DRIVER BEHAVIOUR DURING TRAFFIC SIGNAL CHANGE INTERVAL

KOH PUAY PING

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
NANYANG TECHNOLOGICAL UNIVERSITY

2005

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Koh Puay Ping

School of Civil and Environmental Engineering

A thesis submitted to the Nanyang Technological University
in fulfilment of the requirement for the degree of
Master of Engineering

2005

ACKNOWLEDGEMENTS

Many people have contributed to the completion of this project. Most importantly, I wish to express my great appreciation and gratitude to my supervising professor, Dr Wong Yiik Diew, for his generous support and advice in my preparation of this thesis. I would like to thank Goh Pin Kai, Lee Yew Loong, Neo Kian Heng and Mun Hui Hui for their diligent effort in collecting data, some of which are used in this project.

I am grateful to Mr Steven Ng Chai Huat and Mr Lee Cheok Fai from LTA for providing valuable data and Ms Lim Zhong Yann, Chinese Language lecturer from Nanyang Junior College, for translating the survey form into Chinese.

I would also like to thank the CEE Transportation Laboratory technicians, Mdm Ho Choo Hiang, Mr Liew Kai Liang, Mr Choi Siew Pheng, and Mdm Mai Ju An, for providing their technical support and help.

Also, I wish to express earnest thanks to my family for their continuous encouragement and support.

Last but not least, I am especially grateful to my fellow school mates and friends for their valuable support and feedback.

SUMMARY

Road junctions are places where conflicting traffic movements meet and hence are critical locations for the overall safety performance of the road network. In Singapore, about one-third of accidents occurred at the road junctions, of which around half occurred at signalised junctions. Many of the accidents can be traced to the period of signal change (intergreen) interval.

To enhance safety at the signalised junctions, it is important to understand the design of the traffic signal timing, especially the signal change interval, which requires knowledge of two driver performance parameters: perception-response time (PRT) and deceleration rate. These two parameters were investigated in this study. The 85th percentile PRT values (close to 1 second) and the mean deceleration rates (in the range of 2.8 to 3.4 m/s^2) were close to the normative design values. The study had relied on a vehicle-selection technique in the form of a transition zone to identify drivers in a force-paced driving situation.

Another important safety issue at signalised road junctions is driver's stop versus cross decision. An understanding of the factors that affect driver's decision-making can shed further insights on remedies to improve safety performance of road junctions. Two deterministic schemes (speed versus distance plot and 'A, D' representation) and a probabilistic approach (using logistic regression) were applied to model the decision-making of drivers, It was found that the driver's decision can be better described using probabilistic models.

The binary-outcome logistic model included the main effect variables such as distance, speed, vehicle class, entry lane, light condition, red-light camera (RLC), and risk from opposing vehicle. A higher stopping propensity was associated with variables such as car vehicle type, low approach speed, far distance, presence of an RLC and presence of collision risk with an opposing vehicle.

A perception survey revealed presence of red light cameras, distance from stop line and presence of pedestrians or a vehicle behind as being important considerations in driver's decision-making. A factor analysis reduced 16 variables into 3 conjoint factors of collision/monetary risk, situational factor and road conditions/passenger. Older drivers (aged 41 years and above) as well as female drivers were relatively more likely to stop under the influence of all three factors. About half of the respondents (48%) reported that they 'always try to stop' upon arriving at the junction and this percentage increased to 87% in the presence of an RLC. A logistic regression model suggested that driver's age and gender can influence the driving strategy (try to stop or to cross) employed.

This research showed that a combination of an observational study and a perception survey provided a valuable tool for evaluating driver behaviour and safety operation at a signalised junction.

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

%tile	Percentile
AWL	Advance Warning Lights
BTT	Basic Driving Theory Test
CFA	Principal Factor Analysis
DA	Discriminant Analysis
DIPS	Driver Improvement Points System
FTT	Final Driving Theory Test
GEMS	Generic Error Modelling System
GLIDE	Green Link Determining
GLM	General Linear Modelling
GS	Grade-separated
GSCD	Green Signal Countdown Device
HCV	Heavy commercial vehicle(s)
HDB	Housing Development Board
HV	Heavy vehicle(s)
IR	Involvement ratio
ITE	Institute of Transportation Engineers
Jtn	Junction(s)
K-S	Kolmogorov-Smirnov
LCV	Light commercial vehicle(s)
LED	Light-emitting diode
LHS	Left-hand-side
LTA	Land Transport Authority
LV	Light vehicle(s)
Mid-T	Middle approach of T-junction *(see also T(mid))*
MLE	Maximum likelihood estimation
MT	Foot movement time
NA	Not applicable
NS	Not significant
NTU	Nanyang Technological University
PC	Pedestrian crossing
PDO	Property-damage only (accident)
PET	Post encroachment time
PRT	Perception-response time
R&A	Red and amber (Arrows Light Scheme)
RHS	Right-hand-side
RHT	Risk homeostasis theory
RLC	Right light surveillance camera
RTA	Road traffic accident
S	Significant
Signif.	Significant/Not significant
SL	Stop line
SSR	Regression sum-of-squares
Std. dev.	Standard deviation
T(mid)	Middle approach of T-junction
T(top)	Top approach of T-junction
TTSL	Projected time to stop line
TZ	Transitional zone
UK	United Kingdom
Veh.	Vehicle

LIST OF SYMBOLS

α	Acceleration rate
a	Deceleration rate
A	Calculated acceleration
d or X	Distance from stop line
D	Calculated deceleration
g	Acceleration due to gravity
G	Slope gradient
I	Signal change interval length
l	Dependent variable of DA
l_w	Width of each exit lane
L	Length of vehicle
$L_{SL,PC}$	Distance from stop line to outer limit of the pedestrian crossing
n	Sample size
N	Number of exit lanes
p	Proportion
s_b	Distance in braking
t	Time from amber onset or amber time
T	Point of time at amber onset
$t_{cr,i}$	Mean time to stop line
T_{fil}	Point of time filtering vehicle moved out of the collision area
t_i	Time to stop line
v	Approach speed
w	Width of junction
X_c	Clearing distance
X_s	Stopping distance
λ	Median
μ	Mean
σ	Standard deviation
Φ	Standard normal function
θ	Difference between the disturbance terms

Chapter 1 Introduction

1.1 Background

Every year in Singapore, over two hundred people are killed and many thousands more are injured in road traffic accidents (RTAs) (Traffic Police, 2002a). About a third (around 35%) of the accidents were found to occur at junctions, which are locations where traffic streams from adjoining approaches interact while crossing and/or turning. Thus, junctions are critical locations in the road network from both safety and efficiency (capacity) viewpoints. More than eight decades ago, traffic signals were introduced to road junctions, with the aim of informing drivers of their respective rights-of-way in order to reduce the number of conflict situations. It was found that the installation of traffic signals has indeed reduced the number of certain types of accidents (particularly right-angle collisions) but it has increased the occurrences of other (though less severe) accident types. In terms of signal operation, the signal change interval which is the time from the end of green period of the phase losing right-of-way to the start of the green period of the phase gaining right-of-way, seems to be the most problematic.

In order to reduce the occurrence of accidents at road junctions, it is necessary to study the contributory factors. These factors can be classified under three main categories (Evans, 1991), namely human, vehicle and equipment, and environment. It is claimed that the human factor is directly or indirectly involved in about 80%-95% of all road accidents. This is further supported by the Traffic Police (2001) statistical reports as well as research work done on accident data (Wong et al., 2000) which showed that human factors have the highest degree of contribution. In opinion surveys on driver behaviour carried out in the UK (Jenkins, 1978; Quimby and Drake, 1989; West and French, 1993), the human factor was also identified by the respondents (drivers) as the most important contributor to road accidents.

Since the human factor is such a principal contributor to accidents, it is important to study the problems faced by drivers. At a signalised junction, the signal change interval is the period when many accidents occur. It is during the short signal change interval that drivers have to make a cross versus stop decision. Any inappropriate decision may potentially cause them to have collisions with others. For example, if a driver fails to respond safely and continues through the junction on a red signal, a major right-angle collision may occur. On the other hand, if the driver over-reacts and makes a quick stop, a head-rear collision can occur (Chang et al., 1984).

Thus, a proper and appropriate design of the signal change interval is of utmost importance to ensure safety and efficiency at the signalised junction. The design and operation of the signal change interval involves two important issues, namely, the length of the change interval to provide and the characteristics of the decisions made by drivers in response to the signal change. A good signal change interval is one that allows drivers to have enough time to stop before the stop line or, if they are unable to stop, to be able to clear the junction before the release of the conflicting vehicles and pedestrians. In this regard, a good understanding of driver decision-making in response to the signal change not only allows a better design of the signal change interval but also provides insights into the causation of accidents at the junctions.

In the signal change interval design, the length of the interval is related directly to the human performance parameters of perception-response time (PRT) and average deceleration rate which jointly represent driver performance in response to the change interval. The Institute of Transportation Engineers (ITE) has recommended a design PRT value of 1 second (ITE, 1982) and a comfortable deceleration rate of 15 ft/s^2 or 4.57 m/s^2 (later changed to 10 ft/s^2 or 3 m/s^2). A number of researchers and practitioners (Jenkins, 1969; Wortman and Matthias, 1983; Chang et al., 1985) who studied these two parameters have suggested higher design PRT values than 1 second as well as different deceleration rates. It is fair to say that a consensus conclusion regarding the quantum of the PRT value for design is yet to be reached. In any case, the use of unrealistic values of these two parameters might affect driver compliance with the signal and hence safety. Thus, this warrants the current study to re-examine the validity of the ITE design PRT value of 1 second and deceleration rate of 3 m/s^2 in relation to their applicability to Singapore road junctions.

A good understanding of the influential factors that affect a driver's decision to stop or to cross during the signal change interval is another important issue related to the design of the signal change interval. A study of this decision-making process can provide insights into controlling accident-causing behaviour thereby enhancing safety at the road junctions.

1.2 Objectives and scope of work

The main objective of the study is to describe, classify and model the behaviour of a driver when *he** approaches a signalised junction during the signal change interval. Driver behavioural response models shall be calibrated in an attempt to bring out the influence of human factors in driver decision-making, risk-taking and hence actual on-road behaviour. The scope of the study shall include the following tasks:

i) Studying the characteristics of red-running violations and junction accidents to bring out potential factors that are deemed to contribute to the occurrences of violations and accidents

ii) Investigation into the various aspects of driver performance characteristics (such as the perception-response time and speed change profiles) during the change interval by studying on-road behaviour in an unobtrusive manner; subsequently, driver performance characteristics are modelled with selected traffic and junction factors

iii) Model development to establish relationship between driver stopping probability and various combinations of variables, with comparison under different scenarios

iv) Comparison of probabilistic approach with deterministic approach for studying driver behaviour at road junctions

v) Administration of an in-depth perception survey which serves as a complement in gathering information on the mindset of drivers which is otherwise impossible to obtain directly from the observational field data

**For brevity, the terms 'he', 'him' and 'his' shall be used in this report to include both genders.*

vi) Highlighting possible applications (e.g. assessing the effectiveness of traffic schemes such as the advanced warning lights) of the methods employed in the thesis

Overall, the findings from the research should provide useful information to assess safety performance of signalised junctions in the Singapore environment.

1.3 Organisation of the report

The report is divided into 7 chapters including this introductory chapter which includes the problem statement, concept and study objectives. Chapter 2 deals with the literature review which covers the basic concepts required to develop this research whereas Chapter 3 highlights the methodology used in this study. Road traffic accident and red-running violation statistics obtained from the Traffic Police Department are analysed in Chapter 4 and the results of the observational study and perception survey are covered in Chapters 5 and 6, respectively. Finally, the report ends with a summary, discussions of the present findings and recommendations for future work.

The *Literature review* basically highlights the gaps in present knowledge and the need for the study. It also reviews the fundamental issues such as the design of a signal change interval and the driver limitations on the road.

The chapter on *Data collection and reduction* shows how the data were collected as well as the limitations of the data obtained from various sources. The data are divided into 4 types: accident statistics, violation statistics, on-site observational data and perception survey data.

The next chapter, *Road traffic accidents and red-running violation characteristics*, sheds light on the prevalence and the characteristics of the red-light running crashes and red-running violations in Singapore.

The following chapter forms a substantive part of the report, discussing the various *Results and data analysis from the observational study* as well as the summary of the field-based research findings. This includes driver performance parameters like perception-response time (PRT) and the average deceleration rates as well as the stopping probability profile of drivers during the signal change interval. The advantages and disadvantages of the deterministic versus probabilistic study approaches on driver behaviour are addressed.

The next chapter encompasses the *Analysis and interpretation of the perception survey*. This part serves to complement the observational data, paying due attention to the driver personal characteristics such as age, gender and driving experience on driver decision-making at the signalised junctions.

In the final chapter on *Findings, discussions and recommendations*, important findings and issues relevant to the project are summarised and discussed. Further areas of potential research are also highlighted.

Chapter 2 Literature Review

The first section of *Literature Review* introduces the study of human factors on the road and provides a detailed description of driver characteristics and limitations. The next section covers the traffic signal operation and red-running phenomenon which includes a review of the remedial measures implemented in various countries. The design of the traffic signal change interval is then introduced and the corresponding driver performance characteristics discussed. In the final section, the local traffic environment as applicable to the present study is highlighted.

2.1 The study of human factors on the road

The efficient and safe operations of modern road transportation systems are dependent on three main groups of factors pertaining to: the human, the vehicle and the environment (Ogden, 1990). Although these three groups of factors interact with one another in different ways, it is ultimately the human user who initiates and controls the events. Nevertheless, the road environment should be conducive in facilitating drivers to make rationale and safe decisions. Therefore, it is worthy and important for traffic engineers who design and operate the road system to understand the performance, capabilities and limitations of the road users as well as to identify the deficiencies of the road environment.

An important responsibility of traffic engineers is to design a road system in such a way that the amount of decision-making required of the road users is manageable while the information input to the decision-making process is provided so as to facilitate rapid and correct decisions. In practice, information dissemination and acquisition is complicated by the non-homogeneous characteristics of the human users. That is to say, under a given situation, not all users will react and behave in the same and expected manner.

2.1.1 The driving task

Vehicle driving can be viewed as an activity carried out in a complex, dynamic situation involving control of multiple actions (navigation, guidance and control) at the same time. The driver has to respond to a number of circumstances, including the vehicle, road and traffic conditions, other road users, as well as to make quick decisions to implement his own intentions. The time to respond to a driving situation involves three sequential stages: mental processing time, movement time and device response time (Green, 2003). The first stage encompasses detection and identification of the situation and the mental response selection; this stage concerns both the driver and the environment (e.g. layout of the traffic junction). The second stage applies to only the driver while the last stage involves the vehicle (e.g. engine capacity).

Information perception and processing

Since most of the information received by the driver is through visual input, and it is the most efficient way information gets to him while on the road, it is useful and necessary to have a good understanding of the functioning of the human vision process.

A driver's visual field for reading purpose is quite narrow: 3 to 10 degrees (°) as compared to the vision angle for peripheral detection of objects (ability to detect object or movement but not see clearly) which can be up to 90° to left and right, 60° above and 70° below the line of sight (Ogden, 1996). However, as speed increases, the eye focuses further ahead and visual field gets narrower. For example, the lateral visual angle drops from 180° to about 100° as speed increases to 30 km/h and decreases further to only 40° when the speed reaches 100 km/h. Moreover, human brain can only properly attend to one input at a time and thus drivers usually engage in rapid attention switching in order to get a general picture of the complicated situation being faced before a decision is made. Failure to perform this rapid switching or the inability to pick up the correct information can cause the driver to make incorrect decisions which may end in an accident. This failure usually results from inexperience, health deterioration (getting old), distraction or tiredness.

The overall perception-processing time is dependent on two important conditions, namely the number of stimuli and possible responses, and expectancy. If the number of stimuli increases, then the level of complexity of the situation faced by the driver also increases. Providing the driver with more choices or alternatives complicates the situation further since the driver has to process more information. This, in turn, increases the workload on the driver and thus his decision processing time. As uncertainty about the onset of stimulus (e.g. when the traffic green signal is going to turn amber) increases, so does the decision time.

What the driver decides to do after processing the information depends on the individual and the amount of risk (as discussed later in the following section) he is willing to take.

Movement time

Once a decision is made, the driver must perform the required muscle movement to carry out the intended response. For example, after the driver has decided to brake, it takes some time to lift the foot off the accelerator pedal, to move it laterally to the brake and then to depress the pedal. The pace at which this is performed is affected by the physical capability of the driver, the driver's experience about the situation and the presence of any emotional arousal (during emergency).

Device response time

Mechanical devices (e.g. braking system) take time to actuate, even after the driver has acted. However, this often happens in split seconds and it will not cause any great delay.

Perception-response time

On the whole, the reaction time of drivers or how quickly a driver can respond to an occurrence or appearance of a visual stimulus is one of the important human factors often cited by traffic engineers as affecting safety. For the case of a stopping vehicle, the perception-response time can be divided into three components: perception-decision time (i.e. the interval from the onset of visual stimulus till coming to a decision), braking response time (i.e. the interval from having decided to stop till placing foot on the brake pedal) and vehicle response time (i.e. the instance from the foot being placed on the brake pedal till the beginning of device response, signalled by the onset of brake lights). It would be useful to observe each stage separately; however, since it is difficult to observe the individual components in an unobtrusive manner, it is common to measure the composite perception-decision-response time known simply as the perception-response time.

2.1.2 Driver competency versus driver behaviour

Driver competency (in the context of this study) refers to the driver's perceptual and motor skills, or what the driver is physiologically capable of doing, whereas driver behaviour refers to what the driver actually does on the road (Evans, 1991). The former focuses on capabilities and skills acquired by the driver which are not identical among drivers, but can still be investigated through several methods which include laboratory tests, simulator experiments, controlled field experiments, observations of actual traffic, and so on. However, the latter (driver behaviour) which is essentially dependent upon both the driver's competence (what he is able to do) and his motivation (what he chooses to do), cannot be investigated by experimentation but by extensive, unobtrusive observations of the actual traffic on the road or by a reliable attitudinal survey. Hence, information on driver behaviour tends to be more uncertain than that about driver competency. The distinction between the two concepts is important when gathering driver performance data in traffic studies, especially in road safety remediation works.

2.1.3 Driver characteristics and limitations

There are many individual differences inherent among the human drivers in terms of age, gender, experience in driving, social factors, personality, motivation, emotion, and so on, which inevitably generate different performance characteristics and behavioural traits. The range of driver abilities and limitations presents a big challenge to engineers in designing vehicles, roadways and traffic control devices. Many studies have investigated various aspects of driver abilities and limitations but definitive findings are invariably hard to establish due to the difficulty in obtaining reliable values that are sometimes not even measurable. Some driver characteristics (and limitations) are discussed next.

Old and young drivers

Accident statistics have shown that young drivers (16 to 25 years old) have relatively high accident rate (Evans, 1991). This rate decreases with age (experience) and levels off at around age 30, after which it picks up again, forming a U-shaped curve (see Figure 2.1). This implies that older drivers are also disproportionately represented, besides the young drivers. Although the young and old drivers are often the culpable party in accident occurrences, their involvements are quite different from each other. The older drivers are usually involved in accidents related to degraded visibility or retarded reflexes whereas the young drivers are less experienced in driving, less emotionally mature, and have different social (e.g. alcohol drinking) and motivational needs (e.g. peer pressure) that contribute to their more risky behaviour than other groups of drivers. The different behaviour on the road is further corroborated in findings by Louca et al. (1999) that older drivers (aged 63 to 76 years) drove more defensively and were more concerned with factors that affect their visibility whereas the younger drivers (aged 19 to 24 years) had lower risk perception (that is, they did not seem to heed such information from the road environment). Young drivers were also found to feel greater frustration while driving, enjoyed fast driving and overtaking more and were more ready to take chances than the older drivers (Quenault et al., 1968; Ward and Lancaster, 2001).

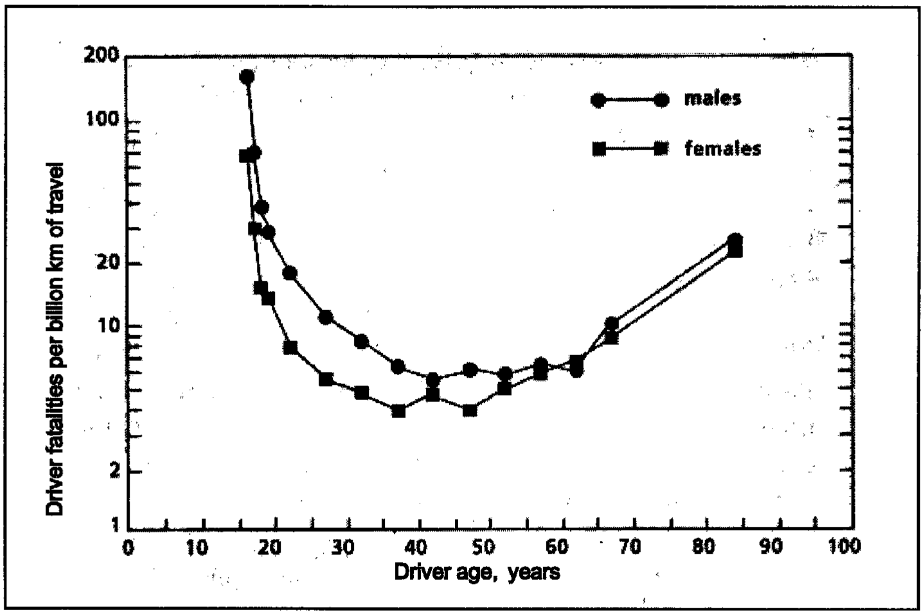


Figure 2.1 Driver fatalities with age *(Evans, 1991)*

Faulkner (1975) studied the accident statistics of London and concluded that young drivers (under the age of 25 years) were most frequently involved in junction accidents when travelling on major roads, particularly at night, in urban areas and when riding motorcycles.

Gender differences

Drummond (1989) found that men and women made inattention errors equally often in older age, whereas inexperience errors were more common among female respondents. Storie (1977) found that whereas men tended to be associated with speeding and driving under influence of alcohol that resulted in accidents more often than women, the latter were more frequently involved in accidents caused by judgement error. Table 2.1 shows the principal differences between male and female drivers.

Table 2.1 Differences between male and female drivers *(Storie, 1977)*

Males more likely	Females more likely
Alcohol used within 12 hours before the accident (3:1)*	Drugs/medication present (2:1)
Lack of attention/alertness	Distraction
Had 1 or more impairment features out of 5**	Look but failed to see (2:1)
Had a previous accident	Failed to look
Had a previous driving offence	Lack of skill
Drove too fast	Lack of care
More often impaired (2:1)	Inexperience
More perceptual errors if over age 65	More difficulty merging right into major road
More often at fault in right-turn***, overtaking, and head-on accidents	More often at fault turning right and at T-junctions
More accidents on curve	More accidents in daylight

** Where a ratio is indicated, the difference was that much greater for that gender*
***Impairments included alcohol, fatigue, drugs, illness, and emotional distress*
**** Equivalent to merging and turning left in North America, as this study was done in England*

Experience in driving

Experience is accumulated as the frequency of driving increases, thus, needless to say, those who are newly qualified as drivers (majority are young drivers between the age of 18 to 24 years) or those who have no access to a vehicle for driving are basically inexperienced drivers. In a study on novice driver performance (Drummond, 1989), the major performance differences drawn between experienced and novice drivers were, for the latter, poorer judgement (gap clearance or speed of other vehicles) and visual capture ability, underestimation of risk and overestimation of their driving ability. A beginner, when first starting out behind the wheel, pays more attention to the coordination of the hands and legs and requires conscious control of the vehicle. At the same time, he learns how to guide the vehicle in the desired path and how to maintain his lateral position on the road while adjusting his speed. As he gets on the road more often, he slowly begins to achieve a feeling of control over his car and the surrounding traffic; thus, the feeling of uncertainty diminishes with an increase in confidence. With more experience, a driver is able to expect some of the situations that might arise by observing others on the road. This allows one to take pre-emptive actions beforehand or be more alert than someone who is new and unable to pick up the cues from the road environment.

Risk taking and risk perception

Risk taking is often ascertained by the experts as the psychological characteristics of sensation seeking and thrill seeking, and as actuarial projections of probabilities and costs (Rothe, 1993). Motorists are faced with all kinds of everyday life decisions on the road such as which route to take that will bring them to their destination on time, whether they should run the red to reach the destination a few minutes earlier but with the risk of getting caught by the surveillance cameras etc. It is thus evident that risk taking (or avoidance) is an intrinsic part of driving. Many psychologists like Naatanen and Summala (1974), Fuller (1984) and Wilde (1988) have outlined models of risk analysis that assume a direct link between motorists' perception of risk and their driving behaviour. It is suggested in risk homeostasis theory (Wilde, 1988 and 1996), hereinafter referred to as RHT, that at any moment of time, road users (drivers) compare the *perceived risk* they experience on the road with the *target safety level of risk* which they are willing to accept and make decisions whether to take action to eliminate any perceived discrepancy. For example, if the perceived risk level is greater than the target level of risk, then the driver will take necessary actions (for example, brake) in order to reduce the risk level. If the perceived risk level is smaller than target risk level, then the driver will take action (for example, speed up) in order to save time (and increase risk level). The target level of risk is defined as the driver's maximum, estimated balance of all expected benefits (e.g. reaching destination earlier, satisfying ego) minus all anticipated costs (including perceived danger of accident). The ability to balance these two risk levels is thus dependent on the perceptual skills, decisional skills and vehicle handling skills of the driver. Thus, it is suggested in RHT that any safety measure should be targeted at lowering the 'target level of risk' of road users if the remediation is to have long lasting effects on safety. A pictorial presentation of RHT is presented in Figure 2.2.

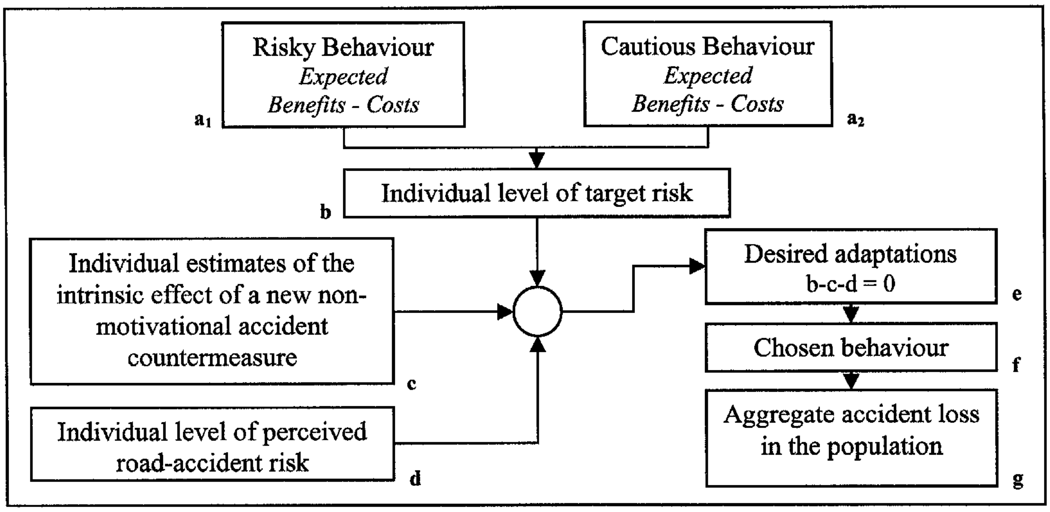


Figure 2.2 Illustration of the Risk Homeostasis Theory (RHT) *(Wilde, 1988)*

The zero-risk model (Naatanen and Summala, 1974) assumes that drivers on the road aim at zero subjective risk. He makes suitable changes to his driving to lower the maximum subjective risk by an amount which he judges to generate a safety margin that is associated with an essentially zero risk of crashes.

However, Fuller (1984) explained risk taking in terms of a threat-avoidance model. The driver is believed to be not so much trying to avoid crashes but attempting to avoid unpleasant experiences that in some cases might be precursors to crashes. It is also believed that each individual driver makes subconscious decisions about alternative responses based on his past conditioning history. For example, a driver who had run the red several times and did not get caught on the red light camera or did not get involved in an accident would be inclined to continue to do so as past experiences suggest to him that red-running is not as risky as it seems. It is also plausible that learner drivers make errors during decision-making due, in part, to their limited 'history'.

The above models suggest that the way a driver responds is dependent on the degree of risk he is willing to take. This risk may vary with the situations, some of which are inherent to the driver while others involve people/objects around him.

Driving at night

Night driving is a special challenge to drivers, especially for older drivers and those with vision problems, because of the greatly-reduced visibility at night. The major degradation in the contrast between the roadway features or hazards and their background might cause serious miscalculations and detection errors. It is already difficult to see huge objects which do not stand out from the background, let alone pedestrians wearing dark-coloured clothing. Furthermore, glare from headlights of other vehicles (Anderson and Holliday, 1995), street lights, or dirty windshields can impair visibility further, causing moments of blindness to the drivers. All these impairments make night-time driving more difficult than during daytime.

On the other hand, there are some situations where a driver's response can be better in reduced light. For example, the Light-Emitting Diode (LED) traffic lights are more conspicuous in darker background with higher contrast and greater visibility (Green, 2000). Hence, the actual performance of drivers under a different ambient condition is hard to quantify. It is imperative that traffic engineers pay good attention (when designing roads, traffic control devices and so on) of the time and distance required by a driver to respond safely under various conditions.

2.1.4 Aberrant driving behaviour

Drivers sometimes make inappropriate decisions when reacting to the prevailing situation which can endanger their own lives. Such aberrant driving behaviour can be a result of either errors or violations.

An *error* is defined as the failure of planned actions to achieve their intended consequences (Parker et al., 1995). Errors in the form of mistakes or slips usually occur when the driver is distracted or tired and they are unintentional. According to the distinction made between mistakes and slips in Generic Error Modelling System (GEMS), mistakes are planning errors whereas slips are execution errors (Reason, 1990). For instance, a driver is considered to be making a mistake in *deciding* to brake in a situation where the appropriate action would have been to accelerate. In contrast, it would be a slip to accelerate when the actual intention was to brake. A variant of execution error is a lapse, where one did not do something which one would normally do. Slips and lapses are usually referred to as one type of error.

Violation is defined as the deliberate infringement of some regulated or socially accepted code of behaviour. An unintended or erroneous violation is a violation committed under unknown consequences. If the violation is done deliberately, it is further classified under malevolent (an act of sabotage or having the intention to cause harm) or non-malevolent. The violations of greatest interest are those having some degree of intentionality but without the goal of causing injury or damage.

Errors and violations differ both in their psychological mechanisms and in the kind of remedial actions necessary to combat them. Errors arise during the information-processing stage and can be minimised by retraining the drivers or redesigning the traffic environment such as using/adding more memory aids or clearer road signs. Violations, on the other hand, should probably be dealt with by attempting to change the drivers' attitudes, beliefs and norms, or by improving the overall safety culture. Actions to curb violations include media campaigns to target the potential violators, usually the youngsters on the road. Enforcement, like traffic police patrolling or 24-hour surveillance camera installation, can be used if the educational approach is ineffective.

Studies done in Sweden by Aberg and Rimmö (1998) and Rimmö (2000) on aberrant driving behaviour found that young drivers, particularly young men, were more likely to *violate* traffic rules (risk-perverse) and were more involved in accidents than older drivers. Mistakes were slightly more often reported in men and diminished with age. With increasing age, it was more common to find drivers making inattention errors. Inexperience errors were found in all ages but were more common in women and drivers who did not drive much.

2.2 Traffic signals

Whenever a driver is on an urban road, there will be many occasions where he has to make stops at junctions (whether unsignalised or signalised) while waiting for his turn to get across. When more vehicles operate on a road, there are more chances for these vehicles to get into conflict with one another at road junctions, and traffic signals are often used as one form of traffic control.

Traffic signals are electrically operated control devices which alternatively direct traffic to stop and to proceed. There are basically two types of control: pre-timed or actuated. They are unlike other road signals (e.g. stop signs) which provide a constant and single directive, but instead change instructions periodically. Traffic signals are usually applied at road junctions when the conflicting traffic increases to a level that is unmanageable without further control. With the use of traffic signals, vehicles approaching a junction from various directions are assigned their respective rights-of-way in an orderly manner, by means of time separation. The signals may interrupt extremely heavy flows to permit the crossing of minor movements which cannot otherwise move safely through the junction. When properly timed, traffic signals may also increase traffic handling capacity of a junction, and when installed under justifiable conditions, they constitute a valuable device for improving traffic safety and efficiency of both pedestrians and vehicular traffic. In particular, traffic signals might reduce certain types of accidents, notably the right-angle collisions, but this is sometimes offset by an increase in the number of rear-end collisions (Michael et al., 1982; Short et al., 1982). Improper usage of traffic signals can cause problems like excessive delay, disobedience of signals and unnecessary diversion of traffic to inadequate alternate routes. Therefore, installation of traffic signals is only warranted when it is likely to produce an overall decrease in the total number of accidents or an overall reduction in costs (despite an increase in the number of less severe accidents).

2.2.1 Red-running at traffic signals and remedial measures

The signal change interval, also known as the inter-green period, denotes the time interval between the green light ending for the vehicular movement losing right-of-way and the green light beginning for the movement gaining right-of-way. It is during this critical period that some drivers are faced with the decision of either proceeding to cross or preparing to stop; an inappropriate decision could result in an accident. A driver may elect to cross and face some degree of risk. The level of risk a driver is willing to take varies from driver to driver and the decision is often the result of a trade-off between the estimated cost and perceived benefits. The benefits include reaching the destination earlier, avoiding discomfort while waiting in the queue and so on, whereas the cost entails the penalty of red-running or even the possibility of getting involved in an accident. However, the risk at an individual level is often viewed as quite low due to the very small possibility of being involved in an accident. Many individuals thus do not consider the risk as a big danger which in fact signifies the possibility of accidents.

The red-running phenomenon and its treatments

From past studies, red-running violations were often found to have some correlation with accidents at junctions. It is usually the red-runners together with the early starters from conflicting traffic streams that form the most accident prone groups. In other words, the higher the proportion of these risky movements (e.g. red-running), the higher the exposure which eventually translates to an increase in the number of accidents. The red-running phenomenon has been investigated in many studies (Ng, 1996; Retting et al., 1999; Lee, 2001; Ding, 2002; Lum, 2002) in order to identify the common traits of violators which might eventually shed lights on the causation of related junction accidents. Red-runners are often divided into three types (see Table 2.2) and these include deliberate (or intentional) offenders, drivers caught in the dilemma zone (unintentional but wary) as well as those who could have entered the junction before the red but were delayed by their own indecision or by slower traffic in front of them (unintentional and inattentive).

Table 2.2 **Types of red-running and possible countermeasures** *(Bonneson et al., 2002)*

Driver Type		Possible Scenario	Type of countermeasure	
			Engineering	Enforcement
Intentional		Congested, cycle overflow	Less Effective	***More effective***
Unintentional	Type A	Incapable to stop	***More effective***	Less Effective
	Type B	Inattentive		

Table 2.2 also summarises the expected effectiveness of the countermeasure alternatives for the different types of red-running violators. Enforcement of traffic regulations is one of the ways to curb red-running violations (particularly deliberate violations). The enforcement basically consists of two types, namely manual police enforcement and the automated system (red light surveillance cameras). Police enforcement though effective in deterrence, is resource-intensive and is impractical to be used round the clock. Thus, the red light surveillance cameras (RLCs) have been introduced in countries like Sweden, 1972; Australia, 1979; Singapore, 1986; Malaysia, 1993; United Kingdom and United States, early 1990s etc. to complement manual police enforcement. Several before-and-after studies have shown that RLCs are effective in reducing the number of violations as well as the number of right-angle collisions though they can induce more rear-end collisions (South et al., 1988; Lawson, 1991; Ng et al., 1997; Lum and Wong, 1998; Retting and Kyrychenko, 2001; McGee, 2003), while noting that there were a few studies (Andreassen, 1995; OHML, 2001) that have suggested otherwise. Most of the drivers at the RLC junctions will stop for fear of being caught and obtaining fines or demerit points. However, surveillance cameras have not been able to curb red-running completely and there is still a minority who choose to cross the junction after red. Deliberate

violations might be due to a general disregard for traffic laws (drivers proceed through a junction so long as they perceive it is safe to do so), a lack of effective and continuous enforcement (drivers might think that the chances of receiving a fine are very small), or driver frustration of long waiting time for their right-of-way.

For cases of red-running that are unintentional, remedial (engineering) measures to reduce the possibility of drivers being caught in the dilemma zone (by either adjusting the traffic signal timing or providing advance warning indicators) can be used.

Speed discrimination is a method tried out in the United States and United Kingdom (Zegeer, 1977; Baguley and Ray, 1989; McCoy and Pesti, 2003) by adjusting (lengthening) the green signal timing to allow a driver caught in the dilemma zone to have enough time to clear the junction. It uses inductive road loops and electronic circuitry that detect an approaching vehicle and extend the green duration (within limits) according to the vehicle's position and speed prior to the onset of amber. Another method related to signal timing is to extend the amber time by 1-3 seconds. Van der Horst (1986) found that an extension of the amber time by 1 second resulted in the number of red-runners reducing by half but the use of longer amber durations is questionable because of undesirable secondary effects (for example, drivers using part of the amber as extended green time).

Providing advance warning indicators to amber onset is another way to help this type of drivers to avoid red-running. Warning indicators can be provided either as *distance* reference aids or *time* reference aids. Distance reference aids are markers placed along the approach towards a junction which suggest to the drivers that if they pass them before the amber onset, they would have enough time to cross the stop line without running the red, and vice versa. However, these aids have been shown not to be effective enough due to wide variations in the approach speeds of vehicles (May, 1968).

Time reference aids, on the other hand, allow drivers to judge a stop versus cross action by the amount of time left before termination of green and are more common. Different forms of these types of aids have been tried out in many countries such as introducing a blinking green towards the end of full green (in Israel) or a blinking amber just before the red, or adding an advance warning sign with flashing beacons to inform drivers to be prepared to stop. Before-and-after studies on the first form of warning device (Mahalel and Zaidel, 1985; Mussa, et al., 1996) have reported similar findings in that the number of red-running violations and the severity of the collisions (namely right-angle collisions) had reduced, but the number of rear-end collisions had increased due to widening of the indecision zone. It also generated a substantial increase of early stops that are not in compliance with the rules of the road (Koll et al., 2004). The warning flashers seemed to have reduced red-light running violations particularly for truck drivers, however their effectiveness diminished in the long run (Farraher et al., 1999). It is interesting to note that, even with only the conventional, green-amber-red (-green) traffic signals, observant drivers who are able to take cues from the surrounding environment to judge the time left, are actually employing simple forms of time reference aids.

2.2.2 Designing the signal change interval

The appropriate choice of the signal change interval can play a very crucial role in maintaining safety at the signalised junctions. The signal change interval is usually characterised by an amber (or yellow) warning indication, and sometimes followed by an all-direction red clearance indication, but the combinations and proportions of the amber and red may vary from country to country. The amber indication typically ranges from 3 to 6 seconds (ADOT, 2001) while the all-red interval normally ranges from 0.1 to 2 seconds (Caltrans, 1996). Excessively long amber periods may eventually result in drivers' disrespect for the traffic signals and unsafe operating practices (for example, treating the amber period as part of the green interval) and are thus undesirable. On the other hand, if the interval is too short, those already in the junction might not have enough time to clear and right-angle collisions might occur. Thus, the signal change interval should be carefully designed.

Signal change interval can be fixed or variable across the road network. A constant signal change interval implies the use of uniform amber and/or all-red duration(s) throughout the whole transportation network and this has the advantage of fixed expectation by the drivers. However, some researchers have argued that the practice is wrong and potentially unsafe (ITE, 1994). On the other hand, a variable signal change interval can accommodate junctions of varying characteristics (e.g. large junction width, high speed limit, etc). The existing practice of determining the variable signal change interval has not changed significantly over the past half century ever since it was recommended by the Institute of Transportation Engineers (ITE). It is essentially a deterministic approach whereby the design calculation is based on an "idealised" or "reasonable" driver's perception-response time and deceleration rate. In other words, the duration of the signal change interval should be the time sufficient for a reasonable driver to cross the junction safely if he is unable to stop comfortably before the stop line. The equations were originally developed by Gazis et al. (1960), and are shown in the following formulations.

For a vehicle to be able to stop without encroaching into the junction area (see Figure 2.3), the available braking distance (LHS of the equation) must be at least equal to the actual braking distance (RHS of the equation) as described by:

$$X - v(PRT) \geq \frac{v^2}{2(a + Gg)} \tag{2.1}$$

where X is the distance of the vehicle from the stop line, PRT is the perception-response time, v is the approach speed, a is the deceleration rate, G is the slope gradient of the approach lane and g is the gravitational constant. Hence, the required *critical stopping distance*, X_s is given by:

$$X_s = \underbrace{v(PRT)}_{\text{Reaction Distance}} + \underbrace{\frac{v^2}{2(a+Gg)}}_{\text{Braking Distance}} \tag{2.2}$$

A vehicle positioned nearer to the junction than this critical stopping distance will not be able to stop without encroaching beyond the stop line. It should be noted that X_s is independent of the change interval.

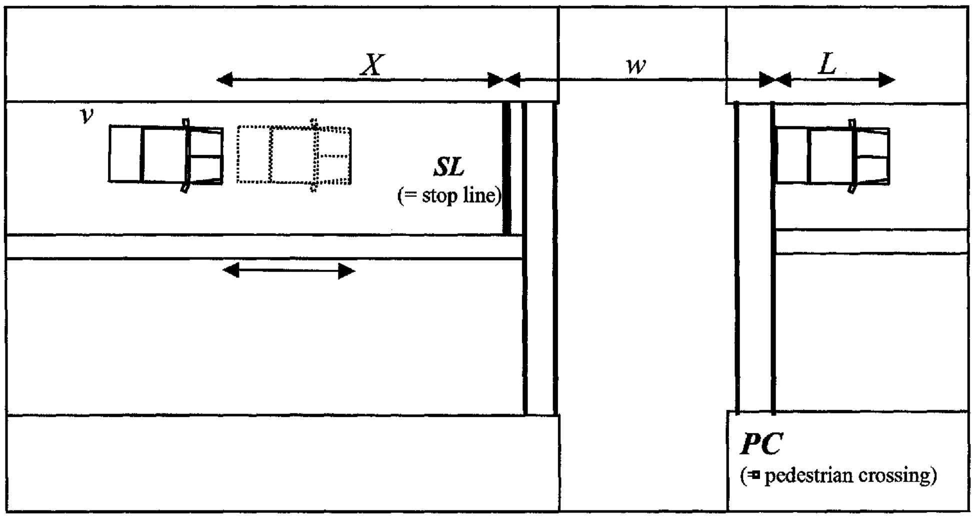


Figure 2.3 **Illustration of the dilemma and option zones** *(Adapted from Liu et al., 1995)*

For a vehicle to proceed and be able to clear the junction area completely before the green appears on the conflicting approach, the following equation is applicable:

$$X + w + L - v(PRT) \leq v(I - PRT) + \frac{1}{2}\alpha(I - PRT)^2 \tag{2.3}$$

where I is the change interval, w is the width of junction and L is the length of vehicle. The LHS of the equation represents the distance to be cleared and the RHS is the distance that can actually be covered at constant speed, v (acceleration $\alpha = 0$).

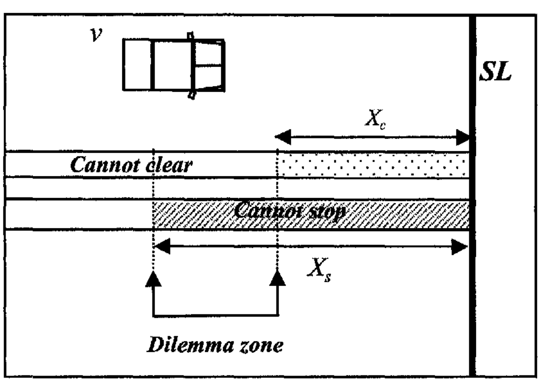
For a vehicle traversing the junction at a constant speed, the furthest distance (known as the *clearing distance*) it can be from the stop line at the amber onset in order to clear the junction area is given by:

$$X_c = vI - (w+L) \tag{2.4}$$

As illustrated in Figure 2.4a, if the stopping distance (X_s) is greater than the clearing distance (X_c), there exists a dilemma zone in which the driver can neither stop nor clear the junction. If the clearing distance (X_c) is greater than the stopping distance (X_s), as shown in Figure 2.4b, there exists an option zone. A *minimum* signal change interval can be found for which a vehicle is just able to stop or to proceed and clear the junction area (at constant speed) by equating the stopping and clearing distances, $X_s = X_c$ such that:

$$I = \underbrace{PRT + \frac{v}{[2(a+Gg)]}}_{Amber} + \underbrace{\frac{w+L}{v}}_{All\text{-}Red} \tag{2.5}$$

Equation (2.5) is adopted by ITE (1982) for computing the signal change interval with a perception-response time of 1 second and a deceleration rate of 3 m/s^2 (10 ft/s^2). The sum of the first two terms of Equation (2.5) allocates the amber interval while the third term determines the red clearance interval. The equation also shows that the amber interval should be lengthened as approach speed increases and should be shortened as approach speed decreases. Some authorities have opted to lower the speed limit instead of increasing the amber duration. It is clear from Equation (2.5) that the change interval is directly dependent on the two driver response parameters of perception-response time, *PRT,* and deceleration rate, *a*.



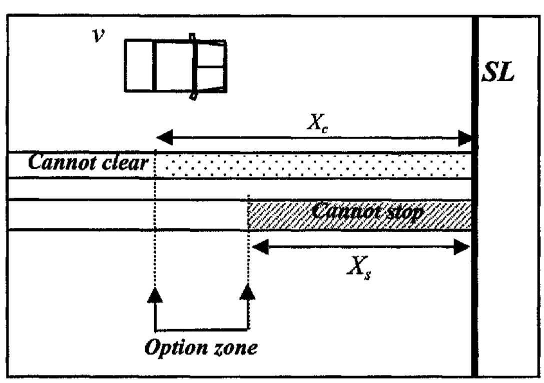


Figure 2.4a Dilemma zone (If $X_c \leq X_s$) Figure 2.4b Option zone (If $X_c \geq X_s$)

(Adapted from Liu et al., 1995)

Another approach in determining variable change interval is by using the stopping propensity of vehicles at the junction. It is based on field observations of the last crossing and first stopping vehicles and does not depend on assumed values of PRT and deceleration rates. Hence, it is thought to be more realistic (ITE, 1985). This method uses a certain desired level of stopping probability to find the corresponding distance away from the stop line. The required change interval length can then be determined by dividing this distance by the operating speed (recommended to use 85^{th} percentile) for that particular junction. However, this method requires extensive and reliable data and is also hampered by the inconsistency of driver behaviour. Consequently, this method is seldom used in practice.

