ROAD SAFETY IMPLICATIONS OF BUS ONLY LANES AND BUS DRIVERS JUNCTION APPROACHING BEHAVIOUR

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CERTIFICATE OF ORGINALITY

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Tse Lai Yin Vincent (Name of student)

ABSTRACT

In Hong Kong, franchised buses, which share over one-third of daily journeys, play an important role in the public transport system. Whether they are being safely operated on roads is crucial to the government and public, but little attention has been paid by local researchers. This study therefore aims to look into two specific issues, which are expected to be crucial to the operation safety of buses.

First, safety impact of the bus-only lane (BOL) system was studied. The BOLs in Hong Kong are mostly adopted in heavily trafficked corridors, similar to other major cities such as London and Seoul. This measure is aimed to improve bus service reliability by rationalizing road space usage, and hence to further increase bus modal share. Its safety issue has however generally been neglected. The conventional Before-After observational study technique and an alternative method were adopted to conduct an evaluation on this issue. Of the seven studied roads with BOLs, decreases of public bus accidents, both the fatal and serious (FS) and fatal, serious and slight (FSS) were reported; while increases of other vehicle FS accident were found. The results appear to suggest that public buses have been benefited from the BOL operation, but non-bus traffic had not or even had been harmed by that.

Second, the driving behavior of bus drivers at signalized junction where most accidents occurred was studied. Through the experiences on red-light violation and Dilemma Zone (DZ) problems, the investigation of this study looked into driver approaching maneuver and decision-making

behavior. Hypothesis tests and binary choice models were adopted to assess the performances of bus drivers at the studied junction. As was commonly expected, bus drivers reported to have better performances in response to facing decision dilemma at the start of amber. The dilemma area where the drivers confront Stop/Go decision was relatively small.

Apart from the simulation model, the hypothesis test results reveal that bus drivers did adjust their approaching speeds at the times near the end of green signal. Such an action helped their responses to dilemma situation and attributed to their better performances. The results infer that the drivers could have higher consistencies in making Stop/Go decision at amber with the provision of signal information. Junction safety could thus be enhanced.

The significances of this research study are: a) it is the first time that the impacts of BOL system on road safety were identified; b) it is the first time that the driving behavior of bus drivers at signalized junction was identified, both in the periods of amber and prior to the start of amber. These findings will contribute to the safety design of BOLs and the effective trainings of bus drivers.

PUBLICATIONS ARISING FROM THE THESIS

Journal paper

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Tse, L.Y., Sumalee, A., Hung, W.T., 2012. Anticipation of amber onset and Dilemma Zone at signal control junction. Transportation Research Part F. (*under review)*

Conference paper

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CHAPTER 1

INTRODUCTION

1.1 Background

If someone says road transport is an essential element to catalyze urbanization of a city, probably no one would dispute. However, the widespread developments of road traffic networks bring an undesirable by-product, i.e. traffic accidents to our societies. According to the World Health Organization, almost 50 million people suffer from non-fatal injuries and approximately 1.2 million are killed on the world's roads every year (WHO, 2009). The injuries cost us 518 million US dollars per year, and thus critical concerns on the operation safety of vehicles have been expressed from the public and governments. There is a need to review and improve the safety design standard of roadways.

In Hong Kong, the annual road safety statistics shows that accidents involving private cars, goods vehicles and motorcycles account for a substantial amount of records every year. The record of private cars in particular were doubled than that of franchised buses in 2010 (HKTD, 2010) as shown in Figure 1-1. Nevertheless, while the number of crashes per 1,000 registered vehicles is derived, the franchised buses appear to be more prone to accidents in among the vehicle groups.

However, one might argue that buses being more prone to accidents is simply due to their high mileages. The missing information of exposure records might lead the interpretation to be biased. Whilst, subject to the availability of exposure record, taking number of accidents per registered vehicles is a direct way to rationalize the comparison. This figure, in fact, aims to raise people awareness on road safety problem of buses in which, by numbers of traffic accidents have often been taken as the only rule to judge.

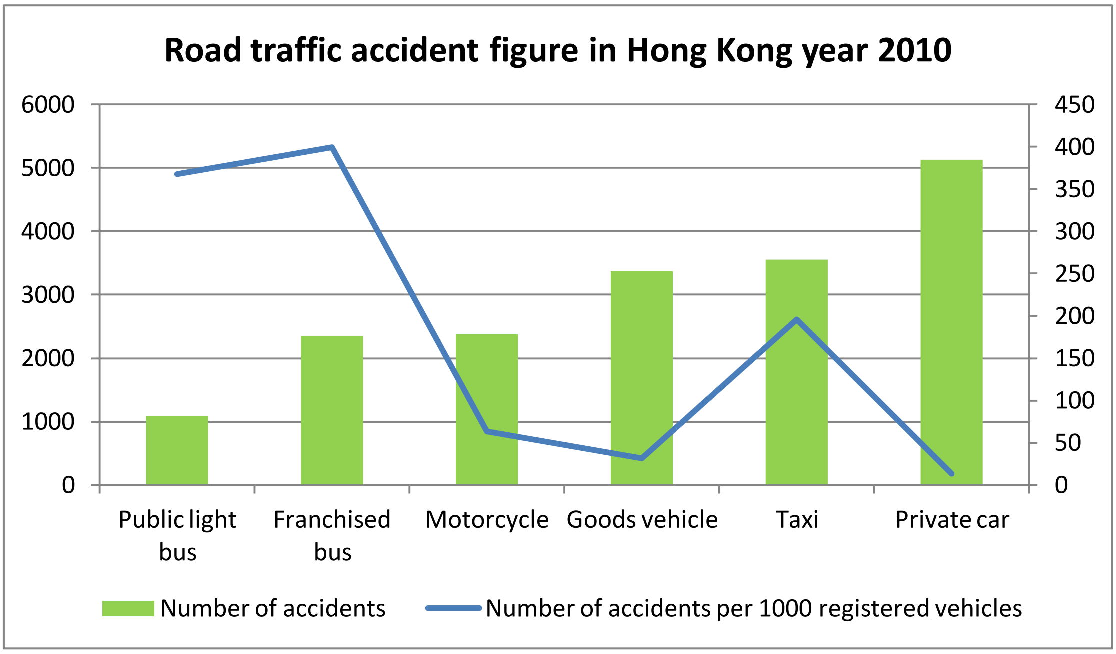


Figure 1-1 Road traffic accident figure in Hong Kong year 2010

Further to the justification on traffic accident records, consideration of initiating safety analyses for a particular type of vehicle is often linked with its significance in the transport system. In the United States (US), for instance, more effort has been exerted on private cars, as they are the major commuting mode and the provision of public transport services in such an area-wide city is not cost-effective.

How about Hong Kong? The statistics shown in Figure 1-2 reveals that franchised buses share over one third of daily journeys, in which the travel demand is similar to that of the rail system. Such the high usage would probably due to the crowded city environment that is not suitable for citizens to own private vehicles. More importantly, the public transport system has been well coordinated to provide convenient, fast and reliable ways for citizens to travel, they thus do not need to own a car.

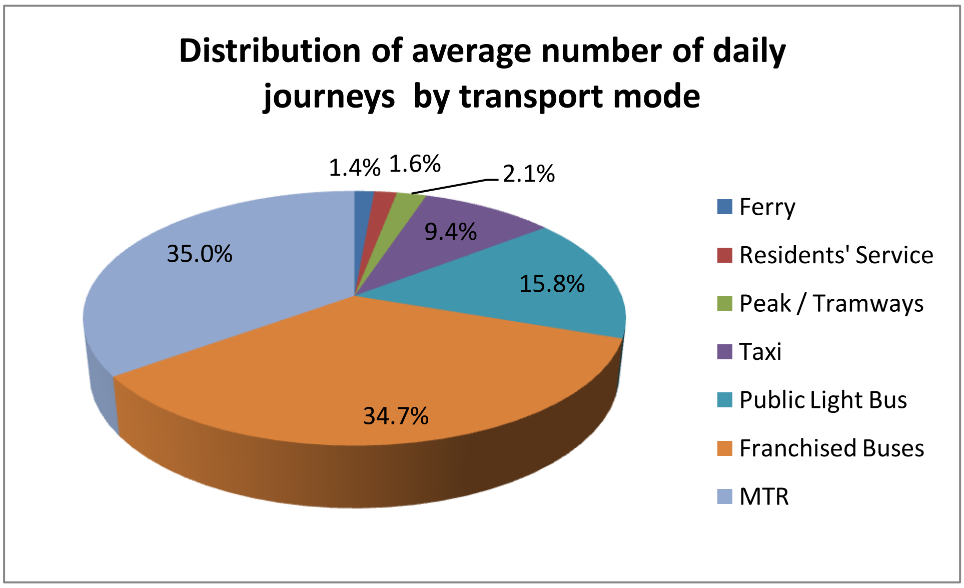


Figure 1-2 Distribution of average number of daily journeys by transport mode

1.2 Need for this study

Because of the important role in carrying passengers in the daily operations of buses, there is a high expectation on the safety operation of buses from passengers and the public. However, this issue has not been well researched.

