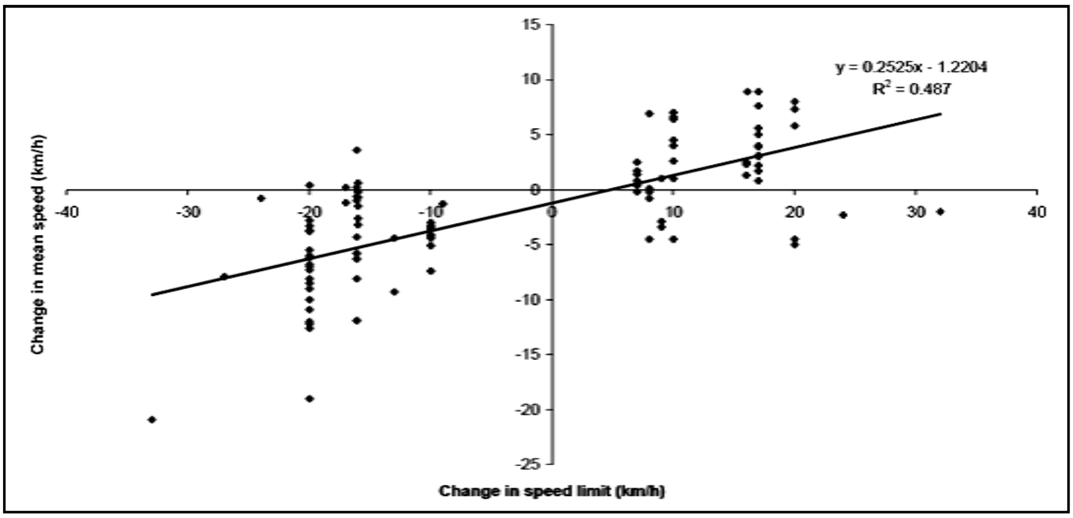

Figure 2.4 – Relationship between change in speed limit and change in mean speed (source: Elvik et al., 2004)

Elvik et al.'s finding echoed an earlier study by Finch et al. (1994), who obtained a relationship between the change in mean speed (ΔS) and the change in the posted speed limit (ΔL) as follows:

$$\Delta S = 0.24\Delta L \tag{2.1}$$

In the same study by Finch et al., a meta-analysis of crash studies was conducted using data from Finland, Denmark, Sweden, Germany, Switzerland and the United States of America. It was found that crashes change by about 5% for every 1 mph (1.6 km/h) change in the mean speed, meaning that if mean speed was to drop by 1 mph, the number of crashes would drop by 5% (see *Figure 2.5*).

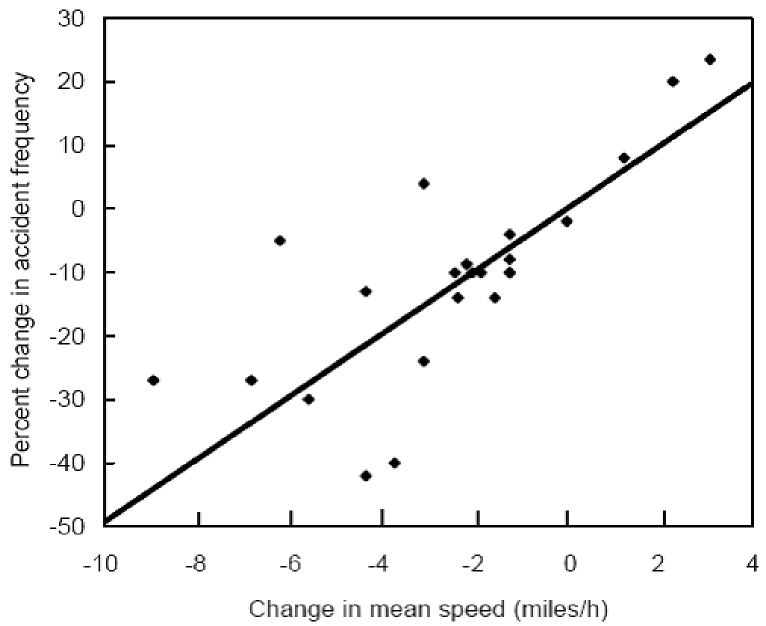

Figure 2.5 – Relationship between mean speed and accidents (Finch et al., 1994)