There has yet to be a consensus among traffic engineers as to whether a uniform or a variable signal change interval is more appropriate. Either way, it is essential to understand and consider the driver performance characteristics in design. Hence, in this study, the PRT and deceleration rate are re-examined (noting that a fixed amber duration approach is used in Singapore).

2.3 Determining the driver performance characteristics

The influence of the driver performance characteristics should be recognised in the design of the signal change interval because it is over this interval that drivers have to respond to the signal change, to either stop the vehicle before the stop line or to cross and clear the junction safely. The use of inappropriate design values (PRT and deceleration rate) can potentially affect driver compliance, safety and even junction capacity. The performance characteristics in the PRT and deceleration parameters can also be used for gauging driver response to changes in the road environment, especially at the signalised junctions, e.g. driver response to the red-light surveillance camera enforcement.

2.3.1 Perception-response time (PRT)

The PRT refers to the time interval from the appearance of the stimulus until action for a specified response has been taken. In the context of the signal change interval, the driver's PRT is the time interval from amber onset (taken to be the point at which the amber comes on) to the instant that he is observed to have acted upon a response (to stop/cross). If the driver decides to stop, he will apply the brakes and the onset of the brake lights is taken as having acted upon the stopping response. There is, however, no way to detect the onset of the crossing response (either continue with constant speed or accelerate) unobtrusively and thus PRT can only be found for the stopping drivers.

There have been numerous studies (see Tables 2.3 -2.5) that attempted to develop data on the perception-brake-reaction time or components of it. These studies can be divided into three main groups: laboratory-based simulation experiments, controlled field experiments (alerted subjects) and unobtrusive field observations (Hooper and McGee, 1983). The first group produced simple laboratory-based response times which are not sufficiently realistic to represent real-life situation. Simulators generally have small field of view and hence test subjects experience smaller cognitive load which leads to smaller PRT. The second group involved drivers responding to either a visual or auditory stimulus in an alerted manner. Most of the experiments did not require the driver to make a decision and suffered from the disadvantage of placing the driver under observation which would cause him to act in a more disciplined manner as compared to normal driving behaviour. Moreover, the use of an auditory stimulus (e.g. sound of a horn) could be expected to require less perception time, as compared to a visual stimulus (signal changing from green to amber). Hence, it is rationalised that PRT values obtained from the field in an unalerted manner should be more realistic. In a recent unobtrusive field study by Wong and Goh (2000), a transitional zone (TZ) was developed for differentiating drivers operating under forced-paced or free-paced conditions as they stopped in response to the signal change. The purpose is to exclude those drivers far away from the stop line who have greater leeway in initiating braking action. By selecting drivers under forced-paced braking, a set of driver performance values that is suited for design purpose can be obtained. This is substantiated by the PRT values (see Table 2.5) that are close to the ITE-recommended value of 1 second (at the 85^{th} percentile). There are, nevertheless, some drawbacks of this naturalistic approach: perception-decision and movement times cannot be measured separately and driver demographics e.g. age and gender cannot be recorded.

Table 2.3 PRT values from lab-based simulators

Researchers	Sample size	PRT (s) Mean	Std. dev.	50%tile	85%tile	Experiment Type
Blackman (1960)	-	0.80	-	-	-	Simulated decision study
AASHO (1965)	-	0.64	-	-	1.00 (95%)	Simulated decision study
Demirarslan et al. (1998)	12 (600 runs)	0.49	0.161	0.43	-	Simulated decision study
Warshawsky-Livne and Shinar (2002)*	72 (720 runs)	(0.35-0.43 RT) + (0.16Male, 0.19Female MT)				Simulated decision study

**PRT (mean) is broken down in 2 parts: RT, the perception-response time and MT, the brake-movement time*

Table 2.4 PRT values from field controlled experiments *(from Taoka, 1982)*

Researchers	Sample size	PRT (s) Mean	Std. dev.	50%tile	85%tile	Experiment Type*
Moss and Allen (1925)	67	0.54	-	0.51	0.68	Apply brakes when a gun shot is heard (A)
MIT (1934)	180	0.66	-	0.60	0.80	Response to brake lights of a lead car (A)
Greenshields (1936)	40	0.78	-	-	1.30 (80%tile)	Response to lead car with and without functioning brake lights (A)
Grime (1952)	155	0.71	-	0.61	1.09	Apply brakes when a pedestrian steps off the pavement (A)
Normann (1953)	53	0.73	-	0.70	0.84	Apply brakes when a brilliant light is activated 700 ft ahead (A)
Chandler et al. (1958)	8	1.55	-	1.50	-	Follow a lead car at a safe distance (UA)
Crawford (1962)	8 (650 runs)	0.81	-	-	-	Response to a traffic signal on test track (UA)
Drew (1968)	1000+	0.52 0.62	-	-	-	Apply brake when the stimulus is activated (A)
Johansson and Rumar (1971)	321	0.75	-	0.66	1.01	Apply brakes when a horn sound is heard (A)
Forbes and Simpson (1968)	-	1.78	0.36	-	-	Response to deceleration manoeuvres (US)
Darroch and Rothery (1972)	-	1.5	-	-	-	Car following and using spectral analysis technique
Rice et al. (1976)	34	0.65	-	-	-	Response to a plastic barrel ejected into path (US)
Sivak et al. (1981)	87	1.38	0.56	-	-	Observe from following car, response of subject car to brake lights of lead car (US)
Summala (1981)	815	2.5 (mode)	-	2.5	3.0	Response to unexpected hazard during night-time (US)

**A: Alerted drivers, UA: Unaware of PRT being recorded, US: Unsuspecting drivers*

Table 2.5 PRT values (of traffic signal change) from unobtrusive field observations

Researchers	Sample size	PRT (s)			
		Mean	Std. dev.	50th %tile	85th %tile
Gazis et al. (1960)	87	1.14	0.32	1.12	1.48
Jenkins (1969)	-	1.16	-	-	-
Limpert (1978)	-	-	-	1.04	1.27 (90%tile)
Wortman and Matthias (1983)	839	1.30	0.60		1.80
Chang et al. (1985)	579	1.30	0.74		1.90
ITE (1994)	-	1.00	-		-
Wong and Goh (2000)	132	0.82	0.21		1.02
Goh and Wong (2002) X-Jtn	70	0.84	0.23		1.06
Goh and Wong (2002) T-Jtn	94	0.87	0.22		1.08

A number of past studies investigated the influence of selected factors on the PRT value. Shorter PRT values were associated with driver anticipation, excellent visibility conditions, urgency, younger drivers, and visual focusing on predetermined target (Taoka, 1982; Green, 2000) while female drivers had an average reaction time slightly longer than male drivers (AAA, 1952; Wright and Shephard, 1978). PRT values obtained from unobtrusive field observations indicated that the perception-reaction time decreases as approach speed increases and is longer when the driver is farther away before the stop line (Williams, 1977; Sheffi and Mahamssani 1981; Chang et al. 1984). Studies that included comparisons between daytime and night-time showed that there was generally not much difference in the PRT and drivers tended to have similar performance during day and night (Wortman and Matthias, 1983; Chang, et al., 1985).

2.3.2 Acceleration and deceleration rates

Drivers approaching a junction at the amber onset can be classified into two categories: those trying to stop and those trying to cross. Aggressive drivers are likely to be the ones who attempt to clear the junction and they will accelerate if they perceive that there is not enough time for them to clear the junction at their prevailing speeds. The maximum acceleration rates for passenger cars and tractor-semitrailer over a range of mass/power ratios are given in Table 2.6 for the different running speed ranges. The mass/power ratio is a measure of the ability of a vehicle to accelerate. The lower the value of this ratio, the better is the vehicle's performance, and hence, the higher is the accelerating capability of that vehicle. The accelerating capability (in m/s^2) is also related to the speed of the vehicle (see

Figure 2.5). The lower the speed, the higher the achievable acceleration rate can be. These maximum acceleration rates are seldom used in normal driving. They are the maximum possible acceleration rates that can be achieved by a given vehicle. The acceptable (operating) acceleration rates are usually at around 0.53 m/s^2 to 0.89 m/s^2 at speeds of 52 km/h and above (AASHTO, 1994).

Table 2.6 Maximum acceleration rates (m/s^2) on level roads *(ITE, 1999)*

Vehicle Type	Mass-to-power ratio (kg/kW)	Speed Range			
		32 to 48 km/h	48 to 64 km/h	64 to 80 km/h	80 to 96 km/h
Passenger Car	15	2.4	2.2	1.9	1.7
	18	2.0	1.8	1.6	1.4
	21	1.7	1.5	1.3	1.2
Tractor-semitrailer	61	0.6	0.5	0.3	0.2
	122	0.4	0.2	0.2	0.1
	182	0.3	0.2	0.1	-
	243	0.3	0.1	-	-

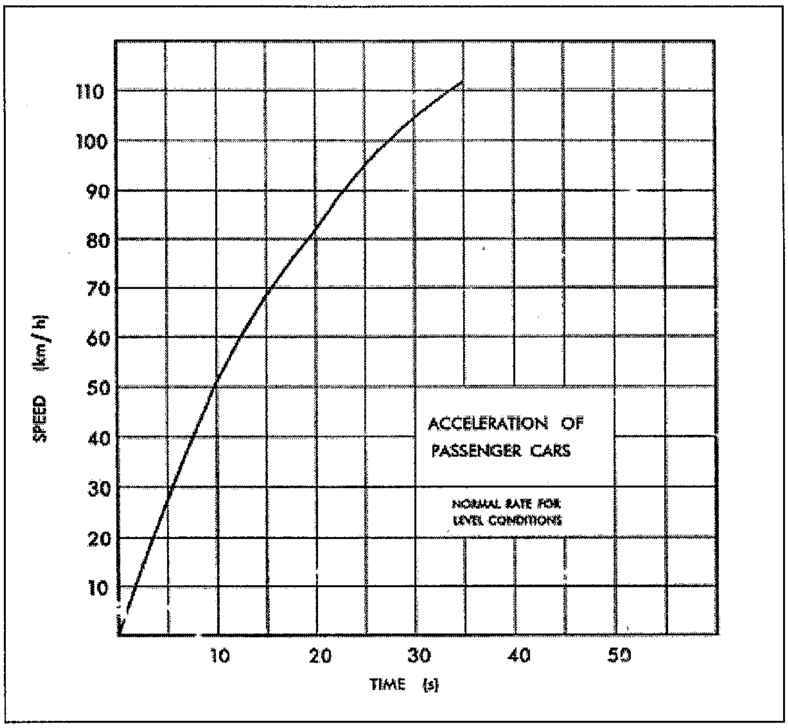


Figure 2.5 Acceleration curve for passenger vehicles *(AASHTO, 1994)*

On the other hand, defensive drivers are more prepared to stop for the traffic lights and may even approach the junction at a lower speed. To slow down a vehicle (except for a motorcycle) and bring it to a complete stop, one has to release the accelerator and step on the brake pedal (usually with the same foot). Upon releasing the accelerator, some deceleration (about 1 m/s^2 at speeds of 100 km/h or higher) occurs as a result of the retarding effect from the resistance to motion and the engine compression forces, a process also known as engine braking (ITE, 1999). It is important to note that the likelihood of drivers relying on engine braking to slow down their vehicles increases as the time gap to the stop line increases. However, for design purposes, researchers usually calculate the deceleration for vehicle brakes only (a more conservative approach). ITE had recommended the use of 4.58 m/s^2 (or 15 ft/s^2) as the deceleration rate for determining the change interval length. This was subsequently reduced to 3.05 m/s^2 (or 10 ft/s^2) in 1983 after re-evaluating the deceleration rate using more extensive field data. Many other jurisdictions and researchers also use ranges that are closer to the latter value and they are summarised in Table 2.7.

Table 2.7 Summary of deceleration rates

Study	Deceleration Rate		Experiment
	m/s^2	ft/s^2	
Gazis et al. (1960)	3.05	10	Cited in ITE (1985)
Williams (1977)	2.0 – 3.0	6.5 – 9.7	Cited in Bissell and Warren (1981), Wortman and Matthias (1983)
Stimpson et al. (1980)	3.05	10	2 four-legged jtns under short and long signal timing, and dry and wet conditions
Sheffi and Mahamssani (1981)	1.52 – 3.35 (for 25 – 55 mph)	5.0 – 11.0 (for 25 – 55 mph)	Isolated signalised jtns with speeds over 35 mph
Wortman and Matthias (1983)	2.14 – 3.93	7.0 – 12.9	6 signalised jtns with varying change intervals with night filming for 2 jtns only
Chang et al. (1985)	2.90	9.5	11 signalised jtns with varying jtn widths, speed limits, change intervals, and controller types, 1035 through and 579 stopping veh. under day and night, dry and wet, and peak and off-peak conditions
ITE (1982)	4.58	15	(Not reported)
ITE (1994)	3.05	10	(Not reported)

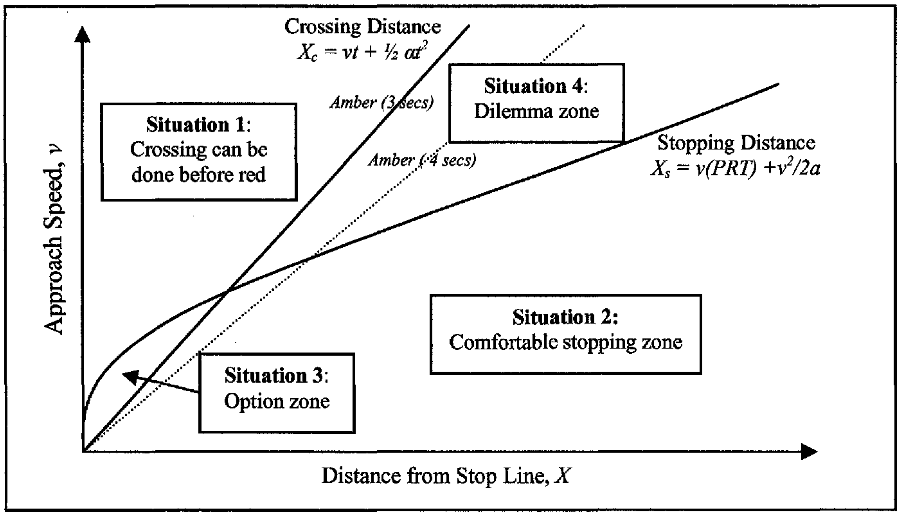
Attempts have also been made by researchers to find relationship between selected factors and the deceleration rates. Chang et al. (1984) found that deceleration rate was affected by approach speed, distance and PRT but the relationship was not a strong one.

2.4 The stop vesus cross decision

Drivers when approaching a signalised junction at the onset of amber are faced with one of four possible situations:

1) Expected to be able to cross the junction before red (usually when vehicle is quite close to the stop line),
2) Expected to be unable to make it pass the stop line before the red appears (usually when vehicle is quite far away from the stop line),
3) Able to either cross the junction safely or stop comfortably before the stop line (option zone),
4) Can neither cross safely nor stop comfortably before the stop line (dilemma zone).

The four different situations are derived based on deterministic design values. Figure 2.6 depicts the situations in a graphical manner. It is usually assumed that deceleration takes place at around 3.05 m/s^2 (10 ft/sec^2) for the case of a stopping vehicle and if crossing, the driver will traverse the junction at a constant speed. However, these zones only describe what a driver can do but they do not or cannot describe what a driver will actually do, not even in the stochastic sense. Thus, these zones can only be used as tools of diagnostics or analysis, but they cannot describe the actual behaviour of drivers.



X_s: Stopping Distance, X_c: Crossing distance from stop line, v: Approach speed, α: Acceleration rate, a: Deceleration rate, PRT: Perception-response time, t: Time from amber onset. (In this case, α = 0, because it is assumed that crossing is done under uniform speed, hence crossing distance is a straight line)

Figure 2.6 The four situations at a signalised junction *(Adapted from Allos and Al-Hadithi, 1992)*

The first situation basically describes that drivers very close to the stop line will cross the junction unless they are delayed by their own decisions and actions or are obstructed by the vehicles in front. The second situation indicates that those very far away from the stop line will have enough time to stop at the stop line unless they deliberately want to run the red. Most researchers are concerned about the two remaining cases where the drivers in the option zone or dilemma zone have to make a decision to cross or to stop. In the option zone, accidents occur when conflicting decisions are made by different drivers. This happens when the leading driver decides to stop while the close-following driver decides to cross and this will result in a rear-end collision. For drivers caught in the dilemma zone, since they are too close to the stop line to make a comfortable stop but yet too far to clear the junction before red (within 3 seconds for most cases in Singapore), they are faced with two unpleasant choices: either to brake harshly and risk coming to a stop beyond the stop line or to accelerate and risk crossing the stop line after red. The usual practice of designing the change interval is to minimise the risk of an accident created by the crossing decision (the more severe right-angle collision) by increasing the amber period. However, this will increase the rear-end collision problem due to the attendant increase in the option zone.

2.4.1 Stopping probability function

The idealised situation in change interval design is the case where the approach can be partitioned into two distinct zones: a crossing zone and a stopping zone (Mahalel and Zaidel, 1985). The probability function of stopping is then a step function as depicted in Figure 2.7. This would mean that all drivers at a distance shorter than a away from the stop line at amber onset will proceed and cross whereas those further than a will stop. In this idealised situation, there will be no rear-end collision as there is a clear partition between those who are going to stop and cross. The number of right-angle collisions can then be minimised by choosing an appropriate change interval length that allows drivers at a distance shorter than a away from the stop line to clear the junction. However, this idealised situation can never happen in real life because driver decisions, like many other human characteristics, are not discrete and deterministic, but continuous and probabilistic. There has been a fair amount of attempts to describe this probabilistic stopping behaviour since early days (Webster and Ellson, 1965; Chang et al., 1985) and the probabilistic nature of the decision-making is represented by Figure 2.8.

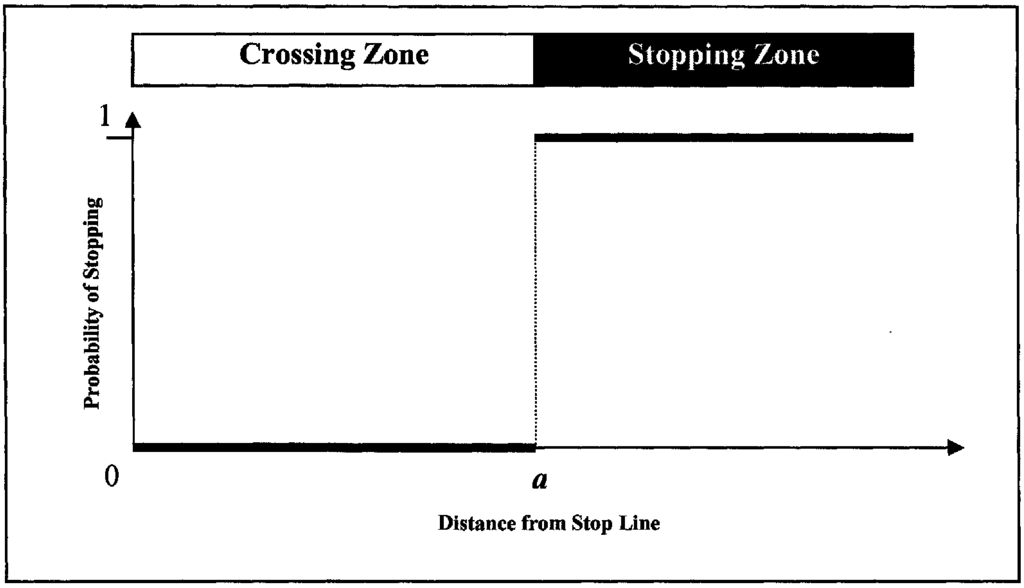


Figure 2.7 **Idealised probability function** *(Mahalel and Zaidel, 1985)*

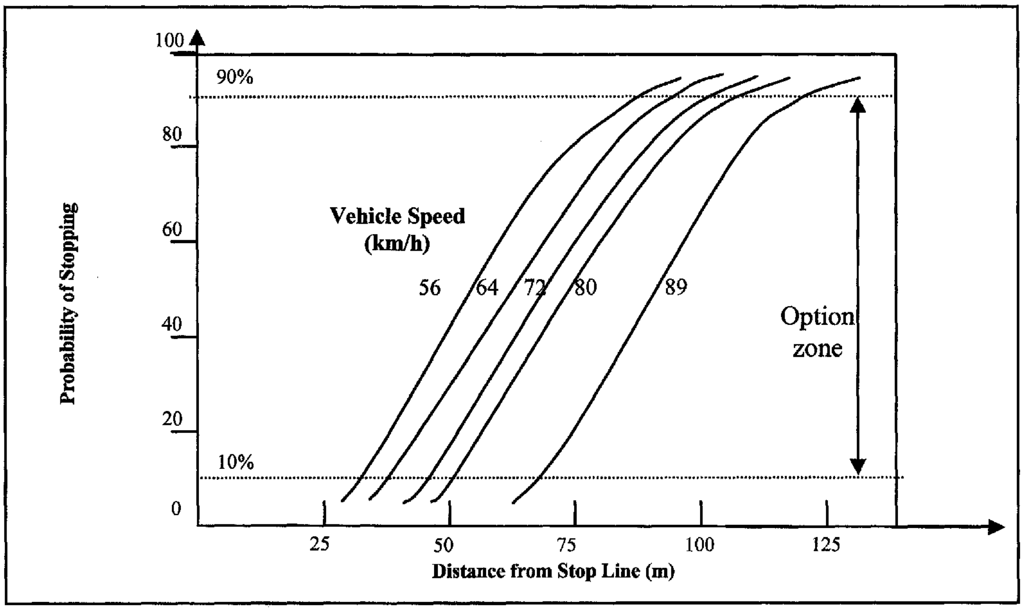


Figure 2.8 **Probability of stopping** *(Adapted from Zegeer, 1977)*

Figure 2.8 represents a stopping probability (stochastic) function for given approach speeds at different distances from the stop line. One can easily find from the function the stopping probabilities of various combinations of approach speed and distance from the stop line. The most problematic zone of a junction approach is when both crossing and stopping probabilities are 0.5. Drivers in this zone exhibit maximal contradictory decisions and thus find themselves subjected to the highest risk of rear-end collisions. It is possible to define different ranges of the probability function as the indecision zone (for example, 40%-60% stopping probability). However, the indecision zone is traditionally defined as the portion between the 10th and 90th percentiles of the stopping probability function. In this indecision zone, there is bound to be some degree of conflicting decisions and rear-end collisions are thus likely to occur. To reduce the likelihood of rear-end collisions is tantamount to minimising the extent of the indecision zone. The upper tail of the probability function indicates the level of red-running and the propensity of right-angle collisions. Thus, by looking at the profile of the stopping probability function, one can assess the performance of the designed signal change interval. For example, a good traffic signal type would be one that minimises the indecision zone and has an upper tail as close to the asymptote of 1 as possible, that is, one that has a probability function as close to the idealised step function as possible.

There are many factors other than speed and position of the vehicle from the stop line that influence the stop versus cross decision-making process. They include driver's motivation and attitude, the amount of predictability of the situation (whether the traffic signal is (not) going to change indication soon), an estimate of the consequences of not stopping (likelihood of running red and getting a fine or of getting involved in a conflict with other road users) and the estimate of the consequences of stopping (discomfort, time wasted, likelihood of a rear-end collision).

2.4.2 Modelling driver decision-making at traffic signals

The outcome of decision-making at the traffic signals is inevitably a case of dichotomous or binary stop versus cross response and thus modelling by means of ordinary linear model is not suitable. A number of researchers, despite the complicated decision-making process, have made serious attempts using various methods to shed light on the processes underlying driver behaviour at the signalised junction while using a limited number of factors (typically speed and distance).

Probit regression model

This is one of the methods used to analyse binary response data. It has a cumulative normal distribution which follows a S-shaped curve for the regression relationship between the probability of the event occurring and its predictors (Harrell, 2001). However, it involves cumbersome calculations and there is no natural interpretation of its regression parameters (for example, one unit increase in its predictor is interpreted as the standard deviation increase of the estimated value in the predicted probit index).

Discriminant analysis

Discriminant analysis (DA) is a technique for classifying a set of observations into predefined classes, based on a set of variables known as predictors or input variables. The linear model of the form $l = b_1x_1 + b_2x_2 + ... + b_nx_n + c$ is built based on a set of observations (training set) for which the classes are known and is then used to predict the class of a new observation with an unknown class. Allos and Al-Hadithi (1992) used DA to model decision-making process with factors that were thought to influence the process. The modelled factors included speed, distance from stop line, number of arms of the junction, length of amber interval, ratio of secondary traffic flow to main traffic, traffic police surveillance, percentage of green time to cycle time and vehicle type. The best relationship was found by modelling all the variables except the last three. DA is commonly used if the dependent variable is dichotomous, but it is being replaced by logistic regression because the latter approach requires fewer model assumptions, is statistically more robust, and is easier to use and understand.

Logistic regression

The logistic regression is suitable, and is also easier, in fitting relationship between the dependent and independent variables if the former is binary or dichotomous (Hosmer and Lemeshow, 2000). Chang et al. (1985) used the logistic regression to model the probability of stopping or crossing as a function of approach speed, distance and time from the stop line. It was found that the first important variable is time, followed by distance and then speed. However, when distance and speed were entered, time became insignificant, hence the final model was reduced to include only distance and speed with 80 percent accuracy in predicting the responses of stopping and crossing. The grade and junction width variables were also added to the model at the later stage.

Recently, Goh (2003) used the logistic regression which included additional explanatory variables (vehicle groups, camera, opposing risk, and lane). Lum and Wong (2001) developed a data logging system for inductance loop detectors suitable for automated data collection of driver movements at the junction in an unobtrusive manner and subsequently used logistic regression to model the relationship of the stop versus cross action with a series of site and operational variables (Lum and Wong, 2002).

2.5 The study environment

The driving and road environment for which this research was conducted is highlighted in order to provide a better perspective to the study.

2.5.1 Driving in Singapore

In Singapore, a prospective driver is required to undergo a series of theory and practical tests in order to obtain a Class 2B licence (for motorcycle with engine capacity not exceeding 200 c.c.) or a Class 3 licence (for motorcar of unladen weight not exceeding 2500 kg). The legal age for applying Classes 2B and 3 licence is 18 and 21 years, respectively. A Class 3 licence is a pre-requisite in qualifying for a heavy vehicle class licence (for omnibuses and heavy motor vehicles exceeding 2500 kg). The theory tests for a Class 3 licence involve two stages, namely Basic Driving Theory Test (BTT) and Final Driving Theory Test (FTT). BTT is to test the learner driver on the basic knowledge on driving such as rules and regulations, traffic signs and signals etc. whereas the FTT aims to enable the learner to master the correct driving technique, and understand safe driving method as well as the mechanism of a car. After these two tests have been satisfactorily completed and coupled with adequate driving practices under the supervision of a certified driving instructor, he can then apply for the practical driving test which he needs to pass within two years of passing FTT. The practical test consists of manoeuvring the vehicle in specially constructed course such as bended curves, hills etc. and on-the-road driving which tests the learner on awareness of other road users and traffic rules. A driving licence is then issued upon satisfactory performance as judged by a qualified examiner. A newly-qualified driver is also required to display a mandatory probationary-plate on the vehicle during his first year of licensure.

For a foreigner (with permit to reside in Singapore for more than 12 months) or a Singapore permanent resident who wishes to drive in Singapore, he is required to take a local Basic Theory Test in order to convert his foreign driving licence to a Singapore driving licence (within 12 months from his first day of entry into Singapore). This is to familiarise non-local licence holder with Singapore's Highway Code. For Singaporeans, the foreign driving licences obtained in other countries are usually not recognised unless they have obtained the licence for more than six years while residing overseas.

Drivers upon reaching 65 years old are required to submit a certificate of medical fitness to the Traffic Police for re-licensing if they wish to continue driving on the road, otherwise they have to surrender the licence to the Traffic Police. Non-compliance shall result in a fine up to $1000 and/or imprisonment of not more than 3 months (AAS, 2002; Traffic Police, 2003).

Singapore operates the Driver Improvement Points System (DIPS), which was implemented by the Traffic Police in March 1983, to identify high-risk motorists or habitual offenders and stop them from driving for a specified period of time (Traffic Police, 2002b). This not only serves as a monitoring scheme for the Traffic Police but also for the drivers themselves. The DIPS allows a driver to accumulate less than 24 demerit points within 24 months before he becomes liable for a driving suspension. Anyone suspended from driving for a year or more has to re-sit both the theory and practical driving tests if he wishes to qualify for a driving licence again. Under the DIPS, the penalties (demerit points and fines) of some of the offences made at a signalised junction are given in Table 2.8. A driver who has a clean driving record for a certain duration (e.g. 3 years) will be awarded an official certificate that allows him to get a percentage waived from insurance or discount on petrol as an incentive.

Table 2.8 Penalties of offences at a junction *(AAS, 2000a and 2001; Traffic Police, 2002a)*

Offence	Penalties	
	Demerit points	Fines (S$)
Hindering flow of traffic	4	
Failing to give way to oncoming traffic at a controlled junction	4	$130 (LV*) $160 (HV)
Forming up incorrectly when turning left or right	4	
Failing to conform to traffic light signals	12	$200 (LV) $230 (HV)
Speeding (exceeding speed limits from 20 km/h)	4-24	$130 - Prosecuted in court (LV) $160 - Prosecuted in court (HV)

**LV refers to light vehicles that include cars, motorcycles, vans, pickups, etc.*
HV refers to heavy vehicles that include lorries, trucks, trailers, buses, etc.

2.5.2 Traffic signals in Singapore

In Singapore, there are 580 signalised (mid-block) pedestrian crossings and 1250 signalised junctions as of early 2004 (LTA, 2004). The amber period of the traffic signal is characterised by a fixed duration of 3 seconds (except for around 20 junctions where the amber interval operates at 4 seconds). The amber period is followed by a brief period (0.2 to 2 seconds) of all-red clearance depending on the type of succeeding phase (see Appendix A for detailed illustrations). Then, the traffic lights for the movement receiving right-of-way turn from red to green with no intermediate amber stage. A noteable feature of the signal system is that right-turning movements (right-hand drive on the left side of road is applicable in Singapore) are permitted during the circular green-light phase for straight-through movements. In other words, under circular green indication, right-turning vehicles are allowed to filter through, so long as there are adequate gaps in the conflicting straight-through vehicular and pedestrian traffic. The circular green is often succeeded by a protected phase (a green arrow) which permits only right-turning movements while the straight-through movements are stopped by the red-circular light. The rationale behind the permissive right-turn on circular green is to maximise capacity while not unduly compromising safety.

Recently, the Land Transport Authority (LTA) introduced the Red and Amber (R&A) Arrow Lights Scheme in January 2000 (LTA, 2002) which expressively forbids drivers to turn (filter through) on circular green even if there are gaps in-between the through opposing flow. It is used when either the straight-through traffic is so heavy that there is hardly any gap for the right-turning vehicles to filter through or the right-turning volume is so large that the usual green arrow is insufficient for most of the vehicles to clear. The red arrow indicates that the right-turns are strictly prohibited both during the circular green-light phase and the amber phase and drivers are to stop behind the stop line till the green arrow shows up. This scheme is intended to not only enhance road safety but also provide more variations in traffic light operations, thereby improving traffic flow. In Australia and New Zealand, this scheme has been found to be effective at junctions with heavy traffic and complex flow characteristics.

As a measure to curb red-running phenomenon, the Traffic Police introduced the red-light surveillance cameras (RLCs) under a five-year implementation programme starting in August 1986 (see Table 2.9). A total of 240 pairs of camera and flash-light housings were installed at 165 signalised junctions over a 5-year period. Subsequently, more RLC housings were selectively installed at other junctions, amounting to a total of 231 sites with RLC system as of 2001. Cameras are deployed on a rotation basis among the housings since there are comparatively fewer cameras than housings.

There are many other measures that the authority has carried out to enhance safety at junctions. One broad-based measure involves enhancing the visibility of the traffic light signals. LTA has carried out a large-scale exercise to replace conventional incandescent bulbs in the traffic signals with Light-Emitting Diode

(LED) signals since October 1999 (AAS, 2000b). The LED light is essentially a

Table 2.9 The 5-year red-light surveillance camera program in Singapore *(Ng, 1996)*

Phase	Completion Date	Number of Junctions treated				Number of housings	Prevailing housing/camera ratio
		T-Jtn	X-Jtn	Multi-legged-Jtn	Total		
I	Aug 1986	6	10	1	17	29	0.97
II	Apr 1987	6	16	1	23	40	2.3
III	Apr 1988	11	17	-	28	48	3.9
IV	Mar 1989	16	17	-	33	45	5.4
V	Apr 1990	37	31	1	69	78	8.0
All	1990	76	91	3	170*	240	8.0**

* *The actual number of junctions treated is less than 170, as housings were added to some of the existing RLC junctions in subsequent phases.*
****The number of cameras was doubled in 1992, from 30 to 60 units*

monochromatic light that is made up of a multitude of tiny bulbs that give out excellent clarity and brightness. Besides, it does not require a filter to obtain the desired colour and is not affected by the sun-phantom effect. With the extremely high durability of about ten years (compared to 9-18 months for incandescent bulbs) and high energy efficiency, maintenance cost will be cut down in the long run. The LED signals are thus in many ways better than the incandescent bulbs. Full implementation of LED signals was accomplished in mid 2001.

2.5.3 Warning indicators to amber onset

LTA has introduced warning indicators like Advance Warning Lights (AWL) and Green Signal Countdown Device (GSCD) to selected signalised locations (road junction or mid-block pedestrian crossing), in recent years. Both give advance warning to drivers of the impending change of the traffic signal from green to amber. The former provides an analogue warning sign that is located some distance upstream of the signal installation and starts blinking two seconds before onset of amber whereas the latter is installed on the signal head and provides a quantitative countdown of time left (from 9 seconds down).

The AWL was first installed on 8th April 2000 and feedbacks on its operation at about 20 different locations had been very positive (The New Paper, 2003). The statistics on the number of summons issued at one of the sites showed that the number of signal-related infringements had dropped from 98 to 19 within two years. The before-and-after accident and violation statistics for other sites are being studied in a follow-up research (Than, 2004) for which the results shall be available in year 2005. There are presently (as of June 2004) a total of 31 sites with AWL. Since the AWLs are usually employed on the approaches at bends, crests or at junctions with physical obstructions, a detailed field study of this device is methodologically difficult.

The GSCD which was activated on 19 January 2003 at the junction of Rochor Road and North Bridge Road was installed for a trial period (LTA, 2003). It thus provided an opportunity to conduct a before-and-after study into the effect of the single GSCD installation which is presently (as of June 2004) still in operation. Several Asian countries like China, Myanmar, India, Malaysia and Thailand are already operating some forms of the green signal countdown device, but the literature on the impacts of GSCD on driver behaviour is very sparse. Thus, a before-and-after study of the signal countdown device (Yap, 2004) is presently in progress and should provide interesting findings.

2.6 Chapter summary

The road transportation system comprises three elements – the human, the vehicle and the road. It is the 'human' element that controls or reacts to the events on the road, hence maintaining the equilibrium among the three. Knowledge of the driver needs, capabilities, motives and goals, his limitations and how he perceives the road and traffic environment is thus of vital input to traffic engineers. Such knowledge can allow an understanding as to why accidents happen and how road user behaviour can be guided to enhance road safety. In this chapter, the numerous human traits and limitations were highlighted.

When on the road, a driver is faced with many occasions of stopping at the junctions where conflicting traffic streams meet. Traffic signals are often used as a form of traffic control. However, there are some drivers who have difficulty in coping with it, especially during the signal change interval.

Many researchers have tried to improve on the change interval design by investigating the two important design parameters – perception-response time and deceleration rate. The studies can be divided into three main groups: laboratory-based simulation experiments, controlled field experiments and unobtrusive field observations. The first group often produced data that are not realistic enough while the second group involved drivers' response to either auditory or visual simulus in an alerted manner. Hence, it is argued that the performance parameters obtained from field observations in an unalerted manner should be more realistic. However, past studies by many researchers were unable to produce parameter values that are close to the design values recommended by ITE (PRT of 1 second and deceleration rate of 3 m/s^2). The use of a transitional zone concept by Wong and Goh (2000) to select forced-paced stop/cross drivers for determining PRT has found the field-observed 85^{th} percentile PRT value and mean deceleration rate to be close to the design values. However, the sample size in Wong and Goh's study was rather small. It is therefore important to collect more field data to validate the design values which also serves to provide a better understanding of the performance characteristics pertaining to driver response to the signal change.

Another issue that was discussed focused on driver's decision-making at the signalised junctions. The stopping probability function can be used as a stochastic approach in representing the variability in driver's decision-making in response to the signal change. Statistical modelling can also bring insights about the various factors involved in the decision-making process. Such knowledge can be useful in understanding accident occurrences at the junctions.

The red-running phenomenon, which is a major problem at signalised junctions, was also discussed. It is clear that red-running violations are related to driver's decision-making and the performance characteristics.

Chapter 3 Data collection and reduction

This chapter first introduces the accident and red-running violation databases. This is followed by an explanation of the experimental design in the observational study. The methods of field data collection and data reduction employed in this study are then described. Lastly, an account is given on the perception survey.

3.1 Accident database and statistics

Good road traffic accident (RTA) records can shed relevant information about driver behaviour on the road, hence it is useful to examine the RTAs. In Singapore, any RTA that involves injury or death within 30 days of the accident should be reported and is investigated by the Traffic Police. Details of each accident case are first recorded on the Accident Data Forms which comprise three parts: General Data, Vehicle/Driver/Passenger Data and Pedestrian Particulars. The details are then verified before storing in computer files, which have been archived since 1985. The data forms were revised in mid-1991 resulting in slightly different formats thus the two data series require appropriate reconciliation if used together. For example, the earlier series included an item as to whether a junction is signalised but this item was subsequently replaced by whether a junction is installed with a surveillance camera. Such a change makes it rather difficult to ascertain whether a junction is signalised or not at the time of the accident event. However, as the emphasis of this study was on the junctions, the signalisation status of the junctions in the later series was determined by matching the accident sites with LTA junction control data.

RTAs that involved property-damage only (PDO) are not required to be reported to the Traffic Police and are often unreported, hence the database for PDO accidents is incomplete. Analysis was thus based on casualty RTAs which were analysed in some detail as an objective of this study. The analyses covered RTAs over the period 1985-2002. The scope of analysis was related in some aspects to an earlier joint research project (NTU-Traffic Police) on the overall characteristics of RTAs for the road transportation system of Singapore (Wong et al., 2000).

3.2 Red-running violation statistics

Apart from the computerised accident database, some amount of red-running violation data were obtained from the Camera Unit of the Traffic Police Department. These data were manually extracted by viewing the red-running violation photographs taken by the red light cameras (RLCs). The RLC is vehicle-actuated starting at about 0.5 seconds after the onset of red. Upon activation by a red-running vehicle, two consecutive photographs are taken 1 second apart by the camera unit installed inside the housing that is located either at the median or the kerb of the road. The exposed films, after developing, can be viewed with a photo viewer. Details such as the date and time of the offence and the time after red are imprinted onto the photographs. Additional information like the vehicle type, the presence of adjacent vehicles, and the surrounding features of the junction can also be identified from the photographic records. Some violation data were coded for the 1999-2001 period involving 13 selected approaches in residential areas: 7 at X-junctions, 4 at top of T-junctions, and 2 at middle of T-junctions (Lee, 2001; Ding, 2002).

3.3 On-site observational study

A substantial part of the present study covered on-site observational work which provided information about on-road behaviour of drivers as they approach the signalised junctions during the signal change interval.

3.3.1 Experimental design

The risk each driver is exposed to at different types of junction approaches varies because of the different site configurations (layouts). For example, at the top approach of a T-junction (see Figure 3.1), it is hypothesised that straight-through driver (A) tends to red-run more often than at other types of junction approaches since there is no risk of opposing right-turning vehicles from the opposite (middle of T, hereafter refer to as mid-T) approach and any opposing movement comes only from the bottom approach. At mid-T approach and at X-junction, driver C faces collision risk from opposing vehicle (B) filtering across traffic gap, except that for mid-T approach, there is no blockage of view by queueing vehicle(s) (D). The different type of risk faced by the driver at the amber onset is expected to affect his stop versus cross decision. Thus, it is beneficial to investigate how a driver behaves at these different types of junction approaches.

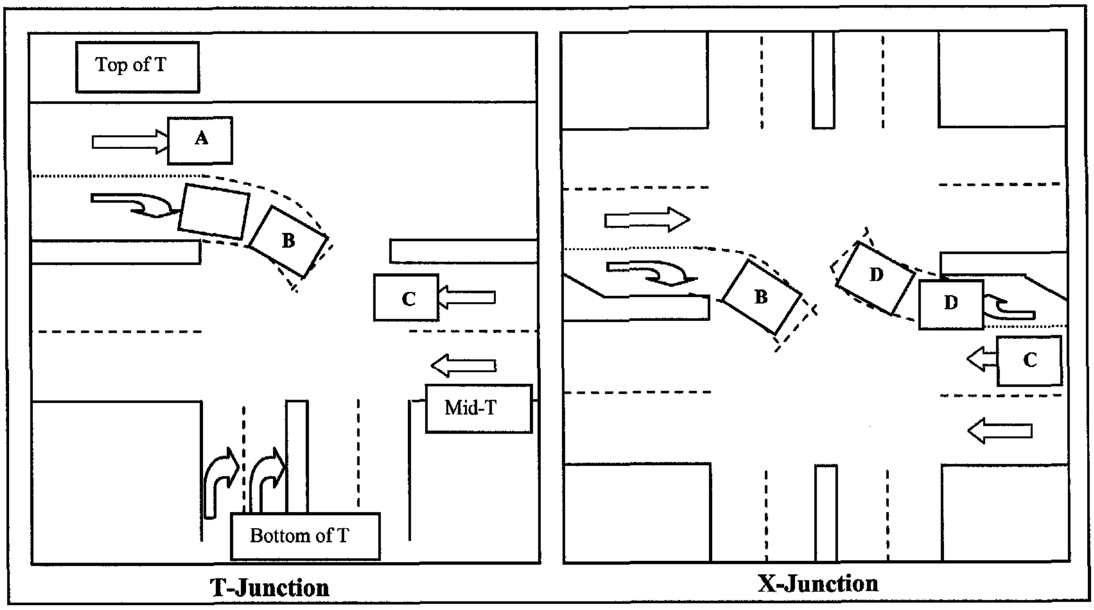
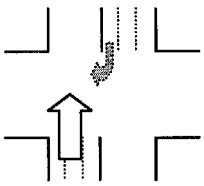
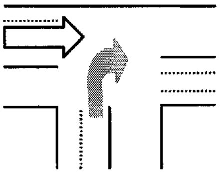
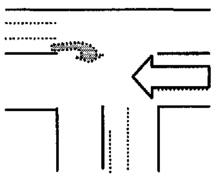
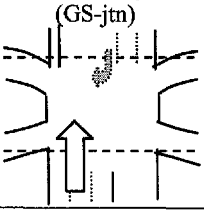


Figure 3.1 **Layouts of T- and X-Junctions**

3.3.2 Site description

In order to facilitate comparison among the different types of risk exposure, a total of 19 approaches at X-, T- and grade-separated (below flyover) junctions (8 at X-junctions, 6 at the top approach of T-junctions, 4 at the mid-T approach and 1 at a grade-separated junction) were studied. Of these, 8 approaches were installed with RLCs. As for approaches without RLC, they were basically located at junctions without any RLC installation. An approach (W2) at a grade-separated junction was studied (in addition to the more common junction types) as it would be interesting to examine how the distinctly different junction attributes (e.g. much larger crossing width, poorer visibility) would affect driver behaviour. The exact locations and the junction layouts can be found in Appendix B. These sites were all located in suburban residential areas. Table 3.1 shows the general characteristics of the study sites. All the junctions had signal phases with an amber interval of three seconds. The road speed limits at these sites were either 50 or 70 km/h, as gazetted in The Road Traffic Act (2002).

Table 3.1 Study site characteristics

Type of junction approach	RLC	Site	Speed limit (km/h)	Number of lanes	
				Straight	Right-turn
Cross junction (X-jtn)	No	W3	50	3	2
		W4	70	3	1
		W5	50	3	2*
		W8**	50	3	1
	Yes	C1	70	3	1
		C2**	70	2	2*
		C3	50	3	1
		C4**	50	2	2*
T junction (T(top)-app)	No	TW1**	50	3	1
		TW4	50	2	1
		TW7	50	3	1
		TW8**	50	3	1
	Yes	TC2**	70	2	2*
		TC3**	50	2	2
(T(mid)-app)	No	TW5	50	3*	NA
		TW6	50	3	NA
	Yes	TC4	70	3	NA
		TC5	50	3	NA
Grade-separated junction (GS-jtn)	No	W2**	70	4	2
					

**One lane is shared*
***Sites also observed for night-time condition*

3.3.3 Data collection

All the sites for this study were selected carefully. The most important factor that influenced site selection was the availability of a vantage point to mount a video camera. Goh (2003) mounted the camera on a tripod positioned on a pedestrian footbridge that was located at an appropriate distance before the stop line. However, there are not many sites with pedestrian bridges positioned at a suitable distance from the junctions. Other means of positioning the camera were tried and this included setting up the cameras along the common corridors of the adjacent high-rise Housing Development Board (HDB) flats. Another approach involved mounting the camera head on an extensible pole that was tied to a lamp-post. Video filming from high-rise buildings was found to be hampered by obstructed views due to trees on the roadside. Elevating the camera head on an extensible pole was found to be feasible and this method could be used to complement sites without (suitable) pedestrian bridges. However, it should be noted that the footages for all sites in this study was filmed from pedestrian bridges. In order to gather data over a sufficient stretch, an observation distance of about 120 metres upstream from the stop line was required. The field of (camera's) view should also contain clear views of the signal heads, stop line and lane markings.

High definition digital video cameras (PANASONIC AG-EZ30E) were used for the field data collection. The digital recording format has an advantage over the conventional analogue format in that the former is able to generate near perfect quality still frames with a discrete recording format of 50 (interlacing) half-frames per second (giving a resolution of 0.02 seconds).