Notwithstanding, concerns on the operation safety of franchised buses have sometimes been expressed, particularly when seriously injured or fatal accident is occurred. In years 2003 and 2009, for instance, two fatal bus accidents on an urban trunk road and a roundabout were reported. The crash details reported by local newspapers are quoted as follows:

At least 21 die as bus plummets from Ting Kau Bridge

At least 21 people were killed and 20 injured when a bus skidded off Tuen Mun Road near Ting Kau Bridge around 6.35am, the Government confirmed on Thursday afternoon.

The double-decker 265M KMB bus was fully loaded when it plunged some 50 meters from the bridge and narrowly missed a village house.

The front of the bus was ripped open; many of the injured were unconscious and blood-stained when being dragged from the wreckage, local TV reported.

…

Three of the injured are in critical condition, fourteen are in serious condition and three are stable, local radio reported.

…

(Source SCMP, 10 July 2003)

Bus driver arrested over fatal crash

Last night, six of the injured, including an eight-year-old boy, were in critical condition in hospital as a result of the accident in Tseung Kwan O early yesterday, while six were in serious condition and seven stable. The remainder had been discharged. Yip Kwan-wun, 17, a Form Five pupil of Camel Divine Grace Foundation Secondary School, was declared dead in United Christian Hospital.

…

Police are investigation whether the Kowloon Motor Bus vehicle on route 692 was travelling above the 50km/h speed limit at the junction of Po Shun Road when it crashed as it made a right turn into Tong Ming Street at about 12.20am. 'If the vehicle had been travelling at a safe speed, the accident would not have happened, 'Chief Inspector Ho Chak-kan of Kowloon East traffic unit said.

But Sai Kung district councilor Francis Chau Yin-ming said the junction was just 200 meters from the point where the speed limit changed from 70km/h to 50km/h. 'The sudden change in speed limit poses danger to motorists, ' he said. 'An accident could easily happen if a driver failed to slow down entering the junction.'

…

Another passenger, Mr Leung, told a radio programme the bus was traveling 'unreasonably fast' and was jolting before it toppled.

…

(Source SCMP, 10 November 2009)

In these two bus-related accidents, though some may argue as rare events, two commonalities were found. First, accidents involving buses often result in a large amount of injuries or fatalities and hence are comparatively severe than the others. This problem is seemingly related to the special feature of buses, as they carry more passengers than the rest of vehicles owing to the public service nature. Second, in addition to roadway designs on safety, the post-event comments from police officers, bus operators and road safety engineers did suggest that having proper driving behavior and attitudes on roads are the key factors to prevent crashes.

To this end, there is a need for conducting studies to ascertain the safety operation of buses.

1.3 Objectives

In this research, the ultimate objective is to improve the safety operation of the franchised buses. To achieve, the focus of this study is set onto the safety performances of buses on bus-only lane and at signalized junction; four specific objectives are thus set as follows:

(i) To identify safety implications on buses and non-bus traffic brought by the bus-only lane system that has been in operation in Hong Kong for over 10 years.

(ii) To evaluate the behaviour of bus drivers at signalized junction, in particular their approaching manoeuvre at the times near the end of green signal and Stop/Go decision-making behaviour at amber.

(iii) To discuss measures for improving the dilemma response of drivers at signalized junction.

1.4 Structure of this thesis

There are totally six sections presented in this thesis. In Chapter 1, background information of road safety level in Hong Kong is described. It then links with the reason why there is a need to conduct the present study as to address the safety issue of franchised buses.

Subsequently, Chapter 2 provides a review of the prior literature concerning the safety studies of buses and non-bus traffic. It aims to point out the deficiency of analyses on bus safety and figure out in what situations, buses are likely to subject to high accident risk on roads.

To accomplish the aims of this study, a number of statistical methods that have been viewed by many as the practical techniques for road safety research are adopted. Methods like hypothesis tests and binary choice regression models are described in Chapter 3.

In Chapters 4 and 5, the evaluations of safety implications brought by the bus-only lane system and bus driver performances at a signalized junction are reported. Though franchised buses are the main focus of this study, efforts are paid onto non-bus traffic as to offer a complete review of the captioned safety issues.

Lastly, the findings of this research study, limitations and suggestions for future work are discussed in Chapter 8.

CHAPTER 2

REVIEW OF ROAD SAFETY STUDIES OF BUSES

2.1 Introduction

As aforementioned, franchised bus is a major transport mode serving one-third of commuters in Hong Kong every day. Whether buses have been safely operating on roads is of paramount importance to the government, passengers and the public. Section 2.2 therefore opens by a brief review of the prior road safety research, pointing out the need of conducting safety studies on buses. It also attempts to explain why bus safety has been disregarded in the past.

Section 2.3 moves on to review the rarely conducted bus safety studies in Hong Kong and elsewhere. It aims to provide an in-depth discussion on the characteristics of bus related accidents and insight into the potential safety problems of buses. Then, in Section 2.4, an attempt is made to identify the locations where buses are likely to have conflicts and thus traffic accidents, either having the crash into properties or with other road users.

Lastly, Section 2.5 reviews the current practices in the design of roadways and at signalized junctions to figure out remedial safety measures for resolving the problems that were identified in the previous section.

2.2 Deficiency of Road Safety Study on Buses

Since the first traffic accident, substantial efforts have been exerted to identify the causes of crashes and means to reduce their occurrences as well as the corresponding injuries. Factors under the three taxonomies including infrastructure, vehicle and road user have been well discussed. It was consistently reported that these factors are influential to accident occurrences (e.g. Shankar et al., 1994; Abdel-Aty and Radwan, 1999; Karlaftis and Golias, 2001; Golob and Recker, 2003; Abdel-Aty and Abdelwahab, 2004; Elvik et al., 2009). As such, numerous attempts were made to diagnose road safety problems. In some major cities like the US, heavy goods vehicles and private cars are the problematic groups constituting a large proportion of total crashes every year. Traffic accidents involving heavy goods vehicles, in particular, often result in large amount of injuries or even fatalities due to its severity of crashes. Thereby, specific investigations and countermeasures are required to resolve their problems (e.g. Joshua and Garber, 1990; Miaou, 1993 and 1994; Milton, 1998; Shankar and Mannering, 1996).

How about buses? They are also large in size and, more importantly, they carry a large amount of passengers while operating. One may then question as if accidents involving buses, similar to that of heavy goods vehicles, are likely to result in serious consequences in crashes. Even so, the bus safety issue has not been adequately addressed. The following statements would probably explain why the issue has been amiss. First, accident records of buses were incomparable to the others especially heavy goods vehicles and private cars. Second, buses are not the major transport mode in some cities and thus people tend to overlook them. Third, bus drivers are generally more experienced in driving and hence they are expected to drive safely.

However, these reasons could erroneously judge the need to have safety analysis of buses under the following contexts. First, as previously defined, accident rate is equal to number of accidents per total distance travelled. The rate of buses is thus often lower than that the others, as they have to travel long distances due to public service nature. Second, whether or not buses are the major transport mode in that city is heavily dependent on travelers' behavior and urban setting. Hong Kong relies heavily on buses the public transport system. Third, without undertaking any assessments on the performances of bus drivers, it is inconclusive to state bus drivers are now safely maneuvering on roads as are commonly expected. As such, the preliminary idea of studying bus safety was initiated.

2.3 Road Safety Studies of Buses in Hong Kong and Elsewhere

After pointing out the need, this section moves on to review the safety studies of buses in Hong Kong and elsewhere. Despite the fact that most of them were conducted in cities where traffic conditions are differing from Hong Kong, their experiences would be valuable to point out the potential safety problems of buses and to strengthen the need to review their safety performances.

(i) In Hong Kong

For years, there has been one safety study on buses in Hong Kong. Evans and Courtney (1985) examined the safety level of buses through an international comparison with the United Kingdom (UK). It was found that in the 80s, accident rate of buses in Hong Kong was almost double than that of the UK. The injury level of Hong Kong was also greater as fatal and serious accidents dominate the crash records, but the figure appears to be attributed to the high involvement of pedestrians. This is because their involvement rate in the bus related accidents in Hong Kong was also doubled.

They also analyzed accident characteristics of franchised buses with the conclusions as follows. (1) There was no clear relation between day-of-week and accident rate, even though the bus and general traffic volumes were both higher on Mondays. (2) Weather conditions did not have significant influence on accidents. In particular, high accident rates were not occurred on rainy days, contradicting the common belief that accidents are likely to occur under wet pavement conditions. (3) Hour-of-duty and accident rate were positively correlated; higher rates of serious and fatal accidents were generally reported near the end of long shifts. (4) Old bus drivers reported to have safer records than young bus drivers, attributing to driving experience and attitude of bus drivers. (5) Driving too fast with respect to general traffic was frequently quoted by the police officer as the cause of bus accidents (Evans and Courtney, 1985).