The relationship between the change in accidents (ΔA) and the change in mean speed (ΔS) by Finch et al. is given by:

$$\Delta A = 4.92\Delta S \tag{2.2}$$

Elvik and Vaa (2004), in their review of various studies related to speed limits, disclosed that by reducing or introducing speed limits, an overall reduction in crash numbers of 13% was attained. Apart from that, they found that lowering speed limits from 110 – 115 km/h to 88 – 97 km/h could result in reductions in fatality crashes and injury crashes by up to 54% and 6% respectively.

The outcome from reducing speed limits on urban roads, particularly arterials and local streets, may not necessarily mirror those effects reported in previously mentioned studies, which tend to focus mainly on rural and motorway speed limits.

The risk of crashes is high on major roads (such as arterials) and minor roads (such as local streets) due to the large number of access points such as driveways. In New Zealand, there was an average 10 fatal crashes and 460 injury crashes per year involving a vehicle entering or exiting a driveway in an urban area between 1996 and 1998 (Patterson et al., 2000).

The Australian experience in reducing the default urban speed limit (DUSL) from 60 km/h to 50 km/h since 1997 provides us with a better understanding of how changes to the speed limit ultimately impacts road safety in urban areas.

Archer et al. (2008) inferred from a number of studies conducted on the safety impact of the new DUSL that crash frequency and severity were considerably lower after its implementation, in spite of the travel speeds experiencing relatively small decreases. Casualty crashes dropped by 8% in Queensland (Walsh & Smith, 1999) and 12% in Victoria (Horeau et al., 2006), while South Australia experienced a 19.8% reduction (Kloeden et al., 2004).

It was also noted that pedestrian safety improved remarkably as a result of the new DUSL, with Horeau & Newstead (2004) reporting a 51% net reduction in pedestrian-related crashes in Western Australia, while in Victoria, reductions of about 25% – 40% were recorded for fatal and serious injury crashes involving pedestrians (Hoareau et al., 2006).

Research has thus far shown that there are some major safety benefits to be reaped from lowering speed limits. Special attention should be drawn to the 50 km/h urban speed limit applied to include residential streets. As previously stated, this speed limit may be too high for such roads, given their function and characteristics.

Several European countries have acknowledged the need to reduce the speed limit for residential streets to 30 km/h, and have seen success from the implementation of what they commonly call “30 km/h zones” or “Zone 30”.

A study of 679 streets in Denmark with the 30 km/h speed limit showed that the number of crashes in the inner areas, i.e. parts of the streets regulated by the speed limit sign, dropped by almost 25%, while the number of casualties fell by nearly 56% (Engel & Thomsen, 1992).

Webster & Mackie (1996), upon studying 20 mph (32 km/h) zones in England, Wales and Scotland, reported that the annual crash rate dipped by 60%, while child-related and cyclist-related crashes decreased by 67% and 29% respectively, as a result of the lower speed initiative. Furthermore, average speeds were down by 9 mph (14.5 km/h) and traffic volumes shrunk by 27%.

In the Netherlands, 30 km/h zones were just as successful in improving road safety in neighbourhoods, with the number of hospital admission crashes decreasing by 27% (Steenaert et al., 2004; cited in SWOV, 2006), and the number of fatalities and casualties per km of road falling by 10% and 60% respectively (Wegman et al., 2006; cited in SWOV, 2006).

It should be noted that these low speed zones incorporate traffic calming schemes that appear to be reducing vehicle speeds to the desired levels. Therefore, the safety improvements are partly due to the accompanying speed control measures. Having a 30 km/h advisory speed sign on its own may not result in the desired safety effects.