Field data collection was restricted to dry weather conditions because the camera is not designed to operate in a moist environment. The best ambient condition to do filming was found to be during the daytime overcast periods as bright sunshine tends to cast unwanted shadows on the roads. However, the filming was not restricted to daytime. Night-time filming was also done for a number of sites (Sites W2, W8, C2, C4, TW1, TW8, TC2, TC3) in order to study driver behaviour under different ambient light conditions. During night-time filming, the colour scheme in the recording can be "enhanced" by using the "white balance adjustment" feature of the video camera which minimises the influence of artificial lighting (e.g. street lamps) on the colour of the subjects, thus making the images of subjects more visible. The periods of study were also chosen to be for low to moderate traffic flow, that is, under relatively non-congested flow conditions.

3.3.4 Data reduction in the laboratory

Data were extracted from the video records by playing the tapes and projecting the footages onto a white board screen. A distance-graduated mesh was then constructed by drawing transverse grid lines on the white board that corresponded to the lane markings on the road (see Figure 3.2). Each grid position was referenced with respect to the stop line of the junction. The grid lines were used for identifying the positions of the subject vehicle which were entered into a spreadsheet together with the event times. The highly-elevated (about 5 m) perspectives (from the pedestrian bridge) afforded good accuracy in determining the wheel-on-grid position since spacing of grids increases with an increase in the angle of elevation. However, the accuracy decreased for the distant grids (those closer to the stop line). Data extraction typically took about 4 hours for every hour of video recording.

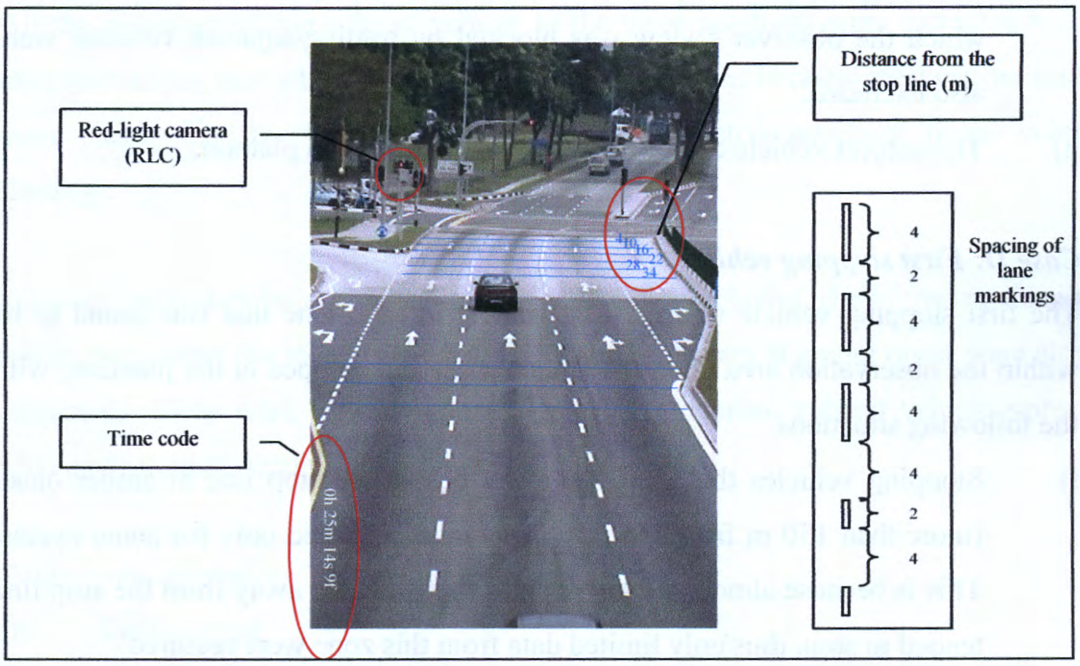


Figure 3.2 Perspective for the data extraction process

The data reduction focused on obtaining data for two groups of vehicles: the last through vehicle and the first stopping vehicle.

Case I: Last through vehicle

The last through vehicle was defined as the last vehicle in each lane that was found to be within the observation area upon the onset of amber and crossed the stop line. This means that if there are a total of three through lanes, the maximum possible number of data points (vehicles) per signal change interval is three. Vehicles with the following situations were considered as valid data points.

i) The vehicle should be located within the observation area during the onset of amber. Vehicles that were very close to the stop line (<30 m) or took less than 2 seconds after onset of amber to cross the stop line were extracted for only some cycles. This is because it was observed that almost all vehicles that were 2 seconds or less from the stop line crossed, thus this zone would not be critical in affecting driver decision-making. As a result, it was decided to reduce the amount of data extraction for fewer of the vehicles positioned in this zone at amber onset in order to conserve resources for collecting more data from the critical zones. In addition, those vehicles for which the observer's view was blocked by trailing/adjacent vehicles were also excluded.

ii) The subject vehicle can be a lone vehicle or part of a platoon.

Case II: First stopping vehicle

The first stopping vehicle was the first vehicle in each lane that was found to be within the observation area upon the amber onset and stopped at the junction, with the following situations.

i) Stopping vehicles that were far away before the stop line at amber onset (more than 130 m from the stop line) were extracted only for some cycles. This is because almost all the vehicles that were far away from the stop line tended to stop, thus only limited data from this zone were required.

ii) The subject vehicle can be a lone vehicle or part of a platoon.

For each subject vehicle, three positions were recorded.

a) Vehicle's distance (from stop line) and time at the *onset of amber*

b) Vehicle's distance and time at a position about *12 m before* the position at amber onset

c) Time when vehicle's rear wheels *crossed stop line* (for a through vehicle) / distance and time at onset of *brake lights* (for a stopping vehicle)

Positions (a) and (b) were required to determine the distance from the stop line and the initial approach speed of the subject vehicle at the onset of amber. The distance and speed of the subject vehicle at the onset of amber have been reported to greatly influence the stop versus cross decision. A driver who is travelling with a high speed and/or is close to the stop line at amber onset is more likely to cross than one travelling at a low speed and/or is far away from the stop line.

Position (c) was for calculating the actual time and speed of crossing (for through vehicle) and the PRT, deceleration rate, braking distance and speed (for stopping vehicle).

All the distances of the subject vehicle in the three positions were extracted with reference to the rear wheels. The rear wheels were used because they can be seen more clearly than the front wheels (a rear-on perspective was used in the video filming).

For each valid data point (either through or stopping vehicle), the following details which may affect the stop versus cross decision of drivers at amber onset were also extracted. They were basically divided into 3 categories: subject vehicle status, road environment conditions, and traffic conditions.

Subject vehicle status:

i) Vehicle type

Drivers of different vehicle types are expected to respond differently to the amber signal as influenced by the performance capabilities of the vehicles. Furthermore, light and heavy commercial vehicles observe a maximum vehicle speed limit of 60 km/h or the road speed limit, whichever is lower. Two-wheelers such as motorcycles and scooters are more manoeuvrable than the rest.

The vehicles were coded according to a set of vehicle classifications as shown in Appendix C. These vehicle types were subsequently aggregated under 4 groups namely car, motorcycle, light commercial vehicle (LCV) and heavy commercial vehicle (HCV).

ii) Lane position

Drivers in the left most lane (kerb lane) and the centre lane are conceivably more likely to cross than those in the right most lane (often a shared lane) since they are laterally further away from the opposing right-turning traffic and thus are facing relatively less risk. However, the left most lane comprises mainly slower moving vehicles (e.g. LCV and HCV, in compliance with Singapore's traffic rules) which might thus result in more vehicles stopping by virtue of their slower speeds. Vehicles on the right most lane are not only facing the most imminent risk of collision but also the highest chance of their sight lines being obstructed by right-turning vehicles queued along the same approach (particularly at X-junctions). The greater uncertainty involved in judging whether an opposing right-turning vehicle is going to filter across may cause some drivers to make a stop decision instead.

The lanes in which the subject vehicle entered and left the observation area were noted. Regardless of the total number of lanes, the left most lane was denoted the 'kerb lane' and the ones on the right (lane(s) with right-turning movements, shared or otherwise) were denoted 'right-most approach lane(s)'. The remaining lanes were denoted as the 'centre lane(s)' (see Figure 3.3).

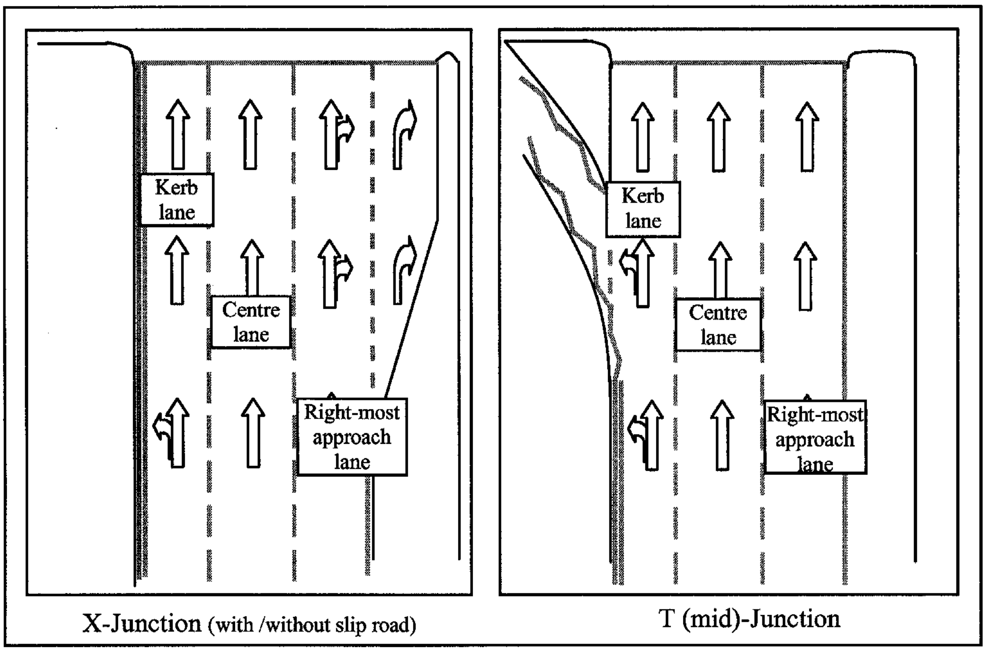


Figure 3.3 Lane position

Road environment conditions:

i) Geometry of the junction

Junction width (minor or major road), number of lanes, and orientation of the lanes, etc. can influence the amount of risk perceived by a driver and thus affect his decision to cross or to stop. For example, a driver from a minor road approaching a major road at a cross junction is expected to be more likely to stop since a longer length of time is required to clear the bigger junction width. In this study, this variable was kept constant by choosing sites with similar junction layouts for each junction type in order to have adequate number of data points for comparison of other factors. The chosen sites were basically the more common junction types in the road network.

ii) Light condition

The reduced visibility during night-time is of interest to researchers as to how the drivers are affected by the ambient light condition. Sufficient data were collected in the early hours of the night (from 7-10pm) at 8 of the 19 daytime sites. It was observed that the traffic volume (see Figure 3.4) for the period between 7-10pm as collected by the Green Link Determining (GLIDE) traffic control scheme, was quite comparable to the traffic volume during when most of the daytime data were collected. Traffic volumes after midnight dropped drastically and hence the flow conditions would not be comparable.

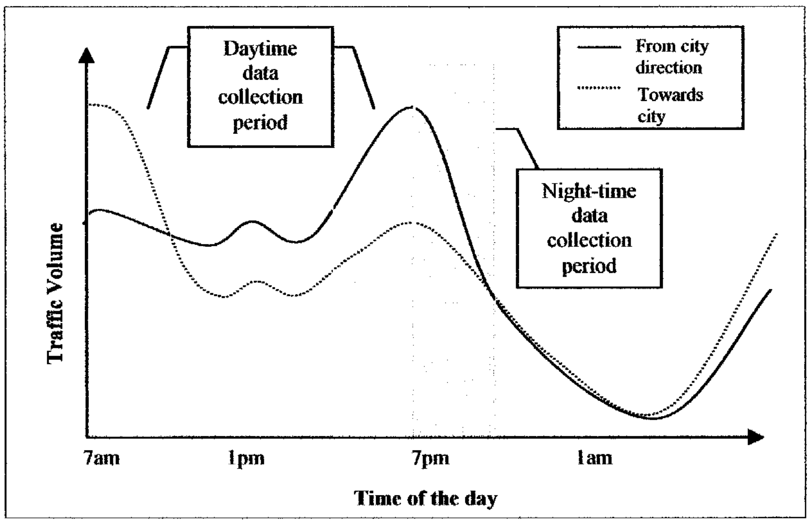


Figure 3.4 Hourly traffic volumes (average profile from GLIDE data)

iii) Presence of red light cameras (RLCs)

The traffic red light surveillance camera is considered to be the most effective deterrent of drivers running the red (Kent et al., 1997; Retting et al., 2003). It was thus reasoned that drivers are more likely to stop at junctions where RLCs are installed. A number of selected sites in this study are installed with RLCs.

iv) Pedestrians

Pedestrians waiting at the refuge islands or side kerbs often commence crossing the crosswalk before the onset of the green man if the junction is clear of approaching conflicting traffic, especially if they are in a hurry. The presence of pedestrians can also influence the decision made by a driver who has to factor in the possibility of the pedestrians attempting to cross. It was hypothesised that the probability of stopping would be higher when there are pedestrians.

A code of "present" was used if pedestrians or cyclists were seen to be waiting either at the left refuge island (or kerb) or at the centre divider, and "absent" otherwise.

v) Presence of cues preceding amber onset

The availability of cues preceding amber onset may alert regular drivers that green is about to end and they have the benefits of "advance warning". However, such cues are only available at certain junction types and (actuated) traffic signal types. More details on this aspect are presented in a later chapter.

Traffic conditions:

i) Other vehicles in the vicinity of the subject vehicle

A vehicle close in front or behind the subject vehicle can affect the stop versus cross decision made by the subject driver as he has to be on his guard against the front vehicle stopping suddenly or the tailing vehicle not wanting to stop. Drivers, upon seeing other vehicles in adjacent lanes stopping or crossing may unconsciously be influenced into deciding whether to stop or to cross. Thus, the presence of surrounding vehicles (front, back and side) of the subject vehicle was also coded. The proximity distance relative to the subject vehicle was classified into 6 categories: A, B, C, D, E, F (see Table 3.2). The coding for "front" and "back" conditions was applicable only to vehicles along the same lane.

Table 3.2 Classification of vehicles' proximity

Code	Situation	Case
A	No other vehicle in approach	Good
B	There are vehicles but are far from the subject vehicle (>4 s)	Good
C	The vehicle is keeping a reasonable distance from the subject vehicle (>2.5 s)	Fair
D	The vehicle is fairly close to the subject vehicle (about 2 s)	Fair
E	The vehicle has a short time gap relative to the subject vehicle (<2 s)	Poor
F	The vehicle is tailgating/ overtaking the subject vehicle or vice versa	Poor

The headway conditions ahead and behind the subject vehicle was also combined for analysis. According to Allsop et al. (1991), drivers are expected to be most likely to stop when they are neither following closely behind (>2 seconds headway) another vehicle nor being closely followed (i.e. free flowing); whereas when they are being sandwiched between two vehicles, they tend to follow through the platoon and hence, are the least likely to stop (Allsop et al., 1991). The proximity relationship between the subject and surrounding vehicles is presented in four scenarios as shown in Figure 3.5.

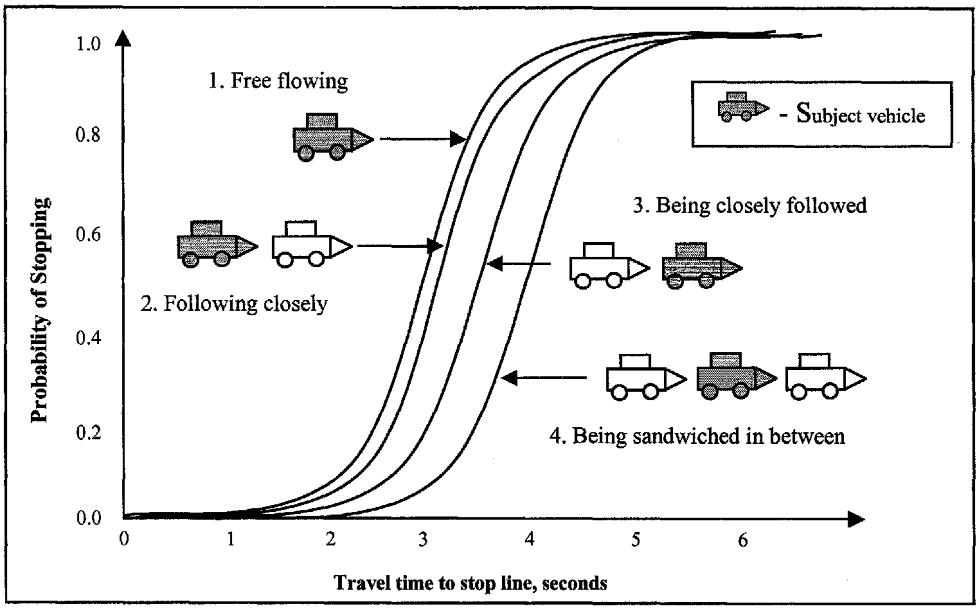


Figure 3.5 Probability of stopping as a function of travel time and proximity of other vehicles *(Allsop et.al., 1991)*

ii) Opposing flow vehicles

The presence and status of the opposing right-turners at a X- or T (mid) junctions are expected to affect the decision of straight-through drivers whether to stop or to cross. A driver proceeding straight across the junction is faced with a higher risk of collision if there is a vehicle awaiting at the opposing right-turn pocket as the latter is permitted to filter across. Right-turning vehicle(s) filtering across, that is, already in the *yellow junction box** at the amber onset may cause some straight-through drivers to slow down or decide to stop when such an interference is judged to have diminished the chance of the latter to clear before red. It should also be noted that at certain junctions, the sightline may be obstructed in detecting opposing right-turning vehicles because of the geometry of the junctions (typically for X-junctions) and/or the presence of other queueing vehicles (typically the "right-most approach lane" vehicles). For these cases, a separate category of "view blocked" was coded. The status of the opposing vehicle was studied and coded as follows (see Table 3.3).

Table 3.3 Classification of opposing vehicle status

Code	Situation of opposing vehicle	Case (applicable to; status)
A	No opposing vehicle in waiting during approach of subject vehicle	X and T (mid) junctions; Absent
B	Vehicle movement constrained by phase change	All T (top) junctions; None
C	Vehicle is waiting behind stop line	Junctions with restrictive right-turn (red-and-amber arrows); Present
D	Vehicle is approaching line of conflict	X and T(mid) junctions; Present
E	Vehicle is waiting close to line of conflict	X and T(mid) junctions; Present
F	Vehicle is moving/has moved into the junction	X and T(mid) junctions: Filtering

The effect of permissive filtering (by opposing right-turn vehicle) on the stopping propensity of straight-through vehicle was studied using the concept of post-encroachment time (PET) (Cooper, 1984). PET is defined as the time difference between the moment an "offending" vehicle passes out of the area of potential collision and the moment of arrival at the potential collision point of the "conflicted" vehicle possessing the right-of-way. In the present case, the filtering vehicle is to wait till there is sufficient gap to make a right turn. Any acceptance of

**area highlighted in a traffic junction to keep traffic flow moving by prohibiting traffic from stopping in the path of crossing traffic, i.e. traffic is not permitted to enter the junction box unless the exit road is clear* short gaps poses a danger to the conflicted straight-through vehicle which has the right-of-way and hence, the filtering vehicle is treated as the "offending" party. To calculate the value of PET, all cases with a filtering vehicle present at amber onset were extracted to obtain the point of time, T_{fil} that the filtering vehicle moved out of the collision area. PET is then calculated using the following equation:

$$\left(d - L + L_{SL,PC} + (N-1) \times l_w\right)/v - \left(T_{fil} - T\right) \qquad (3.1)$$

where d is the distance of the through vehicle from the stop line at amber onset, L is the length of the vehicle from the rear wheel to the front bumper, $L_{SL,PC}$ is the distance from the stop line to the outer limit of the pedestrian crossing (PC), N is the number of exit lanes, l_w is the width of each exit lane (taken to be 3m), v is the approach speed of vehicle at amber onset, T is the reference point of time at the instant of amber (see Figures 3.6 and 3.7).

The PET value was used to classify the opposing vehicle situation either as being a severe conflict (a filtering vehicle with PET≤2.5 seconds) or a moderate to mild conflict (PET>2.5) (Cooper, 1984).

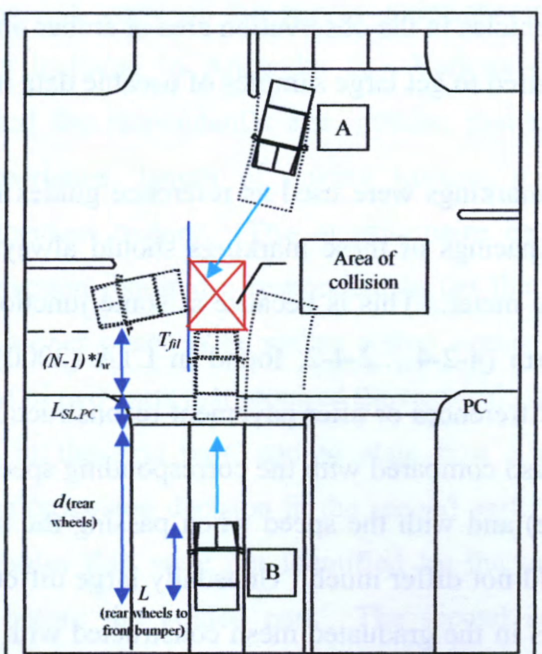


Figure 3.6 Schematic diagram for PET calculation

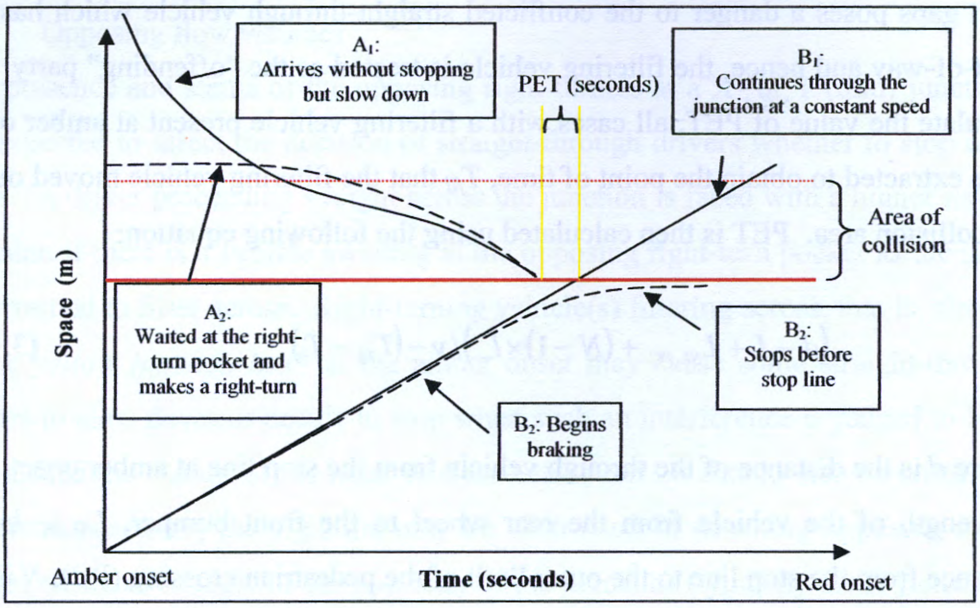


Figure 3.7 **Space-time diagram of vehicle trajectories**

3.3.5 Considerations in data collection and reduction

In Singapore, most of the signalised junctions are under the Green Link Determining (GLIDE) system whereby the coordination of the traffic signals is enhanced and hence facilitating the movement along co-ordinated section. Under non-congested flow conditions (as typical of this study), the co-ordinated traffic streams are able to be discharged smoothly in the early green. This means there are fewer approaching vehicles in the observation area at amber onset. A great amount of time was thus required to get large samples of useable data in this study.

For this study, lane markings were used as reference guides for the distance from the stop line. The spacings of these markings should always be checked on-site using a road distance meter. This is because at some junctions, the markings can deviate from the norm (4-2-4….2-4-2, found in LTA (2000) specifications) as a result of geometric differences or after pavement reconstruction works. The speed at amber onset was also compared with the corresponding speed at brake light onset (for stopping vehicle) and with the speed when passing the stop line (for through vehicle) which should not differ much. Unusually large differences would suggest that there were errors in the graduated mesh constructed with reference to the lane marking spacings.

Another issue that was considered was whether the distance to the stop line should be calculated from the front or the rear axle of the vehicle. For a driver who chooses to cross, the rear of his vehicle has to go beyond the stop line to clear the RLC detector loops while for a driver who chooses to stop, the front bonnet of his vehicle should not cross the stop line. As the emphasis of this study was on driver behavioural response in general, it would be more appropriate to study the driver's performance and decision from where the driver is positioned (i.e. somewhere close to the vehicle front wheel position). Hence, all the distances were transformed from the rear wheel position to front wheel position, using typical wheel-base dimensions (see Appendix C).

3.4 Perception survey

3.4.1 Survey design

A perception study was conducted which served to complement the observational study as some types of information could not be captured from the unobtrusive observational approach. For example, in the field set-up of this study, it was not possible to identify drivers' characteristics such as gender and age. The questionnaire-based survey was aimed at gathering perceptions and attitudes from the general driving population on issues related to driving behaviour at the (signalised) junctions. A copy of the survey questionnaire (both English and Chinese versions) is included in Appendix E. Various driver variables were obtained that included the respondent's age, gender, marital status, occupation, income, driving experience, length of having licence, most frequently-driven vehicle type, and accident history. The questionnaire consisted of four main sections. The first section required a respondent to list the things he as a driver looks out for at the amber onset as he makes a stop versus cross decision. This section was presented in two parts that required the respondent to list the items in an open-ended manner in the first part, and to state how a series of pre-defined variables affected the cross/stop decision in the second part. The open-ended part served to elicit variables that were not identified by the author and hence was intentionally asked before the guided part. The second section of the survey required a respondent to give his likely response to a set of defined scenarios. The third section dealt with the general driving strategies that would be employed by the respondent while approaching a signalised junction. The final section included some questions based on the provision of advance warning to the termination of green signal (e.g. trial implementation of the green signal countdown device).

The survey was targeted at subjects with a valid local driving licence. The emphasis of the survey application was to approach respondents who were judged (by the author) to be willing to spend some time to go through the survey and be conscientious in their responses to the questions. Most of the respondents were engaged more or less by appointment basis. Consequently, the survey sample was not large but the responses were expected to be of high reliability.

3.4.2 Data collection

The perception survey was conducted in two stages namely Stage I and Stage II.

Stage I survey

The Stage I survey was undertaken and administered by Goh (2003) in year 2000 and the sample size was 162. From the literature review and the accident statistics, young drivers were found to be the more culpable group in being involved in road traffic accidents. After examining the profile of the Stage I sample (see Figure 3.8), it was decided that the target sample in Stage II survey should include more young (aged 20-25 years) subjects, to provide sufficient cases for subgroup (young and middle-aged) comparison. This also provided a more balanced representation between experienced and inexperienced drivers. The inexperienced drivers (comprising novices and infrequent drivers) corresponded to subjects less than 25 years old while noting that the legal age of acquiring a driving licence in Singapore is 18 years for motorcycle and 21 years for cars; it is also often the case that those below 25 years old are not economically active or financially well-positioned to own a vehicle. Hence, in the Stage II survey, many subjects were drawn from university undergraduate students.

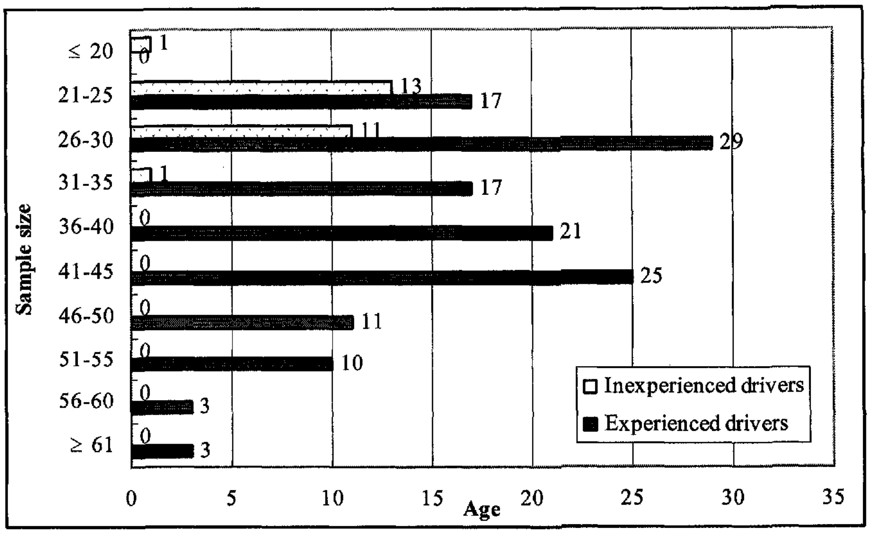


Figure 3.8 **Distribution of inexperienced/ experienced drivers (from Stage I survey)**

The predominant groups of vehicles on the road are cars and motorcycles (see Chapter 5 later). A motorcycle operates quite differently (using combined foot and hand-operated brakes) from a car (using foot brakes only). This provides an interesting scope for comparison between the two groups. Commercial vehicle drivers tend to have a different pattern and degree of usage on the road and a Class 3 licence is set as a pre-requisite for obtaining a HCV licence, thus these drivers are usually more experienced and/or older. However, there would not be sufficient contrasting cases for meaningful comparison (for example, there are very few young but experienced HCV drivers). Hence, it was decided to focus on only the two groups: car drivers and motorcyclists in the survey.

Stage II survey

The questions contained in the Stage II survey questionnaire were basically the same as those in the Stage I survey but with some additional details. There were some minor changes and additions made to the suite of questions. For example, in the first part of the questionnaire under the "Demographic Particulars", the order of questions 4 and 5 (that covered driving experience) was interchanged, in order to improve on the flow of the questions asked. It appeared that some drivers mixed up 'on-road driving experience' with 'length of having driving licence' in the Stage I survey and thus gave inconsistent figures which would affect the analysis later on.

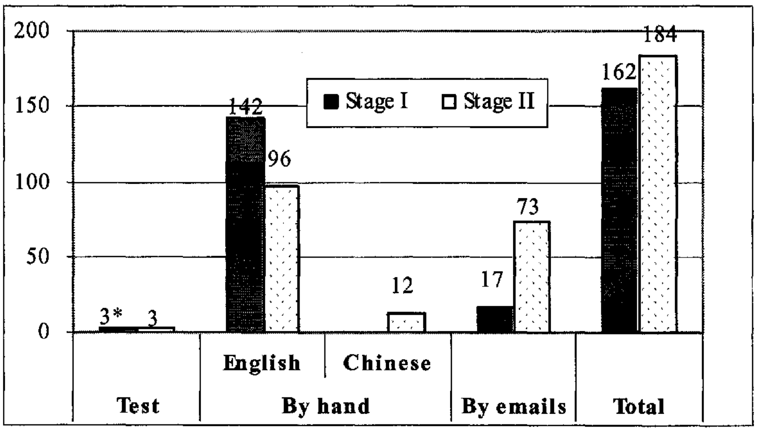
The interchange of questions minimised any ambiguity and led to a 'smoother' sequence, which should thus generate more reliable responses.

For the second part in the first section ("Things that I look out for"), respondents were asked to judge their probable stop versus cross decisions for a series of specified variables in the Stage II questionnaire (instead of ranking the level of importance of each variable as in the Stage I questionnaire). This is to allow a common scale for easy comparison with questions in the later sections.

An additional section (section 4) was added to include some questions on the advance warning indication of the termination of green signal. A separate pilot test was carried out on about 20 subjects regarding this particular issue and a full run of the whole survey instrument was then further tested on several more subjects. As in Stage I survey, the survey questionnaire forms were distributed either by hand or by electronic mails (e-mails). The forms distributed by hand were either completed by the survey administrator (author) together with the respondents or by the respondents themselves whereas those sent by e-mails were self-completed by the recipients. Although it was reported in Stage I survey that the e-mail method had a relatively low response rate (about 10%) due to the fear of computer viruses, it was nevertheless used in the Stage II survey because of a good network of respondents on the net which thus resulted in a fair number of respondents (see Figure 3.9). The response rate had improved probably because most of the respondents on the email list are familiar to the administrator on a "first name basis". It is noted that the response of Chinese survey questionnaires which were originally meant to extend coverage to the Chinese-speaking group was very low, and the information and analysis for this group of drivers was thus very limited. However, it should be a useful reference in future research.

3.4.3 Survey data reduction

After completion of the survey, data reduction of the completed questionnaires was the next step. It involved initial questionnaire editing, data coding, data entry and data editing (Richardson et al., 1995). For face-to-face surveys, field editing was



Not included in total sample size

Figure 3.9 Manners of administrating survey questionnaires (both stages)

always performed right after the completion of each survey to check the completeness and legibility of the responses. Any information found to be missing or unclear was clarified with the respondent while the survey questions were still fresh in his mind. However, this step was contingent upon the cooperation of the respondents.

The completed forms, after editing, were then processed for data coding and entry. Coding of data basically involved the translation of the survey responses into categories suitable for computer processing, after which data entry followed. However, in this study, since the database was not very large, data coding and entry were combined into a single step. The raw responses were first keyed directly into an Excel spreadsheet according to the sequence of the structured questionnaire. The raw responses were then analysed and divided into different categories according to the specific objectives of the study. A simple coding table was then formulated and used to transform all the open-ended and closed-ended questions from character strings into numeric forms, for easy manipulation and handling of data using the SAS program. An example of the coding format is shown in Table 3.4.

Table 3.4 Example of coding table for gender

No	Gender	Code
1	Male	1
2	Female	2
3	No information	3

3.5 Chapter summary

Road traffic accident records from 1985 to 2002 were obtained from the Traffic Police Department. Due to incomplete database for property-damage only accidents, all the analyses were based on casualty accidents only. In addition to the accident records, some red-running violations as captured by the RLCs at several sites (a total of 13 residential sites over the 1999-2001 period) were also available for analyses.

A principal component of the study involved on-site observations of driver performance along the approaches of signalised junctions during the signal change interval, with the aid of high-definition digital video cameras. The unobtrusive field observations served to investigate driver behaviour under everyday normal operation in the road environment which could neither be captured by the RLCs nor shown in the accident records.

Video footages obtained from the field were brought back to the laboratory and the images were projected onto a white board for extraction. The extraction was restricted to the last entering and the first stopping vehicles at each cycle of amber onset. Various factors that were suspected to have some influence on the driver behaviour were extracted for each subject vehicle; they were divided into three main groups: subject vehicle status, road environment conditions and traffic conditions. The first group included vehicle type, lane position, distance and speed at the amber onset, the second group comprised ambient light conditions, presence of RLCs, presence of pedestrians and presence of cues preceding amber onset and the last group covered the status of other vehicles in the vicinity of the subject vehicle as well as the opposing vehicles.

The last part of the study involved a perception survey that was targeted at the drivers. The survey served to complement the observational study and was aimed at collecting information on factors that could not be obtained from the unobtrusive field observations. The questionnaire covered various factors that are likely to affect the driver's stop versus cross decision, his general driving strategies and issues related to the green signal countdown devices.

Chapter 4 Road traffic accident and red-running violation characteristics

The first part of this chapter covers the analysis and findings of the road traffic accidents. The second part examines the characteristics of red-running violations.

4.1 Road traffic accident analysis

For the road traffic accidents (RTAs) analysis, the statistics were examined first for the whole road transportation system of Singapore (national level) followed by analysis only at the junctions, particularly signalised junctions. The characteristics of accidents that involved drivers who disobeyed traffic signals were analysed. In all cases, the study covered only RTAs with casualties (fatalities and injuries) and excluded property-damage only (PDO) accidents.

4.1.1 General RTA trend

A road traffic accident is defined in Singapore as any accident that occurs or originates on a road or public carpark where at least one moving vehicle is involved and where one or more person(s) is injured or killed or where property is damaged. Each year in Singapore, there are around 5200 to 7300 cases of RTAs with casualties. This is equivalent to about 16 casualty RTAs per day. Even though this number is quite small when compared to the total vehicle population, every RTA incurs some heavy costs (injury, loss of time, etc.) and thus the RTA occurrences should be reduced as much as possible. The annual RTA rates (for 1985 to 2002 period) as normalised with resident human population and Singapore-registered vehicle population are shown in Figure 4.1. Both rates followed similar swings or patterns in the 1985-2002 period. There were significant reductions in the second half of the eighties, followed by more gradual improvements till the late nineties and then a cyclic movement in the recent years.

Around 40% of the RTAs were found to take place during night-time (1900 to 0700 hours, the official time interval in Singapore when street lights are on). This constitutes a rather high percentage since the overall traffic volume at night is much lower as compared to daytime. This suggests that attention should also be paid to issues concerning night-time driving.

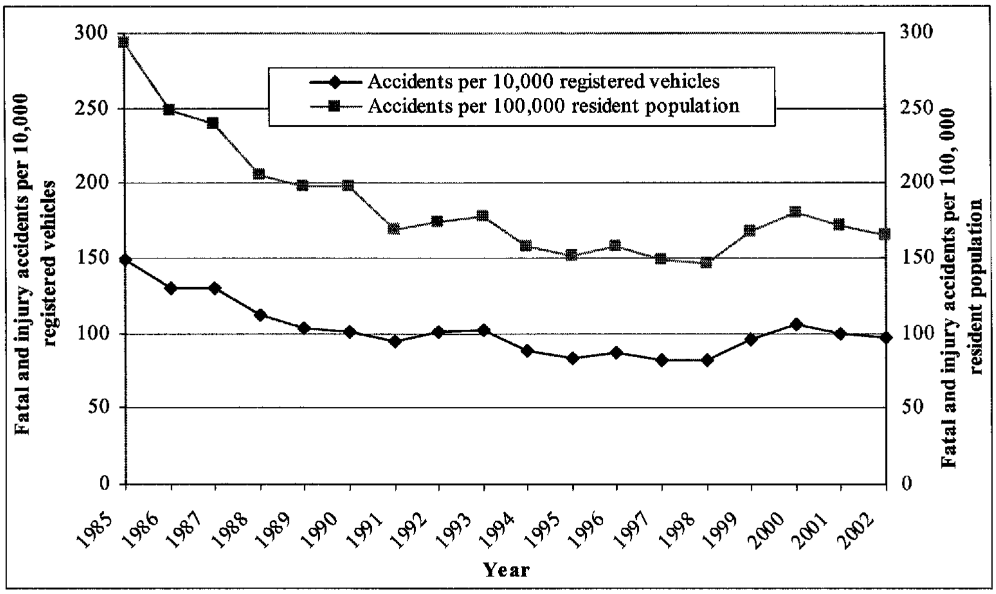


Figure 4.1 Casualty RTA rates at national level

4.1.2 RTAs at road junctions

Over the 1985 to 2002 period, traffic crashes at road junctions accounted for about 35% of the RTAs, of which about half occurred at the signalised junctions. The breakdown of accident counts for the respective type of junctions (X-, T-, and Y-junctions) showed that the majority of the junction accidents took place at X- and T-junctions which are almost equally represented (48.5% and 48.7%). As there are relatively very few Y-junctions as compared to the other junction types in the road network in Singapore, Y-junctions were combined with T-junctions and denoted as three-legged junctions in some of the subsequent analyses.

The types of collisions that occurred at the junctions involved mainly two or more moving vehicles (84%), followed by vehicle-and-pedestrian (8%). The other two collision types, single vehicle and vehicle-and-object, comprised 5% and 2%, respectively. A further breakdown of the collisions involving two or more moving vehicles (multi-vehicle crashes) showed that head-to-side collisions (70%) and rear-end collisions (14%) were the most common types of crashes at the junctions.

The factors that contributed to the crashes and the likely offending party (parties) are also coded in the accident data forms. The accident factors are basically divided into five main categories, namely driver, pedestrian, vehicle, environment and other causes. In any one accident, only one most probable sub-factor is filled for at least one of the five categories. These entries (accident factors and offending party) are based on on-site observation and measurements and professional judgement of investigating officers, supplemented by interviews of accident parties. Nevertheless, due care must be taken when using such information. The common driver-related junction accident factors include turning without due care, failing to keep a proper lookout, failing to give way to traffic with right-of-way, disobeying traffic signals, following too close to vehicle in front, and failing to have proper control of vehicle.

4.1.3 RTAs at signalised junctions

Using the 18-year database (1985 to 2002) from the Traffic Police Department, the accident frequencies by junction type were plotted for both the signalised and unsignalised junctions as shown in Figures 4.2 and 4.3, respectively. It was observed that about two-thirds of the accidents that occurred at the signalised junctions (excluding mid-block signalised pedestrian crossings) were at four-legged junctions (X-junctions) but the corresponding proportion at the unsignalised junctions was about one-third. This is probably due to the lower proportion of unsignalised junctions that are 4-legged (about 10% (unsignalised) versus 60% (signalised)). Profiles of accident rates (defined as the annual number of accidents per signalised junction) for signalised junctions showed that there has been a general decrease in the accident rates, with a more distinct improvement (steeper slope) for the 3-legged signalised junctions (from 2.5 to 0.8 accidents/junction) as compared to 4-legged signalised junctions (2.2 to 1.1 accidents/junction). A further breakdown of the accident data into the types of collisions showed that head-to-side collisions were the most common type (71.9% and 71%) of crashes between moving vehicles that occurred at signalised and at unsignalised junctions respectively. There was a slightly higher percentage of rear-end collisions at signalised junctions (16%) as compared to unsignalised junctions (14%). On the other hand, side-swipe collisions in the same direction (involving two or more vehicles moving too close alongside each other) occurred more often at unsignalised junctions.

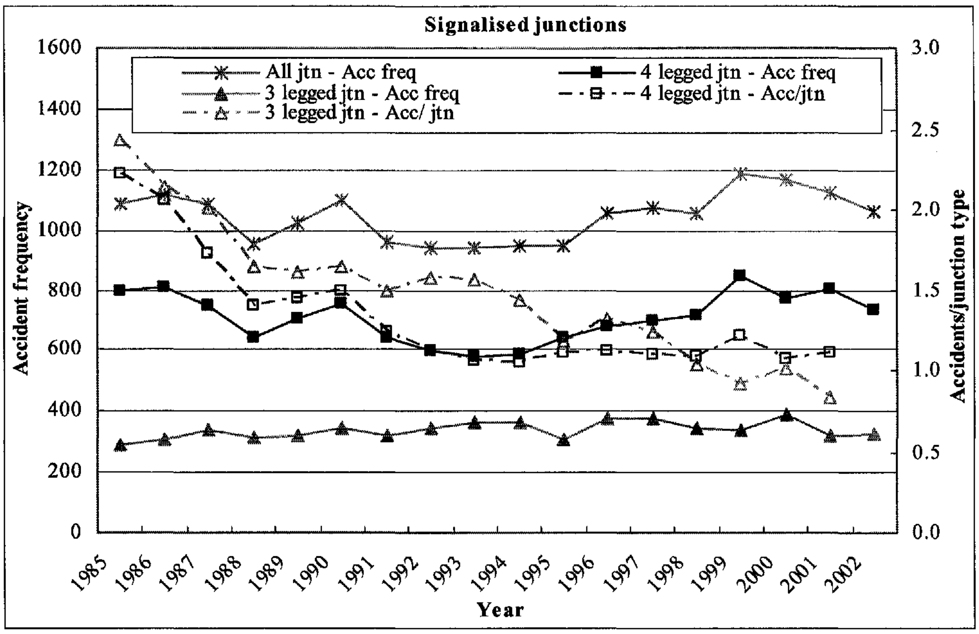


Figure 4.2 Accident frequencies at signalised junctions

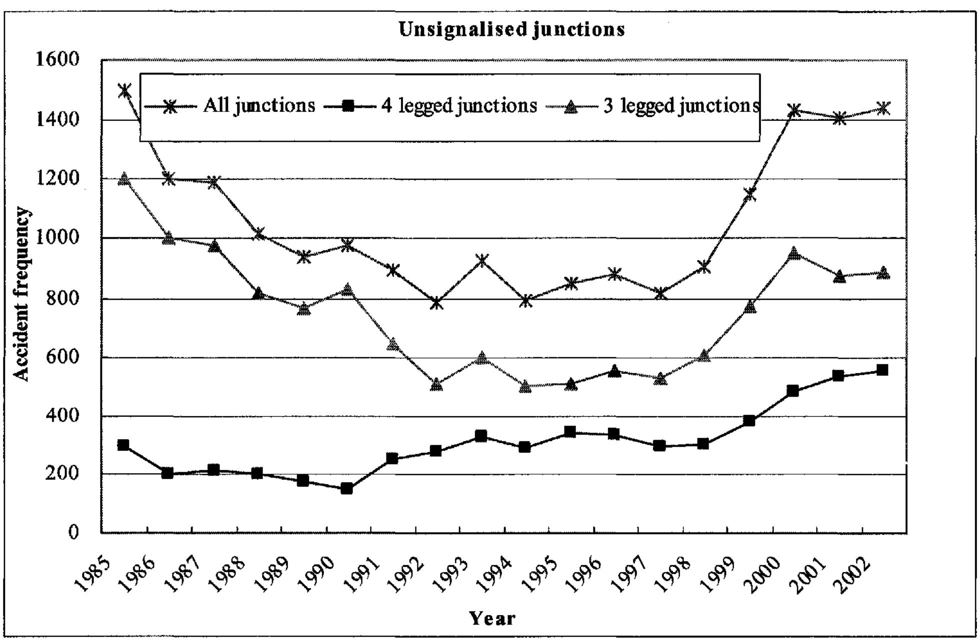


Figure 4.3 Accident frequencies at unsignalised junctions

Two-vehicle crashes constituted about 80% of all collisions at the signalised junctions, hence a more detailed study on this type of accidents is appropriate. The accident factors of the offending party in two-vehicle crashes (where one was identified as the offending party and the other was the non-offender) were examined by the type of collision. It was found that for head-to-side collisions, the four main contributing factors in accidents that occurred at signalised junctions included turning without due care, failure to keep a proper lookout, failing to give way to traffic with right-of-way and disobeying traffic signals. A further breakdown by manoeuvre of the offending parties before the accidents (see Table 4.1) showed that contributory factors such as "turning without due care" and "failure to give way to traffic with right-of-way" were usually associated with right-turners or U-turners and "fail to keep a proper lookout of other traffic" and "disobey traffic signals" with straight-through traffic. This generally highlighted the need to study the problems of Singapore's permissive right-turn rule and the red-running phenomenon.