However, it should be noticed that the above study was conducted in the 80s, in which the situation may have changed 30 years after. Taking it as reference to discuss road safety issue of buses as there had been little foci on them, which is one of the limitations encountered in this study.

(ii) In Sweden

Unlike the other road safety studies, af Wahlberg examined the relationship between accident frequencies and acceleration behavior of bus drivers. A measure specifically used to quantify acceleration forces in lateral and longitudinal directions was introduced. The behavior of bus drivers had been continuously recorded.

In its pilot study, however, there only reported a weak tendency of mean operating speed and left/right maneuver to predict bus accident frequencies (af Wahlberg, 2000). Then, a replication test with additional consideration of the influence of driving environment was undertaken. In the second trial, an increased number of samples, although remained small, was reported with significant correlations (af Wahlberg, 2004b). Thus, continuous measurements had been repeatedly taken in a city environment as to address the small sample size issue. Remarkable improvement in predictive power versus accident frequency of buses was subsequently reported (af Wahlberg, 2007a).

After the proof, attempts were made to explore some special issues that could be influential to the driving behavior of bus drivers and hence accident frequencies of buses. The relationship among the acceleration behavior of bus drivers, number of passengers and accident frequencies of buses was tested. Only a weak correlation was found while number of passengers was held constant. An improved correlation was reported after taking into account larger number of passengers. Even so, more supportive cases for validating the above relation was required (af Wahlberg, 2007b).

Based on the reported association between various health problem indicators and accident frequencies by Yamamoto et al. (2000), further attempt was made onto the relationship between absence records of bus drivers and their accident frequencies. Similarly, the results did not give desirable outcomes as were initially anticipated; only a few study samples reported to have fair correlation between the two parameters. Nevertheless, it was expected that the idea could be further explored as to devise a powerful tool for bus operators to promote work place safety. This tool could finally benefit the safety performances of the large fleets (af Wahlberg and Dorn, 2009).

(iii) Elsewhere

In France, the direct and indirect involvements of buses in accidents account for about 1.4% and 2.2%, respectively, of the total crashes every year. Albeit the figure seems to be incomparable to the others, the study by Brenac and Clabaux (2005) aimed to identify the common features of accidents under the latter category and suggested mitigate measures for improving the situations. According to the accident reports prepared by the police, buses were commonly cited as sight obstacles of other road users, being the leading cause of accidents at bus stops and intersections. Despite the indirect role of buses in these crashes, the bus operation was brought up to public the attention to enhance road safety levels at urban areas, particularly along bus corridors.

In the UK and other Organization for Economic Co-operation and Development (OECD) countries, the overall accident risk of buses was lower than that of private vehicles. While at urban areas, the situation was very different. The risk of being seriously injured or killed resulting from bus related crashes was significantly higher. Buses have their special operational characteristics, for instance, frequent stop-and-go maneuvers due to passenger loading and unloading activities, which increase their accident occurrences especially in heavily trafficked situations (Albertsson and Falkmer, 2005; Noland and Quddus, 2005).

Up to this point, the previous research conducted in Hong Kong, Sweden, France, the UK and other OECD countries addressed diversified issues that could be influential to bus operation safety. The findings are somewhat pointing towards to a common issue that buses may not be safe at some locations as was commonly anticipated. The safety problem is seemingly related to their unique operational characteristics, improper speed choices with respect to general traffic and congested environment at urban areas (Jovanis et al., 1991).

2.4 Accident Prone Locations of Buses

By those experiences, there are concerns on the safety operation of buses. These concerns are somewhat consistent to the prior road safety research that accident risk is comparatively higher at the locations, where high speed and/or conflicts are commonplace (e.g. Perkins and

Harris, 1967; Joksch, 1974). It also explains why there were substantial efforts exerted to look into accidents at highways and intersections (e.g. Tiwari et al., 1997; Aljanahi et al., 1999; Chin and Quddus, 2003; Liu, 2007; Wong et al., 2007).

As for buses, however, there could be an addition concern in the vicinity of bus stops. This is because bus drivers are required to weave between traffic lanes for passenger loading and unloading activities. These bus movements would thus lead to high likelihood of interacting with non-bus traffic, and so conflict or collision while approaching to or departing from the stops (af Wahlberg, 2002 and 2004a; Chimba et al., 2010). Thus, as to give specific discussions on these aspects, the following sections discuss bus accidents at heavily trafficked roadways, junctions and bus stops.

2.4.1 Heavily trafficked roadways

Traditionally, heavily trafficked roadways were noted as one of the hazardous locations owing to the high accident rates and severe crash consequences. To date, there has been an extra concern of the slow operating vehicles increases crash occurrences (Hiselius, 2004; Lord et al., 2005; Kockelman and Ma, 2007; Zheng et al., 2010). Hiselius (2004) reckoned that heterogeneous traffic-flow condition might also induce implicates crash occurrences. It attempted to specify the presence of fast running private cars and slow operating trucks in the accident prediction model. It then tested the model on 83 rural road sections in Sweden with the conclusions that the expected accident rates would be held constant or increased if the proportion of private cars was specified. In contrast, the accident rate was found to decrease if trucks were taken into account in the model. The change was even more significant while the number of trucks increased. The positive safety effect was attributed to an overall reduction of traffic-flow speed on highways derived from an increasing constitution of slow running vehicle especially trucks.

After that, an interesting hypothesis that whether trucks and passenger cars operated on exclusive roadways would improve roadway safety was tested by Lord et al. (2005). They took the valuable opportunity in New Jersey, the US, where there had been a special traffic arrangement on freeways. It was that the outer traffic lane was designated to the mixed traffic including trucks, buses and passenger cars; while the inner traffic lane set to serve passenger cars only. The exploratory analysis revealed that trucks were over-involved in crashes, especially for those happened on the outer traffic lane. The results suggested that trucks were the problematic group on freeways in regard to safety and that might be resolved if exclusive roadways or traffic lanes were provided. Nevertheless, further investigations on the causes of truck-related accidents on outer traffic lane were required to figure out whether the over-involvement was derived from the high heterogeneity of traffic but not any other issues like driving attitudes of truck drivers that had been few discussed.

2.4.2 Junctions

Analogous to highways, junctions have been commonly cited as the accident-prone locations including the signalized and non-signalized junctions (Perkins and Harris, 1967; Wong et al., 2007 and 2008; Archer and Young, 2009). The review on signalized junctions, in particular, raises critical discussions as the design is expected to have systematic control over intersecting traffic and hence is conductive to prevent road users from crashes. However, accident records at signalized junctions in Hong Kong, for instance, account for approximately 15% of total crashes every year (HKTD).

The government therefore initiated a survey study for public light bus drivers, aiming to explore new enforcement strategy as to enhance the deterring effect on the red-light running problem. The focus was paid onto one particular group of drivers, as they are over-involved in seriously injured and fatal accidents at signalized junctions. Interestingly, the results reveal that only the interviewees with intermediate income levels were not sensitive to the new proposed penalty. Furthermore, the public light bus drivers who were young, single or less educated, were found more likely to be involved in similar accidents (Wong et al., 2008).

In spite of the dissimilar focus, the reported perception difference of public light bus drivers in response to the penalty raises a similar concern to the drivers of buses. It is that even though the bus drivers are the group with more driving experiences, there could be variations in driving attitude. The poorly performed or aggressively behaved drivers could be even more risky than those who are inexperienced in driving. Particularly at junctions, drivers are required to obey traffic regulations and pay full attention to roadway conditions as to avoid conflicts or even crashes.

2.4.3 Bus stops

At bus stops, the specific safety concern on buses is that they are likely to have crashes with non-bus traffic while approaching to or departing from the stops. The accident prediction model by Chimba et al. (2010) revealed that the position of traffic lane buses travelled influences their accident occurrences. They also reported an increased accident risk on roadways with more numbers of traffic lane and/or higher traffic volume. These detrimental effects on safety operation of buses were attributed to the increasing conflict prone spots. In particular, while a bus is on outer traffic lane requiring to weave as to approach the nearside bus stops for passenger boarding and alighting. Nevertheless, no differential effect in crash severity was found on different lanes.

af Wahlberg (2002; 2004) discussed a similar issue in Sweden and reported relatively high bus-to-bus accident rates at bus stops. Unlike the above practices by Chimba et al. (2010), the discussions were largely based on the improper driving practice of the bus drivers as they often stop in a few centimeters behind the leading bus at the stops. More importantly, the stops had often been too crowded with illegally parked vehicles and that limited the road space might further increase risk of collision among vehicles. In this regard, several suggestions were given. First, re-arranging bus routes so that buses would be out of the way of the general traffic. Second, bus drivers should adopt greater following headway and stopping distances to the vehicle ahead. Third, a stronger commitment of the authority is required as to prohibit illegal parking.