The drop in the number of road trauma cases as a result of low speed initiatives can be attributed to the reduction of the travel speed, which heightens not only driver alertness but also increases the likelihood of a driver avoiding collision, as the driver has more time and space to activate the brake pedal or perform any other defensive driving manoeuvres.

Under circumstances when a collision is inevitable, a low travelling speed would mean a low impact speed, which could turn out to be life-saving. The risk of a pedestrian dying as a result of being hit by a car moving at 50 km/h is twice as high as the risk at 40 km/h and more than five times higher than the risk at 30 km/h (Rosen & Sander, 2009).

Other benefits of converting residential streets into low speed zones include improvements to the quality of life, as slower traffic might result in reduced noise and exhaust emissions, and streets become more liveable with less people being threatened by fast-moving traffic and more people walking and cycling (T&E, 2001).

2.2.3 *Altering driver behaviour to achieve safer streets*

When a lower speed limit is planned for a residential area, the next step is to get its residents to support the new speed regulation and drivers, who are residents themselves (residing along the affected streets or other streets), to adhere to it. A simple, low-cost approach is through the dissemination of information about the need to reduce speed limits and the benefits from its implementation. While it is not likely that residents would turn down efforts to enhance the safety of their streets, there is always a possibility of them exceeding the speed limit, intentionally or unintentionally.

Predicting how a driver will respond to changes in the speed limit is not an easy task. But, there is a need to understand how their minds work or what inspires them to make decisions when driving.

A driver is influenced by an array of internal and external factors when driving a vehicle on the road. The World Health Organisation lists a total of 32 variables that are believed to affect a driver's choice of speed (see *Table 2.4*). These variables represent three main contributory factors: driver related factors, road and vehicle factors, and traffic and environment factors.

Table 2.4 – Factors affecting choice of speed among drivers (WHO, 2004)

Driver Related Factors	Road and Vehicle Factors	Traffic and Environment Factors
Age	**Road**	**Traffic**
Sex	Width	Density
Reaction time	Gradient	Composition
Attitudes	Alignment	Prevailing speed
Thrill-seeking	Surroundings	**Environment**
Risk acceptance	Layout	Weather
Hazard perception	Markings	Surface condition
Alcohol level	Surface quality	Natural light
Ownership of vehicle	**Vehicle**	Road lighting
Circumstances of journey	Type	Signs
Occupancy of vehicle	Power/weight ratio	Speed limit
	Maximum speed	Enforcement
	Comfort	

Shinar (2007) explains that drivers' choice of speed is governed by individual differences and motivational factors. Age, gender, education and income have diverse effects on speed choice. Men are more likely to speed than women (Jonah et al., 2001) and younger drivers are more likely to speed than older drivers (Horberry et al., 2004). Interestingly, Shinar et al. (2001) found that drivers with higher education and income levels are more likely to exceed speed limits, owing to their familiarity with conflicting arguments and data about speed-crash relationship, and ability to pay stiff penalties for speed violation.

The theory of planned behaviour (Ajzen, 1991) explains that the formulation of our intentions to commit any behaviour is on the basis of our attitude, the subjective norm and the perceived control. Based on this theory, De Pelsmacker & Janssens (2007) developed a model of speed choice behaviour from a survey involving Belgian drivers. The model suggests that the intention to speed is determined mainly by the habit of speeding and the attitude towards speeding, but not much by the affective attitude towards speed limits (refer to *Figure 2.6*).