Table 4.1 Contributory factors associated with manoeuvre before accidents (Head-to-side collisions) at signalised junctions

Main contributory factors (No. of cases)	Manoeuvre before accidents			
	Driving ahead	Turning right or U-turning	Turning left	Others*
Turning without due care (3162)	8.3%	88.0%**	3.2%	0.5%
Failure to give way to traffic with right-of-way (1642)	16.4%	80.0%**	1.9%	1.6%
Failure to keep proper lookout (1495)	54.0%	39.2%	2.4%	4.4%
Disobey traffic signals (755)	87.5%***	9.9%	0.2%	2.4%

**Others include changing lanes, moving off, stopping/slowing down*
***Permissive filtering problem (for vehicles making a right turn)*
****Red-running problem (for vehicles going straight)*

Two factors that were found to be associated with offending parties in rear-end collisions were "following too close to vehicle in front" and "failing to keep a proper lookout". This suggested that the collision vehicles might have made conflicting decisions such that the trailing vehicle could not respond on time to take proper evasive action. From the results in Table 4.2, it is apparent that most of offending parties in rear-end collisions were driving ahead.

Table 4.2 Contributory factors associated with manoeuvre before accidents (Rear-end collisions) at signalised junctions

Main contributory factors (No. of cases)	Manoeuvre before accidents				
	Driving ahead	Stopping/ slowing down	Turning right	Turning left	Others
Following too close to vehicle in front (1031)	83.0%	11.4%	3.6%	0.6%	1.4%
Failure to keep proper lookout (517)	86.8%	6.9%	4.1%	1.0%	1.3%

Running the traffic lights

From the preceding analysis, an important contributory factor of head-to-side accidents at signalised junctions could be the permissive right-turn rule that allows filtering of vehicles (during circular green lantern). However, due to the inherent limitation in coding the variable of accident cause (i.e. there is no specific code for reckless filtering), further detailed analysis was not attempted.

Another important contributory factor to vehicle crashes at the signalised junctions is failure to comply with traffic signals, especially red-running. For the analysis, cases of red-running crashes were subset from the accident database. A red-running crash was defined as a collision that took place at a junction (X-, T- or Y-junction) controlled by a traffic signal and the offending driver(s) was assigned a driver contributory factor of "122-disobey traffic light signals". A small number of cases for which offending driver(s) had manoeuvre-before-accident as "moving-off" was excluded as they constituted the green-jumpers (drivers who moved off before the green lantern comes on).

Accidents involving red-running accounted for about 20% of the casualty crashes that occurred at the signalised junctions. Of the red-runners involved in the crashes, 89% were driving straight ahead and 10% were making a right turn. Table 4.3 shows the number of red-running accidents by severity. There was a rather erratic pattern, with notable increases in recent years. About 77% of the red-running crashes occurred at 4-legged junctions as compared to 23% at 3-legged junctions. After taking into account the population of signalised 4-legged junctions and 3-legged junctions (at a proportion of 2:1), red-running crashes were found to more likely occur at 4-legged junctions than at 3-legged junctions.

Table 4.3 RTAs associated with disobeying traffic signals

	Severity of accidents			
Year	Fatal	Serious injury	Slight injury	Total
1985	6	24	155	180
1986	10	19	150	179
1987	9	20	106	135
1988	3	12	85	100
1989	6	33	82	121
1990	6	17	101	124
1991	3	12	89	104
1992	11	18	153	182
1993	4	22	180	206
1994	14	13	190	217
1995	9	18	165	192
1996	8	26	256	290
1997	22	11	183	216
1998	8	4	177	189
1999	20	10	117	147
2000	17	11	200	228
2001	13	15	299	327
2002	9	11	386	406

An hourly distribution of the red-running crashes (Figure 4.4) showed peak occurrences in the 7pm to 1am period during when the traffic flow was low (but not the lowest).

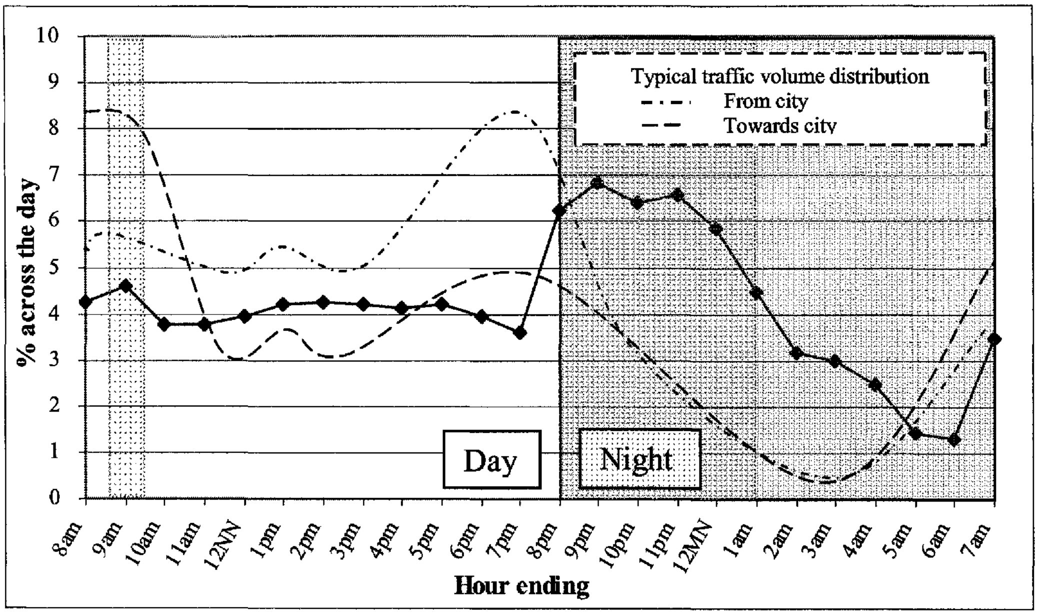


Figure 4.4 Hourly distribution of red-running crashes

In accident studies, it is important to take into account the amount of exposure which is often expressed in terms of the amount of travel (in km), the vehicle and human populations, etc. In the case of a two-vehicle crash involving an offending/non-offending pair, the non-offending entity can be taken to represent the overall driving population, with the presence of the non-offending entity being due to chance, akin to randomised sampling. Here, the non-offending entity to which an offending entity is matched to it, serves as a form of exposure measure. By using an index in the form of a relative accident involvement ratio (IR) in the two-vehicle crashes, the extent to which vehicle or other defined characteristics e.g. driver age, gender, etc are represented in the accidents can be determined. The IR is expressed as the ratio of the percentage of specified offending vehicles/drivers within the offending sample over the percentage of similar non-offending vehicles/drivers within the non-offending sample. A value of IR greater than 1 means that the particular offending group (of defined characteristics) is more frequently represented or has a higher than average accident risk.

Using the above matched pair method, the characteristics of red-runners were studied for two-vehicle accidents in which the straight-through motorist ran the red light and hit the right-turning vehicle which had right-of-way i.e. turning under the green arrow. Analysis based on 2-vehicle crashes is reasonable because it was found that about 91% of the red-running crashes involved only two vehicles.

In assembling the database for analysis, two-vehicle crashes at the signalised junctions were selected where:

i) One driver was identified as the offending party, was moving straight ahead and was assigned a driver contributory factor of "122-disobey traffic light signals;

ii) The other driver was identified as the non-offending party and was making a right-turn.

A total of 838 matched pairs of red-runners versus non red-runners were found from the 1985-2002 accident database.

Figure 4.5 shows the age distribution for the two groups of motorists: red-runners and non red-runners in the accident subset (2-vehicle red-running crashes). Older motorists (above 66 years old) and young motorists (25 years old or below) had an IR value of 2.22 and 1.45, respectively. This means that older and young motorists were more likely to be the culpable groups in running the red. This violation trend is similar to the U-shaped age-related accident involvement curve shown by Evans (1991). This indicated that remediation measures should be concentrated at the two ends of the age profile. The IR values for both male and female drivers were close to 1 (0.99 and 1.09, respectively).

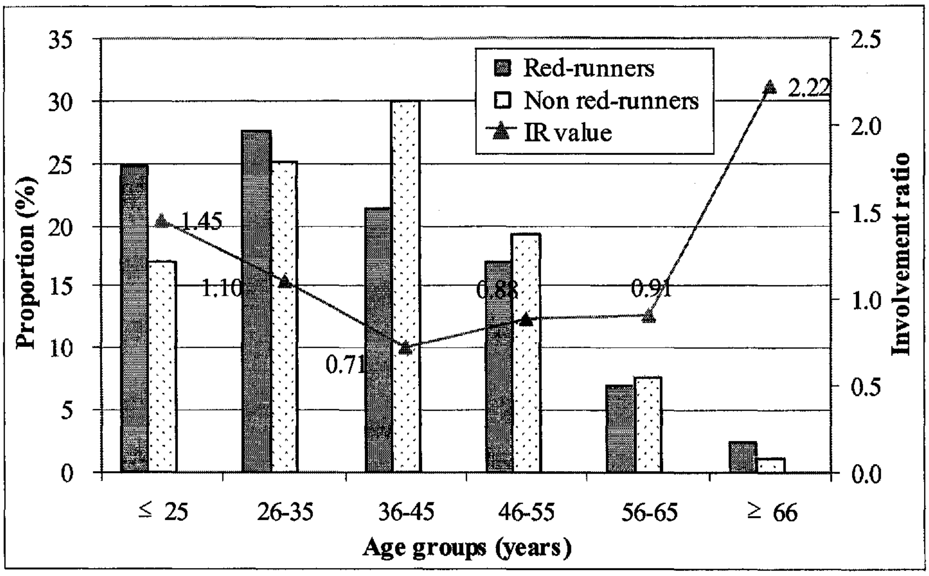


Figure 4.5 Age distribution of red-runners versus non red-runners

The IR was computed for motorists by vehicle groups which produced IR values of 0.88, 1.23, 1.09 and 0.89 for car, motorcycle, LCV and HCV, respectively (see Figure 4.6). Motorcycle had the highest IR (greater than 1); in other words, motorcyclists had the highest tendency to red-run compared to other drivers. This could be because motorcycles have a faster pick-up speed and better manoeuvrability and hence are more "adaptable" in running the red.

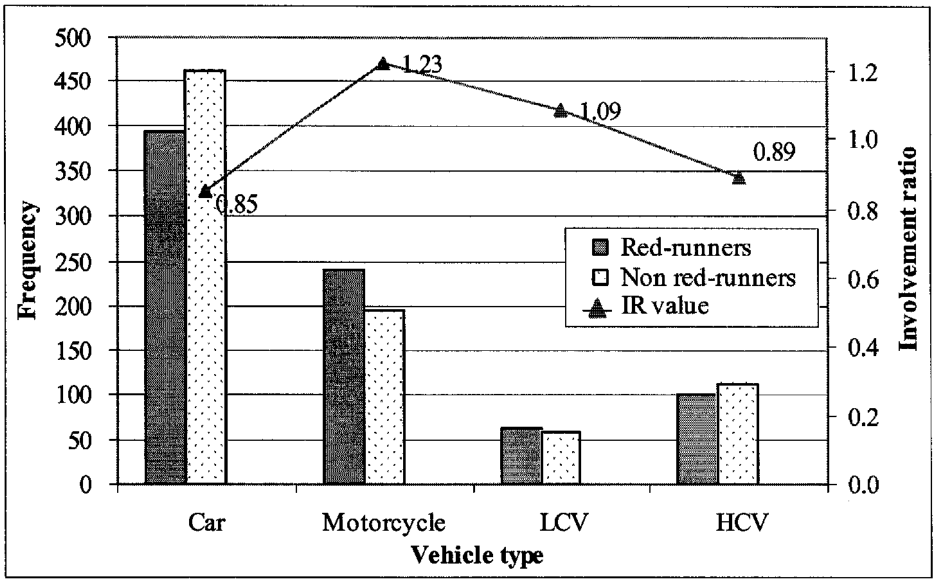


Figure 4.6 **IR values for different motorist type**

Further analysis showed that red-running drivers and their front seat passengers were more likely to be killed or injured than non red-runners. Vehicles of red-runners were found to be more seriously damaged (complete wreck and bad damage) than those of non red-runners (at 46% versus 41%). Hence, more attention should be given to manage red-running violations. One possible way is to project a greater degree of enforcement (e.g. patrol officers) on the road.

4.2 Red-running violation statistics

The total number of prosecuted red-running violations per year for 1997 to 2002 period is shown in Figure 4.7. The statistics were provided by the Traffic Police Department. There was a general decrease in the number of violations throughout the 5 years after 1997. However, these statistics relied greatly on the intensity of camera deployment, hence the numbers should be interpreted with care. Nevertheless, it should be interesting to study red-running violations and their characteristics at the RLC junctions. However, due to limited resources in this study, only selected camera junctions (13) were studied in the recent years (1999-2001). Whenever possible, analysis results were compared with those reported by Ng (1996) who had studied and analysed RLC-captured violation statistics islandwide for the years 1991 and 1992. The violation rates were analysed by types of junction approaches, vehicle groups and hours of the day.

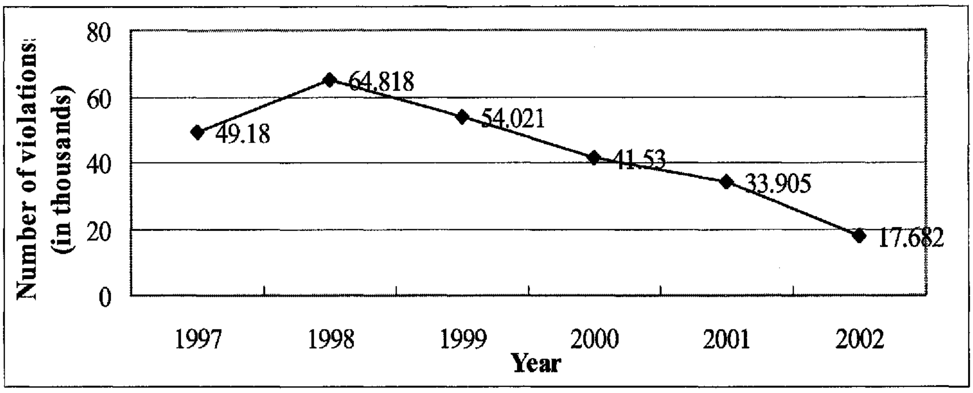


Figure 4.7 **Number of violations per year** *(Traffic Police, 2002a)*

4.2.1 Analysis of violations by junction approach types

The red-running violation rates per day and per hour of camera deployment at a small sample of RLC approaches were tabulated as shown in Table 4.4. It was found that the violation rates at the approaches at T-junctions were higher than those at the X-junctions (See Figure 4.8). The higher violation rates at T-junctions as compared to X-junctions supported the hypothesis of a greater tendency for drivers to violate at the T-junctions due to a lower collision risk in general. This is consistent with Ng's (1996) finding that the mean violation rate at 3-legged junctions (T-junctions) was greater than at 4-legged junctions (X-junctions), significant at 5.4% level.

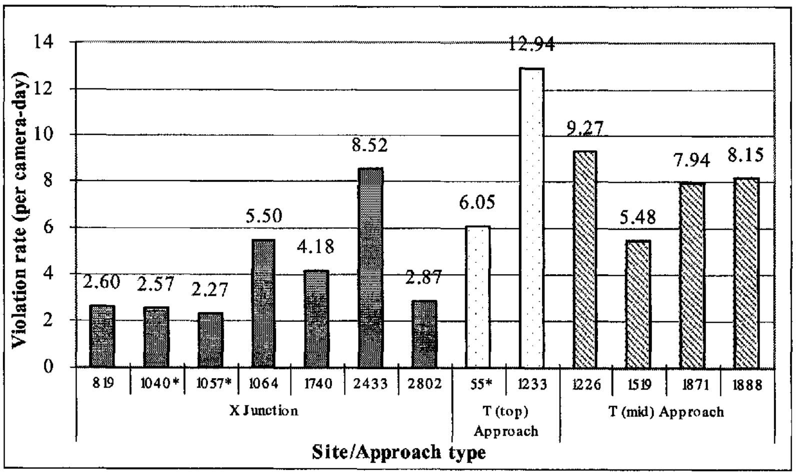


Figure 4.8 Distribution of the violation rates (per camera-day) by approach type

Table 4.4 Violations at different types of junction approaches

Site	Number of violations	Length of camera deployment		Violation rate	
		No. of days	No. of hours	Per day	Per hour
X Junction					
819	29	11.1	267.4	2.60	0.11
1040*	26	10.1	243.2	2.57	0.11
1057*	23	10.1	243.2	2.27	0.09
1064	38	6.9	165.9	5.50	0.23
1740	29	6.9	166.4	4.18	0.17
2433	69	8.1	194.4	8.52	0.35
2802	32	11.1	267.5	2.87	0.12
All X junctions				*4.07*	*0.17*
T (top) Approach					
55*	60	9.9	238.0	6.05	0.25
1233	127	9.8	235.6	12.94	0.54
All T(top) approaches				*9.49*	*0.40*
T (mid) Approach					
1226	91	9.8	235.6	9.27	0.39
1519	11	2.0	48.2	5.48	0.23
1871	70	8.8	211.7	7.94	0.33
1888	80	9.8	235.6	8.15	0.34
All T(mid) approaches				*7.71*	*0.32*

**Sites also used in observational study*

4.2.2 Distribution of red-running violations by time after red

The distribution of the time after red statistics (from 0.6s onwards) of the violating vehicles is shown in Table 4.5. It was found that the majority of the violations (over 90%) happened within the first two seconds after the onset of red, with an exponential decaying effect. Ng (1996) reported the same results that about 55%, 92% and 96% of the red-runners occurred within 1, 2 and 3 seconds after red onset, respectively. There was not much difference among the different types of junction approaches.

4.2.3 Analysis of violations by vehicle groups

In terms of violations by vehicle groups (Table 4.6), car constituted the highest proportion, followed by heavy commercial vehicle (HCV). However, this should not be taken to mean that car drivers have a higher tendency to run the red. In terms of the population of Singapore's registered vehicles, cars have a higher representation than other vehicle groups on the roads thus one can expect more

Table 4.5 Distribution of violations by the time after red

Site	Time after red (seconds)						
	0.6 to 1	1.1 to 1.5	1.6 to 2	2.1 to 2.5	2.6 to 3	>3	All
X Junction							
819	62.1	24.1	6.9	3.4	0.0	3.4	100.0
1040*	65.4	23.1	11.5	0.0	0.0	0.0	100.0
1057*	60.9	26.1	8.7	4.3	0.0	0.0	100.0
1064	44.7	31.6	18.4	0.0	0.0	5.3	100.0
1740	75.9	20.7	3.4	0.0	0.0	0.0	100.0
2433	56.5	34.8	5.8	1.4	0.0	1.4	100.0
2802	71.9	25.0	3.1	0.0	0.0	0.0	100.0
All X junctions	*61.0*	*28.0*	*8.1*	*1.2*	*0.0*	*1.6*	*100.0*
T (top) Junction							
55*	40.0	33.3	10.0	6.7	1.7	8.3	100.0
1233	58.3	26.0	11.0	1.6	1.6	1.6	100.0
All T(top) junctions	*52.4*	*28.3*	*10.7*	*3.2*	*1.6*	*3.7*	*100.0*
T (mid) Junction							
1226	60.4	29.7	6.6	0.0	1.1	2.2	100.0
1519	54.5	27.3	9.1	0.0	0.0	9.1	100.0
1871	65.7	27.1	5.7	0.0	1.4	0.0	100.0
1888	48.8	21.3	15.0	2.5	2.5	10.0	100.0
All T(mid) junctions	*57.9*	*26.2*	*9.1*	*0.8*	*1.6*	*4.4*	*100.0*

**Sites also used in observational study*

Table 4.6 Distribution of violations by vehicle groups

Vehicle type	No. of violations	Proportion of violations (%)	Vehicle population	Vehicle Population (%)	Index of violations
Taxi	41	6.4	19106	2.7	2.4
Car	429	66.6	406589	57.5	1.2
Motorcycle	29	4.5	132318	18.7	0.2
LCV	66	10.2	95607	13.5	0.8
HCV	120	18.6	53336	7.5	2.5
Total	644	100.0	706956	100.0	

violations by car drivers. In order to correct for exposure, the vehicle population statistics (SDS, 2002) were used to compute an index of violation (violation proportion/ vehicle population proportion) for each vehicle group. Taxis were considered as a separate group because of their relatively higher usage on the road. The indices indicated that drivers of taxis and HCV had the highest tendency to run the red. It should be noted that the low index value for motorcycles did not mean that motorcyclists had a low tendency to violate. In fact, motorcyclists had the highest red-running related accident rates, as noted earlier. Motorcycles have a small width and can easily slip through the detection loop by riding through the non-detection zone between the outer edge of the loop and the kerb. Also, motorcyclists often move themselves to the front of the queue by riding in between the queued vehicles.

4.2.4 Analysis of violations by the hour of the day

There are many factors that are correlated with violation rates, and time of the day is one of them. Peak periods such as morning peak (7am to 9am), lunch time and evening peak (5pm to 7pm) are probably the time when many violations would occur since drivers are usually rushing for time during these periods. Violation rates by the hour of the day were compared based on the violations per camera deployment hour.

Figure 4.9 depicts the distribution of hourly violation rates (per camera) across the hours of the day. High hourly violation rates were evident between 8-9am, 1-3pm, and 5-6pm in the daytime, and 8-9pm and 10-11pm during night-time. Some of these high violation hours corresponded to the red-running accident peak hours, typically at morning hour (8am to 9am) and between the late evening and midnight hours. It is not surprising to obtain a low number of violations after midnight given the relatively low traffic volume. A comparison of the violations across the groups of different junction approach types showed that the proportions of violations that occurred at night (7pm to 7am) were lower at X-junctions (29%) than at T-junctions (34%) (see Table 4.7). These proportions were of somewhat similar order as the proportions of accidents that happened at night (about 40%).

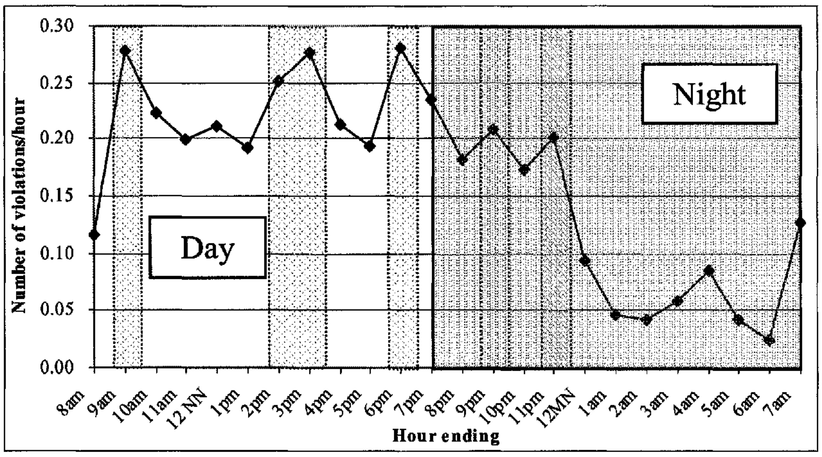


Figure 4.9 Hourly violation rates by time of day

Table 4.7 Day and night comparisons

Site	Day**	%****	Night	%
X Junction				
819	0.0748	69.0	0.0337	31.0
1040*	0.0617	57.7	0.0452	42.3
1057*	0.0946	100.0	0.0000	0.0
1064	0.1085	51.4	0.1025	48.6
1740	0.0901	60.0	0.0601	40.0
2433	0.3035	85.5	0.0514	14.5
2802	0.0860	71.9	0.0336	28.1
All X junctions	*0.1170****	*71.5*	*0.0466*	*28.5*
T (top) Junction				
55*	0.1639	65.0	0.0882	35.0
1233	0.3141	65.5	0.1655	34.5
All T(top) junctions	*0.2390*	*65.3*	*0.1269*	*34.7*
T (mid) Junction				
1226	0.2207	59.8	0.1486	40.2
1519	0.2075	90.9	0.0207	9.1
1871	0.2362	75.8	0.0756	24.2
1888	0.1528	48.6	0.1613	51.4
All T(mid) junctions	*0.2043*	*66.8*	*0.1015*	*33.2*

**Sites also used in observatory study*
***Day and night rates calculated based on the number of violations divided by the deployment hours*
****For junction approach, day and night rates calculated based on the average across all sites of that approach*
*****Day % calculated based on [day rate/(day rate+ night rate)*100]*

4.3 Chapter summary

Traffic crashes at road junctions accounted for more than one-third (36%) of all casualty road traffic accidents and the most common accident types involved 2 or more moving vehicles. Head-to-side collisions represented 70% of all vehicle-to-vehicle crashes at the junctions, followed by rear-end crashes (15%). Overall, the number of accidents showed a decreasing trend, particularly at 3-legged junctions. As for signalised junctions which contributed about half of the junction accidents, the most common vehicle-to-vehicle collisions were also head-to-side and rear-end crashes. An examination of the accident factors of offending parties suggested a need to study Singapore's permissive right-turn rule as well as the red-running situation at signalised junctions.

The accident analysis at the signalised junctions relied on comparisons between samples constituting matched pairs, with each pair comprising an offending party and a non-offending party in a 2-vehicle crash. For accidents related to running the red traffic light at the signalised junction, the most culpable parties were found to be the young (less than 25 years) and the old (≥ 66 years) motorists. Motorcyclists also had proportionally higher representation in red-running accidents. Red-running drivers and their front passengers were found to be more likely to suffer injuries or be killed than non red-runners.

There had been a general decrease in the number of red-running violations (from 64,818 to 16,931 cases) in the last five years (1997-2002). This reflected the sustained effort of the authorities to curb the red-running problem. Violation statistics showed that on a per approach basis, there was a greater tendency for drivers to violate at T-junction approaches.

The majority of the red-running violations (over 90%) occurred within the first two seconds after the onset of red, with an exponential decaying effect. Taxi and HCV drivers were found to have the highest tendency to run the red. High violation rates were evident at morning peak (8-9am), in the early afternoon (1-3pm), evening peak (5-6pm) and some hours before midnight. The proportion of violations at night was 34% at the T-junctions as compared to 28% at the X-junctions.

From the analysis of the accident and violation statistics, it appeared that there are several factors that influence the driver behaviour. They include road geometrical factors (e.g. junction type), driver's demographic characteristics (e.g. age, gender, etc.) and vehicle class. Hence, it is important to study these influencing factors in detail in order to identify and quantify the underlying influence. Effective remedial measures can then be provided accordingly, which would help to decrease the likelihood of a conflict situation or collision.

Chapter 5 Results and data analysis for observational study

This chapter presents the data, analysis and findings of the observational study. The first section covers the concept and the results of using a transitional zone (TZ) in determining the driver's PRT and deceleration rate as well as the sample characteristics. The following section covers the various deterministic frameworks used by other researchers and introduces a probabilistic approach (using logistic regression) to model the stopping probability of drivers with various influencing variables. The final section of this chapter dwells on the influence of advance amber warning signals e.g. environmental cues like blinking green-to-red man and right-turn green arrow on the driver behaviour.

5.1 Defining the transitional zone

As proposed by Wong and Goh (2000), the transitional zone (TZ) is well-suited to differentiate drivers making a cross versus stop decision in a forced-paced situation from those who do so in a free-paced manner. The latter case usually applies to those drivers who are either very close to the stop line (will most likely cross) or those very far away from the stop line (will most likely stop) at the onset of amber.

Goh and Wong (2002) have tried plotting distance against time to illustrate the effect of TZ and found that unless the operating speed environment is relatively constant, different TZs exist for different speed bands which adds to the difficulty in identifying TZ. Hence, a more direct approach was established by plotting the vehicle's *projected time to stop line* (TTSL) at amber onset against the *observed traverse time to cross stop line* (for through vehicles) and the *perception-response time* (PRT) (for stopping vehicles). TTSL is basically the time required to reach the stop line as estimated from the approach speed (assumed to remain constant) and the distance from the stop line at the instant of amber onset.

Figures 5.1 and 5.2 depict sample data points of traverse time and PRT with respect to TTSL at junctions without RLC (no RLC at any constituent approach) and along RLC approaches, respectively for daytime data, whereas Figures 5.3 and 5.4 show

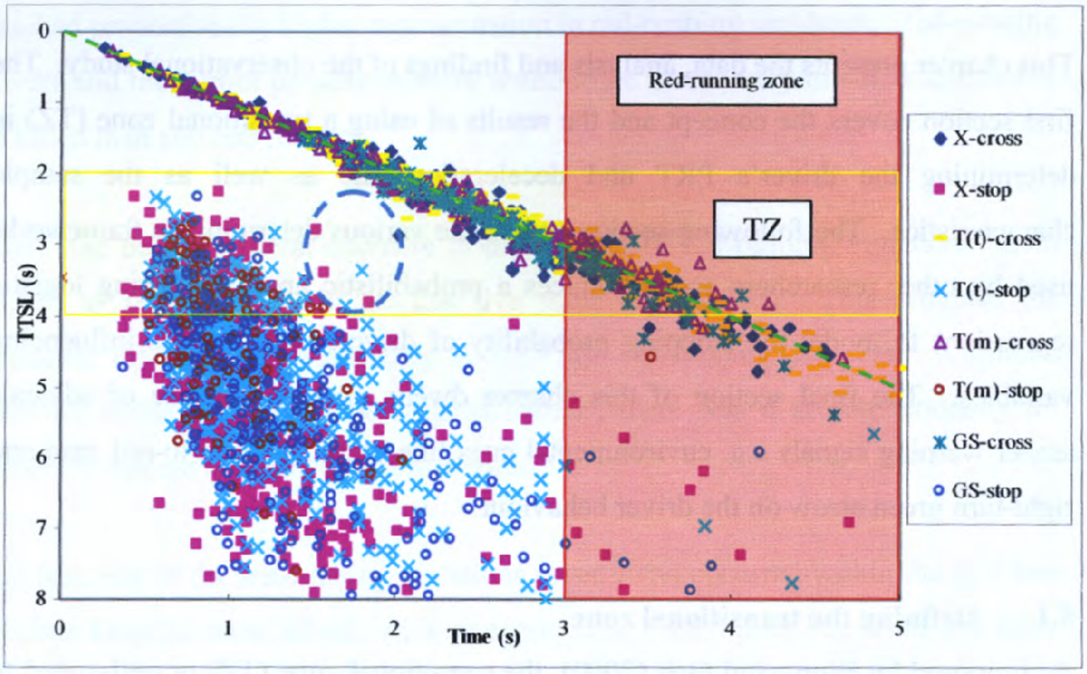


Figure 5.1 TTSL plot for approaches at junctions without an RLC (Daytime)

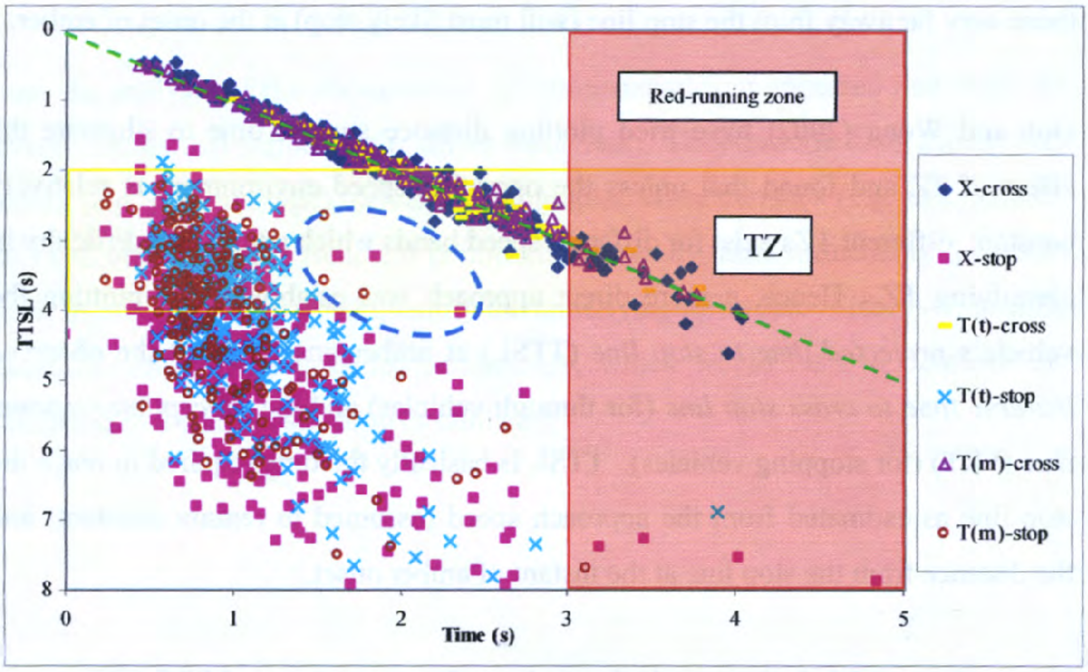


Figure 5.2 TTSL plot for approaches with RLCs (Daytime)

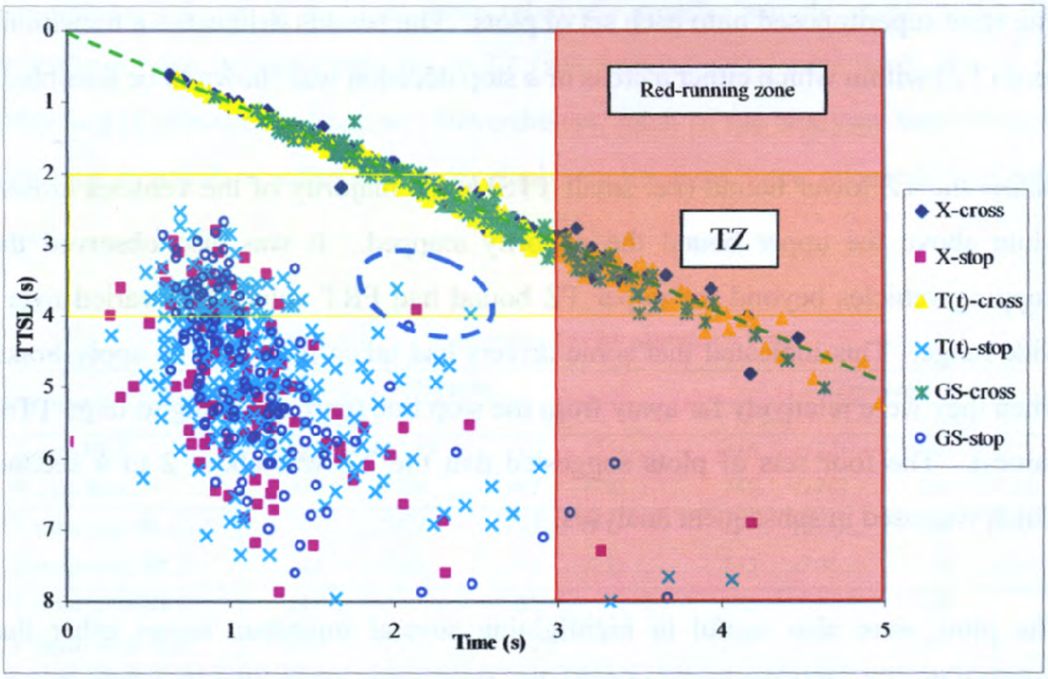


Figure 5.3 TTSL plot for approaches at junctions without an RLC (Night-time)

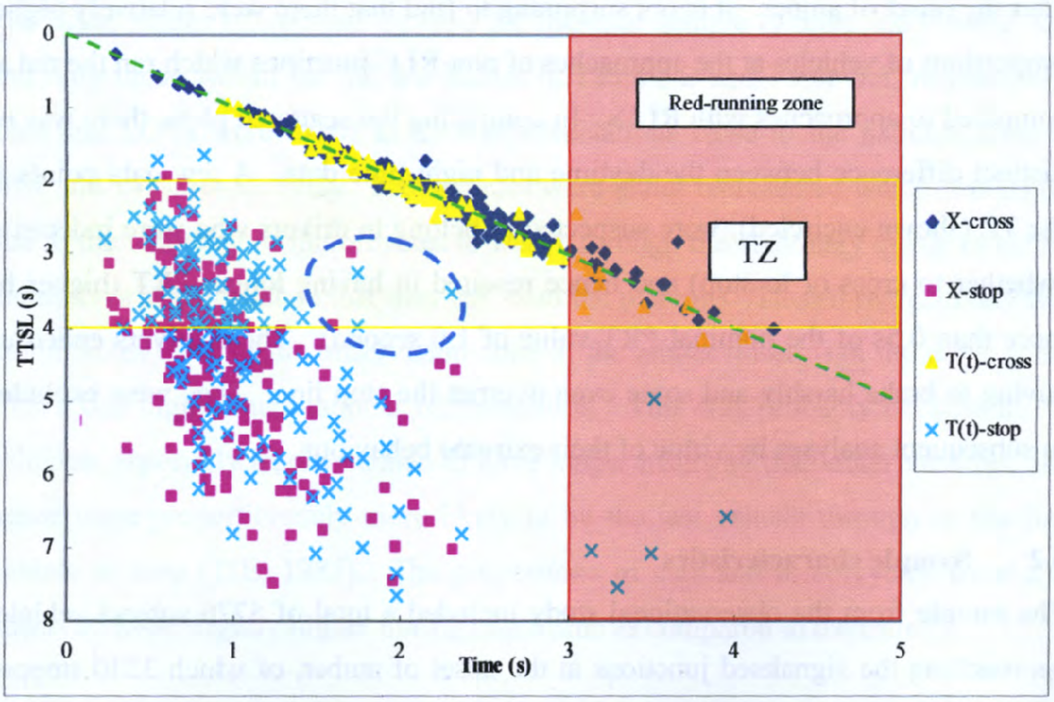


Figure 5.4 TTSL plot for approaches with RLCs (Night-time)

the plots for night-time data. An upper and a lower bound in the TTSL and a unit line were superimposed onto each set of plots. The bounds delineated a transitional zone (TZ) within which either a cross or a stop decision was shown to be feasible.

Below the TZ lower bound (i.e. small TTSL), the majority of the vehicles crossed while above the upper bound the majority stopped. It was also observed that stopping vehicles beyond the upper TZ bound had PRT values that varied over a wide range. This indicated that some drivers had taken their time to apply brakes when they were relatively far away from the stop line (corresponding to large TTSL values). The four sets of plots suggested that the TZ was about 2 to 4 seconds which was used in subsequent analyses.

The plots were also useful in highlighting several important issues other than defining the TZ. For the crossing vehicles, there were points that lie below the unit line which indicated that the vehicles accelerated as they made the crossing whereas those positioned above the line decelerated. Vehicles positioned in the vertical shaded portion were those that crossed the stop line 3 seconds or more (red-runners) after the onset of amber. It is not surprising to find that there were relatively higher proportions of vehicles at the approaches of non-RLC junctions which ran the red as compared to approaches with RLCs. In comparing the scattered plots, there was no distinct difference between the daytime and night-time data. A few data points in the TZ (shown encircled), were suspected to belong to drivers who were indecisive (whether to cross or to stop) and hence resulted in having longer PRT (higher by more than 0.5s of the nominal PRT value of 1.0 second). These drivers ended up having to brake harshly and some even overran the stop line. They were excluded in subsequent analyses by virtue of their extreme behaviour.

5.2 Sample characteristics

The sample from the observational study included a total of 5776 subject vehicles approaching the signalised junctions at the onset of amber, of which 3230 stopped and 2546 crossed. Table 5.1 shows a summary of data points obtained from the various approach types. Several sites were also studied under night-time conditions (refer to Table 3.1) for which the sample numbers are shown enclosed in parentheses. Some of the sites have relatively smaller sample sizes (under 30), typically for the stopping vehicles in TZ (see Appendix D), were partly due to the influence of signal coordination. Nevertheless, most of the analyses were done by approach types, hence the low individual sample sizes were acceptable in most cases.

Table 5.1 Sample size by approach type

Approach Type*	Stopping				Crossing			
	All		TZ		All		TZ	
X non-RLC	*623*	*(117)***	*140*	*(26)*	*415*	*(122)*	*268*	*(73)*
X with RLC	*435*	*(225)*	*161*	*(76)*	*269*	*(178)*	*139*	*(109)*
T (top) non-RLC	*504*	*(242)*	*113*	*(64)*	*499*	*(245)*	*328*	*(152)*
T (top) with RLC	*244*	*(158)*	*118*	*(72)*	*135*	*(106)*	*78*	*(56)*
T (mid) non-RLC	*111*		*52*		*165*		*89*	
T (mid) with RLC	*190*		*106*		*153*		*67*	
GS non-RLC	244	(138)	43	(30)	126	(133)	102	(86)
Total	**2350**	**(880)**	**732**	**(268)**	**1762**	**(784)**	**1071**	**(476)**

**Non-RLC means no RLC for whole junction; with RLC means at least the observed approach has an RLC*
***Numbers in parentheses are night-time data*

5.2.1 Vehicle characteristics

The distributions of vehicles by type for the total sample (within and outside TZ) and only those within the TZ are shown in Table 5.2 and Table 5.3, respectively. Cars and LCVs were found to have representations close to the national level at 60% and 14%, respectively. Motorcycles were under represented which was partly due to the tendency of motorcycles to weave through the stationary queue to gather themselves at the front so that they can head the platoons. Therefore, relatively few motorcycles were in the observation zone at the amber onset. On the other hand, HCVs had higher-than-national representation. This was probably because heavy vehicles, especially trucks, tended to have longer headway than other vehicles, and hence were proportionately more likely to be the last vehicle through or the first vehicle to stop (ITE, 1985). The proportions of cars and motorcycles were also observed to be slightly higher during night-time as compared to daytime.

Table 5.2 Distribution of vehicle by type (All*)

	Mvt.	Car Day	Car Night	Motorcycle Day	Motorcycle Night	LCV Day	LCV Night	HCV Day	HCV Night	Total (Day)	Total (Night)
All Sites	Stop	1234	526	170	74	328	100	618	180	2350	880
	Cross	902	476	209	110	228	69	423	129	1762	784
Veh. Type Total		2136	1002	379	184	556	169	1041	309	**4112**	**1664**
Sample %		51.9	60.2	9.2	11.1	13.5	10.2	25.3	18.6		
National %		60.2		18.6		13.7		7.5			

* *All includes those within TZ and non-TZ zones*

Table 5.3 Distribution of vehicle by type (within TZ only)

	Mvt.	Car Day	Car Night	Motorcycle Day	Motorcycle Night	LCV Day	LCV Night	HCV Day	HCV Night	Total (Day)	Total (Night)
All Sites	Stop	422	175	49	29	111	26	150	38	732	268
	Cross	564	287	126	74	129	38	252	77	1071	420
Veh. Type Total		986	462	175	103	240	64	402	115	**1800**	**744**
Sample %		54.7	62.1	9.7	13.8	13.3	8.6	22.3	15.5		
National %		60.2		18.6		13.7		7.5			

5.2.2 Speed characteristics

Table 5.4 summarises the approach speeds of last crossing and first stopping subject vehicles at approach type in terms of their mean, standard deviation, 85th percentile, minimum and maximum statistics. The mean approach speeds of all sites (see Appendix D) ranged from about 50 to 70 km/h which showed no particular correlation with the applicable road speed limits. The mean speeds of some sites (Sites W4 and C3) were observed to be higher than the rest of the sites, but there was still a wide spread of the speeds within each site, thus making all the sites to be fairly comparable. High mean speeds can be due to either a higher speed limit (such as Site W4) or a longer approach length from the upstream junction. The mean speeds of the night-time data were generally lower than daytime data with the exception of Site C2.

The mean speeds of vehicles travelling along RLC approaches were found to be generally lower than those along non-RLC approaches (except for mid approach of T-junction). Two-sample one-tail Z-tests (see Table 5.5) were performed and it was found that the approach speeds were significantly lower along the above-mentioned RLC approaches. This could be due to the RLC having some effect on the speed of drivers.

Table 5.4 Approach speeds (km/h) of subject vehicles at all the approaches

Approach Type	Time	n	Mean	Std. dev.	85%tile	Min.	Max.
X non-RLC	Day	*1038*	*58.9*	*12.8*	*72.4*	*17.0*	*99.6*
	Night	*239*	*60.5*	*12.0*	*72.7*	*29.3*	*98.3*
X with RLC	Day	*704*	*54.1*	*12.1*	*66.4*	*23.5*	*91.7*
	Night	*403*	*51.0*	*10.0*	*60.1*	*23.6*	*83.1*
T (top) non-RLC	Day	*1003*	*60.3*	*11.9*	*72.0*	*25.9*	*129.2*
	Night	*487*	*56.0*	*10.0*	*65.9*	*25.7*	*84.7*
T (top) with RLC	Day	*379*	*55.3*	*9.2*	*64.7*	*28.8*	*80.0*
	Night	*264*	*52.9*	*10.3*	*63.5*	*21.4*	*83.0*
T (mid) non-RLC	Day	*275*	*56.5*	*10.7*	*67.5*	*28.8*	*83.1*
T (mid) with RLC	Day	*343*	*59.3*	*11.1*	*72.0*	*30.0*	*108.0*
GS non-RLC	Day	370	56.5	9.3	65.7	26.5	87.0
	Night	271	56.0	7.9	64.1	29.9	81.3

Table 5.5 Two-sample 1-tail tests on mean speeds between non-RLC and RLC approaches

Approach Type	z value	p value	Signif.
X	11.787	1.645	S
T(top)	9.394	1.645	S
T(mid)	-3.194	1.645	NS

The mean speeds for crossing and stopping vehicles are summarised in Table 5.6. Two-sample 2-tail Z tests between the stopping and crossing vehicles within the TZ (see Table 5.7) showed no significant difference (at α=5%) for daytime data, and at the X-junctions as well as at the top approach of non-RLC T-junctions for the night-time data. When all vehicles (total sample) were taken in account, the crossing vehicles were found to have significantly higher mean speeds than the stopping vehicles at every type of approach, regardless of daytime or night-time.

5.2.3 Observed traverse time

The observed traverse time of a crossing vehicle is basically the actual amount of time taken by that last crossing vehicle to reach the stop line as referenced from the amber onset. The observed traverse times associated with TTSL equal or more than 2 seconds are shown in Table 5.8 by the approach types, and in Figure 5.5 by RLC and non-RLC approaches.