As discussed so far, the investigations on traffic-flow heterogeneity on roadways and conflict endemic situation at signalized junctions and bus stops underline the need to protect buses from frequent interactions with general traffic. The experiences of Hiselius (2004), Lord et al. (2005), and Chimba (2010) give an insight into enhancing bus safety. More real-life examples are discussed in the following section as for further explorations.

2.5 Feasible Road Safety Measures for Buses

(i) Guidance scheme at toll plazas

In Hong Kong, there had been a safety concern on the conflicting situation at tunnel toll plazas owing to the parallel operation of auto-toll and manual-toll systems. The government therefore attempted to launch a guidance scheme, aiming to assist drivers in recognizing auto-toll and manual-toll lanes while approaching. The scheme included reflective road markings and signage at 200 m before the toll points as to aid drivers to get in the lane early. The follow-up observational study revealed that average lane-changing rate, conflict count and crash count were decreased by 23%, 44% and 38%, respectively (Wong et al., 2006).

(ii) High Occupancy Vehicle (HOV) lane

In San Francisco, the US, the first High Occupancy Vehicle (HOV) lane has been launched since 1975 (Bendtsen, 1961). It has achieved a great success in relieving traffic congestion problem on trafficked roadways by designating exclusive lane(s) for vehicles with a driver and two or more passengers. However, almost all the attention was paid onto system efficiency, few attention was paid onto safety except Golob et al. (1990). They initiated the assessment on the safety impact of the HOV lanes on expressways. That a physical barrier between HOV and non-HOV lanes did not have significant impact on road safety was reported.

In Southern California, however, contradictory results were reported in a survey study on driver perceptions of the rationalization policy on expressways. The drivers responded to the interviewers that they felt uncomfortable regarding safety during the operation of HOV lanes. The discomfort was derived from the large difference in vehicle operating speed and the potential tendency to weave in between two types of lane. They also pointed out that owing to the change of traffic conditions and/or driving attitude, the occurrence of accidents could be influenced thereafter (Billheimer, 1990).

(iii) Intelligent traffic signal

At signalized junctions, besides using red-light cameras to combat violators, another attempt was made to improve signal setting to relieve the dilemma response problem of drivers at amber especially derived from the improperly timed signal (Gazis et al., 1960). Koll et al. (2004), Chiou and Chang (2005), and Lum and Halim (2006), for instance, tried to examine the safety effects of using signal countdown devices or flashing green light at junctions. Throughout the studies, drivers reported to have changes in their approaching behavior while the signal time information was given. They drove faster at the times near the end of green signal, but interestingly stopped more at amber.

Meanwhile, Archer and Young (2009) evaluated the safety effects of three alternative signal treatments at a signal control junction. They aimed to select the most efficient way for improving the undesirable accident records of heavy vehicles at junction. According to the simulation model, the extension of amber signal appears to be the best option. There was, however, a concern whether the drivers had behavioral adaptation afterwards and the improvement could last for a short period of time only. Subsequently, two other alternatives, i.e. green extension for drivers being caught into dilemma zone and all-red extension for potential red-light runners were proposed. The later strategy, in particular, is likely to offer sustainable safety improvements as sought.

In the guidance scheme and the HOV lane, the provisions of advance information for drivers and exclusive roadways for designated vehicles appear to be feasible for protecting buses from accidents. In Hong Kong, the bus-only lanes, which also use to reserve exclusive carriageways for buses, have been implemented in various corridors for over 10 years. Its safety issue, however, has yet been adequately considered. Chapter 4 of this thesis therefore aims to bridge this gap by assessing the changes of crash occurrences after the system implementation. A null hypothesis that the system brings no safety impact on buses and non-bus traffic is tested.

In the traffic signal improvement trials, the provision of signal time information and real-time signal adjustments may help to reduce drivers' responses dilemma. The experience of Archer and Young (2009), in particular, raises a questionable issue whether bus drivers require special care for the same safety problem at junction. Chapter 5 of this thesis therefore aims to evaluate the performance of bus drivers at a signalized junction. Their approaching maneuvers at the impending end of green traffic signal and decision-making behavior at amber are analyzed. The results are then compared with the rest of drivers observed in the site so as to evaluate how well they performed during the study period.

2.6 Summary

In major cities like Hong Kong, London and Seoul, public buses play an important role in carrying passengers from places to places in their daily operations. Whether they are safe on roads is imperative to the government, operators and the public; but the issue has been amiss.

From the above discussions, there seems to be a number of safety concerns of buses while operating in urban areas, particularly under the high-dense road network and heavily trafficked condition. In the next chapter, the focus is moved onto the analytical methods that use to evaluate safety implications of the bus-only lanes as well as the behavior of bus drivers at signalized junction.

CHAPTER 3

ANALYTICAL METHODS FOR SAFETY IMPLICATION AND DRIVER BEHAVIORAL EVALUATIONS

3.1 Introduction

In this chapter, three commonly adopted approaches for evaluating safety implications brought by treatments and driver performances on roadways are illustrated. Two non-experimental observational methods used for examining safety effects of the bus-only lane system on buses and other road users are described in Section 3.2. Then, the statistical inference techniques and predictive models for evaluating bus drivers' approaching maneuvers and decision-making behavior at amber are described in Section 3.3.

3.2 Safety Implication Evaluation Techniques

In road safety research, non-experimental observational before-after analyses are the common practices for evaluating the changes of safety levels before and after the implementation of treatments. Usually, these studies are conducted by means of Empirical Bayes (EB) method (e.g. Hauer, 1997), which has been viewed by many as the best analytical technique in the literature (e.g. Chen et al., 2002; Wong et al., 2006). The mechanism of this method based on the verified comparison group is described. Furthermore, an alternative approach, which uses to address the reliability issue resulting from the incomparable traffic volumes in between the studied site and that of the predictive model is based, is illustrated.

3.2.1 The Comparison Group (CG) approach

(i) Odds ratio test

In the old days, evaluations on the effects of road safety treatments were merely based on the comparison of accident frequencies and/or accident rates. Factors like driving behavior, advancement of vehicular technologies and accident trends, which were hardly to quantify, were not considered in the analyses. Researchers began to question the validity of the evaluations, as the reported changes of safety levels might be partly attributed to these factors, which could otherwise affect the occurrence of traffic accidents.

An odds ratio test was thus introduced, aiming to verify the suitability of the site taken as control subject (termed as "comparison" site hereinafter) for predicting the number of accidents the studied site (termed as "case study" site hereinafter) that would have been expected. The verification usually considers the time 5 to 6 years before the treatments, known as the "before" period. Under this test, the evaluation of changes of safety level before and after the implementation is considered as more robust than direct comparisons. Table 3-1 shows the notations adopted in the test.

Table 3-1 Notations used in the Odds ratio test

"before" period	"case study" site	"comparison" site
1	K_1, κ_1	M_1, μ_1
2	L_2, λ_2	N_2, ν_2
⋮		
j-1	K_{j-1}, κ_{j-1}	M_{j-1}, μ_{j-1}
j	L_j, λ_j	N_j, ν_j
⋮		
m-1	K_{m-1}, κ_{m-1}	M_{m-1}, μ_{m-1}
m	L_m, λ_m	N_m, ν_m

where $\kappa_j, \lambda_j, \mu_j, \nu_j$ are the expected values corresponding to the observed accident counts K_j, L_j, M_j, N_j for each pair of successive years (*j-1, j*) in the "before" period.

The Odds Ratio, ω_j, for each pair of successive years (*j-1, j*) in the "before" period is required to be approximately equal to 1, defined as,

$$\omega_j = {}^{r_{c,j}}\!/_{r_{t,j}} = {}^{\nu_j \kappa_{j-1}}\!/_{\lambda_j \mu_{j-1}} \qquad \text{Eq. 3-1}$$

where

$r_{c,j} = \nu_j/\mu_{j-1}$ is the ratio of the expected number of accidents of the "comparison" site for each pair of successive years (*j-1, j*);

$r_{t,j} = \lambda_j/\kappa_{j-1}$ is the ratio of the expected number of accidents of the "case study" site for each pair of successive years (*j-1, j*); and subscript *c* denotes the "comparison" site without safety treatment and *t* denotes the "case study" site with safety treatment in the "after" period.