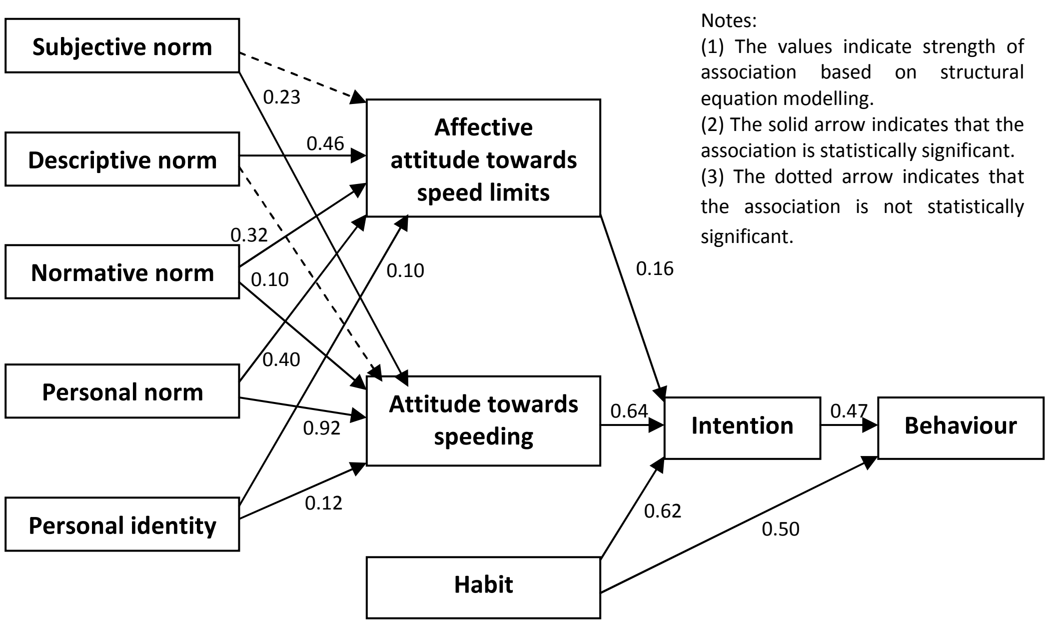

Figure 2.6 – The model of speed choice behaviour showing strength of association between relevant concepts

The variables used in De Pelsmacker & Janssens' study are explained in *Table 2.5*, while *Table 2.6* sums up the influence level of variables that were found to be significantly associated with driver behaviour. Habit seems to have a major effect on driver actions, with most drivers having a strong propensity to agree that they frequently drive over the speed limit, speed without thinking and drive fast because they do it all the time.

Table 2.5 – Explanation of the variables used in De Pelsmacker & Janssens' study

Variables	**Description**
Affective attitude towards speed limits	What I feel about respecting speed limits *(i.e. nervous / fun / annoyed)*
Affective attitude towards speeding	What I feel about speeding *(i.e. happy / excited)*
Attitude towards speeding	What I think about speeding *(i.e. it is a reckless behaviour / it makes me mad seeing people speed)*
Attitude towards speed controls	What speed controls I think might deter speeding *(i.e. higher fines / more speed cameras)*
Attitude towards accidents	What I think about safety as a result of respecting speed limits *(i.e. lowers chance of accident / enables me to stop faster in case of emergency)*
Subjective norm	What I think other people think about me with regards to speed limits *(i.e. my best friend/child/spouse thinks I may never exceed the speed limit)*
Descriptive norm	What I think other people would do if I respect the speed limit *(i.e. people will overtake me / drive closely to my car)*
Normative norm	What I would do, seeing as other people are doing it (i.e. my speed is just like the speed of other drivers)
Personal norm	What I think I should do based on my personal values *(i.e. I feel bad after speeding / I have a strong obligation not to exceed the speed limit)*
Personal identity	What I think about my own driving skills *(i.e. I know what to do in emergencies / I am better than the average driver)*
Habit	What I usually do when driving *(i.e. I frequently drive faster than the speed limit / I drive fast because I do it all the time)*
Intention	What I would do in future *(i.e. I will obey the speed limit the next time / I will continue driving fast)*

Table 2.6 – Total effects of variables considered and their speeding behaviour in order of importance