Table 5.6 Mean speeds of stopping and crossing vehicles

Approach Type	Time	TZ n	TZ Stop	TZ n	TZ Cross	All n	All Stop	All n	All Cross
X non-RLC	Day	140	61.2	268	59.6	623	57.9	415	60.4
	Night	26	65.6	73	62.1	117	58.7	122	62.2
X with RLC	Day	161	55.0	139	55.0	435	52.9	269	56.1
	Night	76	51.3	109	52.5	225	49.7	178	52.9
T (top) non-RLC	Day	113	63.7	328	61.9	504	58.7	499	62.1
	Night	64	58.4	152	57.5	242	54.5	245	57.6
T (top) with RLC	Day	118	56.8	78	55.5	244	54.5	135	56.6
	Night	72	52.0	56	57.8	158	50.1	106	57.0
T (mid) non-RLC	Day	51	56.2	89	57.8	110	53.8	165	58.4
T (mid) with RLC	Day	106	59.4	67	60.7	190	58.4	153	60.6
GS non-RLC	Day	43	57.8	102	59.1	244	54.9	126	59.6
	Night	30	60.2	86	56.5	138	54.7	133	57.4

Table 5.7 Two-sample 2-tail Z tests on mean speeds between stopping and crossing vehicles

Approach Type	Time	TZ z value	TZ p value	TZ Signif.*	All z value	All p value	All Signif. (α=5%)
X non-RLC	Day	1.259	0.208	NS	-3.054	0.002	S
	Night	1.413	0.158	NS	-2.256	0.024	S
X with RLC	Day	-0.040	0.968	NS	-3.252	0.001	S
	Night	-0.781	0.435	NS	-3.208	0.001	S
T (top) non-RLC	Day	1.541	0.123	NS	-4.474	7.68e-6	S
	Night	0.556	0.579	NS	-3.439	0.001	S
T (top) with RLC	Day	0.206	0.837	NS	-2.123	0.034	S
	Night	-3.510	0.000	S	-5.724	1.04e-8	S
T (mid) non-RLC	Day	-0.827	0.408	NS	-3.517	0.000	S
T (mid) with RLC	Day	-0.705	0.481	NS	-1.680	0.093	S (α=9%)
GS non-RLC	Day	-0.781	0.435	NS	-4.761	0.000	S
	Night	3.000	0.003	S	-2.949	0.003	S

**Hypothesis tests were carried out at level of significance, α=0.05, unless stated otherwise*

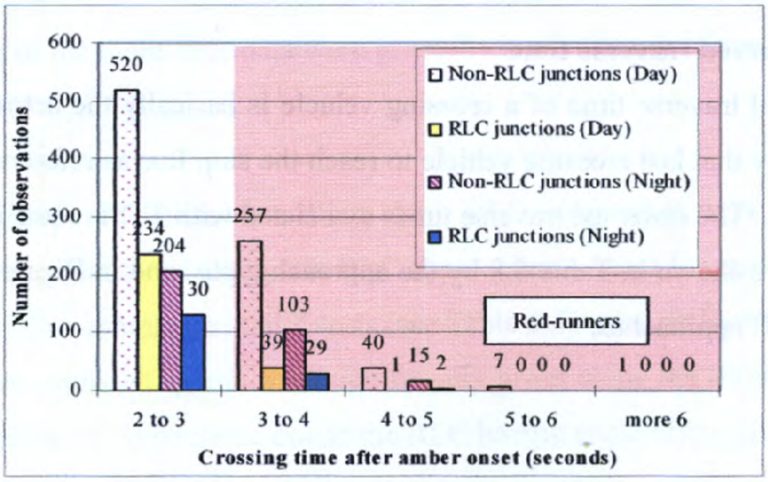


Figure 5.5 Distribution of the observed traverse times

Table 5.8 Observed traverse time (for crossing vehicles) with TTSL equal or more than 2 secs

Approach Type	Site	Time	n	Median	Mean	Std. dev.	85%tile	Min.	Max.
X non-RLC	W3	Day	135	2.6	2.7	0.5	3.1	2.0	4.6
	W4	Day	69	2.9	3.0	0.6	3.6	2.0	5.2
	W5	Day	23	2.5	2.5	0.5	2.8	1.9	3.9
	W8	Day	58	2.9	3.0	0.6	3.7	1.9	4.4
		Night	76	2.7	2.8	0.6	3.4	1.7	4.5
	All	*D*	*285*	*2.6*	*2.8*	*0.6*	*3.4*	*1.9*	*5.2*
		N	*76*	*2.7*	*2.8*	*0.6*	*3.4*	*1.7*	*4.5*
X with RLC	C1	Day	30	2.4	2.6	0.5	3.1	2.0	4.0
	C2	Day	45	2.4	2.6	0.5	3.1	1.9	3.9
		Night	71	2.5	2.5	0.5	2.9	1.9	3.9
	C3	Day	29	2.4	2.5	0.5	3.1	1.9	3.7
	C4	Day	38	2.5	2.6	0.5	3.2	1.9	4.0
		Night	39	2.5	2.6	0.6	3.3	1.9	4.2
	All	*D*	*142*	*2.4*	*2.6*	*0.5*	*3.1*	*1.9*	*4.0*
		N	*110*	*2.5*	*2.6*	*0.5*	*3.1*	*1.9*	*4.2*
T (top) non-RLC	TW1	Day	140	2.8	2.9	0.8	3.7	2.0	6.3
		Night	57	2.7	2.8	0.6	3.5	1.9	4.6
	TW4	Day	32	2.7	2.8	0.7	3.4	1.9	5.3
	TW7	Day	100	3.1	3.2	0.8	4.0	1.7	5.9
	TW8	Day	94	2.8	2.8	0.6	3.4	1.8	4.5
		Night	103	2.9	3.0	0.7	3.8	2.0	5.0
	All	*D*	*366*	*2.9*	*3.0*	*0.7*	*3.7*	*1.7*	*6.3*
		N	*160*	*2.8*	*2.9*	*0.6*	*3.6*	*1.9*	*5.0*
T (top) with RLC	TC2	Day	32	2.4	2.4	0.5	2.7	1.8	3.8
		Night	35	2.5	2.6	0.5	3.1	2.0	4.1
	TC3	Day	46	2.4	2.6	0.6	2.9	1.9	3.5
		Night	35	2.5	2.6	0.5	3.1	2.0	4.1
	All	*D*	*78*	*2.4*	*2.4*	*0.4*	*2.8*	*1.8*	*3.8*
		N	*58*	*2.4*	*2.6*	*0.5*	*3.1*	*1.9*	*4.1*
T (mid) non-RLC	TW5	Day	37	2.9	2.9	0.6	3.5	2.0	4.2
	TW6	Day	55	2.9	2.9	0.6	3.5	1.9	4.7
	All	*D*	*92*	*2.9*	*2.9*	*0.6*	*3.5*	*1.9*	*4.7*
T (mid) with RLC	TC4	Day	33	2.3	2.4	0.4	2.7	1.9	3.4
	TC5	Day	34	2.6	2.7	0.4	3.1	2.1	3.8
	All	*D*	*67*	*2.5*	*2.5*	*0.4*	*2.9*	*1.9*	*3.8*
GS non-RLC	W2	Day	110	2.6	2.8	0.6	3.4	1.9	5.1
		Night	90	2.7	2.8	0.6	3.5	1.9	4.6

Any vehicle with observed traverse time in excess of 3 seconds is a red-runner (since all junctions have amber duration of 3 seconds). There were a total of 305 and 40 red-runners at non-RLC approaches and at approaches with RLCs, respectively, for daytime data and similarly, a total of 118 and 31 for night-time data. The number of red-runners decreased exponentially as time after red increased which is similar to the pattern of red-running violations as captured by the

RLCs (in section 4.2.2). In other words, most of the red-running occurred shortly (within one second) after the red light was displayed. This suggested that engineering measures focused on driver recognition of, and response to, the amber indication are likely to be cost-effective in reducing red-running.

About 85% of the crossing vehicles (with TTSL≥2 seconds) managed to clear the stop line within the 3 seconds of amber at the RLC approaches but less than two-thirds (about 63%) did so at non-RLC junctions. The mean traverse time for the GS approach was not distinctively different (shorter) than from that of the X-junction approaches. This could mean that a wider junction does not necessarily discourage drivers to cross, given the same amber period. The 85^{th} percentiles of the traverse times for the non-RLC X, T(top), T(mid) and GS approaches were 3.4, 3.7, 3.5 and 3.5 seconds, respectively. This suggested that the present red clearance times of 0.6 – 1 seconds (X, T(mid) and GS approaches) and 2 seconds (T(top) approach) (see Appendix A) would not be sufficient for some vehicles.

5.3 Determining driver performance parameters

The designed length of a signal change interval (see Equation 2.3) is dependent on the PRT and deceleration rate. The higher the PRT value, the longer is the required interval. The higher the deceleration rate, the shorter is the required interval. It is thus important to know the characteristics of these two driver performance parameters in order to have an effective design of the signal change interval.

5.3.1 Perception-response time (PRT)

The PRT in this study was determined by taking the time difference between the instant that the brake lights were lit and the amber onset. Table 5.9 shows the summarised results of the PRT values obtained from samples in the TZ as well as the total samples, at different types of junction approaches. Importantly, the 85^{th} percentile PRT values (0.96 - 1.20 seconds) within the TZ were close to the ITE's design value of 1 second.

Table 5.9 Observed PRT values

Approach Type	Time		n	Mean	Std. dev.	85%tile	Min.	Max.
X non-RLC	Day	TZ	140	0.88	0.26	1.14	0.40	1.84
		All	623	1.41	1.08	1.84	0.38	10.74
	Night	TZ	26	0.86	0.24	1.10	0.28	1.30
		All	117	1.20	0.58	1.68	0.28	4.20
X with RLC	Day	TZ	161	0.81	0.22	1.06	0.24	1.48
		All	435	1.16	0.73	1.52	0.04	6.04
	Night	TZ	76	0.75	0.23	0.96	0.26	1.60
		All	225	0.99	0.52	1.30	0.26	5.92
T (top) non-RLC	Day	TZ	113	0.92	0.26	1.20	0.52	1.80
		All	504	1.30	0.65	1.80	0.52	6.02
	Night	TZ	64	0.96	0.44	1.16	0.48	3.48
		All	244	1.05	0.47	1.42	0.44	4.28
T (top) with RLC	Day	TZ	118	0.84	0.23	1.06	0.44	1.58
		All	244	1.05	0.47	1.42	0.44	4.28
	Night	TZ	72	0.87	0.28	1.14	0.24	1.74
		All	158	1.19	0.74	1.66	0.24	4.56
T (mid) non-RLC	Day	TZ	51	0.89	0.24	1.10	0.04	1.58
		ALL	110	1.04	0.45	1.28	0.04	3.60
T (mid) with RLC	Day	TZ	106	0.78	0.22	0.98	0.24	1.78
		All	190	0.96	0.56	1.20	0.24	6.08
GS non-RLC	Day	TZ	42	0.85	0.15	0.98	0.54	1.18
		All	235	1.51	0.88	2.26	0.38	5.34
	Night	*TZ*	*30*	*0.88*	*0.17*	*1.02*	*0.60*	*1.40*
		All	*138*	*1.26*	*0.63*	*1.54*	*0.60*	*4.16*

Two-sample 2-tail Z tests were performed to compare the mean PRT values for various combinations of approach types (see Table 5.10). Within the TZ, there was no significant difference (at α=5%) in the mean PRT values among approaches without RLC, and among approaches with RLCs (with one exception), during the daytime. There were, however, significant differences between approaches with RLCs and approaches without an RLC, at junctions of the same configuration. The PRT values of drivers in the presence of RLCs were generally lower than when there was no RLC. This could be that drivers were generally better prepared or more decisive when stopping at approaches with RLCs.

Fewer comparisons were made for the night-time data due to the smaller set of study sites, and the influence of the RLC was not clear. In comparing the mean PRT values within the TZ between daytime and night-time situations at identical sites, no significant differences were found. Overall, it appeared that the TZ can generate consistent results for the PRT parameter across junctions of various layout configurations and possibly ambient light conditions, but with distinction made between approaches with and without RLCs. As for the comparisons using the total

Table 5.10 Two-sample 2-tail Z test results

Test	TZ		All	
	z value	Signif.	z value	Signif. (α=5%)
Daytime				
X non-RLC vs T (top) non-RLC	-1.15	NS	2.20	S
X non-RLC vs T(mid) non-RLC	-0.26	NS	6.13	S
T (top) non-RLC vs T (mid) non-RLC	0.67	NS	5.02	S
GS non-RLC vs X non-RLC	-0.86	NS	1.40	NS
GS non-RLC vs T(mid) non-RLC	-0.94	NS	6.64	S
GS non-RLC vs T(top) non-RLC	-1.94	S (α = 5.2%)	3.36	NS
X RLC vs T (top) RLC	-1.18	NS	2.34	S
X RLC vs T (mid) RLC	1.08	NS	3.78	S
T (top) RLC vs T (mid) RLC	2.10	S	1.86	S (α = 6%)
X non-RLC vs X RLC	2.50	S	4.49	S
T (top) non-RLC vs T (top) RLC	2.43	S	5.85	S
T (mid) non-RLC vs T (mid) RLC	2.83	S	1.32	NS
Non-RLC junctions vs RLC junctions	4.58	S	8.65	S
Night-time				
X non-RLC vs X RLC	2.09	S	3.30	S
T (top) non-RLC vs T (top) RLC	1.33	NS	0.16	NS
X non_RLC day vs night*	0.33	NS	3.03	S
T (top) non-RLC day vs night*	-0.91	NS	1.30	NS
GS non-RLC day vs night	-0.81	NS	3.26	S
X RLC day vs night*	1.29	NS	2.74	S
T (top) RLC day vs night*	-0.88	NS	-2.12	S

**Comparison made using identical sites*

samples, the results were mixed; the mean PRT values were found to be generally lower at night which could be due to the greater contrast (from afar) of the signal indications during night-time.

Attempts were made to fit the observed PRT values (within the TZ) with suitable statistical distributions. The log-normal distribution (see Equation 5.1) was reported to be the best-fitting distribution for observed PRT values (Taoka, 1982). Only the mean, standard deviation and median statistics are required for fitting the log-normal distribution, with the cumulative probability distribution function *F(t)* defined by

$$F(t) = \int_0^t \frac{1}{t\xi\sqrt{2\pi}} e^{\left[-\frac{1}{2}\left(\frac{\ln t - \ln \lambda}{\xi}\right)^2\right]} dt \qquad (5.1)$$

where $\xi = \sqrt{\ln\left(1+\frac{\sigma^2}{\mu^2}\right)}$, σ = std. dev., μ= mean, λ= median

Kolmogorov-Smirnov (K-S) tests (see Appendix F) were done to compare the observed and modelled cumulative distributions for all the approach types and it was concluded that the log-normal distribution indeed provided a good fit for the distribution of PRT values within the TZ (at 1% significance level). Cumulative profiles using the log-normal distribution were produced for the PRT values from this and past studies as shown in Figures 5.6 and 5.7. It can be seen that the 85th percentile values from the present study were much nearer to the ITE design value of 1 second as compared to those from the past studies. Approaches with RLCs (solid points) were also found to have smaller PRT values than those without. The PRT profile for the approach at the grade-separated junction showed a tighter band of values (smaller variance) compared to the other approaches. There was greater variability in the night-time PRT values as compared to the corresponding daytime values. With the exception of the top approach of T-junction with RLC, the variances were significantly different at α=5% using F-test.

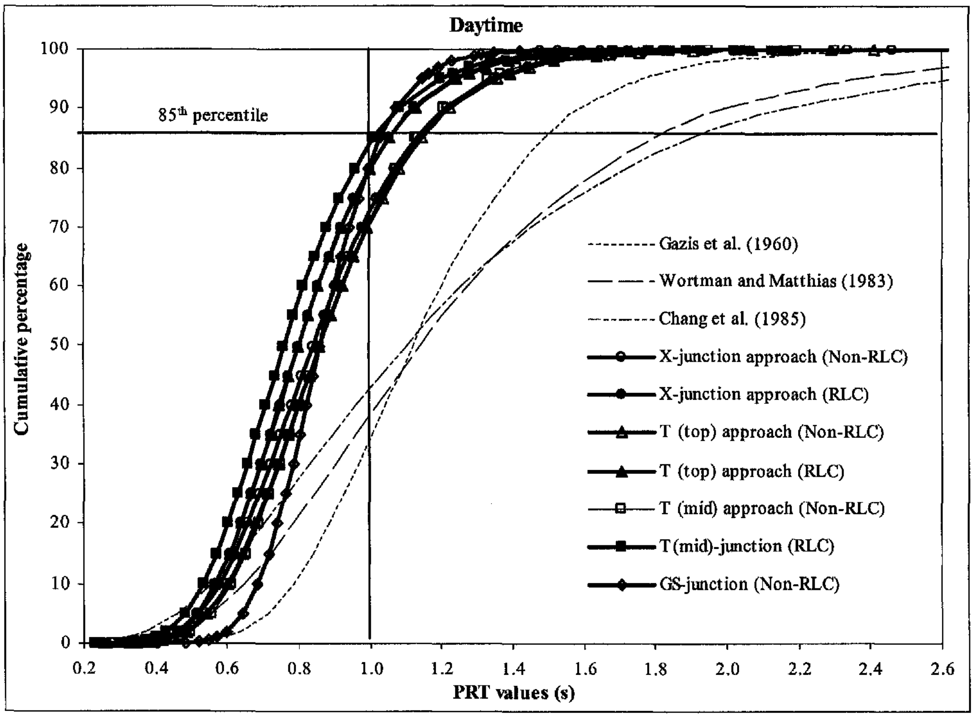


Figure 5.6 Cumulative distributions of PRT (for daytime only)

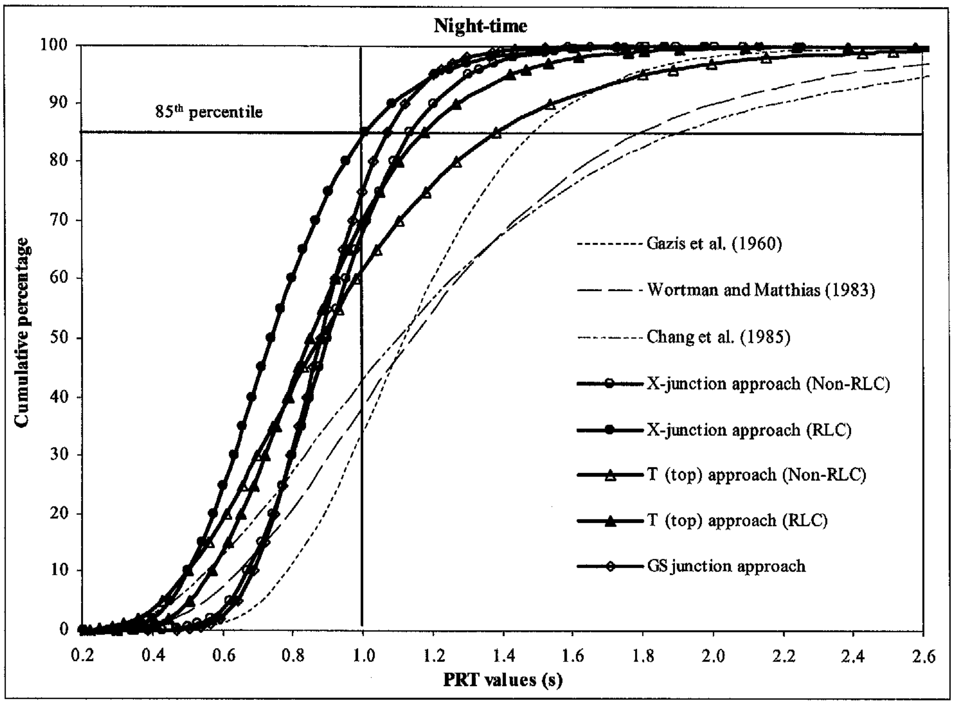


Figure 5.7 Cumulative distributions of PRT (for night-time only)

A general linear modelling (GLM procedure) was performed in order to find out which selected factors affected the PRT within the TZ. When the variables were modelled one at a time (univariate analysis), the variables: speed, RLC, vehicle class, opposing class, proximity of the front vehicle, headway and approach type were found to be significant at 95% level of confidence. Using the stepwise regression method, the variable with the highest regression sum-of-square (SSR) value or the R-square value was first chosen to enter into the model. This was followed by choosing the variable with the largest increase in SSR value in the presence of the first variable. Continued effectiveness of the variable that was already in the model was then assessed before adding new variables. The procedure continued until reaching a stage where no additional variable can be inserted or deleted.

The final model contained the following variables: RLC, opposing class, speed and distance from stop line of the vehicle at amber onset, and vehicle class. Tables 5.11 and 5.12 show the modelled variables and the summarised results of the GLM procedure. The PRT value tended to be smaller when the approach is installed with an RLC. This could be due to drivers being more decisive upon a "stopping strategy" along an approach with an RLC. As for vehicle class, it was found that HCV and motorcycle had smaller PRT values than the reference group (car). This suggested that among those who stopped, the HCV drivers were better prepared in stopping (given the greater inertia of heavy vehicles) whereas the quicker response time for the two-wheelers was probably due to the quicker mechanism used in braking: joint hand-foot brakes (for motorcycles) as compared to foot-brakes (for other vehicle types). Smaller PRT values were also found to be associated with motorists who faced the possible risk of collision with opposing right-turners. It should be noted that the R-square value was 0.112, indicating that the overall fit of the model was not good (or the relationship between PRT and the variables may not all be linear). The value of the intercept was quite high compared to the mean value of the dependent variable. (This suggested that there was scope for improvement, such as including additional variables.) However, this did not detract from the interpretation of the results as this part of the analysis was only to identify the type of variables that affect PRT.

Table 5.11 GLM results* of single-variable entry (against PRT)

Variable	Level	R^2	SSR	F value*	Pr > F	Effect (α=5%)
Distance	Continuous	0.002	0.130	1.93	0.1646	NS
Speed	Continuous	0.007	0.484	7.24	**0.0073**	S
Vehicle class	Discrete	0.010	0.677	3.38	**0.0178**	S
Entry lane	Discrete	0.001	0.084	0.63	0.5344	NS
Lane change	Discrete	0.000	0.014	0.20	0.6528	NS
RLC**	Discrete	0.028	1.901	29.05	**<0.0001**	S
Pedestrian	Discrete	0.002	0.114	1.68	0.1949	NS
Light condition	Discrete	0.000	0.029	0.43	0.5100	NS
Front***	Discrete	0.007	0.471	3.48	**0.0313**	S
Back***	Discrete	0.002	0.106	0.78	0.4603	NS
Side	Discrete	0.003	0.231	1.70	0.1827	NS
Headway***	Discrete	0.008	0.525	2.59	**0.0518**	S (α=5.2%)
Opposing class	Discrete	0.022	1.417	4.23	**0.0008**	S
Approach type**	Discrete	0.042	2.828	7.27	**<0.0001**	S

** SAS- generated GLM results are shown in Appendix G*
*** Variables RLC and Approach type are a linear function of each other, so either one is included in the final model*
**** Variable headway is a function of the variables front and back, so either one is included in the final model*

Table 5.12 GLM multivariate model

Variables	Level	Estimate	t-value	Pr>|t|
Intercept	Continuous	1.208	22.49	**<0.0001**
Distance	Continuous	0.007	5.65	**<0.0001**
Speed	Continuous	-0.011	-7.88	**<0.0001**
Vehicle class	Car	Reference	-	-
	Motorcycle	-0.011	-0.35	0.7287
	LCV	0.018	0.76	0.4503
	HCV	-0.079	-3.43	**0.0006**
RLC	Absent	Reference	-	-
	Present	-0.077	-4.51	**<0.0001**
Opposing class	None	Reference	-	-
	Present	-0.055	-2.87	**0.0042**
	Absent	0.024	0.74	0.4602
	Severe conflict	-0.165	-2.16	**0.0313**
	Moderate-mild conflict	-0.064	-1.83	0.0670
	View blocked	-0.069	-2.66	**0.0079**

5.3.2 Deceleration rate

The deceleration rate was averaged over the distance at the point that the brakes were applied and until the vehicle stopped (at the painted stop line). The deceleration rate was calculated using the following equation:

$$a = \frac{v^2}{2s_b} \tag{5.2}$$

where a is the deceleration rate (m/s^2), v is the initial approach speed (m/s), and s_b is the distance in braking. This equation was adopted from the motion equation ($v^2 = u^2 + 2as$).

Table 5.13 presents the deceleration rates employed by drivers at different types of junction approaches. The mean deceleration rates were found to vary between 2.8 and 3.4 m/s^2 for stopping vehicles within the TZ which were higher as compared to the total samples. This is not unexpected because drivers in the TZ are those who are nearer to the stop line and tend to brake more harshly in order to stop while those further away can decelerate at their desired pace. The 85th percentile

Table 5.13 Deceleration rates

Approach Type	Time	Site	n	Mean	Std. dev.	85%tile	Min.	Max.
X non-RLC	Day	TZ	140	3.36	0.78	4.06	1.62	5.70
		All	623	2.24	0.91	3.22	0.53	5.70
	Night	TZ	26	3.43	0.77	4.34	1.61	5.02
		All	117	2.23	0.90	3.04	0.43	5.02
X with RLC	Day	TZ	161	3.09	0.84	3.95	0.64	5.82
		All	435	2.33	0.97	3.27	0.57	6.93
	Night	TZ	76	2.79	0.78	3.70	1.34	4.67
		All	225	2.14	0.82	2.88	0.48	5.92
T (top) non-RLC	Day	TZ	113	3.38	0.85	4.01	1.38	7.96
		All	504	2.36	0.88	3.21	0.65	7.96
	Night	TZ	64	3.08	0.80	3.80	1.04	5.93
		All	242	2.23	0.82	3.06	0.77	5.93
T (top) with RLC	Day	TZ	118	3.35	0.83	4.09	1.80	6.20
		All	244	2.70	1.05	3.72	0.97	6.20
	Night	TZ	72	3.26	1.00	4.49	1.87	6.21
		All	158	2.56	1.24	3.62	0.79	8.90
T (mid) non-RLC	Day	TZ	51	2.91	0.75	3.69	0.85	4.58
		All	110	2.39	0.81	3.40	0.85	4.58
T (mid) with RLC	Day	TZ	106	3.38	1.03	4.36	1.05	6.81
		All	190	2.76	1.11	3.97	0.55	6.81
GS non-RLC	Day	TZ	42	3.18	0.85	4.20	1.67	5.37
		All	235	2.14	0.82	2.84	0.57	5.37
	Night	TZ	30	3.26	0.87	3.97	0.08	5.07
		All	138	2.17	0.85	3.04	0.08	5.07

deceleration rates in the TZ were observed to be about 3.7 to 4.5 m/s^2. Hypothesis tests between day and night data showed that the mean deceleration rates were significantly lower at night at X-RLC approaches and at T(top) non-RLC approaches.

The GLM procedure was applied to model the deceleration rates within the TZ. The univariate results in Table 5.14 shows that speed, distance, PRT, vehicle class, status of the front vehicle, opposing class, entry lane and approach type had significant effects on deceleration rates and thus were chosen to be included in the multivariate model. The final multivariate results are shown in Table 5.15.

The mulitvariate model had an intercept value of -0.668 which was significantly different from zero, hence indicating a certain amount of unmodelled component. However, with an R^2 value of 0.80, the GLM multivariate model should be

Table 5.14 GLM results of single-variable entry (against deceleration rate)

Variable	Levels	R^2	SSR	F value*	Pr > F	Effect (α=5%)
Distance	Continuous	0.031	23.327	31.62	**<0.0001**	S
Speed	Continuous	0.321	243.549	471.31	**<0.0001**	S
Vehicle class	Discrete	0.076	57.649	27.27	**<0.0001**	S
Entry lane	Discrete	0.009	6.952	4.60	**0.0102**	S
Lane Change	Discrete	0.001	0.632	0.83	0.3621	NS
RLC	Discrete	0.002	1.238	1.63	0.2022	NS
Pedestrian	Discrete	0.002	1.655	2.19	0.1390	NS
Light condition	Discrete	0.007	5.269	6.97	**0.0084**	S
Front	Discrete	0.013	9.828	6.58	**0.0014**	S
Back	Discrete	0.008	5.651	3.76	**0.0235**	S
Side	Discrete	0.002	1.736	1.15	0.3169	NS
Headway	Discrete	0.016	11.417	5.10	**0.0017**	S
Opposing class	Discrete	0.021	15.239	4.10	**0.0011**	S
PRT	Continuous	0.026	19.847	26.78	**<0.0001**	S
Approach type	Discrete	0.034	26.689	5.85	**<0.0001**	S

Table 5.15 GLM multivariate model of deceleration rates

Variables	Level	Estimate	t value	Pr > |t|
Intercept	Continuous	-0.668	-7.37	**< 0.0001**
Speed	Continuous	0.130	58.12	**< 0.0001**
Distance	Continuous	-0.085	-45.60	**< 0.0001**
PRT	Continuous	1.208	24.14	**< 0.0001**
Vehicle class	Car	Reference	-	-
	Motorcycle	-0.050	-1.04	0.2968
	LCV	-0.043	-1.14	0.2531
	HCV	-0.073	-2.08	**0.0382**

** R^2 = 0.797 SAS-generated result are shown in Appendix G*

sufficiently strong to describe the deceleration rate. From the results, deceleration increased directly with vehicle approach speed and the PRT value and inversely with distance from the stop line. HCV was found to have a significantly lower deceleration rate (due in part to different vehicle mechanism e.g. being more difficult to achieve rapid deceleration) than a car.

Attempts were made to record the distance and time of the subject vehicle at regular (space) intervals so as to estimate the rate of change of speed and hence the acceleration/deceleration profile. It was found that there would be large errors in computing the rate of speed change over small intervals (particularly near the stop line), hence the acceleration/deceleration profile of vehicles was not studied. However, it was possible to tell from the difference between TTSL and the actual traverse time whether a through vehicle had, on average, accelerated, decelerated or remained at about the same speed as it proceeded through the junction.

A further analysis on the speed changes (acceleration/deceleration) was performed for the following categories of vehicles: those that cleared successfully, ran the red, and stopped successfully. The calculated acceleration and deceleration concept proposed by Robertson (1991) was used in this study. It was assumed that the acceleration and deceleration of the vehicle started after a time lag. For calculated deceleration, the time lag for stopping vehicles was the actual measured PRT value of each individual vehicle while for crossing vehicles, an average PRT value (≈0.85 seconds, estimated from stopping drivers) was used. For the calculated acceleration, the applicable time lag is the PRT less foot movement time taken as 0.2 seconds (Green, 2000) since acceleration can be initiated merely by depressing the accelerator further.

A calculated acceleration, A, is the average acceleration (initiated after a time lag) that would be required for a vehicle travelling at a constant initial speed, v, and at a distance, d, from the stop line at the amber onset, to just reach the stop line at red onset. A negative value of A implies that a vehicle travelling at its initial speed without any speed change would reach the stop line before red onset. The value of 'A' was computed as:

$$A = \frac{2(d - vt)}{(t - (PRT - 0.2))^2} \qquad (5.3)$$

where t is the amber duration (typically 3 seconds).

A calculated deceleration (or braking), D, is the average deceleration (initiated after a time lag) that would be required to bring a vehicle, travelling at a constant initial speed, v, and at distance, d, from the stop line, to just stop at the stop line. The value of D would be negative if the vehicle travelling at its initial speed would reach the stop line in less than PRT seconds after amber onset i.e. the vehicle would have gone beyond the stop line even before any deceleration can take place, and stopping at the stop line is not possible. Hence D shall take on a positive value only (for TTSL >PRT). Large absolute value means that the vehicle was near to the stop line at the amber onset whereas small absolute value means that it was far away from the stop line. The value of 'D' was computed as:

$$D = \frac{v^2}{2(d - v(PRT))} \tag{5.4}$$

Cumulative profiles of the calculated acceleration and deceleration values for three different cases (stopped (TTSL≤5), crossed successfully (TTSL≥2) and red-ran (TTSL≥2) are shown in Figures 5.8 to 5.10. Initially, the night-time data were separated from the daytime data. However, the night-time data showed only a slight lateral shift to the left (drivers stopping at a closer distance from the stop line) at each approach type, suggesting that night-time condition had not greatly influenced the driver's decision to stop/cross. Hence, the night-time data were consequently combined with the daytime data.

Referring to Figure 5.8, some small proportions of those vehicles that stopped at RLC approaches (about 10-25%) would have been able to cross the junction if the initial speed had been maintained; the proportions were relatively smaller at non-RLC junctions. This finding suggested that most vehicles will cross the junction if possible and stop only when unable to clear. That relatively more drivers needlessly stopped at RLC approaches indicated the deterrent effect of RLCs. The calculated deceleration for those who stopped (see Figure 5.8) revealed fair proportions of motorists who braked at a rate beyond the comfortable rate suggested by ITE (of 3 m/s^2). The proportions were somewhat higher at RLC approaches than those at junctions without an RLC; this means that there were relatively more drivers stopping at a shorter distance from the stop line at RLC approaches.

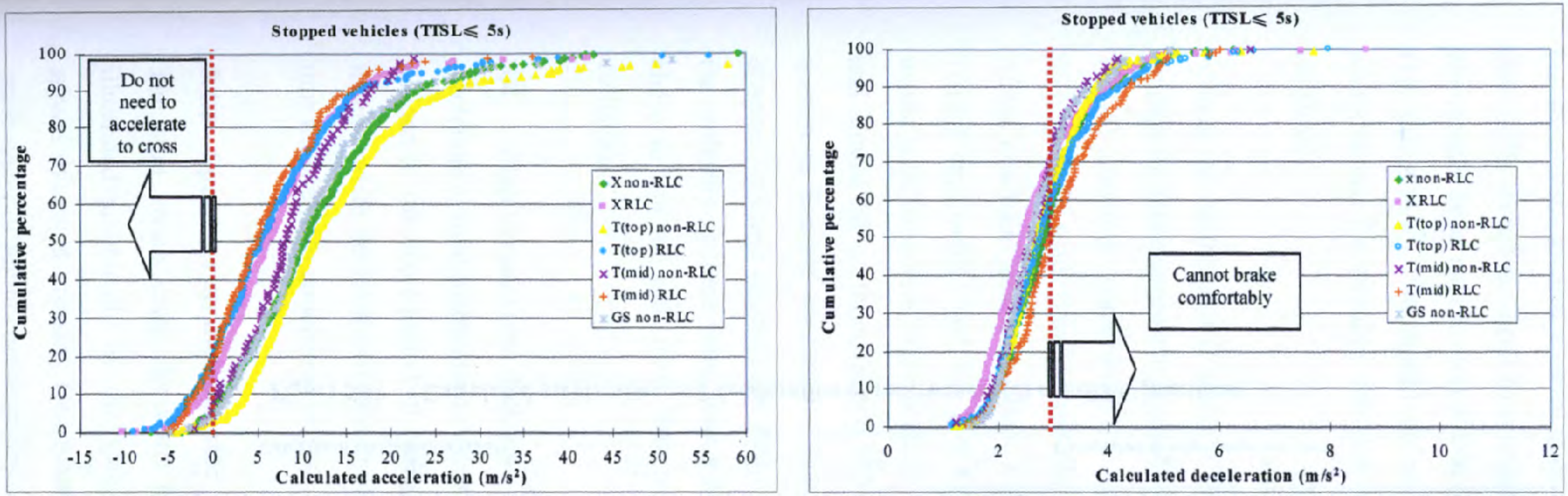


Figure 5.8 Calculated acceleration and deceleration of stopping vehicles

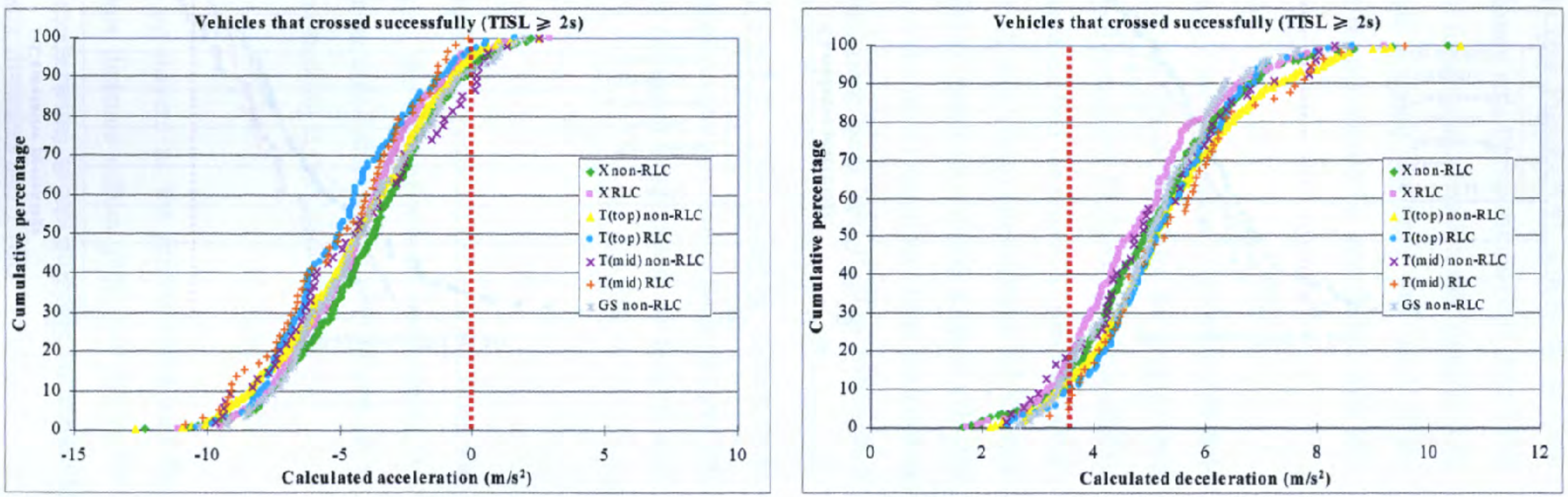


Figure 5.9 Calculated acceleration and deceleration of vehicles that crossed successfully

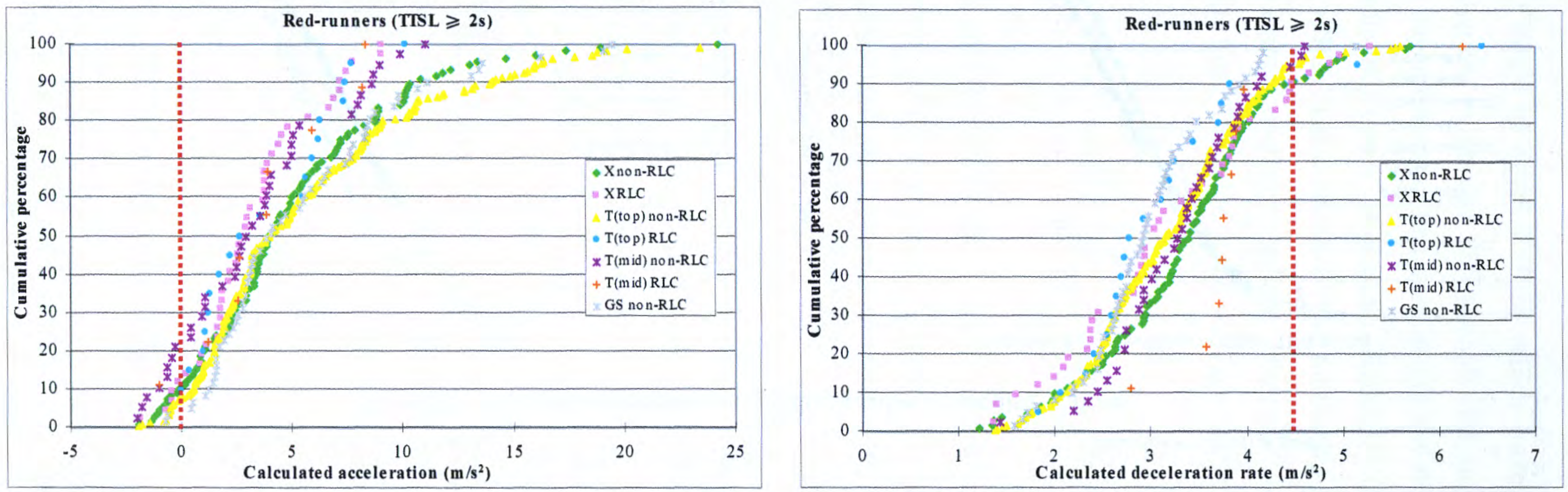


Figure 5.10 Calculated acceleration and deceleration of red-runners (at non-RLC junctions)

For those vehicles that crossed successfully (see Figures 5.9), almost all of them (86-100%) would not need to accelerate. Some small proportions (less than 15%) would have been able to stop within the comfortable deceleration rate suggested by ITE (of 3 m/s^2). It should be noted that a single lag time was used in the computations for crossing vehicles, so the results should be interpreted with this constraint.

Among the red-runners (Figures 5.10), it was found that there were very few red-runners for those approaches installed with RLCs (42, 20 and 9 for X-, T (top)- and T(mid)-junctions, respectively). The small numbers hindered any conclusive findings to be made, thus the red-runners were studied for non-RLC junctions only. At the non-RLC junctions, about 7.5% (for X and T(top) approaches), 22.5% (for T(mid) approaches) and 5% (for GS junction approach) of the subject vehicles would have been able to cross successfully if the initial speed had been maintained and almost all of them (above 90%) would have been able to stop within at a maximum feasible deceleration rate of about 4.5 m/s^2 (using the 85^{th} percentile observed average deceleration rate in section 5.3.2). This should be of concern to the authority as there were quite a number of drivers who could have stopped but chose to run the red; these drivers could be major contributors to head-to-side collisions.

5.4 Stop versus cross decision

Accidents at road junctions are often caused by inappropriate driver's decisions and actions in the short period of change during the right-of-way re-assignment. An inappropriate decision can land the driver on a collision course with others. It is thus important to understand driver decision-making at the traffic signals.

5.4.1 Speed versus distance plot

The stop versus cross decisions made by drivers at the amber onset can be illustrated graphically by the speed versus distance scatter plot that shows the spread of actual crossing (red-running or otherwise) versus stopping movements made under different combinations of speeds, distances and TTSL.

With reference to Figures 5.11 and 5.12 (that included both daytime and night-time data), the four situations faced by the drivers were basically delineated by the stopping distance curve ($X_s=v(PRT) + v^2/(2a)$) and the crossing distance line ($X_c=vt$), using the design *PRT* value of 1 second, and a design deceleration, *a*, of 3 m/s^2 (10 ft/s^2) and an amber time, *t*, of 3 seconds. These delineating lines were superimposed onto the speed versus distance plot data points so as to examine how well the 4-situation scheme can differentiate the driver decisions.

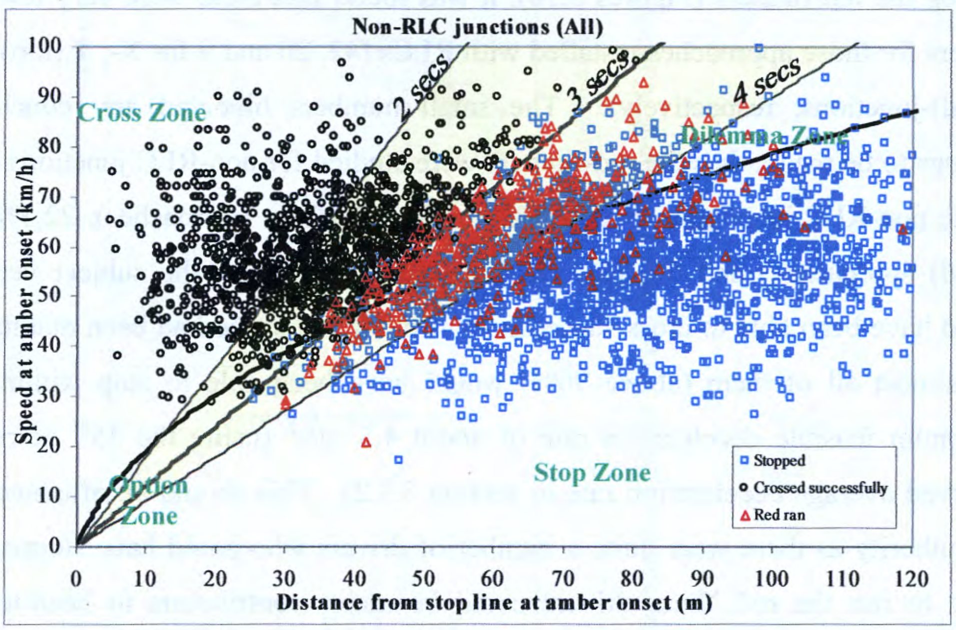


Figure 5.11 **Speed versus distance plot for approaches at non-RLC junctions**

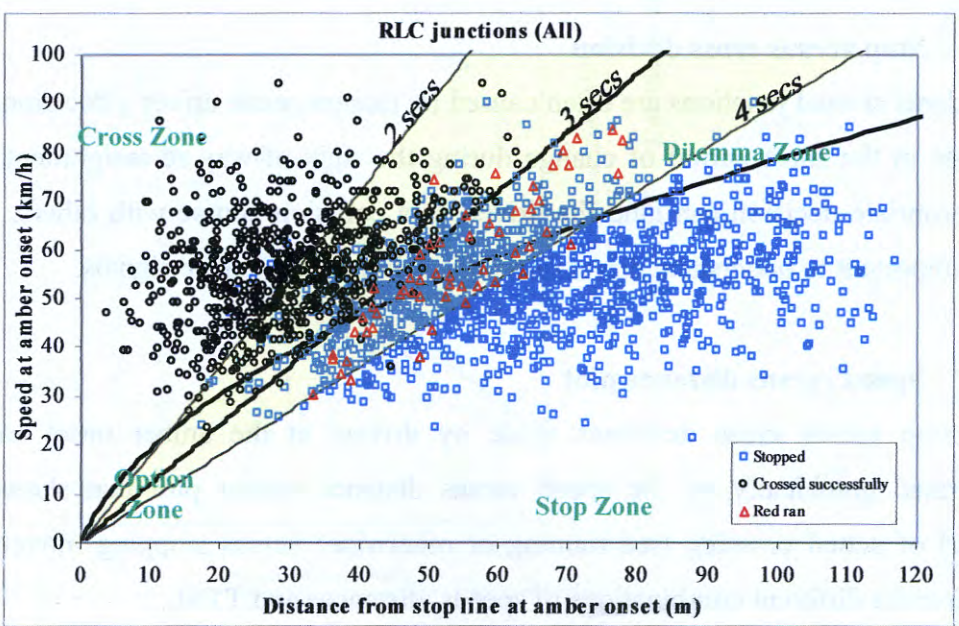


Figure 5.12 **Speed versus distance plot for RLC approaches**

It can be observed from Figures 5.11 and 5.12 that the majority of the crossings were located within the cross zone, and the stoppings in the stop zone. However, stopping vehicles could belong to any of the 4 situations and there were a lot more crossings (typically red-runners) in the dilemma zone at non-RLC approaches as compared to RLC approaches. This showed that the four-situation scheme is unable to accurately describe driver choice under different situations (e.g. presence/absence of RLCs, daytime/night-time). Nevertheless, the type of red-runners: either deliberate (could have stopped but chose to cross and ended up red-running) or unintentional (those in the dilemma zone) could be roughly distinguished.