However, the Odds Ratio, ω_j, obtained by Eq. 3-1 from the sample of four accident counts and an approximation for the Odds Ratio sample variance would be biased estimates. An unbiased estimator for the Odds Ratio sample and the Odds Ratio sample variance is thus used to remove the random effect of accident count and estimation bias (Hauer, 1997). The Odds Ratio sample and the Odds Ratio sample variance for each pair of successive years (*j-1, j*) become,

$$\hat{o}_j = \frac{K_{j-1}N_j}{L_j M_{j-1}}\left(1 + \frac{1}{L_j} + \frac{1}{M_{j-1}}\right)^{-1} \quad \text{Eq. 3-2}$$

and

$$\hat{s}_{o_j}^2 = \hat{o}_j^2\left(\frac{1}{N_j} + \frac{1}{K_{j-1}} + \frac{1}{L_j} + \frac{1}{M_{j-1}}\right) \quad \text{Eq. 3-3}$$

There is also a possibility to obtain a negative lower confidence interval of the Odds Ratio from Eq. 3-1 and Eq. 3-2, violating the non-negative nature of the parameter. Therefore, to avoid the presence of negativity, the modified Allsop approach (Wong et al., 2005) is used. An unbiased estimator of the natural logarithm transformed Odds Ratio sample and its sample variance for each pair of successive years (*j-1, j*) are then given by,

$$\hat{Y}_j = lnN_j\left(1-\frac{1}{2N_j lnN_j}\right)^{-1} + lnK_{j-1}\left(1-\frac{1}{2K_{j-1}lnK_{j-1}}\right)^{-1}$$

$$-lnL_j\left(1-\frac{1}{2L_j lnL_j}\right)^{-1} - lnM_{j-1}\left(1-\frac{1}{2M_{j-1}lnM_{j-1}}\right)^{-1} \qquad \text{Eq. 3-4}$$

and

$$\hat{s}^2_{Y\,j} = \hat{Y}_j^2\left(\frac{1}{N_j}+\frac{1}{K_{j-1}}+\frac{1}{L_j}+\frac{1}{M_{j-1}}\right) \qquad \text{Eq. 3-5}$$

For a pair of "case study" and "comparison" sites with *(m-1)* years accident records in the "before" period, the sample mean of the natural logarithm transformed Odds Ratio and the estimated sampling variance of this mean are given by (Wong et al, 2005; Allsop et al., 2011),

$$\bar{Y} = \frac{1}{m-1}\sum_{j=1}^{m-1}\hat{Y}_j \qquad \text{Eq. 3-6}$$

and

$$s_{\bar{Y}}{}^2 = \frac{2}{(m-1)^2}\sum_{j=2}^{m-1}cov\left(\hat{Y}_{j-1},\hat{Y}_j\right) + \; Max\left\{\frac{1}{(m-1)^2}\sum_{j=1}^{m-1}\left(\frac{1}{N_j}+\frac{1}{K_{j-1}}+\right.\right.$$

$$\left.\left.\frac{1}{L_j}+\frac{1}{M_{j-1}}\right), \frac{1}{(m-1)(m-2)}\left[\sum_{j=1}^{m-1}\hat{Y}_j{}^2-(m-1)\bar{Y}^2\right]\right\} \qquad \text{Eq. 3-7}$$

The selected "comparison" site is not suitable for predicting accident counts of the "case study" site by this method, if the sample mean of the logarithm transformed Odds Ratio in the times when the treatment had not been applied in the "before" period is too far from zero, assuming that the sample mean is normally distributed. That is, the site shall be rejected for further analysis, if either the 95% lower or upper bound confidence interval of the sample mean of the logarithm transformed Odds Ratio does not include zero as follows, $\bar{Y} < -1.96s_{\bar{Y}}$ or $\bar{Y} > 1.96s_{\bar{Y}}$.

(ii) Accident count estimation

Using the verified “comparison” site, the number of accidents the “case study” site that would have been expected in the “after” period, if the treatment had not been applied could be estimated. Table 3-2 shows the notations used in the estimation.

Table 3-2 Notations used for the accident count estimation

	“case study” site	“comparison” site
Before	K, κ	M, μ
After	L, λ	N, ν

where $\kappa, \lambda, \mu, \nu$ are the expected values corresponding to the observed accident counts K, L, M, N of the “case study” and “comparison” sites in the “before” and “after” periods.

The expected number of accidents the “case study” site would have in the “after” period if the treatment has not been applied is estimated by,

$$\hat{\pi} = r_t K \qquad \text{Eq. 3-8}$$

where

$r_t = \lambda/\kappa$ is the ratio of the expected number of accidents of the “case study” site in the “after” and “before” periods; and subscript t denotes the “case study” site with safety treatment in the “after” period.

However, the ratio r_t cannot be found directly. Referring to the result of the Odds ratio test, the selected “comparison” site is verified to have homogeneous accident trend with the "case study" site, i.e. the Odds Ratio is approximately equal to one. The ratio r_t can thus be equated equal to r_c, and so r_t can be estimated by,

$$\hat{r}_t = \hat{r}_c = \frac{N}{M}\left(1 + \frac{1}{M} + s_{\bar{Y}}{}^2\right)^{-1} \qquad \text{Eq. 3-9}$$

where

$r_c = \nu/\mu$ is the ratio of the expected number of accidents of the "comparison" site in the "after" and "before" periods; $s_{\bar{Y}}$ is the variance of odds ratio sample; and subscript c denotes the "comparison" site without safety treatment in the "after" period.

In the sampling estimate of the variance of the Odds Ratio, Hauer (2004) noted that the value obtained from a sequence of observed values is generally larger than the actual variance of the Odds Ratio. The difference was suggested arising from the Poisson variation in accident counts. The estimate of the actual variance of the Odds Ratio, $s_w{}^2$, is thus obtained by the subtraction of two components. First, the average of estimated variances of the observed Odds Ratio samples for each pair of successive years *(j-1, j)*. Second, the estimated sampling variance of the observed Odds Ratios as follows:

$$s_w{}^2 = \frac{1}{(m-2)}\left[\sum_{j=1}^{m-1} \hat{Y}_j{}^2 - (m-1)\bar{Y}^2\right] - \frac{1}{m-1}\sum_{j=1}^{m-1} \hat{s}_{Y_j}^2 \qquad \text{Eq. 3-10}$$

In some instances, the estimate of the actual variance of the Odds Ratio, $s_w{}^2$ obtained from Eq. 3-10 may possibly be negative. If so, the parameter is replaced by zero throughout the calculation.

After the modification of the estimated variance of the Odds Ratio, an unbiased estimator of π and variance of π thus are thus determined by,

$$\hat{\pi} = \hat{r}_t K = \frac{NK}{M}\left(1 + \frac{1}{M} + {s_w}^2\right)^{-1} \qquad \text{Eq. 3-11}$$

and

$$\hat{s}_{\pi}^2 = \hat{\pi}^2\left(\frac{1}{N} + \frac{1}{K} + \frac{1}{M} + {s_w}^2\right) \qquad \text{Eq. 3-12}$$

(iii) Safety impact estimation

In consequence, safety implication of the “case study” site *i* subject to the treatment in the “after” period termed “accident changing factor” is given by,

$$\theta_i = \frac{L_i}{\pi_i} \qquad \text{Eq. 3-13}$$

The estimates of the “accident changing factor” and the variance of this factor of the “case study” site *i* are given by,

$$\hat{\theta}_i = \frac{L_i}{\hat{\pi}_i}\left(1 + \frac{\hat{s}_{\pi i}^2}{\hat{\pi}_i^2}\right)^{-1} \qquad \text{Eq. 3-14}$$

and

$$\hat{s}_{\theta i}^{\,2} = \hat{\theta}_i^2\left(\frac{1}{L_i} + \frac{\hat{s}_{\pi i}^2}{\hat{\pi}_i^2}\right) \qquad \text{Eq. 3-15}$$

assuming that the estimated factor follows the Normal distribution. Thus, the null hypothesis is said to be rejected if the value one lies either below the 5th percentile or above the 95th percentile estimate of the factor, i.e. $\hat{\theta}_i - 1.96\hat{s}_{\theta i} > 1$ or $\hat{\theta}_i + 1.96\hat{s}_{\theta i} < 1$.

(iv) Estimation of combined effect

In the previous analysis, when assessing the safety implications of the treatment, there could be a problem associated with the small sample size of the individual sites so that the reported statistical significance of changes would be low (Hauer, 2004). To address this problem, an aggregated analysis was conducted for an overall assessment of the safety implications derived from the treatment. The pooled “accident changing factor” and the variance of this factor of all the “case study” sites are estimated by,

$$\hat{\varphi} = \frac{\sum_{i=1}^{k} L_i}{\sum_{i=1}^{k} \hat{\pi}_i}\left(1 + \frac{\sum_{i=1}^{k} \hat{s}_{\pi_i}^2}{\left(\sum_{i=1}^{k} \hat{\pi}_i\right)^2}\right)^{-1} \qquad \text{Eq. 3-16}$$

and

$$\hat{s}_{\varphi}^2 = \hat{\varphi}^2\left(\frac{1}{\sum_{i=1}^{k} L_i} + \frac{\sum_{i=1}^{k} \hat{s}_{\pi_i}^2}{\left(\sum_{i=1}^{k} \hat{\pi}_i\right)^2}\right) \qquad \text{Eq. 3-17}$$

where the subscript denotes the ”case study” site *i*. Similar to the previous analysis, the null hypothesis is rejected if the value one lies either below the 5th percentile or above the 95th percentile estimate of the pooled factor, i.e. $\hat{\varphi} - 1.96\hat{s}_{\varphi} > 1$ or $\hat{\varphi} + 1.96\hat{s}_{\varphi} < 1$.