Variables	Size of Effect (significance)
Habit	0.787 (<0.001)
Intention	0.471 (<0.001)
Personal norm	0.307 (<0.001)
Attitude towards speeding	0.300(<0.001)
Affective attitude towards speed limits	0.077 (0.027)
Subjective norm	0.074(<0.001)
Normative norm	0.057 (0.024)
Personal identity	0.042 (0.023)
Descriptive norm	0.031 (0.151)

Road safety surveys in the Netherlands revealed that there has been a drop in driver compliance with speed limits over time and as expected, drivers were less inclined to obey speed limits in lower speed environments. About 40% of the drivers adhered to the 50 km/h speed limit and close to 30% adhered to the 30 km/h speed limit. It was also found that drivers in these environments exceeded speed limits mainly to adapt to traffic and out of haste. Drivers also recognised that they had exceeded the limits without actually realising it and did it for sheer enjoyment (SWOV, 2010).

If a street is to be given a 30 km/h speed limit, it is important that the street should look like a 30 km/h street. Coupled with the fact that speeding is instinctively habitual or intentional, the need to incorporate speed reducing elements in the design of a 30 km/h street is vital not only to present a "drive slow and carefully through our street" image, but to modify driver behaviour by restricting speeding actions through physical alterations to the street.

2.3 Review of neighbourhood traffic management

The adverse effects of speeding in neighbourhoods can be narrowed down to issues pertaining to safety and liveability. Fast moving traffic elevates the risk of crashes and perceptions that a street is not safe for walking, cycling or playing, and emits exterior sounds that may disrupt the tranquillity of neighbourhoods.

In order to allay the problem of speeding, the factors influencing speed choice need to be understood before speed management programs are implemented. Driver behaviour modification, particularly in controlling the speeding habit or intention to speed, can be successfully done through alternative street designs that restrain drivers from driving too fast.

Traditionally, traffic enforcement programs and speed signs were used to slow traffic but they had minimal effect in mitigating speeding problems in neighbourhoods. Subsequently, speed management techniques aimed at altering driver behaviour through innovative street designs were introduced and were proven to be effective. One such technique is traffic calming, which relies on the concept of using physical and visual devices to persuade motorists to slow down.

The Institute of Transportation Engineers (Ewing, 1999) defines traffic calming as follows:

> *"Traffic calming involves changes in street alignment, installation of barriers, and other physical measures to reduce traffic speeds and/or cut-through volumes, in the interest of street safety, liveability, and other public purposes."*

This definition provides a solid explanation of traffic calming as it aptly describes the general method, purpose and benefit. However, one tends to wonder why this updated definition does not include the notion of "altering driver behaviour" as defined by Lockwood (1997). Perhaps, the former is more workable in the sense that it does not depend on changing behaviour, which may be a sensitive subject to some.

The physical devices used in traffic calming can be divided into two broad categories: vertical deflections and horizontal deflections.

Vertical deflections are raised segments that force drivers to slow down in order to minimise unpleasant bumping or vibrating sensations. Examples of vertical deflections are speed humps, speed tables, speed cushions, raised intersections, rumble strips and textured surfaces (cobbled or interlocking paving blocks).

Horizontal deflections are lateral shifts in the roadway that create non-linear driving paths, thus encouraging slow and safe movement through the shifts. Horizontal deflections also include constrictions of the roadway which cause drivers to lower their speeds in order to avoid encroaching into the path of oncoming traffic or to stop and give way when the constriction permits only one vehicle at a time. Examples include mid-block narrowings, angled slow points, chicanes and central islands.

Non-physical measures such as centreline and edgeline lane striping, optical speed bars, signage, stop signs and turn restrictions are also regarded as traffic calming tools, but studies have shown that these measures have little or no effect in reducing traffic speeds and volumes, but are more effective when combined with physical measures (Ewing & Brown, 2009).