It should also be noted that the zone bounded by the 2 seconds and 4 seconds TTSL diagonal lines can be taken as the transitional zone (TZ) as defined earlier. A mixture of decisions can be observed within the TZ.

5.4.2 The 'A, D' representation

Using the calculated acceleration and deceleration rates of vehicles (obtained in section 5.3.2), an 'A, D' representation (Robertson, 1992) can be plotted to show which of the 4 situations (cross, stop, option and dilemma) each driver faced at the point of amber onset. The 'A, D' scheme basically shows at the amber onset, the acceleration (or deceleration) required for each individual vehicle if it were to cross the stop line at the juncture of red onset (or to stop at the stop line), and the actual outcome (decision made).

Using a maximum operating acceleration rate (A*) and deceleration rate (D*) of 1 m/s^2 (refer to section 2.3.2) and 4.5 m/s^2 (refer to section 5.3.2), respectively, the 4 situational zones can be identified by the 4 partitioned areas as illustrated in Figures 5.13 and 5.14.

i) *Cross zone* is defined as the area where the required deceleration to stop at the stop line is higher than 4.5 m/s^2 and where required acceleration to cross is smaller than 1 m/s^2 or there is no need for acceleration in order to cross the stop line before red

ii) *Stop zone* is the portion where the required deceleration to stop is less than 4.5 m/s^2 and the required acceleration to cross is more than 1 m/s^2

iii) *Option zone* is the portion where both required deceleration and acceleration rates are small

iv) *Dilemma zone* is the portion where both required deceleration and acceleration rates are high

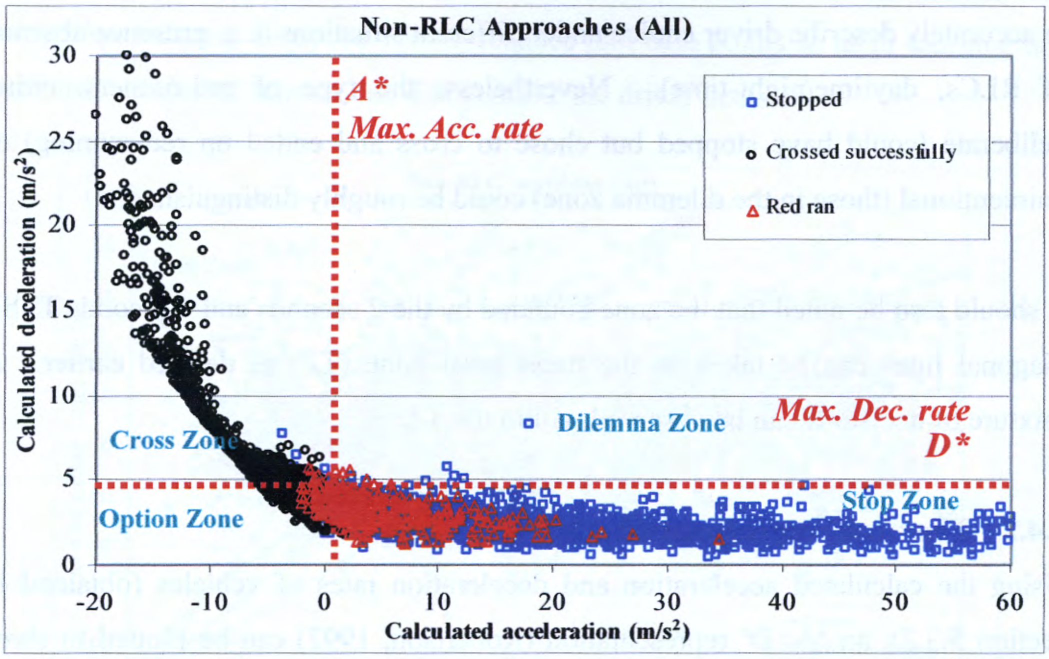


Figure 5.13 The 'A, D' representation for approaches at non-RLC junctions

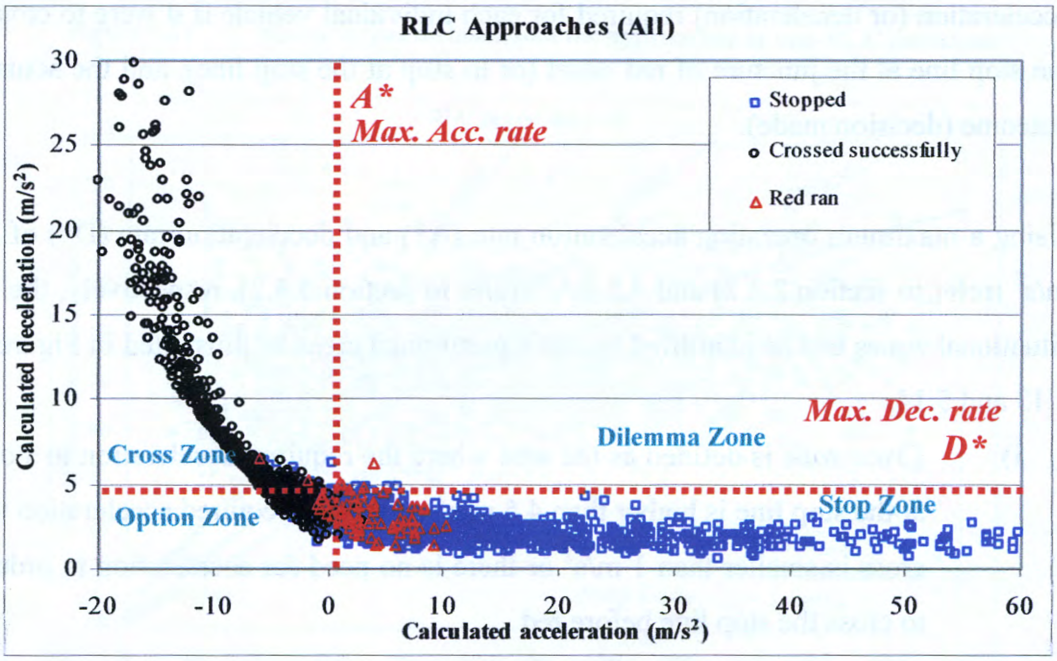


Figure 5.14 The 'A, D' representation for RLC approaches

Figures 5.13 and 5.14 show that almost all the vehicles positioned in the cross zone did manage to cross successfully and most of the red-runners were positioned within the stop zone (82% and 76%). This means that those who could have been able to stop elected to cross and ended up running the red, tantamount to deliberate red-running. Some of the red-runners in the cross zone might have been delayed by slower traffic in front and ended up red-running. A number of vehicles in the cross zone could have crossed successfully even without acceleration, but they chose to brake harshly (at a deceleration rate of more than 5 m/s^2) in order to stop, especially at the RLC approaches. These would be the drivers averse to running the red but they could pose a danger by braking harshly. Most of the stoppings were made where the required deceleration rates ranged from 0.5 to 4 m/s^2 in which the upper bound seemed to be somewhat lower than the maximum deceleration rate of 5.5 m/s^2 suggested by Robertson (1992).

Comparison between the two deterministic schemes

The two schemes described thus far were compared for which the conventional speed-distance scheme is shown in Table 5.16, and the 'A, D' scheme in Table 5.17. By comparing the two tables, it is clear that there were mixed proportions of crossings and stoppings in each of the four zones, typically the dilemma and option zones, at the RLC and non-RLC approaches. This is because the speed versus distance plot and the 'A, D' representation are engineering constructs and can only give information on what a driver can do and not the actual outcome. Moreover, for both schematics, the 4 situational zones were based on certain deterministic assumptions: *PRT=1 s* and *average deceleration rate=3* m/s^2 (for the speed versus distance plot) and *maximum allowable acceleration rate=1* m/s^2 and *maximum allowable deceleration rate=4.5* m/s^2 (for the 'A, D' representation), and hence produced different proportions. On the other hand, driver decision is inherently stochastic in nature and should be represented in a probabilistic manner. From Tables 5.16 and 5.17, the percentage of stopping was also observed to be slightly lower for all 4 zones during night-time than daytime, suggesting that drivers were less likely to stop during night-time.

Table 5.16 Distribution of the crossings and stoppings over the 4 zones (I)

Situational Zone	Speed versus distance plot					
	Non-RLC jtn			RLC approach		
	%Stopped	%Crossed successfully	%Red ran	%Stopped	% Crossed successfully	%Red ran
Cross	3.8 (2.8)*	93.3 (94.7)	3.0 (2.5)	16.5 (13.4)	83.1 (84.9)	0.5 (1.7)
Stop	90.7 (90.3)	1.1 (0.2)	8.2 (9.4)	97.7 (94.8)	0.5 (0.3)	1.8 (4.9)
Option**	25.0 (0.0)	75.0 (100.0)	0.0 (0.0)	33.3 (83.3)	66.7 (16.7)	0.0 (0.0)
Dilemma	56.2 (49.7)	6.5 (4.2)	37.4 (46.2)	85.9 (75.4)	1.9 (6.6)	12.3 (18.0)

**Values in parentheses represent night-time data*
***This zone had relatively small sample sizes, hence the values should be interpreted with care.*

Tables 5.17 Distribution of the crossings and stoppings over the 4 zones (II)

Situational Zone	'A, D' representation					
	Non-RLC jtn			RLC approach		
	%Stopped	%Crossed successfully	%Red ran	%Stopped	% Crossed successfully	%Red ran
Cross	2.2 (1.3)	96.0 (97.7)	1.8 (1.0)	7.6 (7.3)	92.4 (91.3)	0.0 (1.5)
Stop	84.0 (82.8)	1.0 (0.3)	15.0 (16.8)	95.2 (93.5)	0.7 (0.0)	4.1 (6.6)
Option	17.0 (8.8)	71.0 (75.5)	12.0 (15.7)	47.4 (35.5)	50.6 (59.8)	2.0 (4.7)
Dilemma**	66.7 (50.0)	4.2 (0.0)	29.2 (50.0)	63.6 (100.0)	0.0 (0.0)	36.4 (0.0)

5.4.3 The logistic regression

A more quantitative analysis (probabilistic approach) in the form of logistic regression was performed to examine the stopping probability for a driver at the onset of amber.

Why use Logistic Regression?

The binary outcome or response of driver decision-making can be described by the *stopping probability*. Given the binary or dichotomous response, the logistic regression is a suitable technique for regression analysis. Logistic regression allows the independent variables to be continuous, categorical or both. The difference between logistic and linear regression modelling is in the choice of the parametric model and its assumptions. Once this difference is accounted for, the analysis of the logistic regression follows the same principle as that of the linear regression. A logistic regression model is used not only for describing the relationship between the mean response (e.g. probability of stopping) and predictor variables but is also useful for making predictions, for example, the probability that a driver would stop at a signalised junction under a given set of conditions.

The Logistic Regression Model

The logistic regression does not model the relationship between the dependent variable and the explanatory variables directly, but through the logic function (that is, the natural logarithm of odds of $Y = 1$) which generates the predicted value of the dependent variable in terms of probability of $Y = 1$. The model is defined by:

$$\mathrm{E}(Y/x) = \log odds(Y = 1)) = \ln\left[\frac{p}{1-p}\right] = b_0 + b_1X_1 + b_2X_2 + \mathrm{K} + b_iX_i \quad (5.5)$$

This logit model or the logistic regression model assumes a linear relation between the log of odds and the independent variables, X_1, X_2,..., X_i. The maximum likelihood estimation (MLE) is used to obtain the estimates of the model parameters (logit coefficients). This is in contrast to the use of ordinary least squares estimation of coefficients in regression where one tries to minimise the sum of squared distances of the data points to the regression line. The use of MLE seeks to maximise the log likelihood instead. After the coefficient estimates are computed, the predicted probability that event Y occurs can be obtained as follows:

$$p(Y = 1) = \frac{e^{(b_0 + b_1X_1 + \mathrm{K} + b_iX_i)}}{1 + e^{(b_0 + b_1X_1 + \mathrm{K} + b_iX_i)}} \quad (5.6)$$

The interpretation of b_i is not as straightforward as the slope in a linear regression. If parameter b_i is positive, then p, the predicted probability of ($Y = 1$), is higher for higher values of X_i, and vice versa. A more intuitive interpretation of the logit coefficient is using the odds ratio where the odds of an event ($e^{\text{parameter estimate}}$) is defined as the ratio of probability that an event occurs to the probability that it fails to occur. For example, if the odds ratio, $e^{b_1} = 2$, then one unit change in X_1 would result in the event to be twice (0.67/0.33=2) as likely to occur, while holding other predictors constant. Negative coefficients lead to odds ratios less than one; if $e^{b_1} = 0.67$, then a unit change in X_1 leads to event being less likely (0.4/0.6=0.67) to occur. The aforementioned applies to cases where the independent variables are continuous. For discrete (categorical) independent variables with two or more levels, the odds ratio is with respect to the reference level. As an example, suppose one wishes to know the stopping probability (Y=1) of a driver at a signalised junction and one of the variables (e.g. X_2) is the presence of RLC (reference level: approach without RLC). An odds ratio of 5 would indicate that the probability of stopping is 5 times higher at an approach installed with an RLC than at an approach without an RLC, keeping all other variables constant. In simpler terms, as the probability of an event occurring increases, the odds and log odds increase too.

The logistic response function is basically a monotonic and sigmoidal S-shaped curve and is approximately linear (for $E\{Y\}$ between 0.2 and 0.8) except at its ends. It also has asymptotes at 0 and 1 and thus meets the constraint of $0 \leq E\{Y\} \leq 1$ because its outcome variable is either 0 or 1.

Program used to perform logistic regression

There are many programs that can be used to perform logistic regression, namely SPSS, SAS, STRATA, LIMDEP, etc. However, SAS being readily available and relatively easy to use, was employed in this research. SAS is a comprehensive collection of data analysis and report generation software routines, and it is able to do most types of statistical modelling. More details of the SAS package for logistic regression can be found in Allison (1990) and Stokes et al. (1999).

Independent Variable selection

A central issue in the modelling task is concerned with which and how many variables should be included in the model. The traditional approach is to minimise the number of variables in the model so that the resultant model is more likely to be stable and easily understood. The more variables there are in the model, the greater the estimated standard errors, and the more dependent on the observed data (or conditions) the model becomes. The traditional approach might lead to important factors that may influence the ultimate model to be overlooked. Another approach is to include all behaviourally and logically relevant variables in the model, regardless of their statistical significance. This is based on the fact that it is possible for individual variable to exhibit no strong confounding effect on the outcome but when taken collectively, considerable confounding can be present in the data. The model, on the other hand, might become overfitted and produce numerically unstable estimates. Both approaches belong to the extreme ends of statistical model building, thus in this research, a hybrid method as recommended by Hosmer and Lemeshow (2000) was used.

List of Independent Variables

Variables that are either shown in the past literature or intuitively known to the author to have considerable effect while making the stop versus cross decision were included in the first step of model building based on univariate analysis of each variable. They are listed in Table 5.18.

Table 5.18 List of variables chosen for analysis

No.	Variable	Abbreviation	Type*	Unit/level
1	Distance of subject vehicle from stop line at amber onset	Distance	continuous	m
2	Speed of subject vehicle at amber onset	Speed	continuous	km/h
3	Projected time to stop line at amber onset	TTSL	continuous	s
4	Vehicle type	Vehicle class	discrete	Car, Motorcycle, LCV, HCV
5	Entry lane	Entry lane	discrete	Centre, Kerb, Right-most Approach
6	Lane change	Lane change	discrete	Present, Absent
7	Light condition	Light condition	discrete	Daytime, Night-time
8	Presence of red-light camera	RLC	discrete	Absent, Present
9	Presence of pedestrian whose path conflicts with the path of subject vehicle	Pedestrian	discrete	Absent, Present
10	Presence of pre-indicator prior to amber onset (Green arrow for right-turner)	Green arrow	discrete	None, Absent, Present-short, Present-long
11	Presence of nearby vehicles with respect to subject vehicle: Front, Back, Side	Front, Back, Side	discrete	Good, Fair, Poor**
12	Headway of subject vehicle	Headway	discrete	Free flowing, Closely following, Being closely followed, Being sandwiched
13	Status of opposing vehicles	Opposing class	discrete	None, Present, Absent, Filtering-severe or moderate/mild conflict, View blocked
14	Site	Site	discrete	W3, W4, W5, W8, C1, C2, C3, C4, TW1, TW4, TW7, TW8, TC2, TC3, TW5, TW6, TC4, TC5, W2
15	Junction approach type	Approach type	discrete	X-jtn, T(top)-app, T(mid)-app, GS-jtn

** All variables are either continuous or discrete (categorical)*
***Levels of vehicle proximity as defined in Table 3.2 on page 53*

Step-by-step variable selection for the model

Univariate analysis of each variable was done by fitting a univariate logistic regression model that contained that single independent variable to test the significance of the coefficient by using the likelihood ratio test. For continuous independent variable, the mean, standard deviation, 15^{th}, 50^{th} and 85^{th} percentile values and minimum and maximum values were found. For nominal, ordinal and continuous independent variables with few integer values, a contingency table of outcome versus k levels of the independent variable was also plotted (see Appendix G). This additional step is to ensure that there is no complete or quasi-complete separation in the data. Quasi-complete (or complete) separation occurs when there is a zero cell in the contingency table or when there is small (or no) overlapping in the interval between minimum and maximum values for Y=1 (stop) and Y=0 (cross); this suggests that there are sparse data or missing cell counts. Variables with quasi-complete or complete separation can cause undesirable outcome and should not be used. In order for such variables to be used, one should either collapse the categories in a sensible way, eliminate the category totally or use it as a continuous variable. Any variable for which the univariate likelihood ratio chi-square test has a p-value < 0.25 or with known logical importance was considered as a likely candidate for inclusion in the multivariate analysis (Hosmer and Lemeshow, 2000). Table 5.18 summarises the results of the univariate analysis, showing the deviances (error associated with the model when only intercept is included in the model for the case of D_1 (without variable) and when independent variable(s) is included in the model for the case of D_2 (with variable)) and the likelihood ratio test p-values.

From the results in Table 5.19, it is noted that distance, speed and TTSL (time to stop line) were all significant in the univariate model and should be included for the multivariate analysis. However, when TTSL was modelled together with distance and speed, the latter two variables became insignificant (see Appendix G). This is because TTSL (time) is a ratio of distance and speed, thus either (distance and speed) or time is to be used in the model but not both. The significance of each variable in the model can be assessed by the value G, the log-likelihood statistic.

Table 5.19 Results of univariate analysis

Variable	-2Log Likelihood D1(Without Variable)	D2(With Variable)	G =D1 – D2	Likelihood Ratio Test Pr>χ²
Distance[1]	7926.046	4466.951	3459.095	<0.0001
Speed[1]	7926.046	7798.319	127.727	<0.0001
TTSL[1]	7926.046	3256.463	4669.583	<0.0001
Vehicle class	7926.046	7881.719	44.327	<0.0001
Entry lane	7926.046	7913.055	10.665	0.0048
Lane change	7923.720	7916.004	10.042	0.0015
Light condition	7926.046	7917.324	8.722	0.0031
RLC[2]	7926.046	7905.747	20.299	<0.0001
Pedestrian	7817.351	7813.136	4.215	0.0401
Green arrow[3]	7926.046	7899.011	27.035	<0.0001
Front[4]	7818.519	7804.054	14.465	0.0007
Back[4]	7818.519	7789.068	29.451	<0.0001
Side	7818.519	7812.407	6.112	0.0471
Headway[4]	7818.519	7767.575	50.944	<0.0001
Opposing class[3]	7793.552	7669.149	124.403	<0.0001
Site[2]	7926.046	7765.343	160.703	<0.0001
Approach type[2]	7926.046	7854.018	72.028	<0.0001

** Variables with superscript (1, 2, 3 and 4) are inter-related as functions of each other*

The higher the value of G, the higher is the significance of the variable in the model. Table 5.20 shows that speed, distance and their interaction term (distance×speed) have a slightly lower G value which technically means that TTSL should be used in the model in favour of speed, distance and their interaction. However, using TTSL also has its limitation because a fast moving vehicle far away from the stop line has the same TTSL as a slow moving vehicle close to the stop line and both cases need not necessarily give the same stopping probability. Thus, it was decided to model speed, distance, their interaction term (basic model) together with other significant variables.

Table 5.20 Use of distance and speed or time variable

Variable	-2Log Likelihood D1(Without Variable)	D2(With Variable)	G =D1 – D2	Likelihood Ratio Test Pr>χ²
Distance	7926.046	4466.951	3459.095	<0.0001
Speed	7926.046	7798.319	127.727	<0.0001
TTSL	**7926.046**	**3256.463**	**4669.583**	**<0.0001**
Distance, Speed	7926.046	3285.192	4640.854	<0.0001
Distance, Speed, Distance×Speed	**7926.046**	**3258.752**	**4667.294**	**<0.0001**

Each of the remaining variables was added to the basic model one by one and the deviances of the basic model without and with the variable were checked. The variable with the largest change in deviance was added to the model and the remaining variables were then compared one on one again. Through this process, the variables selected for the model were vehicle class, entry lane, RLC, green arrow and opposing class. It is noted that since the variables green arrow and opposing class formed a linear relationship with each other (the presence of right-turn green arrow preceding amber onset is only applicable to top of T-junction whereas opposing class is applicable to X- and mid of T-junctions) hence, only one (opposing class) was chosen to be included in the model. (The variable green arrow is presented in another model later on in this chapter.)

All the main effect variables, including all possible interaction terms, were modelled in establishing the 'full' model. The interaction terms (with the exception of distance×speed) were first analysed by dropping them one by one to check for any significant change in the deviance. Three interaction terms *(RLC×opposing class; RLC×distance; RLC×speed)* were found to result in significant changes in the deviance and were thus retained in the model. Some interactions were deemed to exist between the variables '*Light condition*' (which was further subdivided into day, dusk (1900-2000) and night) and *RLC*; the (*RLC×Light condition*) interaction was found to improve the fit of the model and was thus retained. The final model is shown in Table 5.20 and the complete SAS output is presented in Appendix G.

Using equation 5.7 and the parameter estimates from Table 5.20, the probability of stopping at amber onset is

$$p(Y=1)=\frac{e^{-4.88+0.24A-0.09B-11\mathrm{E}^{-4}A\times B-1.21C-0.10D-0.57E+0.59F+\mathrm{KKKK}-0.75J\times H-0.92J\times 1}}{1+e^{-4.88+0.24A-0.09B-11\mathrm{E}^{-4}A\times B-1.21C-0.10D-0.57E+0.59F+\mathrm{KKKK}-0.75J\times H-0.92J\times I}} \qquad (5.7)$$

where for each continuous variable, numerical scale based on the unit specified in Table 5.17 was used; for each discrete variable (e.g. vehicle class) with k levels, (k-1) dummy variables were constructed (see Table 5.22). For example, for vehicle class variable comprising of 4 levels (car, motorcycle, LCV and HCV), 3 dummy variables were required (see Table 5.22). The 1st dummy variable can be assigned a value of 1 (with the remaining as zeros) to denote a motorcycle; likewise the second dummy variable can be assigned a value of 1 (with the remaining as zeros) to denote a LCV, and so on. The case of all dummy variables being zeros shall be the reference level of car.

Table 5.21 Results of the final logistic regression model

Variable	Class	Designation	Estimate	Std. Error	Pr > χ^2
Intercept	Continuous		-4.8839	1.0054	**<0.0001**
Distance	Continuous	A	0.2419	0.0183	**<0.0001**
Speed	Continuous	B	-0.0944	0.0177	**<0.0001**
Distance×Speed	Continuous	A×B	-0.0011	0.0003	**<0.0001**
Vehicle class	Car	Reference			
	Motorcycle	C	-1.2091	0.1950	**<0.0001**
	LCV	D	0.1005	0.1745	0.5647
	HCV	E	-0.5665	0.1536	**0.0002**
Entry lane	Centre	Reference			
	Kerb	F	0.5927	0.1376	**<0.0001**
	Right most	G	-0.1403	0.1600	0.3805
Light condition	Day	Reference			
	Dusk	H	0.2197	0.2330	0.3459
	Night	I	0.3534	0.2189	0.1064
RLC	Absent	Reference			
	Present	J	3.0377	0.6681	**<0.0001**
Opposing class	None	Reference			
	Present	K	0.7144	0.1929	**0.0002**
	Absent	L	0.6065	0.2616	**0.0204**
	Filtering-S_conflict	M	3.6373	0.9260	**<0.0001**
	Fitering-M_conflict	N	1.3668	0.4010	**0.0007**
	View blocked	O	1.4845	0.2754	**<0.0001**
RLC× Distance	RLC×Distance	J×A	0.0348	0.0126	**0.0059**
RLC× Speed	RLC×Speed	J×B	-0.0334	0.0153	**0.0292**
RLC×Opp. class	Present×Present	J×K	-0.9804	0.2739	**0.0003**
	Present×Absent	J×L	-1.1736	0.4423	**0.0080**
	Present×S_conflict	J×M	-1.8012	1.4253	0.2063
	Present×M_conflict	J×N	-1.1147	0.6479	0.0853
	Present×View blocked	J×O	-1.7944	0.3684	**<0.0001**
RLC×Light condition	Present×Dusk	J×H	-0.7507	0.3311	**0.0234**
	Present×Night	J×I	-0.9215	0.3167	**0.0036**

Table 5.22 Dummy variables for the 'vehicle class' variable

Vehicle class	Dummy variables		
	D_var1	D_var2	D_var3
Car	0	0	0
Motorcycle	1	0	0
LCV	0	1	0
HCV	0	0	1

Goodness of fit of the generated model

The appropriateness of fitted regression model should be examined before it is accepted for use. The present model was checked at every stage of its development to ensure that the model remained appropriate. There are several measures that can be used to determine the significance, or goodness of fit, of a logistic regression model. The three principal measures are, the G-statistic (or likelihood ratio test or deviance test), Pearson statistic and Hosmer-Lemeshow statistic. Since it is common for the regression model designer to refer to more than one test, all three tests were used in this research. In all cases, the following hypotheses were tested:

> H_o: *The model provides a good fit of the data*
> *(There is no significant difference between observed and model fitted data.)*
> H_1: *There is a significant difference between observed and model fitted data.*

All these test statistics have approximate chi-square distributions. If they are larger than a tolerable value, there is sufficient evidence against a good fit in the model. This would mean either the variables in the model were insufficient to explain the observed values well enough or there were some influential outliers that significantly affected the fit of the model. In fact, in the preliminary stage, it was observed from the diagnostic tests that there were some observations which were found to cause a poor fit in the model. After identifying and analysing these observations, it was found that they were the very late red-runners (those that crossed 5 or more seconds after amber onset). There were only small number of the extremely late red-runners (less than 10) and they were excluded from the analysis. The presence of pre-indicator (right-turn green-arrow) seemed to present a somewhat different stimulus, resulting in some motorists initiating early braking. Observations under pre-indicator environment were excluded from the main analysis, and are examined separately in a later section.

The overall fit of the model was found to improve significantly when site 'W2' (approach at the grade-separated junction) was removed from the model. This could be the relatively quite different site layout and characteristics as compared to all the other approach types. Besides, with only one site of this approach type in the study, it might not be appropriate to include it in the general model. Hence, the final model was generated using a total of 4682 sample points, excluding those from W2.

From the Hosmer and Lemeshow, Deviance and Pearson goodness-of-fit tests, the final model was found to have a relatively good fit for the observed data as the chi-square (χ^2) statistic was smaller than the critical value of a chi-square distribution (with p-values for $Pr>\chi^2$ not less than 0.05). In other words, there was no clear evidence to reject the null hypothesis (*H_o: The model provides a good fit of the data*). From the table of 'association of predicted probabilities and observed responses' (part of the results generated by the logistic regression model), it was found that the percentage of concordant observations was 96.7 (which is close to 100), and the values of Somers' D (0.934), Gamma (0.934) and c (0.967) were close to one. These statistics suggested that the model fitted the data relatively well. The Cox and Snell R^2 and Nagelkerke R^2 values were 0.5988 and 0.8013, respectively (the closer to 1, the better is the model).

Logistic regression can also be used to classify observations as events (Y=1) or non-events (Y=0) as is done in discriminant analysis. This step is done to evaluate the predictive accuracy of the model before it can be used to predict the outcome. As shown in Table 5.23, the observed values for the dependent outcome and the predicted values (at a probability cut-off value of p=0.50) were cross-classified. The cut-off value was selected to be 0.50 because the group sizes used were relatively balanced. The model was able to correctly predict 90% of the cases.

Table 5.23 Classification table at cut-off value of p=0.50

Actual group	Predicted group		Percent Correct
	1 (stop)	**0 (cross)**	
Y=1 (stop)	2334	225	90.3
Y=0 (cross)	250	1872	89.3
Percent of cases correctly classified			89.9

Interpretation of the calibrated logistic regression model

In the model, the intercept value of -4.88 which is significantly different from 0, indicated that there were explanatory variables which might have been omitted. Nevertheless, this shall not detract from the findings of the calibrated model. In general, a positive parameter estimate for a continuous variable means that, as X increases, the probability of the (stop) event occurring increases; for a discrete variable, it means that maintenance at that particular level increases the likelihood of stopping as compared to the reference level. As expected, a vehicle was found to be more likely to stop (positive estimate) when it was far away from the stop line and/or its approach speed was slow. Among the vehicle types, motorcycle and HCV were found to react to the amber onset quite differently from car being about 3.4 times ($1/e^{-1.21}$) and 1.8 times less likely to stop than car, respectively. Motorcycles were less likely to stop probably because of their agility in maneouvering as well as the least likelihood of getting caught by the RLCs (by crossing between the kerb and detector loops). HCVs were less likely to stop than cars because of their difficulty in coming to a stop, despite a heavier penalty for red-running. (On the same token, those HCVs that stopped did so with a greater celerity as evident in the shorter PRT.) The stopping propensity of LCV was not significantly different from car (the reference) at 95% confidence interval. Vehicles in the left most lane (kerb) were about 1.8 times more likely to stop than those in the centre lane. The coefficients associated with the variables 'RLC', 'Opposing Class' and 'Light', being part of the interaction terms, did not represent wholly the 'main effect' but would also represent the 'conditional effect', i.e., the effect of the variables when their corresponding moderator was pegged at a defined level. Thus, during daytime, vehicles travelling along the top of a T-junction (i.e. opposing class 'None') installed with an RLC were about 21 ($e^{3.04}$) times more likely to stop than those at similar approaches but without an RLC. In terms of the opposing risk, a vehicle was found to be most likely to stop if there were a filtering vehicle in the junction box during amber onset, followed by a blocked view by other vehicles, and when there were vehicles present in the opposing right-turn pocket, as compared to the baseline case of absence of risk (top of T-junction). These are consistent with the hypotheses postulated earlier on in Chapter 3. A graphical plot of the various cases of opposing class against TTSL (for cars travelling at 50 km/h in the centre lane towards non-RLC junctions during daytime) is given in Figure 5.15. As a comparison, cars travelling at 70 km/h were also plotted on the same axes for the two extreme cases.

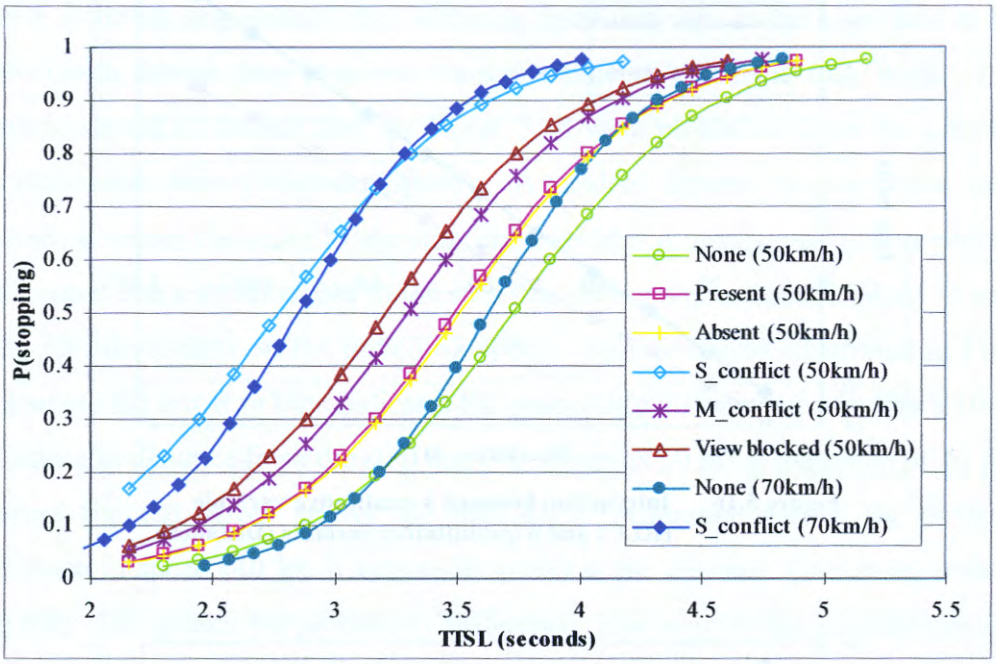


Figure 5.15 Cases of opposing class versus TTSL

For the 2 qualitative (categorical)-quantitative (continuous) interaction terms (RLC×Distance and RLC×Speed), graphical plots between the predicted log odds for the presence and absence of RLC and distance (speed) are shown in Figures 5.16 and 5.17. The two nonparallel slopes are indicative of the interaction and the divergence can be interpreted as the magnitude of the interaction. The effect of RLC is greater (steeper log odds) as distance increases or as speed decreases, respectively. The interaction term (RLC×Opp_cls) indicated that the relationship between the stopping decision and type of opposing situations present at approaches with RLCs was different with that at approaches of junctions without RLCs. The parameter estimates of the interaction terms showed the effect of RLCs on the different opposing situations. For instance, as a vehicle approached a junction, the effect of RLCs on the stopping decision would be the least (among the opposing situations) if the view of the opposing movement was blocked, relative to the baseline case for no opposing movement. Similarly, the other interaction term

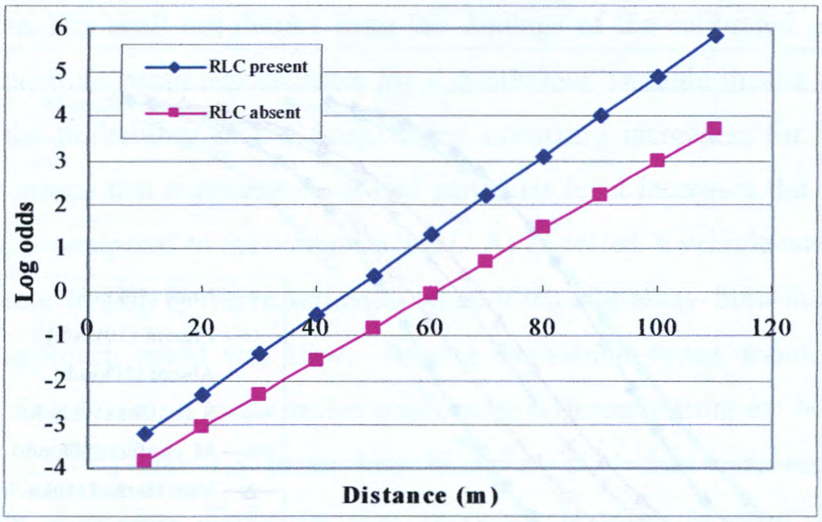


Figure 5.16 **Interaction between a qualitative variable (RLC) and a quantitative variable (Distance)**

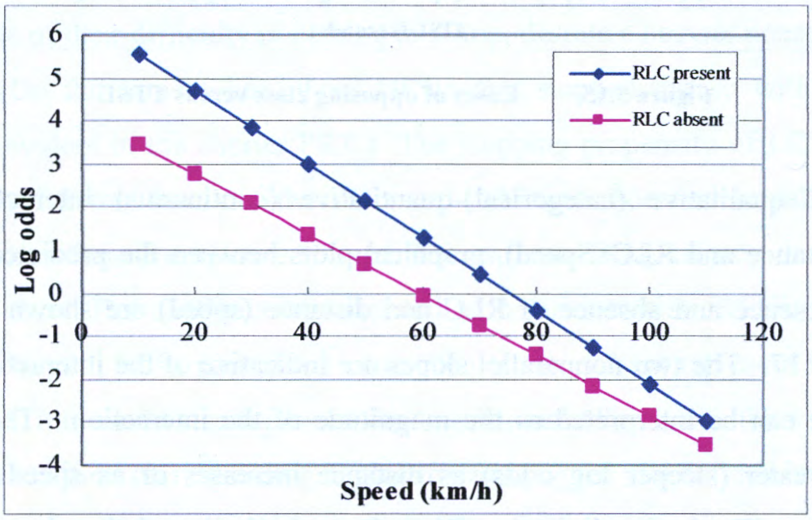


Figure 5.17 **Interaction between a qualitative variable (RLC) and a quantitative variable (Speed)**

For a given speed, the stopping probability increases as distance increases and for a given distance, the stopping probability decreases as speed increases. However, the magnitude of influence of these variables on the stopping probability is not constant. For instance, a driver close to the stop line travelling at a slow speed can have a different stop versus cross decision from one who is far away and at high speed (even though they required the same time to cross the stop line). TTSL isolines, shown as dashed lines in Figure 5.18 were plotted to show the effects of the interaction term (Distance×Speed). A distinct upward sloping trend in the isolines at nearer distances to the stop line indicates a distance-dominant decision. This means that a driver closer to the stop line during amber onset is likely to cross, being less dependent on his travelling speed. This is clearly illustrated in Figure 5.18 where the arrow in blue indicates the probability difference caused by a 10-unit difference in distance from the stop line (40 m versus 50 m) at the speed of 40 km/h whereas the red arrow shows the probability difference caused by a 10-unit difference in speed (40 km/h versus 50 km/h) at the distance 40m away from the stop line. The greater the probability difference (blue arrow), the more influential is the change in the variable. Likewise, using a similar analogy, the change in probability was observed to be more influenced by the difference in speed compared to distance, at the right side of the plot, hence indicating a speed-dominant decision. The non-uniformity of the influence of distance and speed on the stopping probability makes it difficult to demarcate the stopping and crossing drivers, as attempted by the deterministic schemes.

Figure 5.19 shows a visualisation plot (based on actual decision - stopped or crossed) of the logistic regression model for the speed band of 60-70 km/h. The hollow data points represent the drivers who crossed while the solid points are for drivers who stopped. It can be observed that most of the points on the right top corner (high probability of stopping) are solid circles and those on the left bottom corner (low probability of stopping) are hollow circles, hence, showing that the use of a probabilistic approach (using logistic regression) is suitable.

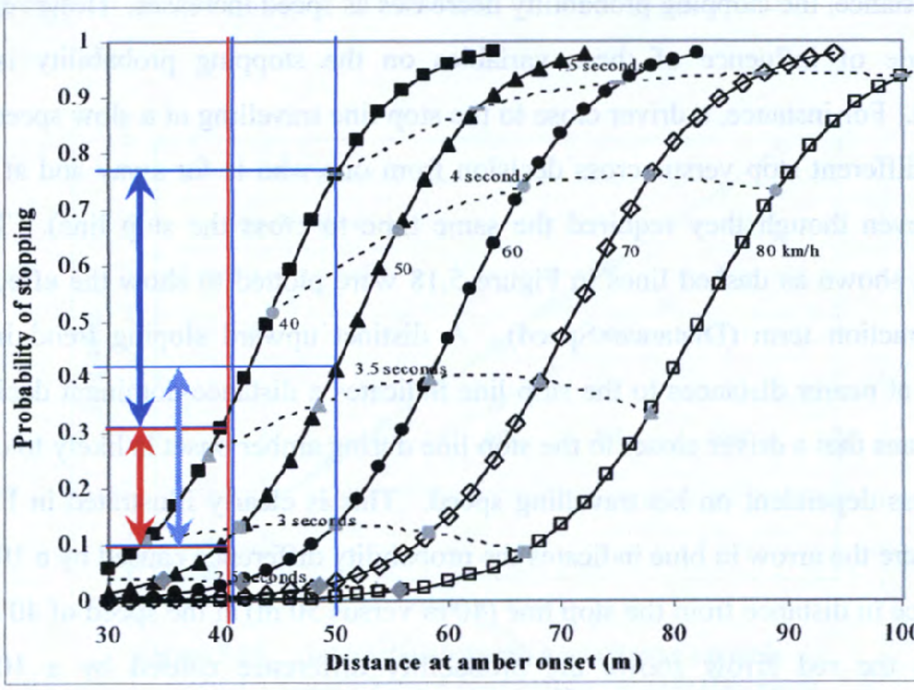


Figure 5.18 **Logistic regression plot**

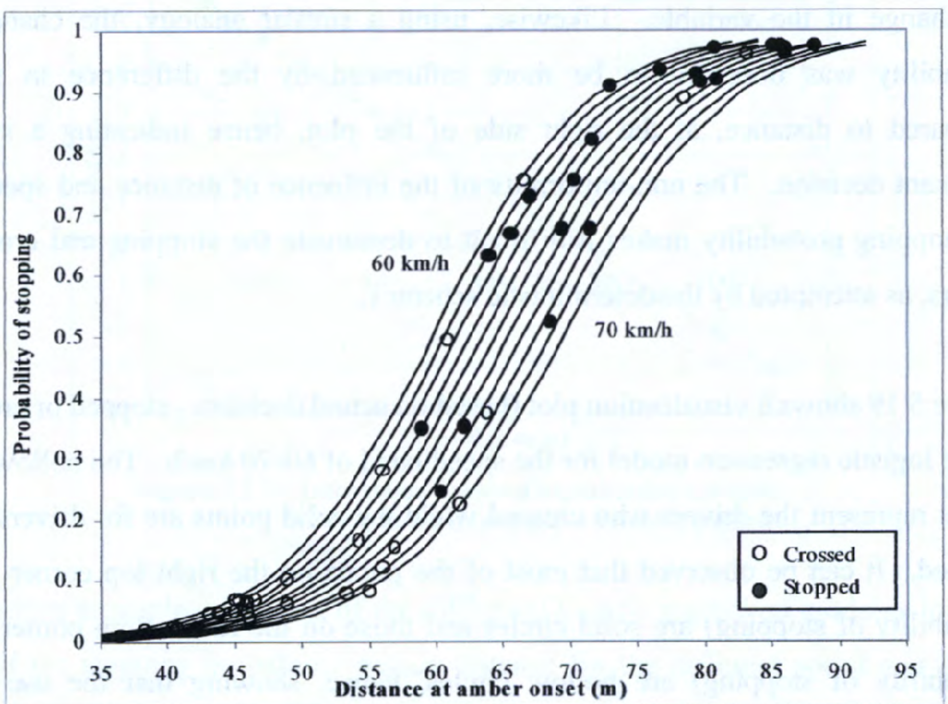


Figure 5.19 **Visualisation plot for 60-70 km/h speed**

5.5 Applications

The probabilistic approach using a logistic regression is a useful and powerful technique to study how each individual variable affects the stop versus cross decision of drivers at amber onset. Sometimes, some of the basic variables, though significantly influential, were not included in the model because they were either linearly related with some other variables or the effects were only applicable to certain subsets of the data. One such variable is the case of unstructured cues inherent in the road environment, as discussed in the following sections.

5.5.1 Getting cues from the road environment

Observant drivers are usually able to detect cues from the environment (duration of traffic signal indication, status of vehicle/pedestrian movements) that point to the impending change of the traffic signals. The type of cues available depends on both the junction type and the traffic conditions. For example, drivers can observe the discharge status of the traffic stream ahead. A dispersed vehicle platoon at an advanced stage of discharge at a junction with linked signal progression would suggest that the green phase has been active for some time and shall terminate any time soon. Drivers observant of such pre-indicators may utilise the additional information to aid their decision-making in responding to the amber signal. Two types of cue were examined in this study namely the right-turn green arrow at the top of T-junction and the pedestrian signal. Analysis on the influence of these additional cues is indirectly useful in assessing the applicability of time reference aids such as the green signal countdown and advance warning lights which are relatively more difficult to study (either because of their rarity or site constraints e.g. being located at bends).

Green-arrow onset at T-junctions

At most of the approaches on the top of the T-junctions in Singapore, the green arrow (for the right-turners) is usually vehicle-actuated and precedes the blinking arrow together with the amber onset, the latter for straight-through vehicles. Thus, the presence of the green-arrow naturally implies that the amber is due to show up next (See *Case I* of Figure 5.20). Such cue is especially relevant at junctions with relatively short green arrow period. It should be noted that the length of the green-arrow period varies from junction-to-junction and from cycle-to-cycle, being dependent on the demand of right-turning traffic flow. Sometimes, the green arrow phase might even be skipped (*Case II*) due to extremely low traffic demand for right-turning movement, hence acting as contrasting cases for comparison.

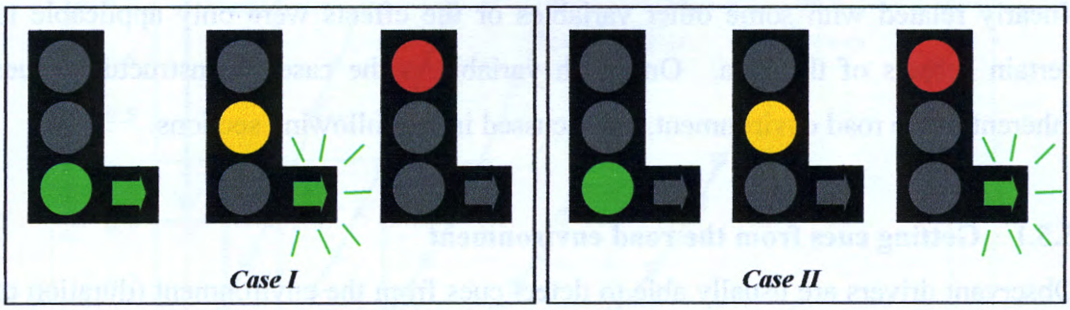


Figure 5.20 Schematic diagrams showing the sequence of traffic lights

Out of the 4 top approaches of T-junctions investigated in this study, two of them (TW1 and TW7) were found to have sufficient number of the constrasting cases to be used for analysis. The two sites were chosen because they have relatively short, vehicle-actuated green arrow phase and have the same speed limit of 50 km/h. A comparison of the approach speed and the driver performance parameters (PRT and average deceleration rate) between vehicles arriving with and without advance indicator was done using 2 sample 2-tail Z-tests (see Table 5.24). It was found that there was no significant difference (at 95% confidence interval) in the mean speeds when under the presence of green arrow and absence of green arrow. The performance parameters (PRT and deceleration rate) under a forced-paced situation did not differ significantly under the influence of a pre-indicator. However, when all subject vehicles were considered, the PRT value was found to be significantly lower while the deceleration rate was significantly higher (at 5.6% level) in the presence of green arrow. This suggested that the provision of "green termination" warning indicator induced more drivers further away from the stop line (TTSL>4) to be better prepared to stop and their deceleration rates were also somewhat higher.