3.2.2 An alternative approach

(i) Accident count estimation

Despite the popularity of the CG approach, the estimation based on the EB method may be unreliable if the traffic level of the investigation site is out of the valid boundary that the prediction model is based (Jensen, 2008). In Sweden, for instance, an alternative approach was adopted to test the safety effects of blue cycle crossings at signalized intersections, because the sites are located far away from the major traffic axes.

This alternative approach, namely the second-best non-experimental observational method, adopts a general comparison group to account for accident trends and changes in traffic volumes. An adjustment is also made for the long-term accident trend from the “before-before” to “before” period. It aims to account for the presence of abnormally high number of accidents and provide an estimate of the correction needed to allow for the regression-to-mean problem. The number of accidents that the “case study” site would have been expected if the treatment had not been applied in the “after” period is determined by (Jensen, 2008),

$$N_{Aft,Exp,case\ study} = N_{Bef,Obs,case\ study}\ C_{Trend}\ C_{Traffic} C_{RTM} \qquad \text{Eq. 3-18}$$

where

$N_{Aft,Exp,case\ study}$	is the expected number of accidents of the “case study” site had the treatment not been applied in the “after” period;
$N_{Bef,Obs,case\ study}$	is the observed number of accidents of the “case study” site in the “before” period;
C_{Trend}	is the correction factor for the overall accident trend obtained from the “comparison” site;
$C_{Traffic}$	is the correction factor for traffic flow variations between “case study” and “comparison” sites;
C_{RTM}	is the correction factor for the regression-to-mean problem.

The individual correction factors for the overall accident trend, traffic flow variations and regression-to-mean problem are,

$$C_{Trend} = N_{Aft,Obs,comparison} / N_{Bef,Obs,comparison} \quad \text{Eq. 3-19}$$

$$C_{Traffic} = \left[\frac{(AADT_{Aft,case\ study}/AADT_{Bef,case\ study})}{(AADT_{Aft,comparison}/AADT_{Bef,comparison})}\right]^{0.5} \quad \text{Eq. 3-20}$$

$$C_{RTM} = N_{Bef,Exp,case\ study} / N_{Bef,Obs,case\ study} \quad \text{Eq. 3-21}$$

and

$$N_{Bef,Exp,case\ study} = N_{Bef-bef,Obs,case\ study}\ C_{Trend}\ C_{Traffic} \quad \text{Eq. 3-22}$$

where

$N_{Bef,Exp,case\ study}$ is the expected number of accidents of the "case study" site in the "before" period;

$N_{Bef-bef,Obs,case\ study}$ is the observed number of accidents of the concerned road in the "case study group" site in the "before-before" period;

$AADT_{Aft,case\ study}$ is the Annual Average Daily Traffic (AADT) record of the the "case study" site in the "after" period.

These correction factors are expected to enhance the estimate of the expected number of accidents. However, it should be noticed that the correction factor for the regression-to-mean problem is applied only if a significant difference in between the expected and observed numbers of accidents in the "before" period is found.

(ii) Safety impact estimation

In consequence, safety implication of the "case study" site *i* subject to the treatment in the "after" period termed "safety effect" is given by,

$$\eta_i = \left(\frac{N_{Aft,Obs,case\ study,i}}{N_{Bef,Obs,case\ study,i}}\right) \Big/ \left(\frac{N_{Aft,Obs,comparison,i}}{N_{Bef,Obs,comparison,i}}\right) \quad \text{Eq. 3-23}$$

However, as defined by Jensen (2008), only an overall estimate of the safety effect of all the "case study" sites was done. This estimation is the safety effect of all the "case study" sites was done. This estimation is based on the Log Odds method of meta-analysis (Fleiss, 1981; Elvik, 2000). It uses to address the large variation problem of the correction factors, and so the variation of the expected numbers of accidents by considering statistical weight average of the estimated safety effects. The statistical weight of the natural logarithm of each estimated safety effect under the fixed effects model is,

$$w_i = \frac{1}{v_i} \qquad \text{Eq. 3-24}$$

with the variance,

$$v_i = \frac{1}{N_i} + \frac{1}{K_i} + \frac{1}{L_i} + \frac{1}{M_i} \qquad \text{Eq. 3-25}$$

where N_i, K_i, L_i and M_i are the four accident counts under the "comparison" and "case study" groups that are used to calculate the estimated "safety effect" of site *i*, assuming that there is no systematic variation in the estimate of safety effects in the set of studied sites.

However, there is a possibility that there exists a systematic variation in the estimate of safety effects in the set of studied sites. To test the amount of heterogeneity in the estimates of safety effect, the test statistic *Q* is used and given by (Shadish and Haddock, 1994),

$$Q = \sum_{i=1}^{k} w_i y_i^2 - \left(\sum_{i=1}^{k} w_i\, y_i\right)^2 / \sum_{i=1}^{k} w_i \qquad \text{Eq. 3-26}$$

where

$y_i = \ln(\eta_i)$, is the natural logarithm of the estimated safety effect η_i.

It assumes that the test statistics *Q* has a Chi-square distribution with *k-1* degrees of freedom, where *k* is the number of estimates of safety effect that have been considered. If this test statistic is found to be statistically significant, the random effects model shall be applied instead. The calculation of the statistical weight is thus modified to include a component to reflect the systematic variation of the estimates of safety effect among cases. The statistical weight and variance of the site *i* become (Shadish and Haddock, 1994),

$$w_i = \frac{1}{v_i} \qquad \text{Eq. 3-27}$$

with

$$v_i = \left(\frac{1}{N_i} + \frac{1}{K_i} + \frac{1}{L_i} + \frac{1}{M_i}\right) + \sigma_\theta^2 \qquad \text{Eq. 3-28}$$

where

$$\sigma_\theta^2 = [Q - (k-1)]/c \qquad \text{Eq. 3-29}$$

$$c = \sum_{i=1}^{k} w_i - \left[\sum_{i=1}^{k} w_i^2 \,/\, \sum_{i=1}^{k} w_i\right] \qquad \text{Eq. 3-30}$$

The weighted mean estimate of the safety effects and the 95% confidence intervals for this estimate based on a set of studied sites for either fixed effects model or random effects model is then given by,

$$\bar{\eta} = exp\left[\sum_{i=1}^{k} w_i\, y_i / \sum_{i=1}^{k} w_i\right] \qquad \text{Eq. 3-31}$$

and

$$\eta_{95\%CI} = exp\left[\left(\sum_{i=1}^{k} w_i\, y_i / \sum_{i=1}^{k} w_i\right) \pm 1.96 / \sqrt{\sum_{i=1}^{k} w_i}\right] \qquad \text{Eq. 3-32}$$

The null hypothesis that the treatment has bought no safety impact to the studied site is rejected if the value one lies either below the 5th

percentile or above the 95th percentile weighted mean estimate of the safety effect, i.e. $\eta_{Lower\ 95\%CI} > 1$ or $\eta_{Upper\ 95\%CI} < 1$.

3.3 Driver Behavioral Evaluation Techniques

Besides using non-experimental observational methods to examine the safety implications brought by treatments, there is indeed another widespread practice in road safety research for evaluating driver performances on roadways. This section therefore moves on to illustrate four analytical methods, which have been commonly adopted for the comparison of quantities and the prediction of binary outcomes. In the first and the second part, two statistical hypothesis tests for the comparison of mean and variance differences of pairs of populations are described. Then, two predictive techniques including an aggregated binary logit model (commonly known as logistic regression model) and disaggregated binary logit model for the prediction of traveler choices are discussed in the third and the forth parts.