Traffic calming is commonly applied as a spot treatment to a single street, or as an area-wide scheme covering a cluster of streets. The latter may be termed Local Area Traffic Management (LATM).

Used regularly in Australia and New Zealand, LATM considers neighbourhood traffic-related problems and their solutions in the context of the local area, which is defined as an area consisting of only local streets and collectors. It necessitates that all physical measures be treated as a series of interrelated devices rather than as individual treatments (Austroads, 2008).

2.3.1 The beginnings of traffic calming

Looking back at history, it was the residents who first initiated measures to slow down vehicles on their residential streets. In the late 1960s, residents of Delft in the Netherlands decided to take action into their own hands by placing paving stones on their streets to form a meandering path so that speeding motorists who frequently passed through their neighbourhood would slow down (Kjemtrup & Herrstedt, 1992; Stillings & Lockwood, 2001). Traffic did slow down, but more importantly, their action gave birth to what is now known as "traffic calming".

Dutch officials recognised this public intervention as an effective speed reduction strategy and it inspired them to create and legalise the "*woonerf*". A *woonerf* is a Dutch word that simply means "street for living". A *woonerf* is characterised by streets that are shared by non-motorised and motorised road users. It was established that non-motorised users, predominantly pedestrians, are at the apex of the hierarchy and motorists are 'intruders' who are required to drive at very low speeds. *Woonerven* (plural of *woonerf*) are further typified by the non-existence of curbs and sidewalks and the placement of trees, planters and other obstacles on the street. This is to present *woonerven* as public spaces intended for local residents (Zeeger et al., 2002).

The idea of physically modifying streets to slow down vehicles soon spread to other countries in Europe. Denmark amended its Road Traffic Act in 1976 to give importance to playing and walking. Thus, the new regulations allowed the establishment of roads where motorists were considered as secondary road users and had to yield to pedestrians – the primary road users. The Danish equivalents to the *woonerven* were called "Section 40 areas" or "shared areas". Next came the establishment of "silent roads", which were 30 km/h zones supported by the use of physical speed control devices (Kjemtrup & Herrdstedt, 1992).

Germany experimented with this idea in the late 1970s and it was the Germans who came up with the term "traffic calming", a translation of what they called *verkehrsberuhigung*. They went on to implement area-wide traffic calming schemes and conducted extensive studies that turned out to be advantageous, leading to a warm global reception towards this idea (Ewing, 1999). In the 1980s, the "Tempo 30" zones were introduced, with neighbourhoods converted into 30 km/h speed zones and traffic calming devices used extensively. Tempo 30 zones were soon adopted by countries across Europe.

The traffic calming experience in United Kingdom dates back to the early 1960s when the Buchanan Report (Buchanan, 1963) acknowledged that the increase in traffic was threatening the quality of urban living. Consequently, much emphasis was given to controlling traffic volumes and virtually none to controlling speeds. The Urban Safety Project, which prominently featured traffic volume control measures, was launched in 1982 to reduce traffic accidents, but received criticism over its modest impact on crash rates. By 1990, the application of speed control measures started to gain status. With the 1992 Traffic Calming Act and 1993 Traffic Calming Regulations in place, a wider range of traffic calming tools were used in the design of safer streets (Ewing, 1999).

The beginnings of traffic calming in Australia were similar to that in the UK, owing to the influence of British town planning. Initially, the idea of local traffic restraint was adopted as an environmental improvement strategy. That soon changed in the late 1970s when the Australian Road Research Board (ARRB) started to document the safety motivation for local traffic restraints and to promote the concept of "environment of care" in local traffic management and street design. Soon after, the Australian area-wide traffic calming schemes or what they call LATM programs were implemented throughout Australia (Brindle, 1992).

The first reported traffic restraint measures reported in the United States were in the late 1940s or early 1950s when street closures and traffic diverters were employed to treat problem streets. But it was not until the 1970s that full-scale traffic management plans covering larger areas were implemented (Ewing, 1999).

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