Table 5.24 Two-sample 2-tail Z-tests between cases with (x_1) and without (x_2) green arrow

					H₀: $\bar{x}_1 = \bar{x}_2$, H₁: $\bar{x}_1 \neq \bar{x}_2$			
	n_1	n_2	$\bar{x}_1$	$\bar{x}_2$	z value	z crit	p value	Signif.
Speed (Stop only)	127	181	60.72	59.36	0.959	1.960	0.337	NS
Speed (Thru only)	91	171	61.06	63.28	-1.513	1.960	0.130	NS
Speed (All)	215	352	60.86	61.26	-0.387	1.960	0.699	NS
PRT (TZ only)	27*	24*	0.91	0.95	-0.079	1.960	0.937	NS
PRT (All)	124	181	1.28	1.42	-1.981	1.960	0.048	S
Deceleration rate (TZ only)	27*	24*	3.44	3.50	-0.472	1.960	0.637	NS
Deceleration rate (All)	124	181	2.44	2.25	1.914	1.960	0.056	S (α = 5.6%)

** Sample sizes were small, generated results should be interpreted with due care*

A normal-distribution probability plot (using equation (5.8), as introduced by Prashker and Mahalel, 1989) against time to stop line (TTSL) of vehicles from the onset of amber (see Figure 5.21) was used to analyse the green arrow effect on driver decision-making. The probability equation has the form given by:

$$P(stop) = \int_{-\infty}^{t_i - t_{cr,i}} \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{1}{2}\left(\frac{\theta}{\sigma}\right)^2\right] d\theta = \phi\left(\frac{t_i - t_{cr,i}}{\sigma}\right) \qquad (5.8)$$

where $t_{cr,i}$ =mean time to stop line, σ =standard deviation, θ =difference between the disturbance terms, t_i=time to stop line, Φ =standard normal function. The function 'PROC PROBIT' in SAS was utilised to find the values of $t_{cr,i}$ and σ for the different cases. As expected, vehicles in the presence of green arrow were observed to be more likely to stop compared to those without the benefits of the green arrow. The indecision zone (see Chapter two for details) was reduced (from 2.1 to 1.7 seconds) when there was an advance warning (presence of green arrow) of amber onset.

A further analysis using logistic regression was done and it was found that speed, distance, vehicle group and green arrow effect were significant as a combined model. Figure 5.22 represents a selected case: cars at two speeds: high speed (70 km/h) and low speed (50 km/h). It was found that cars travelling at a higher speed (in darker shades) had smaller indecision zone (steeper slope) than those travelling at a lower speed. This suggested that the provision of warning indication had helped those travelling at a high speed. The plot also shows that for cars nearer to the stop line (TTSL less than about 3.5 seconds) at the onset of amber, low-speed vehicles were more likely to stop whereas those with TTSL more than 3.5 seconds, high-speed vehicles were more likely to stop.

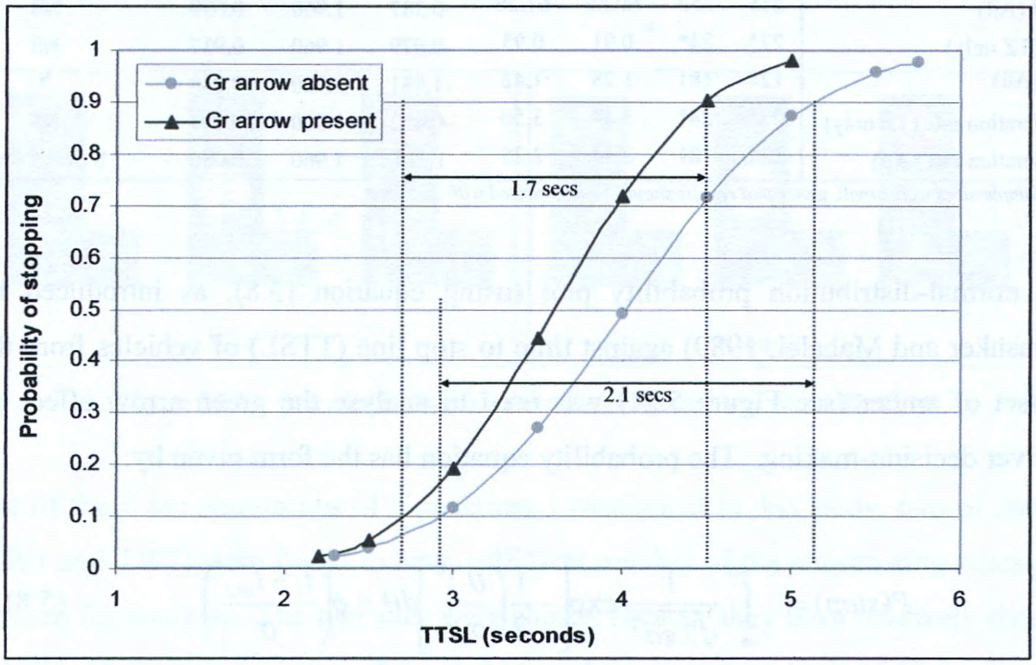


Figure 5.21 **Probability plots for cases with and without green arrow**

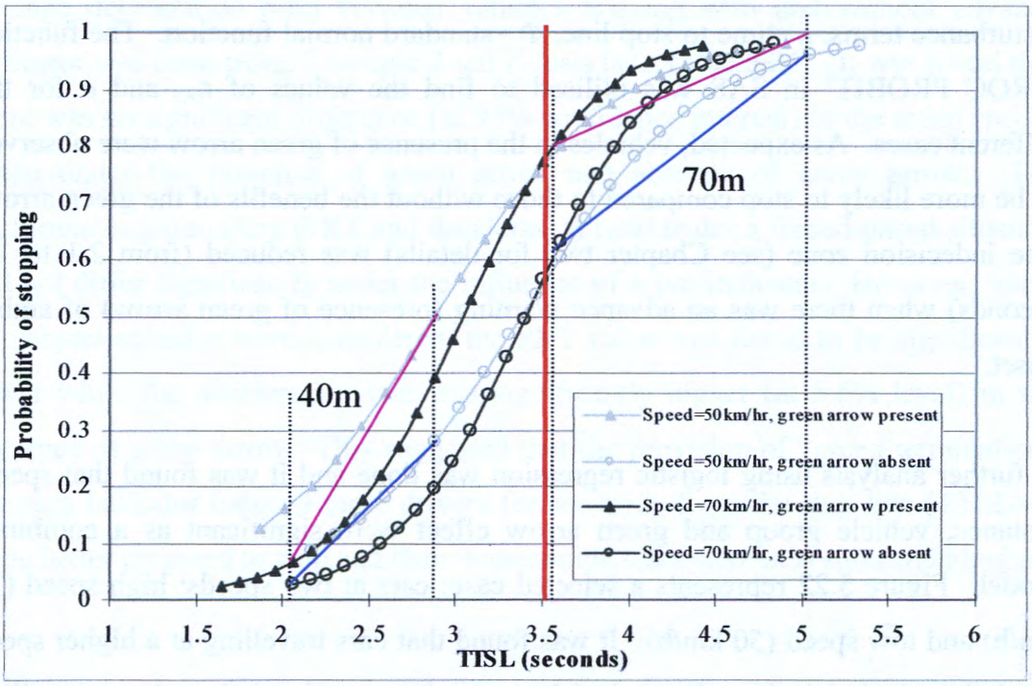


Figure 5.22 **Probability plots for cases of high and low speed vehicles**

Pedestrian signal at Mid-T junctions and X-junctions

Another example of a cue that is only applicable to certain types of approaches (X-junctions and mid-T junctions) is the pedestrian signal light (walking green man). During quiet traffic flow periods, the interval of the vehicle green phase is often governed by the pedestrian crossing requirement. This means that the vehicle green phase can be expected to terminate shortly after the end of the pedestrian green man signal. An approaching driver, upon noticing that the green man is blinking or has turned red, can take cue that the amber is about to show up. In this case, the driver can either speed up if he decides to cross, or slows down and prepares to stop otherwise. The status of the "green man" thus acts as a cue to the driver of the impending termination of the vehicle green signal. However, since this phenomenon occurs essentially during quiet period and most of the work in this study was done during periods with moderate traffic flow, there were no sufficient sample sizes for a detailed study.

5.6 Chapter summary

A total of 5776 sample points were collected from the observational study of which 3230 vehicles stopped and 2546 crossed. The concept of a transitional zone-TZ (2 to 4 seconds of the TTSL) for identifying forced-paced drivers was introduced. The TZ was used for studying the two driver performance parameters: PRT and deceleration rate. The 85th percentile PRT values within the TZ at all junction approach types were found to be relatively close to the ITE design value of 1 second. This supported the appropriateness of using a TZ to obtain the performance parameters. The log-normal distribution was found to fit the PRT values. A general linear model showed that the variables of distance, speed, vehicle group, opposing class and RLC had significant effects on the PRT values in the TZ, though the overall fit of the model was not good.

The deceleration rates of drivers under the forced-paced situations (within TZ) were expectedly higher as compared to those far away from the stop line. A GLM model with a reasonable fit ($R^2 = 0.80$) was obtained using the variables of distance, speed, PRT and vehicle group. Basically, deceleration increased as speed and PRT increased, and as distance decreased. Heavy commercial vehicles were found to have significantly lower deceleration rates than cars, probably because of the different mechanism of the vehicles (e.g. higher inertia and longer braking distance).

The results of the deterministic schemes: speed versus distance plot and the 'A, D' representation provide useful findings regarding the red-runners. Red-runners were often found to be either in the stop zone or dilemma zone in both the speed versus distance plot and the 'A, D' representation. Red-runners in the stop zone were basically those who were able to stop but chose to cross and ended up red-running, and those in the dilemma zone who could neither stop comfortably nor cross without red-running. Remedies for the first group should be aimed at encouraging drivers to stop for the red light whereas measures like providing adequate signal timing (amber length) or advance warning indicators could help the second group of drivers who were 'forced' to run the red.

It was found that there were relatively higher proportions of red-runners at approaches located at junctions that are not installed with the red-light cameras (RLCs) as compared to approaches with RLCs. This suggested that the use of RLCs is an effective means of reducing the number of red-runners. It was also found that most of the red-runners would have been able to stop at a deceleration rate of less than 4.5 m/s^2.

This study also highlighted the deficiencies of the two deterministic schemes. Although the possible outcomes of crossing or stopping decisions could be analysed diagnostically, the probability of each decision remains unknown. It was thus useful to apply a probabilistic approach (using logistic regression model) to describe the decision-making process.

The calibrated logistic regression model was found to have a reasonable fit and it included the main effect variables of distance, speed, vehicle class, entry lane, RLC, opposing class and light condition, and the interaction terms of distance×speed, RLC×distance, RLC×speed, RLC×opposing class and RLC×light condition. Motorcycles and HCVs were found to be less likely to stop than cars and vehicles in the kerb lane were more likely to stop than those in the centre lane, while the presence of filtering vehicles was found to significantly increase the likelihood of stopping by approaching vehicles. The four interaction terms indicated the effect of RLCs being affected by the various corresponding variables. For example, the effect of RLCs was greater at a further distance away from the stop line and at a lower speed.

The effect of the presence of pre-indicator of amber onset (right-turn green arrow) on the drivers' decision to stop or cross was analysed at two T-junctions. It was found that the probability of stopping was generally higher in the presence of a green arrow (or driver anticipation of the amber onset) which supported the idea of providing additional information to drivers. The provision of this pre-indicator had also narrowed drivers' indecision zone, hence reducing the likelihood of conflicts (or rear-end collisions) between two drivers along the same lane. The narrowing of the indecision zone was more pronounced for lower-speed vehicles (less than 60 km/h) in the TZ. This suggested some form of warning indicators (like GSCD) would be useful together with an integrated use of a speed limit control.

Chapter 6 Analysis and interpretation of the perception survey

This chapter covers various aspects of the perception survey. The response characteristics and the profiles of respondents are first introduced. Survey items are then covered in a sequence similar to the order in the survey questionnaire which included: 'Variables that affect driving decision', 'Driving strategy' and 'Advance warning signal impact analysis'. Exploratory analyses were carried out on all parts of the survey in order to have a better understanding of the data. Wherever feasible, more in-depth analyses (confirmatory statistical analyses) were used to test whether the data supported specific hypotheses.

6.1 Response characteristics

Table 6.1 shows the item-by-item response statistics for the 2 survey stages. After excluding partially completed questionnaires (with at least 1 complete section being left blank), the sample size amounted to 162 and 184 numbers for Stage I and Stage II, respectively. Of these, 320 were car drivers and 26 were motorcyclists. All analyses utilised samples from both stages, unless stated otherwise. As shown in Table 6.1, the majority of the items had full or nearly 100 percent responses; missing entries were questions that were overlooked and those with illogical or multiple responses. Items with some amount of non-response were respondent particulars such as vehicle type and monthly income, and the third-ranked response in 'Things to look out for'. The somewhat lower response level for the vehicle type was expected as not all the respondents had regular access to a vehicle. The amount of income earned could be a sensitive question to some respondents and hence a lower response level. As for the third-ranked response in the open-ended question, not all respondents elected to list three entries as requested; this could be a case of being unable to come up with 3 items quickly. This was not unexpected since open-ended questions have been found to have a greater likelihood of respondent leaving them blank (Jackson, 1988; Reja et al., 2003). There were fewer cases of not having 3 responses in Stage II as greater effort was made to elicit a full response during the course of the survey. The analyses that followed are based on the number of completed responses to each question. In other words, when analysing a variable, a record was excluded if it had a missing value in that particular variable.

This approach is acceptable when the level of non-response for individual items is not high (Richardson, 2000). (It is noted that Table 6.2 provides the descriptions of the abbreviated variables in Table 6.1.)

Table 6.1 Response statistics of survey questions

Section	Question	Stage I	Stage II	Total
Respondent particulars	Age	162 (100%)	184 (100%)	346 (100%)
	Gender	162 (100%)	184 (100%)	346 (100%)
	Marital status	157 (97%)	183 (99%)	341 (99%)
	Occupation	160 (99%)	180 (98%)	340 (98%)
	Access to vehicle	161 (99 %)	183 (99%)	344 (99%)
	Driving record	162 (100%)	184 (100%)	346 (100%)
	Vehicle transmission type **	-N.A.-	178 (97%)	-N.A.-
	Vehicle type & capacity*	162 (100%)	174 (95%)	336 (97%)
	Traffic accident history	162 (100%)	184 (100%)	346 (100%)
	Income	153 (94%)	180 (98%)	333 (96%)
1 (Part 1) Things to look out for (open question)	1st thing	162 (100%)	184 (100%)	346 (100%)
	2nd thing	159 (98%)	184 (100%)	343 (99%)
	3rd thing	146 (90%)	178 (97%)	324 (94%)
1 (Part 2) Things to look out for	Far front veh.***	162 (100%)	184 (100%)	-N.A.-
	Near front veh.	162 (100%)	184 (100%)	
	Rear veh.	162 (100%)	183 (99%)	
	Side veh.	162 (100%)	184 (100%)	
	Opp. rt-turn veh.	162 (100%)	183 (99%)	
	X-flow veh.	161 (99%)	184 (100%)	
	Pedestrian	162 (100%)	184 (100%)	
	Enforcement	162 (100%)	184 (100%)	
2 Effects of common scenarios	Urgent	162 (100%)	184 (100%)	346 (100%)
	Green wave	162 (100%)	182 (99%)	344 (99%)
	Stopped	162 (100%)	183 (99%)	345 (100%)
	Accident-prone	162 (100%)	184 (100%)	346 (100%)
	T vs X-junction	161 (99%)	184 (100%)	345 (100%)
	Minor road	161 (99%)	183 (99%)	344 (99%)
	Heavy traffic	162 (100%)	184 (100%)	346 (100%)
	Passenger	162 (100%)	184 (100%)	346 (100%)
	Wet road	162 (100%)	184 (100%)	346 (100%)
	Night**	-N.A.-	184 (100%)	-N.A.-
3 Driving strategies	Non-RLC	160 (99%)	183 (99%)	343 (99%)
	RLC	161 (99%)	183 (99%)	344 (99%)
	Red-running	161 (99%)	184 (100%)	345 (100%)
	Amber signal	161 (99%)	184 (100%)	345 (100%)
	Anticipation	162 (100%)	184 (100%)	346 (100%)
	Distance/time	162 (100%)	184 (100%)	346 (100%)
	Driver**	-N.A.-	182 (99%)	-N.A.-
4 Impact of green signal countdown device (GSCD)	Passed through**	-N.A.-	184 (100%)	-N.A.-
	General impact**		184 (100%)	
	End of green signal**		184 (100%)	
Comments		19 (12%)	32 (17%)	51 (15%)

**Items not featured in the early part of Stage I survey*
***Additional items in Stage II survey*
****Abbreviation (refer to Table 6.2)*

Table 6.2 Variable descriptions and their corresponding abbreviations

Variable description	Abbreviation
Far front vehicle(s)	Far front veh.
Near front vehicle(s)	Near front veh.
Rear vehicle(s)	Rear veh.
Vehicle(s) at both sides (moving in the same direction)	Side veh.
Waiting vehicle(s) at opposite right-turn lanes	Opp. rt-turn veh.
Waiting vehicle(s) at cross-flow lanes	X-flow veh.
Pedestrian(s) waiting to cross the junction	Pedestrian
Presence of police vehicles/ red-light cameras	Enforcement
Need to get to destination urgently	Urgent
Passed the last few junctions under a green wave	Green wave
Have to stop at the last few junctions	Stopped
Aware that the junction is dangerous/ accident-prone	Accident-prone
If junction is T-junction instead of a X-junction	T- vs X- junction
Travelling along a minor road instead of major road	Minor road
Heavy traffic flow	Heavy traffic
There are passenger(s) in the vehicle	Passenger
The road surface is wet	Wet road
If it is at night	Night

6.2 Profiles of respondents

The respondents' characteristics were first profiled (see Table 6.3). The respondents were principally car drivers while there were a small number of motorcyclists (26). The small, all-male motorcyclist sample was used only in limited comparison with the car drivers. The following respondent profiles describe car drivers only.

Table 6.3 Profile of respondents by different categories

Category	Level		Stage I	Stage II	All
Vehicle Type	Car		158	162	320
	Motorcycle		4	22	26
For cars only					
Age group	Young	≤ 25	30 (19%)*	90 (56%)	120 (38%)
	Middle-aged I	26 – 40	78 (49%)	52 (32%)	130 (41%)
	Middle-aged II	41 – 55	45 (28%)	17 (10%)	62 (19%)
	Old	Above 55	5 (3%)	3 (2%)	8 (3%)
Gender	Male		100 (63%)	116 (72%)	216 (68%)
	Female		58 (37%)	46 (28%)	104 (33%)
Experience in driving	Inexperienced	Equiv. to ≤ 182 days of on-road exp.	26 (16%)	57 (35%)	83 (26%)
	Experienced		132 (84%)	105 (65%)	237 (74%)
Vehicle transmission type**	Manual		-	74 (48%)	-
	Automatic		-	81 (52%)	-
Type of driver (self-rated)**	Skilful		-	46 (29%)	-
	Cautious		-	101 (63%)	-
	Aggressive		-	13 (8%)	-

** Values in parentheses are percentages*
***Only available in Stage II survey*

In terms of age, the proportion of respondents 25 years or younger was larger when compared to the general driver population in Singapore. This was intentional as they have been found to form the most culpable group in red-running accidents (as mentioned in earlier chapters). The younger (and often) inexperienced drivers formed a contrasting segment to the older (and often) more experienced drivers. There were relatively few respondents (8) above 55 years and they were combined with the 'Middle-aged II' group (41-55 years) in subsequent analyses. The marital status of the respondents was found to be correlated with age (Pearson p=0.71). About two-thirds of the respondents were male. This proportion corresponded to the Singapore's gender distribution of Class 3 driving licence holders (SDS, 2001).

In order to divide the respondents into experienced and inexperienced drivers, the on-road experience of each respondent was calculated in terms of driving days (On-road driving experience *(years)*×Driving frequency *(days/week)*×52 *(weeks/year)*). Any driver who had a driving experience less than 182 driving days equivalent to half a year of daily driving was considered as inexperienced while noting that the official probation period for novice driver in Singapore is a year.

Vehicle transmission types were either manual or automatic. There were some numbers of each type in the sample.

In terms of stated occupation, students and those in the professional/technical field comprised about 30% each while those involved in administration/managerial and sales made up another 10% each. Given the very small representation of some occupation groups, no analysis was performed by the occupation of the respondents (or the amount of income which correlated with the type of job).

The characteristics of the car driver respondents were used to stratify the analyses according to the 5 categories as shown in Table 6.3.

6.3 Variables that affect driving decision

Under the 'Things that I look out for' (Section 1, Part 1), respondents listed the things (by order of importance: 1st thing, 2nd thing,...) that they looked out for as the traffic light changed from green to amber. To account for the greater degrees of non-response in 2nd and 3rd things, the responses were divided into three groups: Ans(1,2,3) (94.1%), Ans(1,2) (5.0%) and Ans(1) (0.9%). Within each group, factors of descending weightage (at 2/3 of preceding item) were applied as shown in Table 6.4. These factors were chosen to represent geometric scaling.

Table 6.4 Weighting factors

Group	n	%	Weighting factors		
			1st thing	2nd thing	3rd thing
Ans(1,2,3)	301	94.06	0.47	0.32	0.21
Ans(1,2)	16	5.00	0.60	0.40	-
Ans(1)	3	0.94	1	-	-
Total	320	100.00	-	-	-

For coding and analysis, the strings of descriptions (up to three) cited by respondents were deciphered and coded. Being an open-ended format, some strings contained "generalised" descriptions which could be decomposed into more basic variables. For such descriptions, the basic variables were identified and weighted equally. For example, a string describing "Presence of surrounding vehicles" can be decomposed into front, rear and side vehicle variables, and a contribution weight of a third each was distributed among the three variables. The frequencies of citations were then accumulated for each variable (see Table 6.5).

The frequencies of citations were weighted using the factors in Table 6.4. The weighted scores were determined and the sum of the weighted scores were normalised by the 320 number of respondents (see normalised score). It should be noted that since the weightage factors were arbitrarily chosen, the final normalised score should be interpreted as being a form of relative scale only.

Table 6.5 Variables cited by respondents (car drivers only) in 'Things I look out for'

Variables	Ans(1,2,3) 1st thing	Ans(1,2,3) 2nd thing	Ans(1,2,3) 3rd thing	Ans(1,2,3) W. *score	Ans(1,2) 1st thing	Ans(1,2) 2nd thing	Ans(1,2) W. score	Ans(1) 1st thing	Total W. score	Normalised score
Distance	58.5	31.5	13.0	40.3	5.0	0.0	3.0	0.0	43.3	0.135
Speed	19.0	29.0	16.0	21.6	0.0	0.0	0.0	0.0	21.6	0.067
Time	6.0	10.5	10.0	8.3	1.0	2.0	1.4	1.0	10.7	0.033
Front veh.	41.8	18.5	20.0	29.8	1.0	1.8	1.3	0.3	31.4	0.098
Rear veh.	29.2	44.5	58.5	40.2	3.0	3.3	3.1	0.3	43.7	0.137
Side veh.	4.6	6.0	7.8	5.7	0.0	0.3	0.1	0.3	6.2	0.019
Opp. rt-turn veh.	20.6	43.2	28.0	29.4	1.0	2.5	1.6	0.0	31.0	0.097
X-flow veh.	8.0	14.5	6.5	9.8	0.0	0.0	0.0	0.0	9.8	0.031
Pedestrian	50.4	35.5	44.0	44.3	3.0	1.0	2.2	0.0	46.5	0.145
Enforcement	45.0	44.0	62.0	48.3	2.0	2.0	2.0	1.0	51.3	0.160
Others**	9.0	16.0	21.0	13.8	0.0	1.0	0.4	0.0	14.2	0.033

**W. score represents weighted score using factors in Table 6.4*
***Others include traffic volume, junction width, etc.*

The predominant items listed by the car drivers were the presence of enforcement, the presence of pedestrians, the presence of a rear vehicle and the distance from the stop line. As a contrast, the predominant items listed by motorcyclists included distance from stop line, presence of enforcement and opposing flow. It was not surprising that the presence of a rear vehicle behind the motorcyclist was not perceived as important given that motorcyclists usually ride in between the lanes.

From Stage I 'Things I look out for' Part 2 results, the variables that were found to be important were near front vehicle, RLC, pedestrian, opposing flow and a rear vehicle (see Appendix H for details). For the Stage II survey, the manner that respondents would be affected by the similar set of variables in making their cross/stop decision was assessed over a 5-point A-E scale (see Figure 6.1). For each variable, the score was translated to a 1-5 numerical scale (A=1; B=2;...) and the score mean was computed. Score means were similarly computed for variables in 'Effects of common scenarios' (Section 2 of questionnaire). These variables, together with score means are shown in Table 6.6.

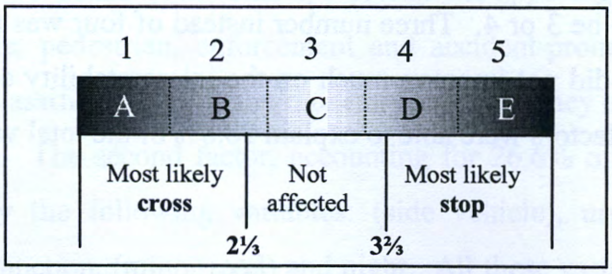


Figure 6.1 5-point scale

Table 6.6 Variables affecting the stop versus cross decision and their score means

Cross (<2.33)	Not Affected (3±0.67)	Stop (>3.67)
Urgent (2.09*)	Stopped (3.02)	Enforcement** (4.67)
	T- vs X-junction (2.97)	Near front veh.** (4.48)
	Side veh. (2.87)	Wet road (4.19)
	Green wave (2.80)	Heavy traffic (4.11)
	Far front veh. (2.69)	Accident-prone (4.10)
	Minor road (3.30)	Pedestrian** (4.05)
	Rear veh.** (2.65)	Passenger (3.88)
	Night (3.47)	Opp. rt-turn veh.** (3.81)
	X-flow veh. (3.48)	

**Numbers in brackets indicate the mean score*
***Factors found to be "Very Important or Important" in Stage I survey*

One variable, the urgency to get to a destination, was found to induce a motorist to cross; a total of 8 variables were found to be associated with a stopping decision, namely the presence of enforcement, presence of near front vehicles, opposing vehicles and pedestrians, heavy traffic flow, at accident-prone junction, accompanying passengers in the vehicle and under wet road conditions. The response pattern was somewhat consistent with the findings in the observational study, such as the influence of RLCs (enforcement) and opposing flow vehicles. Those survey variables that could not be studied in the observational study provided additional insights on how they may affect the driver decision. Hence, the perception survey not only supplemented the observational study but also provided corroborative information to some extent.

In order to consolidate the 18 variables (see Table 6.6), a principal factor analysis (PFA) was done using the SAS program (PROC FACTOR) on the 162 car drivers from the Stage II survey. A correlation matrix was first formed to exclude clearly uncorrelated variables in the consolidation process. (The variables excluded were: far front vehicle and rear vehicle). After reviewing the common criteria used by other researchers (see Table 6.7), it was decided to set the optimum number of conjoint factors to be 3 or 4. Three number instead of four was used subsequently because the latter did not improve much on the interpretability of the solution and the selected three factors were able to explain 98.8% of the total variance.

Table 6.7 Guidelines used in determining number of conjoint factors to retain

Guidelines	Number of conjoint factors to retain
Kaiser-Guttman rule: Factors with eigenvalues greater than 1	3
Factors with a greater-than-average eigenvalue (0.434)	3
All factors with a positive eigenvalue	9
Cattell scree plot	1, 3, 5, 9 or 13
Kim and Mueller (1986): Factors that account for at least 10% of the common variance	3

The factor loadings (or regression coefficients) and the respective communalities (the proportion of variance that each variable has in common with other variable(s)) for each variable are tabulated in Table 6.8, with some having moderately high values. A regression coefficient greater than 0.3 was used as a threshold (see underlined coefficients) to represent significant contribution of the factor in predicting a variable (or variable).

Table 6.8 Factor loadings

Variables	Factor 1	Factor 2	Factor 3	Communalities
Near front veh.	<u>0.408</u>	-0.158	0.165	0.21
Side veh.	<u>0.318</u>	<u>0.313</u>	-0.016	0.24
Opp. rt-turn veh.	<u>0.748</u>	0.064	-0.106	0.55
X-flow veh.	<u>0.699</u>	0.167	-0.051	0.54
Pedestrian	<u>0.629</u>	-0.046	0.243	0.52
Enforcement	<u>0.701</u>	-0.132	-0.095	0.45
Urgent	-0.081	<u>0.776</u>	-0.111	0.53
Green wave	0.061	<u>0.630</u>	-0.018	0.41
Stopped	0.076	<u>0.707</u>	-0.071	0.49
Accident-prone	<u>0.463</u>	0.198	0.199	0.42
T- vs X-Junction	-0.093	<u>0.549</u>	0.267	0.46
Minor road	-0.074	<u>0.327</u>	<u>0.430</u>	0.38
Heavy traffic	0.130	-0.064	<u>0.495</u>	0.27
Passenger	0.061	-0.050	<u>0.773</u>	0.60
Wet road	-0.047	0.018	<u>0.618</u>	0.38
Night	-0.019	<u>0.444</u>	<u>0.338</u>	0.42
Type of factor	Collision/monetary risk	Situational factor	Road conditions/ passenger	Total %variance explained
% Variance explained	**57.3**	**26.6**	**14.8**	**98.8**

The resulting factor structure suggested that the variables with the highest loadings on the first factor were near front vehicle, side vehicle, opposing right-turn vehicle, cross flow vehicle, pedestrian, enforcement and accident-prone junction. These variables can be classified as "collision/monetary risk" and they explained 57.3% of the total variance. The second factor, accounting for 26.6% of the variance, was best identified by the following variables: (side vehicle), urgent, green wave, stopped, T-vs X-junction, (minor road) and night. All these variables are related to the "situational factor" faced by the driver. The third factor had variables such as minor road, heavy traffic, passengers, wet road and (night). This factor basically explained the "road conditions/passenger" and accounted for 14.8% of the variance. Hence, the variables affecting a driver's stop versus cross decision can be reduced to collision/monetary risk, situational factor, road conditions/passenger factor and the two unconsolidated variables of presence of far front vehicle and presence of rear vehicle.

6.3.1 Analysis by respondent characteristics

The survey data of 162 respondents and 16 explanatory variables were analysed on the decision to cross or stop at the amber onset based on 5 groups and 3 conjoint factors. Tables 6.9 and 6.10 show the factor scores (using PROC SCORE) and mean scores (of unconsolidated variables) for a variety of respondent characteristics. High positive scoring on the factor (as indicated by the arrow in Figure 6.2) means that the particular driver group generally chose a higher score towards the right-hand end of the scale ('more likely to stop' decision) than average when faced with that factor.

Middle-aged II (aged 41 years and above) and female drivers scored highly on all the three conjoint factors as compared to their counterparts. This means that they belonged to the groups who would be more likely to stop when faced with the three conjoint factors. Inexperienced drivers stated that they were more likely to be influenced by the presence of collision/monetary risk and type of situational factor as compared to experienced drivers while the road conditions/passenger did not appear to influence both groups. There was basically no distinct influence upon the stopping decision for the two vehicle transmission types (manual or automatic). The type of driver as rated by the respondent himself can probably serve as an indicator as to whether a driver pays attention to the surrounding situations while making the cross/stop decision. For example, a driver who rated himself to be skilful or aggressive was found to be more likely to cross under the presence of any of the three factors as compared to one who rated himself to be cautious.

Table 6.9 Factor mean scores by respondent groups (consolidated factors)

Category	Level	n	Factor mean score		
			Factor 1	Factor 2	Factor 3
Age group	Young	87	0.007	-0.064	-0.100
	Middle-aged I	51	-0.069	-0.118	-0.019
	Middle-aged II*	20	0.143	0.578	0.482
Gender	Male	113	-0.128	-0.183	-0.129
	Female	45	0.320	0.459	0.324
Experience in driving	Inexperienced	55	0.118	0.185	-0.040
	Experienced	103	-0.063	-0.099	0.021
Vehicle transmission type	Manual	72	0.006	-0.132	-0.080
	Automatic	79	-0.031	0.083	0.030
Type of driver	Skilful	45	-0.192	-0.278	-0.058
	Cautious	98	0.087	0.152	0.062
	Aggressive*	13	-0.035	-0.225	-0.161

**Level had sample size less than 30 and results should be interpreted accordingly*

Table 6.10 Mean scores by respondent groups (unconsolidated variables)

Category	Level	n	Mean score	
			Far front veh.	Rear veh.
Age group	Young	87	2.73	2.64
	Middle-aged I	51	2.35	2.67
	Middle-aged II*	20	3.40	2.65
Gender	Male	113	2.74	2.61
	Female	45	2.57	2.76
Experience in driving	Inexperienced	55	2.62	2.62
	Experienced	103	2.82	2.72
Vehicle transmission type	Manual	72	2.73	2.69
	Automatic	79	2.62	2.56
Type of driver	Skilful	45	2.87	2.46
	Cautious	98	2.59	2.79
	Aggressive*	13	2.62	2.46

The variables 'far front vehicle' and 'rear vehicle' had mean scores that were between 2.5 and 3 for almost all respondent characteristics, indicating that the variables did not have much influence on the stopping decision. This finding was not dissimilar to previous results when the variables were taken as a whole (2.65-rear vehicle and 2.69-far front vehicle in Table 6.6).

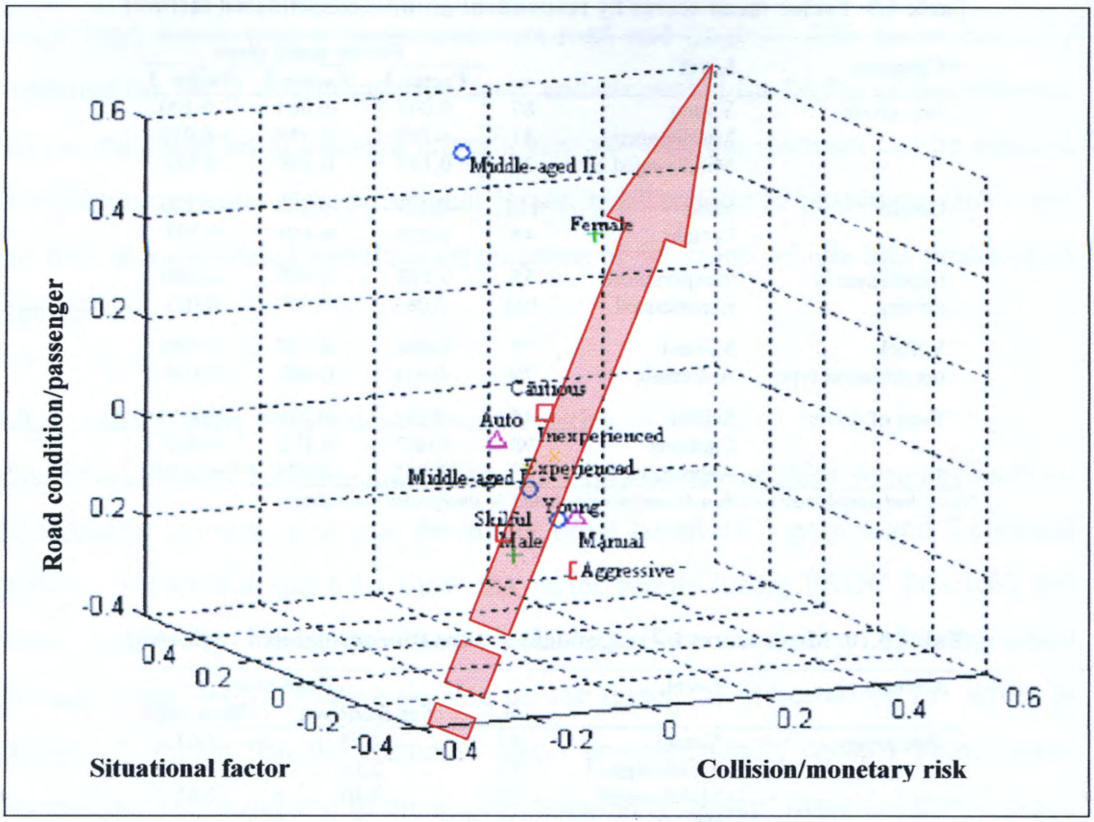


Figure 6.2 **3-D scatter plot of the factor scores**

6.4 Driving strategy

Several questions were asked on the general driving strategy (Section 3 of the questionnaire). About half (49%) of the respondents who were car drivers reported being likely to stop when met with amber light (without an RLC) and this percentage increased to about 87% in the presence of RLCs. The percentage was reduced to 31% (8 out of 26) for the motorcyclists in the absence of an RLC but rose to 100% in the presence of RLCs. The strong positive effect of RLCs in encouraging drivers to stop was quite evident.

Table 6.11 shows the adoption of "stopping strategy" upon arriving at a signalised junction with and without an RLC, categorised by respondent characteristics. Two-tail statistical tests of proportions revealed a smaller proportion of young and male drivers adopting a "stopping strategy" as compared to the older drivers (aged above 41 years) and female drivers, respectively in the absence of an RLC. Car drivers who rated themselves as skilful were significantly less likely to adopt the "stopping strategy" compared to those who rated themselves as "cautious", whether or not there were RLCs.

Table 6.11 Proportion of drivers adopting the stopping strategy

Group	Level	Normal situation (no RLC)			Under presence of RLCs		
		Cross	Stop	Proportion (Stop)	Cross	Stop	Proportion (Stop)
Age group	Young	71	49	0.41*	21	99	0.83
	Middle-aged I	65	64	0.50	15	114	0.88
	Middle-aged II	25	43	0.63*	6	63	0.91
Gender	Male	124	90	0.42*	33	181	0.85
	Female	37	66	0.64*	9	95	0.91
Experience in driving	Inexperienced	41	42	0.51	11	72	0.87
	Experienced	120	114	0.49	31	204	0.87
Vehicle** transmission type	Manual	41	33	0.45	9	65	0.88
	Automatic	41	40	0.49	14	67	0.83
Type of driver**	Skilful	30	15	0.33*	13	32	0.71*
	Cautious	47	54	0.53*	8	93	0.93*
	Aggressive	8	5	0.38	2	11	0.85

**there was significant difference between the two levels within each group when tests of proportions (at 5% level of significance) were performed*
***Stage II data only*

On the questions pertaining to drivers' understanding of red-running offences (driving rules and regulations), about 72% of the drivers indicated permissive entry as long as they have crossed the stop line before red, of which slightly more than half (about 52%) would choose a crossing strategy. If such drivers were attempting to beat the lights, it would be hazardous for the rest of the road users, especially for those opposing flows receiving rights-of-way. About three-fifths (58%) of the respondents stated that the purpose of the amber was to tell the drivers that those who were close to the junction should attempt to cross unless they could not do so (too far away).

Most of the respondents (83.6%) agreed that familiarity of the route did affect their decision-making upon reaching the road junction. Similar trends were observed for the motorcyclists.

The respondent was also probed on the basis (distance or time) that he made the decision whether to cross or to stop. About 71% stated that they judged by how close or far they were from the junction which is consistent with the effect of distance dominance scenario as suggested in the observational study.

A forced-entry multiple logistic regression of "driving strategy" under no-RLC condition with variables of age, gender, driving experience, vehicle transmission type and self-reported driver type revealed only age and gender being significantly associated with the driving strategy. Older drivers (≥26 years) were found to be about 3 times ($e^{estimate}$) more likely to stop at the signalised junctions than young drivers, and female drivers were about 2.7 times more likely to stop than male drivers (see Table 6.12). A case favouring a crossing strategy was that of a driver who perceived that the purpose of the amber signal was to inform drivers who were close to the junction to cross and those too far to stop. Hence, this perception survey had been able to draw out the three variables of age, gender and the understanding of the amber signal that can influence the stopping decision of drivers. The results can be used to complement the field-observed behaviour.

Table 6.12 Results of logistic regression

Variable	Class	Estimate	Standard Error	$Pr>\chi^2$
Intercept	Continuous	-0.5099	0.2280	**0.0253**
Age group	Young	Reference	-	-
	Middle-aged I	0.5162	0.2725	**0.0582**
	Middle-aged II	1.1676	0.3387	**0.0006**
Gender	Male	Reference	-	-
	Female	0.9992	0.2568	**0.0001**
Understanding of	Yes	Reference	-	-
the amber signal	No	-0.5181	0.2537	**0.0411**

6.5 Advance warning signals (Section 4 of questionnaire)

From the sample of 162 responses (Stage II survey), about one-quarter (25%) had driven through a GSCD before. A comparison between those who had experienced the device and those who had not (but merely heard from news or heard-for-the-first-time in this survey), served to distinguish between 'feedback-after-experience' and 'by-intuition' responses. It was found that about three-fifths of the respondents stated that the device would help them to simplify decision-making and enhance safety (see Figure 6.3). These proportions did not differ much between those who had driven through a GSCD and those who had not, with the exception that a relatively smaller proportion of those drivers who had actually driven through a GSCD felt that the device induces more drivers to beat the red.

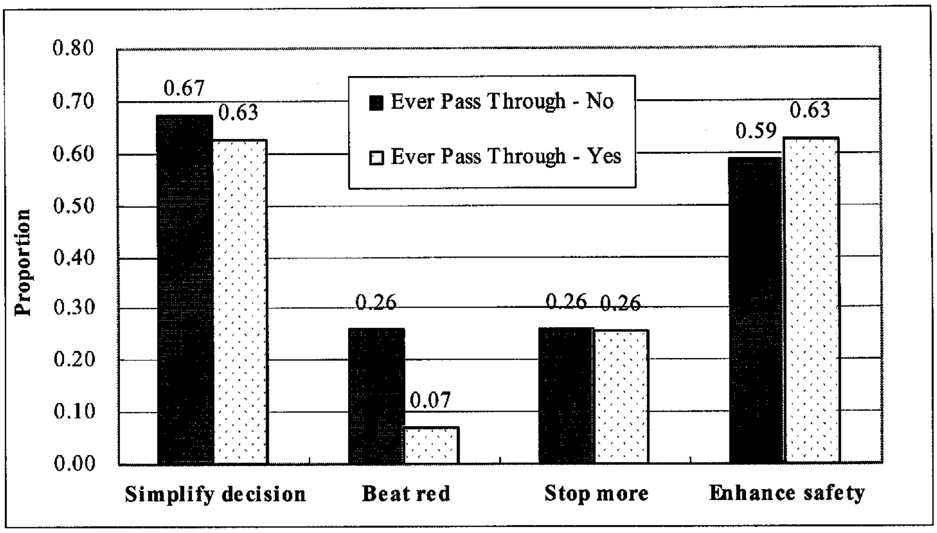


Figure 6.3 General impact of GSCD

The general impact of the GSCD was analysed by the 5 driver characteristics (age, gender, driving experience, vehicle transmission type, driver type). There was no significant difference in proportions between experienced and inexperienced drivers as well as between male and female drivers (see Table 6.13). The proportion of young drivers (aged less than 25 years) who perceived that the GSCD encourages more drivers to beat the red or more drivers to stop was significantly higher compared to the rest of the drivers. A higher proportion of female drivers (67% versus 57% for male) was found to agree that the device could enhance safety although the difference was not significant (at 5% level of significance). Drivers operating automatic transmission vehicle tended to perceive that the GSCD induces more drivers to beat the red than drivers operating vehicles with manual transmission (26% versus 18%). A relatively lower proportion of the respondents who rated themselves as cautious drivers felt that the device encourages drivers to beat the red but a relative higher proportion of them stated that the device encourages more drivers to stop when compared to other driver groups. However, it should be noted that the number of 'aggressive' drivers was small (13) compared to 'skilful' (46) and 'cautious' (101) drivers.

Table 6.13 General impact of the GSCD

	Simplify			Beat red			Stop more			Safety		
	Yes	No	p**	Yes	No	p	Yes	No	p	Yes	No	p
Age group												
Young	59	31	0.66	25	65	0.28*	27	63	0.30*	52	38	0.58
Middle-aged I	33	19	0.63	9	43	0.17*	11	41	0.21*	33	19	0.63
Middle-aged II	15	5	0.75	0	20	0.00	4	16	0.20	12	8	0.60
Gender												
Male	75	41	0.65	25	91	0.22	29	87	0.25	66	50	0.57
Female	32	14	0.70	9	37	0.20	13	33	0.28	31	15	0.67
Experience												
Inexperienced	40	17	0.70	12	45	0.21	17	40	0.30	35	22	0.61
Experienced	67	38	0.64	22	83	0.21	25	80	0.24	62	43	0.59
Vehicle Transmission Type												
Manual	49	25	0.66	13	61	0.18*	20	54	0.27	43	31	0.58
Automatic	53	28	0.65	21	60	0.26*	21	60	0.26	49	32	0.60
Driver												
Skilful	29	17	0.63	12	34	0.26*	3	37	0.08*	29	17	0.63
Cautious	66	35	0.65	19	82	0.19*	30	71	0.30*	59	42	0.58
Aggressive	10	3	0.77	3	10	0.23	3	10	0.23*	8	5	0.62

** significantly different*
***proportion*

A good proportion (83%) of the respondents agreed that they tended to anticipate the need to cross/stop if they were familiar with the route. On this basis, when they were also asked whether there was any way in which they could anticipate the termination of the green signal and to list all of them, only 68 out of 162 (42%) replied “Yes”. The relatively lower response to this question might be because the succeeding question required the respondent to list out (in words) all the ways and hence some might just want to get away without the hassle of putting in the responses (by choosing the option “none”). However, the available points given by the respondents were nevertheless useful in interpreting the use of advance warning signals, and the majority (about 53%) noted observing the pedestrian signal man along the same direction as the approach. Other ways included observing the traffic signals from afar, inferring from the appearance of green arrow at the T-junctions and surmising from the traffic ahead (volume and speed). A further breakdown of those who had listed some ways showed that experienced drivers were more likely to pick up pre-empted indications from the road surroundings compared to inexperienced drivers (43% versus 29%). This is consistent with what has been postulated in the literature review.