3.3.1 Statistical hypothesis test

(i) Two-sample t-test

When testing the difference of the means between two populations, there are two hypothesis-testing options. First is a test to infer the mean of one population is greater than the mean of another population. Second is a test of whether two population means are equal, without any prior intention that one mean is greater than the other. In transportation research, the second one is the most common test and is presented below where the null hypothesis states that the two means are equal. The popularity of this test is because there is often an interest to know if there are any changes/differences of the targeted parameters such as speed, travel time and accident rates among places, time-of-day and travelers.

$$H_0: \mu_1 = \mu_2$$
$$H_1: \mu_1 \neq \mu_2 \qquad \text{Eq. 3-33}$$

However, owing to the limited resources to conduct widespread survey for the targeted issues, in particular when conducting roadside observation to record travelers' behavior on roads, researchers often confront the small sample size problem (defined as $n_1 < 25$ and $n_2 < 25$). In this case, it assumes that the targeted two populations follow the Normal distribution with unequal variances s_1^2, s_2^2; the test statistics therefore has approximately a t distribution with degrees of freedom as follows:

$$t = \frac{\mu_1 - \mu_2}{\sqrt{(s_1^2/n_1 + s_2^2/n_2)}} \qquad \text{Eq. 3-34}$$

and

$$df = \frac{\left(s_1^2/n_1 + s_2^2/n_2\right)^2}{\left[\left(s_1^2/n_1\right)^2/(n-1)\right] + \left[\left(s_2^2/n_2\right)^2/(n_2-1)\right]} \qquad \text{Eq. 3-35}$$

Regarding the test statistics, the expression in the numerator is the difference between μ_1 and μ_2 of the two populations under the null hypothesis; the denominator is the standard error of the difference between the two sample means. The $(1-\alpha)100\%$ confidence interval for the difference between the two population means is thus given by,

$$CI_{95\%} = (\mu_1 - \mu_2) \pm t_{\alpha/2}\sqrt{(s_1^2/n_1 + s_2^2/n_2)} \qquad \text{Eq. 3-36}$$

In case the variances of the two populations are equal, there is an alternative test statistics *t* for comparing the difference between the two population means as follows:

$$t = \frac{\mu_1 - \mu_2}{\sqrt{s_p^2(1/n_1 + 1/n_2)}} \qquad \text{Eq. 3-37}$$

with

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} \qquad \text{Eq. 3-38}$$

The pooled variance s_p^2 is determined on the basis of a sample variance s_1^2 obtained from a sample of size n_1, and a sample variance s_2^2 obtained from another sample of size n_2.

Regarding the test statistics, the expression in the numerator is the difference between μ_1 and μ_1 of the two populations under the null hypothesis with the degrees of freedom $n_1 + n_1 - 2$, which are associated with the pooled estimate of population variance. The $(1 - \alpha)100\%$ confidence interval for the difference between the two population means is thus given by,

$$CI_{95\%} = (\mu_1 - \mu_2) \pm t_{\alpha/2}\sqrt{s_p^2(1/n_1 + 1/n_2)} \qquad \text{Eq. 3-39}$$

(ii) F-test

In consequence, there is sometimes an interest to know the equality of the variances of the two populations, i.e. whether the σ_1^2 and σ_2^2 are equal. For instance, to determine if the variations of driver reaction time of the targeted two populations are similar so as to infer either group of drivers are comparatively safe while following a leading vehicle and that exercises hard braking suddenly due to the traffic ahead.

Assume that the sample variance s_1^2 of a sample with size n_1, and a sample variance s_2^2 of another sample with size n_2 are available under the two populations. The null and the alternative hypotheses are given as follows:

$$H_0: \sigma_1^2 = \sigma_2^2$$

$$H_1: \sigma_1^2 \neq \sigma_2^2 \qquad \text{Eq. 3-40}$$

the test statistics based on the *F* distribution with degrees of freedom $n_1 - 1$ and $n_2 - 1$ is defined as,

$$F = S_1^2/S_2^2 \qquad \text{Eq. 3-41}$$

The null hypothesis that the variances of the two populations are equal is rejected if $f_0 > f_{\propto/2,n_1-1,n_2-1}$ or $f_0 < f_{1-\propto/2,n_1-1,n_2-1}$ at the $\propto\%$ significance level.

3.3.2 Predictive model

(i) Aggregated binary logit model

The aggregated binary logit model, which is commonly known as the logistic regression model, has been widely adopted for modeling discrete outcome situations; for instance, traveler mode choice in transportation system and injury severity of traffic accidents (Al-Ghamdi, 2002; Yan et al., 2005). In this model, the endogenous variable represents the population proportion of the occurrence of a discrete outcome event, which generally denoted as *1* and *0*. The explanatory variables can be both continuous and discrete such as speed, vehicle type and traffic volume. They are used to explain and predict the relationship and the occurrence of the event.

For person *i* takes the action $(y_i = 1)$ under the situation that when $U_i > 0$, the probability of taking the action (Hosmer and Lemeshow, 2000),

$$P(y_i = 1) = \frac{1}{1+\exp(-U_i)} \qquad \text{Eq. 3-42}$$

with the net utility function,

$$U_i = \boldsymbol{\beta X} = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \cdots + \beta_k X_{k,i} \qquad \text{Eq. 3-43}$$

where

$\boldsymbol{\beta}$ represents the coefficients $\beta_0, \beta_1, \beta_2, \dots, \beta_k$;

$\boldsymbol{X}$ represents the explanatory variables $X_1, X_2, \dots, X_k$.

The coefficients are then obtained by the maximum likelihood estimation (MLE) technique with the likelihood function,

$$L(\boldsymbol{\beta}) = \prod_{i=1}^{n} P(y_i = 1) = \prod_{i=1}^{n} \left(\frac{1}{1+\exp(-U_i)}\right) \qquad \text{Eq. 3-44}$$

As for simpler manipulation of the estimation of model parameters, the log of likelihood function becomes,

$$LL(\boldsymbol{\beta}) = ln\left[\prod_{i=1}^{n} \left(\frac{1}{1+\exp(-U_i)}\right)\right] = \sum_{i=1}^{n} ln[1 + exp(-U_i)] \qquad \text{Eq. 3-45}$$

(ii) Disaggregated binary logit model

The disaggregated binary logit model is an alternative for modeling discrete outcome situations in transportation research, but it has however been few adopted in road safety studies. More importantly, the disaggregated model is capable of examining the probability of the occurrence of a discrete outcome event (Ben-Akiva and Lerman, 1985), while the aggregated model can only be used to examine the population proportion (Hosmer and Lemeshow, 2000).

In this model, the probability of person *i* takes the action $(\mathrm{y_i} = 1)$ under the situation that $\mathrm{U_{i,1}} > \mathrm{U_{i,0}}$ is given by (Ben-Akiva and Lerman, 1985),

$$P(y_i = 1) = \frac{\exp{(U_{i,1})}}{\exp{(U_{i,1})} + \exp{(U_{i,0})}} \qquad \text{Eq. 3-46}$$

with the utility functions for the two alternatives as follows,

$$U_{i,1} = \beta_1 x_{i,1} + \varepsilon_{i,1}$$
$$U_{i,0} = \beta_0 x_{i,0} + \varepsilon_{i,0} \qquad \text{Eq. 3-47}$$

where the former parts of the two functions refer to the deterministic component; x_i denotes the vector of explanatory variables and β denotes the vector of coefficients. The later parts of the functions refer to the random component with the assumption that ε_i follows the Gumbel distribution.

Similarly, the coefficients are obtained by the MLE technique with the likelihood function,

$$L(\beta) = \prod_{i=1}^{n} P(y_i = 1) = \prod_{i=1}^{n} \left(\frac{\exp\,(U_{i,1})}{\exp\,(U_{i,1}) + \exp\,(U_{i,0})} \right) \quad \text{Eq. 3-48}$$

and for simpler manipulation of the estimation of model parameters, the log of likelihood function becomes,

$$LL(\beta) = \sum_{\mathrm{i}=1}^{\mathrm{n}} \left[U_{i,1} - ln \sum_{k=0}^{1} \exp\,(U_{i,k}) \right] \quad \text{Eq. 3-49}$$

3.4 Summary

In this chapter, the non-experimental observation method for the evaluation of safety implications brought by treatments, the statistical inference tests for comparing the quantities such as approaching speed of targeted populations, as well as the predictive models for examining the probability of the occurrence of a discrete event are reviewed.

In Section 3.2, the Comparison Group approach and an alternative approach namely the "second-best" method that uses to measure the changes of safety levels before and after an implementation of safety treatments are described. Throughout the investigation, the influence of observed and unobserved factors like traffic volume, driving behavior and accident trend are controlled for. These evaluation techniques apply to assess the safety implications of the Hong Kong bus-only lane system as illustrated in Chapter 4.

In Section 3.3, the two-sample t-test and F-test that use to measure the mean and variance differences of the interested parameters; and the two binary logit models that use to simulate discrete outcome situations are illustrated. For the case considered in this research study, these techniques apply to examine the approaching behavior and decision making behavior of bus drivers at signalized junctions at the time during the amber phase. The results are then compared with other road users as to infer whether bus drivers surpass other road users at the studied locations in safety aspect as was commonly expected and discussed in Chapter 5.

CHAPTER 4

SAFETY IMPLICATIONS OF BUS LANE ON BUSES AND NON-BUS TRAFFIC

4.1 Introduction

As was previously discussed, public buses have not been adequately researched and hence whether the buses are safe on roads as anticipated has not been well considered. According to the safety studies as reviewed in Chapter 2, there are two issues requiring specific efforts to address. One of them related to safety operation of the exclusive roadways for public buses is discussed in this Chapter.