6.6 Chapter summary

A perception survey can be a very useful and efficient means to substantiate or complement on-site observations in studying driver behaviour. When executed properly, such a survey can provide reliable in-depth information as well as the motives and attitudes behind drivers' decisions to stop or cross at the signalised junctions. The extensive use of self-completed questionnaire schedule in this study greatly reduced manpower and interviewer bias.

Car drivers formed the bulk of the respondents, at 92.0%. The analyses of car drivers were done in terms of 5 characteristics (age, gender, driving experience, vehicle transmission type and driver type) which allowed useful comparisons. Motorcyclists were considered as a separate group to see how (if at all) a distinctly different vehicle type affected driver behaviour.

The most prominent things that car drivers listed as influencing their decision upon approaching a signalised junction during amber onset were the presence of enforcement, pedestrians and a rear vehicle, and distance to stop line. Factor analysis was used to reduce 16 common variables into 3 conjoint factors of collision/monetary risk, situational factor and road conditions/passenger. From the factor mean score of each factor, it was found that older drivers as well as female drivers generally chose a higher score (more likely to stop) on all the 3 conjoint factors compared to their younger or male counterparts. Inexperienced drivers were more likely to be influenced by the collision/monetary risk and situational factor than experienced drivers.

The strong positive effect of RLCs was further demonstrated whereby the percentage of respondents choosing the option 'will most likely stop' rose from 49% to 87% for the car drivers without and with an RLC, and 31% to 100% for the motorcyclists. There were also significantly higher proportions of the older and female drivers adopting the 'stopping' strategy. Car drivers who rated themselves as 'skilful' drivers were, not unexpectedly, less likely to adopt a stopping strategy as compared to those who rated themselves as 'cautious' drivers.

A logistic regression model showed that age and gender were the only personal characteristics (out of the 5 driver characteristics) that significantly influenced the driver strategy adopted by car drivers. Respondents who concurred with the option that the purpose of the amber signal is to allow those who are close to the stop line to cross were less likely to adopt a stopping strategy.

About 60% of the respondents reported that the GSCD would simplify their decision-making process and enhance safety. From the things listed by the respondents regarding the ways in which they can anticipate the termination of the green signals, it appeared that provision of the advance warning signals might be a helpful measure to aid decision-making.

In general, this perception survey was able to draw out 2 important influencing factors: age and gender that are likely to influence driver decision-making at the signalised junctions.

Chapter 7 Findings, Discussions and Recommendations

This concluding chapter encompasses five main parts namely, the general motivation behind the study, the research methodology, the main results and findings, discussions on issues regarding the study and finally recommendations for future work.

7.1 About the present study

Traffic signal is the dominant type of junction traffic control in Singapore where there are about 1250 installations in operation (as of early 2004). The signals are used at the junctions to inform drivers (and other road users) of their respective rights-of-way in order to facilitate more efficient movements as well as safer management of conflicting flows. Unfortunately, accidents still occur at the signalised junctions, especially during the signal change interval, due to one or more road users failing to cope with the prevailing situation. The junctions are therefore hot spots in terms of road safety as well as road capacity. Remedial measures have been tried which often met with limited success due to inadequate knowledge of driver behaviour and associated performance at the traffic signals. Hence, the main focus of the research was to examine driver behaviour at the traffic signals by investigating in detail the driver performance characteristics in responding to the signal change interval.

7.2 Research methodology

The research involved a mass-data analysis of the accident and violation statistics at signalised junctions in the preliminary, followed by a detailed investigation on the driver behaviour using on-site observations and a perception survey. The accident/violation analysis served to highlight the problems faced by drivers at the signalised junctions as well as to bring out some of the factors deemed to be associated with aberrant driver behaviour which may sometimes lead to accidents.

The main thrust of this research was, however, aimed at studying the normal driver behaviour on the road using an unobtrusive field observational method. Various aspects such as junction approach types, presence of red-light cameras, ambient light conditions (daytime versus night-time driving) and many other factors that may affect the driver performance characteristics as well as the driver stopping propensity were investigated in detail. General linear and logistic regression models were used to develop the relationships.

The final part of the study involved a perception survey that was used to complement the field observations. This survey served to bring out the possible influence of personal-related factors like age, gender, etc. on the driver performance as well as the mindset about driving.

7.3 Results and findings

The results of this study cover findings in four main areas: accident statistics, red-running violation statistics, observational study and perception survey.

7.3.1 Accident statistics

Statistics of road traffic accidents for a period of 18 years (1985-2002) that involved casualties were obtained from the Traffic Police Department and used for detailed investigations. About a third of the accidents occurred at junctions; of these, about half occurred at signalised junctions.

Accidents at signalised junctions

About two-thirds of the accidents at signalised junctions occurred at four-legged (X-) junctions. Of the signalised junction accidents, head-to-side collisions were the most common type, followed by a smaller proportion of rear-end collisions. Based on the analysis of the listed contributory factors and the records of manoeuvres before the accidents, it was evident that the right-turn permissive filtering and red-running should be of major concerns to the operations of signalised junctions.

Involvement ratio (IR)

The relative road traffic accident involvement ratio (IR) was an index used in this study to serve as a basis to determine the extent to which vehicles (or other defined characteristics of the drivers) were involved in accidents. IR represents the ratio of the percentage of specified offending vehicles/drivers within the offending grouop over the percentage of paired non-offending vehicles/drivers within the non-offending group. A value of IR greater than 1 means that the particular offending group (of defined characteristics) was more frequently represented or had a higher than average accident risk.

Red running-related accidents

Red-running related accidents made up about 20% of the road traffic accidents that occurred at signalised junctions. Their occurrences were quite prominent during the 7pm to 1am period when traffic volumes would be moderate. About three-quarters of these accidents occurred at the X-junctions. The most culpable party in red-running accidents were the young (less than 25 years) and the old (≥ 66 years) drivers/riders. Motorcyclists had the highest accident IR value of 1.23 and hence were more likely to be involved in red-running accidents when compared to the general driving population. Red-running drivers and their front passengers were more likely to suffer injuries or be killed than non red-runners.

7.3.2 Red-running violation statistics

There was a greater tendency for drivers to run the red traffic lights at T-junction approaches. The majority of the violations (over 90%) occurred within the first two seconds after onset of red with an exponential decaying effect. Taxi and HCV drivers were found to have the highest tendency to run the red. However, it should be highlighted that the low violation rate of motorcycles did not mean their lower tendency to red-run but might be due to their relatively lower detection rate. This was suggested by their high violation-related accident rate. High violation rates were evident in the morning peak (8-9am), early afternoon period (1-3pm), evening peak (5-6pm) and some hours before midnight.

7.3.3 Observational study

The aim of the observational study was to observe in an unobtrusive manner the performance characteristics of driver behaviour at different approach types (X-junction approach, top and middle approaches of T-junctions and at grade-separated approach), varying ambient conditions (day or night) and other site factors.

The study environment

In the present study environment (Singapore), a constant amber length of 3 seconds and a narrow range of all-red clearance interval (0.6 to 2 seconds) are widely used at most of the junctions, apart for a few junctions with 4-second amber. Recently, the authorities have implemented traffic device aids such as the advance warning lights (AWLs) and the green signal countdown device (GSCD) at some junctions, with the aim of providing a safer environment to the drivers and other road users.

Sample characteristics

A total of 5776 subject vehicles (3230 stopped and 2546 crossed) were observed and their data analysed. There was no bias in choosing the subject vehicle type to extract. The last crossing and first stopping vehicles were extracted per cycle, with the exceptions of a few vehicles that were either very near or very far away from the stop line at the amber onset. There was a good spread of vehicle speeds within each site, hence making all sites to be fairly comparable. From the observed traverse time of crossing vehicles, the number of red-runners was found to decrease exponentially with time into the red which is similar to the pattern of red-running violations as captured by the RLCs. It was found that a wider junction does not necessarily discourage drivers to cross, given the same amber period.

Driver performance parameters

Perception-response time (PRT) is one of the two important performance parameters required in designing the change interval. This study used a transitional zone (TZ) to separate free-paced drivers from forced-paced drivers when responding to the signal change. The 85th percentile PRT values within the TZ were close to the ITE design value of 1 second. The PRT values were found to be generally lower for junctions installed with RLCs. There were no significant differences in the PRT values among the approach types and possibly between different ambient light conditions. The influential variables included vehicle speed and distance from the stop line at amber onset, RLC, collision risk with opposing right-turning traffic, and vehicle type.

The mean deceleration rate, being another performance indicator used in designing the change interval, was found to vary between 2.8 and 3.4 m/s^2 for stopping vehicles within the TZ. These values were lower when all subject vehicles were considered. The maximum operating deceleration rate was observed to be about 3.7 to 4.5 m/s^2, estimated at the 85th percentile level. The variables of speed, distance, vehicle class and PRT had a relatively good correlation with the deceleration rate.

Drivers' decision-making

The speed versus distance plot is one of the deterministic schemes used to group drivers into the four different zones of 'stop, cross, option and dilemma'. It was found that the majority of those who crossed did so in the 'cross' zone, and those who stopped did so in the 'stop' zone. However, these proportions were not constant under different situations (e.g. presence/ absence of an RLC, day/ night-time). Another deterministic plot, the 'A,D' representation which used the estimated acceleration and deceleration rates required to safely cross the junction or stop before the stop line, showed a similar inconsistency among the different situations.

Stopping probability

Logistic regression was used in this study to model the different site variables that can affect the stopping propensity of drivers. The results obtained from the logistic regression model showed that distance from the stop line, approach speed, presence of an RLC, the entry lane and the type of opposing class were important variables affecting the stopping probability. A vehicle would be more likely to stop when it was far away from the junction and/or travelling at a lower speed and under the presence of an RLC. Motorcyclists and HCV drivers were less likely to stop than car drivers and vehicles travelling in the centre lane were less likely to stop than when in the kerb lane. The propensity of stopping increased when there was a greater likelihood of colliding with an opposing vehicle. The effect of RLCs varied with speed, distance, type of opposing class and the ambient light condition.

An application of the driver behavioural study was contrived by making use of the available data (involving cases with and without pre-amber onset indicator). The response parameters, PRT and deceleration rates, were not significantly different for vehicles positioned in the TZ. However, the test case suggested that the provision of "green termination" warning indicator induced more drivers further away from the stop line (TTSL>4) to be better prepared to stop. The probability of stopping was generally higher and the indecision zone was reduced under the presence of a green arrow (or driver anticipation of the amber onset). The effect was more pronounced for lower-speed vehicles.

7.3.4 Perception survey

The other major component of this study was the perception study. The survey was aimed at identifying the mindset of drivers arriving at a junction during the signal change interval. The most prominent things listed by car drivers perceived as influencing their decision upon arriving at the signalised junction were the presence of enforcement, pedestrians, distance to the stop line and the presence of a rear vehicle. From the choices indicated by the respondents, it was observed that older drivers and female drivers were the ones who reported to be most likely to adopt a stopping strategy under the various pre-defined cases. Inexperienced drivers were more likely to be affected by the collision/monetary risk and junction/road condition factors than those who were experienced. About half of the respondents (48%) reported that they 'always try to stop' upon arriving at the junction and this percentage increased to 87% in the presence of an RLC. Car drivers who rated themselves as 'skilful' drivers were found to be less likely to adopt a stopping strategy as compared to those who rated themselves as 'cautious' drivers, which is not unexpected.

A multiple logistic regression model showed that age and gender were the personal characteristics (out of 5 driver characteristics) that significantly affected the strategy adopted by car drivers. Those who stated that the amber interval is for those who are close to the stop line to have enough time to clear also had a higher tendency to adopt a 'try to cross' strategy at the amber onset.

7.4 Discussion

Two major conflicting parties at a signalised junction are those going straight ahead and those making a right-turn from the opposing direction. In the Singapore context, since the right-turn manoeuvre is permitted during the circular green, right-turn vehicles (if any) would be queued in the extended pockets which are located close to the zone of conflict (with straight-through traffic). The tendency (possibility) of these vehicles to filter across complicates the decision work load of the straight-through drivers. The problem of running the red lights which can lead to red-running crashes also deserves continuing attention and warrants considerable resources for remediation; the types of countermeasures shall depend on identifying the type of violators (either deliberate or not).

Accident and violation statistics, though useful, are limited in scope either because of missing/incomplete entries or due to lack of contrasting groups (non-violators) for comparison. As such, this research project which adopted the unobtrusive on-site observations is useful in several areas. A better understanding of the driver performance parameters allows practitioners to fine-tune the signal system towards providing a safer environment, given that the current system is far from perfect. The use of a transitional zone (that separates forced-paced drivers from free-paced drivers) to study the driver performance characteristics was shown to be applicable to different junction approach types and possibly to varying ambient light conditions; this technique is thus quite robust. Realistic operating parameters (approach speed, average deceleration rate, PRT, etc) found from the study should also be useful for validating the variables used in the design of other road elements (e.g. the provision of adequate sight distance at road curves), in calibrating and validating computer-based simulation models, and for evaluating the performance of novel traffic control devices.

Another safety issue at the signalised junction is the driver's decision-making (to stop or cross) during the signal change interval. The study used the stopping probability to describe the way in which the driver's choice progresses from one extreme (most likely to cross) to the other (most likely to stop), under different on-the-road scenarios. Many factors that were found to influence the driver's decision-making. Hence, a two-pronged (hybrid) method was used in the research involving an on-site observational study that covered mostly the prevailing situational and environment conditions, and a perception survey that dealt with the mindset of drivers. Although the variables from the two datasets could not be cross-validated, some of the potentially more influential factors could still be inferred from each dataset. It should be noted, however, that a perception survey may not portray accurately the actual driver's decision as compared to the observational study.

The methodology involving unobtrusive field observations can be an effective means (as an alternative to looking at accidents and violation data which may be sparse for particular sites) in assessing the effects of novel traffic control devices, given that sufficient sample points can be collected in a short period of time. Moreover, the availability of better balanced data (both violator and non-violator) facilitates the calibration of statistical models to describe the phenomenon of interest. In this regard, the model should aim for sufficient generality for broad-based application rather than having the best (statistical) fit.

7.5 Recommendations

The accident statistics used in this study have not incorporated the series of recent accident data coded using a revised format which includes movement codes. These movement codes should facilitate more rigorous analysis for example, the pre-crash direction of travel of the accident vehicles. It is recommended to update the accident analysis as more records become available. Specific combinations of pre-crash movements can then be examined for approaches at a junction (especially important for T-junctions).

From the perception survey, it is apparent that the personal characteristics of drivers can affect the decision-making process, therefore it would be desirable that the observational study includes some means of identifying drivers' age and gender. However, it should be born in mind that such information is hard to obtain (and will require enormous amount of manpower) complemented by more sophisticated recording technology.

Another issue worth noting is the uncertainty among engineers and researchers whether drivers will adapt to an increase in the yellow change interval (typically the amber duration) and continue to run the signals even under a longer amber duration. An engineering study on the effect of lengthening the amber duration on red running will thus be beneficial in assessing the effectiveness or the need in providing a longer amber duration. However, care should be taken when comparing the results given that approaches with a 4-second amber are typically located at wide junctions.

The present project has investigated certain aspects of the permissive filtering system in Singapore such as how it affected the normal driving situation. The video footages obtained from this study can be further utilised to study and evaluate the system by studying the gap commonly accepted by drivers as well as to conduct a more in-depth conflict analysis.

This study has highlighted a 'construed' case of the provision of amber onset pre-indicator. The findings suggested that an advance warning signal works better with enforcement such as red-light cameras or speed cameras. These measures, when implemented together, serve to help those who are less capable of coping with the signal change situation (unintentional violators) as well as to stop those who deliberately violate the rules. However, implementation of such measures should be evaluated with appropriate before-and-after study, possibly using a similar methodology as described in this study.

REFERENCES

1. AAA (1952). "Age and complex reaction time", Traffic Engineering and Safety Department Report No. 41, American Automobile Association. [Cited in Green, 2000].

2. AAS (2000a). "Bad driving habits: are you guilty of them?", Motoring News and Car Review, Automobile Association of Singapore. Retrieved 12-Apr-2003 from http://www.aas.com.sg

3. AAS (2000b). "New road signals for safer roads ahead", The Automobile Association of Singapore. Retrieved 22-Jun-2002 from http://www.aas.com.sg/features/archive/otr03003.htm

4. AAS (2001). "New penalties for traffic offenders", Motoring News and Car Reviews, Automobile Association of Singapore. Retrieved 12-Apr-2003 from http://www.aas.com.sg

5. AAS (2002). "Only 65-year-olds need submit certificate of medical fitness", Motoring News and Car Reviews, Automobile Association of Singapore. Retrieved 12-Apr-2003 from http://www.aas.com.sg

6. AASHO (1965). "A policy on geometric design of rural highways", American Association of State Highway Officials, Washington, D.C., USA. [Cited in ITE, 1985].

7. AASHTO (1994). "A policy on geometric design of highways and streets", American Association of State Highway and Transportation Officials, Washington, D.C., USA.

8. Aberg, L. and Rimmö, P.A. (1998). "Dimensions of aberrant driving behaviour", Ergonomics, Vol. 41, No. 1, pp. 39-56.

9. ADOT (2001). "621 signal phase change interval", Traffic Engineering Policies, Guidelines and Procedures, Section 600 – Traffic Signals, Arizona Department of Transportation, USA.

10. Allison, P.D. (1990). "Logistic regression using the SAS system: theory and application", SAS Institute Inc., Cary, NC, USA.

11. Allos, A.E. and Al-Hadithi, M.I. (1992). "Driver behaviour during onset of amber at signalised junctions", Traffic Engineering and Control, Vol. 27, No. 5, pp. 312-317.

12. Allsop, R.E., Brown, I.D., Greoger, J.A. and Robertson, S.A. (1991). "Approaches to modelling driver behaviour at actual and simulated traffic signals", TRRL Contractor Report 264, Transport and Road Research Laboratory, Crowthorne, Berkshire, UK. [Cited in Bonneson et al., 2002].

13. Anderson, S.J. and Holliday, I.E. (1995). "Night driving: effects of glare from vehicle headlights on motion perception", Ophthalmic and Physiological Optics, Vol. 15, No. 6, pp. 545-551.

14. Andreassen, D. (1995). "A long term study of red light cameras and accidents", Research Report ARR 261, Australian Road Research Board, Australia.

15. Baguley, C.J. and Ray, S.D. (1989). "Behavioural assessment of speed discrimination at traffic signals", TRRL Research Report 177, Transport and Road Research Laboratory, Crowthorne, Berkshire, UK.

16. Bissell, H.H. and Warren, D.L. (1981). "The yellow signal is not a clearance signal", Institute of Transportation Engineers Journal, No. 2, Vol. 51, pp. 14-17.

17. Blackman, A.R. (1960). "Driver behaviour during the amber period of traffic lights", Road Research Laboratory, Crowthorne, Berkshire, UK. [Cited in ITE, 1985].

18. Bonneson, J., Zimmerman, K. and Brewer, M. (2002). "Engineering countermeasures to reduce red-light-running", Research Report 4027-2, Cooperative Research Program, Texas Transportation Institute, Texas Department of Transportation, Texas, USA.

19. Caltrans (1996). "Traffic manual", Chapter 9, California Department of Transportation. Retrieved 28-Sep-2002 from http://www.dot.ca.gov/hq/traffops/signtech/signdel/chp9/chap9.htm

20. Chandler, R.E., Herman, R. and Montroll, E.W. (1958). "Traffic dynamics: studies in car following", Operations Research, Vol. 6, pp. 165-184. [Cited in Taoka, 1982].

21. Chang, M.S., Messer, C.J. and Santiago, A.J. (1984). "Evaluation of engineering factors affecting traffic signal change interval", Transportation Research Record 956, Transportation Research Board, National Research Council, Washington D.C., pp. 18-21.

22. Chang, M.S., Messer, C.J. and Santiago, A.J. (1985). "Timing traffic signal change intervals based on driver behaviour", Transportation Research Record 1027, Transportation Research Board, National Research Council, Washington, D.C., pp. 20-30.

23. Cooper, P.J. (1984). "Experience with traffic conflicts in Canada with emphasis on "post encroachment time" techniques", Technical paper in Proceedings of the NATO Advanced Research Workshop on International Calibration Study of Traffic Conflict Techniques, Institute of Road Safety Research SWOV, The Netherlands, 25-27 May, pp. 75-96.

24. Crawford, A. (1962). "Driver judgement and error during the amber period at traffic lights", Ergonomics, Vol. 5, No. 4, pp. 513-532. [Cited in Taoka, 1982].

25. Darroch, J.N. and Rothery, R.W. (1972). "Car following and spectral analysis", Traffic Flow and Transportation, American Elsevier Publishing Company. [Cited in Taoka, 1982].

26. Demirarslan, H., Chan, Y. and Vidulich, M. (1998). "Visual information processing: perception, decision, response triplet", Transportation Research Record 1631, Transportation Research Board, National Research Council, Washington D.C., pp. 35-42.

27. Ding, Y. S. (2002). "Characteristics of late red-runners at signalised road junctions", B. Eng. Final Year Project Report, School of Civil and Environmental Engineering, Nanyang Technological University, Singapore. [Unpublished].

28. Drew, D.R. (1968). "Traffic flow and control", McGraw-Hill, New York, USA. [Cited in Taoka, 1982].

29. Drummond, A.E. (1989). "An overview of novice driver performance issues – literature review", Report No. 5, Monash University Accident Research Centre, Australia.

30. Evans, L. (1991). "Traffic safety and the driver", Van Nostrand Reinhold, New York, USA.

31. Farraher, B.A., Weinholzer, R. and Kowski, M.P. (1999). "The effect of advanced warning flashers on red light running – A study using motion imaging recording system technology at Trunk Highway 169 and Pioneer Trail in Bloomington, Minnesota", Compendium of Technical Papers for 69th Annual ITE Meeting, Institute of Transportation Engineers, Washington, D.C., USA.

32. Faulkner, C. R. (1975). "Ages of drivers involved in some junction accidents", TRRL Supplementary Report 131, Transport and Road Research Laboratory, Crowthorne, Berkshire, UK.

33. Forbes, T.W. and Simpson, M.E. (1968). "Driver and vehicle response in freeway deceleration waves", Transportation Science, Vol. 2, No. 1. [Cited in Taoka, 1982].

34. Fuller, R. (1984). "A conceptualism of driving behaviour as threat avoidance", Ergonomics, Vol. 27, No. 11, pp. 1139-1155. [Cited in Fuller, R. (1988). "On learning to make risky decisions", Ergonomics, Vol. 31, No. 4, pp. 519-526.].

35. Gazis, D., Herman, R. and Maradudin, A. (1960). "The problem of amber signal light in traffic flow", Traffic Engineering, Vol. 30, No. 7, pp. 19-26. [Cited in Taoka, 1982, in ITE, 1985 and in Liu, C., Herman, R. and Gazis, D.C. (1995). "A review of the yellow interval dilemma", Transportation Research, Vol. 30, No. 5, pp. 333-348.].

36. Goh, P.K. and Wong, Y.D. (2002). "Driver perception-braking response latency during the signal change interval", Proceedings of The International Conference on Seamless and Sustainable Transport, Centre for Transportation Studies, Nanyang Technological University, Singapore, 25-27 November, pp. 163-171.

37. Goh, P.K. (2003). "Driver performance during the traffic signal change interval", Master of Engineering Thesis, School of Civil and Environmental Engineering, Nanyang Technological University, Singapore. [Unpublished].

38. Green, M (2000). "'How long does it take to stop?' Methodological analysis of driver perception-brake times", Transportation Human Factors, Vol. 2, No. 3, pp. 195-216.

39. Green, M. (2003). "Driver reaction time", Visual Expert, Human Factors. Retrieved 28-Oct-2003 from http://www.visualexpert.com/Resources/reactiontime.html

40. Greenshields, B.D. (1936). "Reaction time in automobile driving", Journal of Applied Psychology, Vol. XX, pp. 353-358. [Cited in Taoka, 1982].

41. Grime, G. (1952). "Traffic and road safety research at Road Research Laboratory, England", Proceedings of the 31st Annual Meeting of the Highway Research Board. [Cited in Taoka, 1982].

42. Harrell, F.E. (2001). "Regression modeling strategies: with applications to linear models, logistic regression, and survival analysis", Springer-Verlag, New York, USA.

43. Hooper, K.G. and McGee, H.W. (1983). "Driver perception-reaction time: Are revisions to current specification values in order?", Transportation Research Record 904, Transportation Research Board, National Research Council, Washington D.C., pp. 93-97.

44. Hosmer, D.W. and Lemeshow, S. (2000). "Applied logistic regression", 2nd Edition, John Wiley and Sons Inc., New York, USA.

45. ITE (1982). "Transportation and traffic engineering handbook", 2nd Edition. Prentice Hall, Englewood Cliffs, New Jersey.

46. ITE (1985). "Determining vehicle change intervals: a proposed recommended practice", Report prepared by ITE Technical Council Committee 4A-16, Institute of Transportation Engineers, Washington, D.C., USA.

47. ITE (1994). "Determining vehicle signal change and clearance intervals", Informational Report prepared by ITE Technical Council Task Force 4TF-1 (Thompson, B.A., Chairman), Institute of Transportation Engineers, Washington, D.C., USA.

48. ITE (1999). "Traffic engineering handbook", Fifth edition, Prentice Hall, Inc., Washington, D.C., USA.

49. Jackson, W. (1988). "Research methods: Rules for survey design and analysis", Prentice Hall Inc., Ontario, Canada.

50. Jenkins, D.G. (1978). "International drivers' behaviour research association cross-national attitudes and opinions survey: report of UK findings", TRRL Supplementary Report 403, Transport and Road Research Laboratory, Crowthorne, Berkshire, UK.

51. Jenkins, R.S. (1969). "A study of selection of yellow clearance intervals for traffic signals", Report TSE-TR-104-69, Michigan Department of State Highways and Transportation, Lansing, USA. [Cited in ITE, 1985 and in Wortman and Matthias, 1983].

52. Johansson, G. and Rumar, K. (1971). "Driver's brake reaction times", Human Factors, Vol. 13, No. 1, pp. 23-27. [Cited in Taoka, 1982].

53. Kent, S., Corben, B., Fildes, B. and Dyte, D. (1994). "Red light running behaviour at red light camera and control intersections", Monash University Accident Research Centre, Report 73. Retrieved 23-Dec-2003 from http://www.general.monash.edu.au/muarc/rptsum/es73.htm

54. Kim, J.O. and Muller, C.W. (1986). "Factor analysis: statistical methods and practical issues", Quantitative Applications in the Social Sciences, Sage University Paper, Beverly Hills, London, No. 14.

55. Koll, H., Badar, M. and Axhausen, K.W. (2004). "Driver behaviour during flashing green before amber: A comparative study", Accident Analysis and Prevention, Vol. 36, pp. 273-280.

56. Lawson, S.D. (1991). "Red-light running: accidents and surveillance cameras", Report No. AA/BCC 3, Birmingham City Council – AA Foundation for Road Safety Research, Birmingham, UK.

57. Lee, H. (2001). "Characteristics of red-running violations", B. Eng. Final Year Project Report, School of Civil and Structural Engineering, Nanyang Technological University, Singapore. [Unpublished].

58. Limpert, R. (1978). "Motor vehicle accident reconstruction and cause analysis", The Michie Company, Charlottesville, Virgina, USA. [Cited in Taoka, 1982].

59. Liu, C., Herman, R. and Gazis, D.C. (1996). "A review of the yellow interval dilemma", Transportation Research – A, Vol. 30, No. 5, pp. 333-348.

60. Louca, G., Karlaftis, M. and Kanellaidis, G. (1999). "Investigating driver attitudes and behaviour on highways", Workshop on Car Drivers in Proceeding of the 14th International Cooperation on Theories and Concepts in Traffic Safety (ICTCT), Caserta, Greece, 2001.

61. LTA (2000). "Land Transport Authority: Standard details of road elements". Retrieved 10-Sep-2003 from http://www.corenet.gov.sg/einfo/docs

62. LTA (2002). "Using it right – red and amber arrows", Journeys Issue 38, Land Transport Authority, Singapore. Retrieved 27-Aug-2002 from http://www.lta.gov.sg/MenuFrame5.htm

63. LTA (2003). "Countdown timers for vehicles", What's New, Land Transport Authority, Singapore. Retrieved 23-Jan-2003 from http://www.lta.gov.sg/corp_info/index_corp_new.htm

64. LTA (2004). "Catching the green wave", Journeys March 04 Issue, Land Transport Authority, Singapore, pp. 4-5.

65. Lum, K.M. and Wong, Y.D. (1998). "An overview of red-light surveillance cameras in Singapore", ITE Journal on the Web, Institute of Transportation Engineers, Washington, D.C., pp. 87-91.

66. Lum, K.M. and Wong, Y.D. (2001). "Traffic data logging system for red-running violation studies", Traffic Engineering and Control, Vol. 42, No. 10, pp. 362-365.

67. Lum, K.M. (2002). "Impacts of red light cameras on traffic characteristics and interactions at signalised junctions", Doctor of Philosophy Thesis, School of Civil and Environmental Engineering, Nanyang Technological University, Singapore. [Unpublished].

68. Lum, K.M. and Wong, Y.D. (2002). "A study of stopping propensity at matured red light camera T-intersections", Journal of Safety Research, Vol. 33, No. 3 , pp. 355-369.

69. Mahalel, D. and Zaidel, D. M. (1985). "Safety evaluation of a flashing green light in a traffic signal", Traffic Engineering and Control, Vol. 26, No. 2. pp. 79-81.

70. May, A.D. (1968). "Clearance interval at traffic signals", Highway Research Record 221, Highway Research Board, National Research Council, Washington D.C., pp. 41-71. [Cited in Mussa et al., 1996].

71. McCoy, P.T. and Pesti, G. (2003). "Dilemma zone protection on high-speed signalized intersection approaches: advance detection versus advance warning flashers and advance detection", 82nd Annual Meeting, Transportation Research Board, Washington, D.C., 12-16 January.

72. McGee, H. W. (2003). "The impact of red-light camera enforcement on crash experience", ITE Journal, Institute of Transportation Engineers, Vol. 73, No.3, pp. 44-48.

73. Michael, S.S., Gerald, A.W. and Chia, J.C. (1982). "Effects of traffic signal installation on accidents", Accident Analysis and Prevention, Vol. 14, No. 2, pp. 135-145.

74. MIT. (1934). "Report on Massachusetts highway accident survey", CWA-ERA project, Massachusetts Institute of Technology, Cambridge. [Cited in Taoka, 1982].

75. Moss, F.A. and Allen, H.H. (1925). "The personal equation in automobile driving", Transactions of the Society of Automotive Engineers, Part I, Vol. XX, pp. 497-510. [Cited in Taoka, 1982].

76. Mussa, R. N., Newton, C.J., Matthias, J.S., Sadalla, E.K. and Burns, E.K. (1996). "Simulator evaluation of green and flashing amber signal phasing", Transportation Research Record 1550, Transportation Research Board, National Research Council, Washington D.C., pp. 23-29.

77. Naatanen, R. and Summala, H. (1974). "A model for the role of motivational factors in drivers' decision-making", Accident Anlaysis and Prevention, Vol. 6, No. 3-4, pp. 243-261. [Cited in Karwowski, W. and Mital, A. (1986). "Applications of fuzzy set theory in human factors", Advances in Human Factors/Ergonomics, Vol. 6. Elsevier, New York, USA.].

78. Ng, C.H. (1996). "Impacts of surveillance cameras on safety at signalised junctions", Master of Engineering Thesis, School of Civil and Structural Engineering, Nanyang Technological University, Singapore. [Unpublished].

79. Ng, C.H., Wong, Y.D. and Lum, K.M. (1997). "Impacts of red-light surveillance cameras on road safety in Singapore", Road and Transport Research, Australian Road Research Board, Vol. 6, No. 2, pp. 72-81.

80. Normann, O.K. (1953). "Braking distances of vehicles from high speeds", Proceedings of the 32nd Annual Meeting of the Highway Research Board, Washington, D.C., pp. 421-436. [Cited in Taoka, 1982].

81. Ogden, K.W. (1990). "Human factors in traffic engineering", Institute of Transportation Engineers Journal, pp.41-46.

82. Ogden, K.W. (1996). "Safer roads: a guide to road safety engineering", Avebury Technical, Aldershot, UK.

83. OHML (2001). "The red light running crisis. Is it intentional?", Office of the House Majority Leader (OHML), U.S. House of Representatives, USA.

84. Parker, D., Reason, J.T., Manstead, A.S.R. and Stradling, S.G. (1995). "Driving errors, driving violations and accident involvement", Ergonomics, Vol. 38, No. 5, pp. 1036-1048.

85. Prashker, J.N. and Mahalel, D. (1989). "The relationship between an option space and drivers' indecision at signalized intersection approaches", Transportation Research, Part B, Methodological, Vol. 23B, pp. 401-414.

86. Quenault, S.W., Golby, C.W. and Pryer, P.M. (1968). "Age group and accident rate – driving behaviour and attitudes", Road Research Laboratory Report LR167, Ministry of Transport, Crowthorne, Berkshire, UK.

87. Quimby, A. and Drake, S. (1989). "A follow-up to the UK's IDBRA driver attitude survey", TRRL Research Report 216, Transport and Road Research Laboratory, Crowthorne, Berkshire, UK.

88. Reason, J. (1990). "Errors and violations on the roads: a real distinction?", Ergonomics, Vol. 33, No. 10/11, pp. 1315-1332.

89. Reja, U., Manfreda, K.L., Hlebec, V. and Vehovar, V. (2003). "Open-ended vs. close-ended questions in web questionnaires", Metodoloski zvezki, Developments in Applied Statistics, Ljubljana, Slovenia, Vol. 19, pp.159-177.

90. Retting, R.A., Ulmer, R. G. and Williams, A. F. (1999). "Prevalence and characteristics of red light running crashes in United States", Accident Analysis and Prevention, Vol. 31, No. 6, pp. 687-694.

91. Retting, R.A. and Kyrychenko, S.Y. (2001). "Crash reductions associated with red light camera enforcement in Oxnard, California", Insurance Institute for Highway Safety, Arlington, Virginia, USA.

92. Retting, R.A., Ferguson, S.A. and Hakkert, A.S. (2003). "Effects of red light cameras on violations and crashes: a review of the international literature", Traffic Injury Prevention, Vol. 4, pp. 17-23.

93. Rice, R.S., Dell'Amico, F. and Rasmussen, R.E. (1976). "Automobile driver characteristics and capabilities – the man-off-the-street", Paper 760777, Society of Automobile Engineers Transactions. [Cited in Taoka, 1982].

94. Richardson, A.J. (2000). "Workshop report on item non-response", Transport Surveys: Raising the Standard, Transportation Research E-Circular E-C008, Transportation Research Board, National Research Council, Washington D.C., USA.

95. Richardson, A.J., Amp, E.S. and Meyburg, A.H. (1995). "Survey methods for transport planning", Eucalyptus Press, University of Melbourne, Victoria, Australia.

96. Rimmö, P.A. (2000). "A four factor model of self-reported aberrant driving behaviour", Department of Psychology, Uppsala University, Sweden. Retrieved 12-Jan-2003 from http://www.psyk.uu.se/hemsidor/traffic/ICTTP2000_Bern/Paper_Rim_Bern.htm

97. Robertson, S.A. (1991). "Driver behaviour at traffic signals: acceleration and braking at amber onset", Proceedings of Behavioural Research in Road Safety II, University of Manchester, UK 18-19 September, pp. 79-92.

98. Robertson, S.A. (1992). "A qualitative analysis of driver behaviour at traffic signals", Report to the Rees Jeffreys Road Fund, Transport Studies Group Note, University of College London, UK.

99. Rothe, J.P. (1993). "Beyond traffic safety", Transaction Publisher, New Brunswick, New Jersey, USA.

100. SDS (2001). "Licensed to drive", Singapore Department of Statistics, Singapore, Papers & Analyses. Retrieved 15-Oct-2003 from http://www.singstat.gov.sg/papers/snippets/licence.html

101. SDS (2002). "Vehicle Statistics 2002", Singapore Department of Statistics, Singapore. Retrieved 22-Aug-2003 from http://www.singstat.gov.sg/keystats/keystats.html

102. Sheffi, Y. and Mahamssani, H. (1981). "A model of driver behaviour at high speed signalised intersections", Transportation Science, Vol. 15, No. 1, pp. 50-61. [Cited in Chang el al., 1984].

103. Short, M.S., Woelfl, G.A. and Chang, C.J. (1982). "Effects of traffic signal installation on accidents", Accident Analysis and Prevention, Vol. 14, No. 22, pp. 135-145.

104. Sivak, M., Post, D.V., Olson, P.L. and Donohue, R.J. (1981). "Driver responses to high-mounted brake lights in actual traffic", Human Factors, Vol. 23, No. 2. [Cited in Taoka, 1982].

105. South, D. R., Harrison, W. A. and King, M. (1988). "Evaluation of the red-light camera program and the owner onus legislation", Report SR/88/1, Victoria Road Traffic Authority, Melbourne, Australia.

106. Stimpson, W.A., Zador, P.L. and Tarnoff, P.J. (1980). "The influence of the time duration of yellow signals on driver response", Institute of Transportation Engineers Journal, Vol. 50, No. 11, pp. 22-29.

107. Stokes, M.E., Davis, C.S. and Koch, G.G. (1999). "Categorical data analysis using the SAS system", SAS Institute Inc., Cary, NC., USA.

108. Storie, V.J. (1977). "Male and female car drivers: differences observed in accidents", TRRL Laboratory Report LR 761, Transport and Road Research Laboratory, Crowthorne, Berkshire, UK.

109. Summala, H. (1981). "Driver steering reaction to a light stimulus on a dark road', Ergonomics, Vol. 24, No. 2. [Cited in Taoka, 1982].

110. Taoka, G. T. (1982). "Statistical evaluation of brake reaction time", ITE Compendium of Technical Papers (Aug 22-26, 1982), Institute of Transportation Engineers, Chicago, Illinois, pp. 30-36.

111. Than, M. M. (2004). "Driver performance at signalised junction with advanced warning devices", Masters of Science Dissertation, School of Civil & Environmental Engineering, Nanyang Technological University, Singapore. [Still in progress].

112. The New Paper (2003). "Fewer red-light runners because of this...", Singapore Press Holdings Ltd, Singapore. Retrieved 4-Jan-03 from http://newpaper.asia1.com.sg/topstories/0,4133,TopStories,00.html

113. The Road Traffic Act. (2002). Revised edition of Subsidiary Legislation, Chapter 276, Singapore National Printers Ltd (Government Printers).

114. Traffic Police (2001). "Road traffic accidents", Statistical Report Singapore 2001.

115. Traffic Police (2002a), "Traffic Police news release on road accident situation", Traffic Accident Report, Traffic Police Department, Singapore. Retrieved 13-Dec-2002 from http://www.spinet.gov.sg/stativ/tp_report/tp_stats2001/index.htm

116. Traffic Police, (2002b). "Advanced theory of driving", The Official Handbook to prepare students for the Final Driving Theory Test, 6th edition, Pacific Communications Pte Ltd, Singapore.

117. Traffic Police, (2003). "Amendment to age for medical examination of elderly drivers", Traffic Police, Singapore. Retrieved 12-Apr-2003 from http://www.spinet.gov.sg/faq/tpamendmedi/index.htm

118. Van der Horst, R. (1986). "Driver decision making at traffic signals", Transportation Research Record 1172, Transportation Research Board, National Research Council, Washington D.C., pp. 93-97.

119. Ward, R.L. and Lancaster, R.J. (2001). "International review of the individual factors contributing to driving behaviour", HSE Research Report 016, HSE Books, Sudbury.

120. Warshawsky-Livne, L. and Shinar, D. (2002). "Effects of uncertainty, transmission type, driver age and gender on brake reaction and movement time", Journal of Safety Research, Vol. 33, No. 1, pp. 117-128.

121. Webster, F.V. and Ellson, P.B. (1965). "Traffic signals for high speed roads", Road Research Laboratory Technical Paper 74, Crowthorne, UK. [Cited in Menzies, A. and Nicholson, A. (2003). "Analysing the amber dilemma problem using risk analysis techniques", IPENZ Transportation Group, Institution of Professional Engineers New Zealand. Retrieved 1-Dec-2004 from http://www.ipenz.org.nz/ipenztg/ipenztg_cd/cd/2003_pdf/09_Menzies_Nicholson.pdf].

122. West, R. and French, D. (1993). "Direct observation of drivers, self-reports of driver behaviour, and accident involvement", Ergonomics, Vol. 36, No. 5, pp. 557-567.

123. Wilde, G.J.S. (1988). "Risk homeostasis theory and traffic accidents: prepositions, deductions and discussion of dissension in recent reactions", Ergonomics, Vol. 31, No. 4, pp. 448-468.

124. Wilde, G.J.S. (1996). "Beyond the concept of risk homeostasis", Accident Analysis and Prevention, Vol. 18, No. 5, pp. 377-401.

125. Williams, W.L. (1977). "Driver behaviour during the yellow signal interval", Transportation Research Record 644, Transportation Research Board, National Research Council, Washington D.C., pp. 75-78. [Cited in Bissell and Warren, 1991 and in Wortman and Matthias, 1983].

126. Wong, Y.D., Hau, L.P. and Fan, H.S.L. (2000). "A study of Singapore road traffic accident characteristics", Research Report NTU/CTS/00-05, Centre for Transportation Study, Nanyang Technological University, Singapore. [Unpublished].

127. Wong, Y.D. and Goh, P.K. (2000). "Driver perception-response time for braking action during signal change interval", Road & Transport Research Journal, ARRB Transport Research Ltd., Vol. 9, No. 3, pp. 17-26.

128. Wortman, R.H. and Matthias, J.S. (1983). "Evaluation of driver behaviour at signalised intersections", Transportation Research Record 904, Transportation Research Board, National Research Council, Washington, D.C., pp. 10-21.

129. Wright, G.R. and Shephard, R.J. (1978). "Brake reaction time: effects of age, sex, and carbon monoxide", Archives of Environmental Health, Vol. 33, pp. 141-150. [Cited in Green, 2000].

130. Yap, Z. L. (2004). "Driver performance in responding to termination of green signal indication", Masters of Science Dissertation, School of Civil & Environmental Engineering, Nanyang Technological University, Singapore. [Still in progress].

131. Zegeer, C.V. (1977). "Effectiveness of green-extension system at high-speed intersections", Research Report No. 472, Bureau of Highways, Department of Transportation, Kentucky, USA.

APPENDIX A

Signal timing design in Singapore

(provided by Lee Cheok Fai, LTA, as on 19/12/2002)

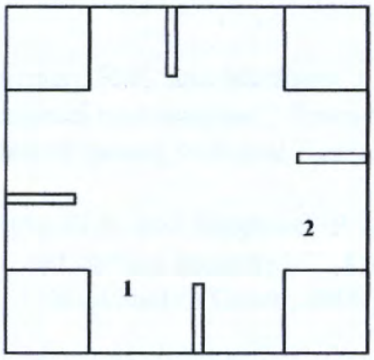


Figure A1 Layout of a X-Junction

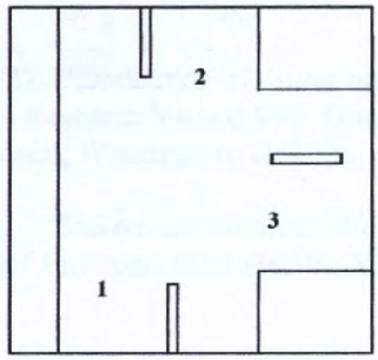
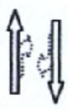
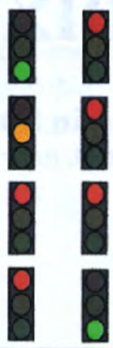
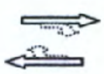
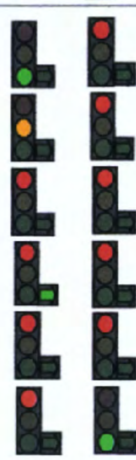
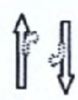
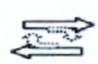


Figure A2 Layout of a T-Junction

Table A1 Phases and signal timing (X-Junction)

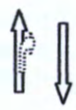
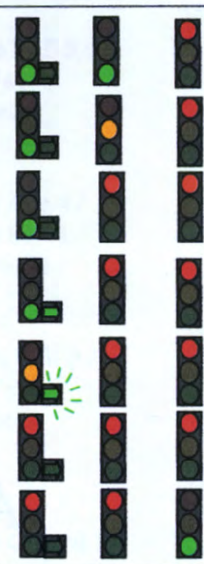
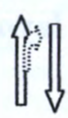
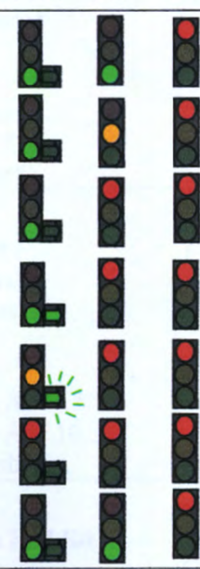
Phase	Diagram	Signal timing	1	2	Diagram	Signal timing	1	2
A								
		3 sec Amber 4 sec All Red						
B								
A								
		3 sec Amber 0.6 – 1 sec All Red				3 sec Amber 0.6 - 1 sec All Red 3 sec Flashing green arrow 2 sec All Red		
B		3 sec Flashing green arrow 2 sec All Red			SKIPPED			
C								
A								
		3 sec Amber 2 sec All Red						
B								
		3 sec Amber 2 sec All Red						
C								


Filtering allowed if there are gaps in opposing through flow traffic


Right Turn Green Arrow lights up, opposing through flow traffic are stopped


Strictly no filtering allowed unless green arrow lights up. Right turning vehicles are to wait behind stop line

Table A2 Phases and signal timing (T-Junction)

Phase	Diagram	Signal timing	1	2	3
A					
		3 sec Amber 0.6 – 1 sec All Red			
B					
		3 sec Amber + Flashing green arrow 2 sec All Red			
C					
A					
B	SKIPPED	3 sec Amber 3 sec Flashing Green Arrow 2 sec All Red			
C					
A					
		3 sec Amber 0.6 – 1 sec All Red			
B					
		3 sec Amber 4 – 6 sec Red			
C	SKIPPED				