4.2 Bus-only lane (BOL) system

A bus-only lane or bus lane, which provides exclusive road capacity for public buses, aims to increase average operating speed and improve reliability of bus services in urban areas, particularly along highly congested corridors. The first bus lane has been in operation since 1960 in Baltimore, the United States (Bendtsen, 1961). Since then, bus lanes have been popularly used by transport administrations due to the public service nature, which raises public acceptability of such road capacity rationalization policy.

In the United States (US), bus lanes are mostly situated in motorways interconnecting heavily populated city centers where traffic congestion is commonplace. London and Hong Kong, however, establish their bus lane systems mainly in urban areas. The system in London, in particular, has reached great success in improving bus service reliability (Atkins et al., 2004; Hodges, 2007). The government therefore introduced a more extensive system as to further increase bus modal share by the provision of reliable public bus service. Besides, bus lane systems in New York (the US), Rouen (France), Seoul (Korea) and Beijing (China), for example, reported of analogues improvement. Non-bus traffic, though, suffered from slight increases in travel time after the implementations (Kim, 2003; Kim et al., 2010; Levinson et al., 2002; Atkins et al., 2004; Hodges, 2007).

To accommodate different situations and the needs of specific sites as well as traffic conditions, bus lane designs have been greatly modified. Currently, there are four common bus lane types including Guided Busway (GBW), Exclusive Curbside Bus Lane (ECBL), Exclusive Median Bus Lane (EMBL) and Exclusive Contra-flow Bus Lane (ECFBL). The primary objective of having various types of design is to achieve better bus service reliability and necessarily the fast operating speed of buses. The ECBL, in particular, is the prime example of bus lane designs, requiring the least modification of the existing traffic lanes. It is therefore expected to have no significant impact on traffic safety while operating, and has been widely adopted due to its simplicity. Nevertheless, other bus lane designs have their own advantages under different situations, of which some of them are about safety.

In the literature, reviews of the bus lane systems were largely focused on changes of passenger travel time and bus service reliability (e.g. Levinson et al., 2002; Hodges, 2007; Viegas and Lu, 2000). Few attentions were paid onto the changes of accident occurrences except Brownfield and Devenport (1989). They are the pioneers addressing the safety issues of the with-flow bus lanes in restricted access streets and the contra-flow bus lanes in central, inner and outer London areas. That the land use pattern, pedestrian activity level and traffic level were suggested associated with the accident rates in the area around each bus lane.

Recently, the study by York et al. (2008) assessed the influence on traffic safety of permitting motorcycles to use bus lanes in Westminster City, London. Increases of accident rates in some studied areas were reported, but the results were inconclusive to state the permission for motorcycles to use bus lanes eroding safety because the significance levels were fairly low. In another example, in Seoul, Korea, Kim et al. (2010) reported an overall declining trend of fatal and seriously injured traffic accidents after the implementation. The findings, however, might not be generalized to the other types of bus lane, because only the EMBL was considered and that is indeed the only bus lane system there. More importantly, this bus lane design physically separates buses from general traffic with barriers along the median. In the above examples, the roads implemented with bus lanes reported to have changes of safety levels after the implementation. The changes are seemingly related to the type of bus lane, traffic conditions and spatial characteristics nearby.

In Hong Kong, due to the rising demand from passengers, the bus operators have continuously upgraded their bus fleet and expanded their services. The government has also paid on-going efforts to ensure the efficient use of limited road space. A number of road rationalization measures such as cancellation of routes with low utilization, reduction of service frequencies and route amalgamations had been undertaken. However, as to further enhance the operating efficiency of buses, the government sought for the implementation of an exclusively busway system. It aimed to give buses some degree of priority in the use of road space where traffic congestion is commonplace. A feasibility study of the use of BOL system was thus commissioned, and the first bus lane began to operate since 1995.

To date, the system has been operated in Hong Kong for over ten years. Its influence on traffic safety, however, has not been adequately studied. The investigation presented in this chapter aims to contribute to this area by assessing the changes of safety levels of buses and non-bus traffic. The results are expected to give practitioners some insights into safety performances of the bus-only lane system and design considerations for future implementations. It might also give a feedback to the investigation by Evans and Courtney (1985) that whether the road rationalization measure is feasible to tackle the high accident rate problem of buses in high-dense road networks in urban areas.

Albeit the focus of this investigation is on buses, there is an interest to know as if the system implicates operation safety of non-bus traffic. Therefore, in addition to franchised public buses hereinafter called Public Buses, the non-bus traffic hereinafter called Other Vehicles were considered. The objective of this study was thus to examine the null hypothesis that the occurrences of fatal, serious and slight (FSS), and fatal and serious (FS) accidents involving Public Buses and Other Vehicles on the roads implemented with bus-only lanes remain unchanged while they are in operation.

4.3 Study sites

According to the Transport Bureau of the Hong Kong government, the sites chosen for bus lane implementation were based on a principle that the carriageway is an inter-district traffic corridor and forms vital link between home and work places. Based on this, a total of 22km long ECBLs have been implemented in various districts.

Seven of them, which are approximately 13km long in total, were selected, because their implementation dates were officially documented by the Legislative Council. The information is thus creditable for evaluating the changes of accident occurrences before and after the implementations. More importantly, these seven bus lanes constitute more than a half of the BOL system in length, having different varieties of traffic conditions, road layouts, operation hours and coverage areas. Therefore, they could be considered as the representatives of the system.

Table 4-1 gives detailed information of the seven selected bus lanes including speed limit, road type, and bus lane operation hours; bus lane length, total number of bus/non-bus lane(s), and annual average daily traffic (AADT); presence of bus stops, crossings and junctions as well as the possibility for buses to interact with pedestrians.

Table 4-1 Detail information of the seven studied bus lanes

Road Name	Speed Limit (km/h)	Road Type [a]	Operation hours	Bus lane length (km)	Number of Bus lane(s) / Non-bus lane(s)	Presence of Bus stop / Junction / Crossing	Implementation Year
Wong Chuk Hang Rd	50	Urban Trunk Road	0700-0900 (EB) 1600-1900 (WB)	1.0	1 / 1	Yes / No / No	
Nathan Rd	50	Primary Distributor	0700-1900	2.0	1 / 2	Yes / Yes / Yes	
Prince Edward Rd East	70	Urban Trunk Road	24hrs	0.3	1 / 3	Yes / No / No	1997
Gloucester Rd	50	Urban Trunk Road	24hrs	0.4	1 / 3	Yes / No / No	
Hennessy Rd (A)	50	Primary Distributor	0700-2400	0.4	1 / 2	Yes / Yes / Yes	
Hennessy Rd (B)	50	Primary Distributor	0700-0900	0.4	1 / 2	Yes / Yes/ Yes	
Tuen Mun Rd	70	Rural Trunk Road	0730-0900	8.5	1 / 2	No / No / No	1995

[a] Urban/Rural Trunk Road: roads connecting the main centers of population; Primary Distributor: roads forming the major networks of urban area.

Note: studied sites with bus lanes and comparison sites are located in these same road sections.

Road Name	AADT (veh/day) [b]	Possibility to interact with pedestrians	Remarks
Wong Chuk Hang Rd	45,020	No	Continuous bus lane, near the toll plaza area of Aberdeen Tunnel.
Nathan Rd	34,360	Yes	Discontinuous bus lane, run across junctions and pedestrian crossing facilities.
Prince Edward Rd East	119,480	No	Continuous bus lane, designated for passenger boarding and alighting.
Gloucester Rd	165,020	No	
Hennessy Rd (A)	24,160	Yes	Discontinuous bus lane, run across junctions and pedestrian crossing facilities, near tram track: (A) with and (B) without physical separation.
Hennessy Rd (B)	28,510	Yes	
Tuen Mun Rd	95, 000	No	Continuous bus lane, inter-district main road.

[b] Annual Average Daily Traffic record documented in Annual Traffic Census 2004 published by Transport Department Hong Kong SAR.

4.4 Accident data

The evaluation of the BOL system is based on the observed accident counts of Public Buses and Other Vehicles at the times before and after the implementation and during and outside the operation hours. As previously described in Chapter 3, the time before and after the system was implemented is defined as the “before” and the “after” period, respectively. There is however a question as if the accidents happened at the times during the bus lane installation period belongs to the former or the latter category.

Owing to the following reasons, accident records immediately before and after the documented implementation date were categorized as the “before” and the “after” period, respectively, in the analysis. First, there is no information regarding the durations of the installation period of the seven bus lanes studied. Second, the road-marking paving work in Hong Kong generally takes place at off-peak periods and lasts for at most two weeks time. Hence, the installation is expected to have slight or even no impact on traffic safety.

Accident records documented in the traffic accident database system (TRADS) were used for the analysis. The system has been incorporated by the Transport Department and Hong Kong Police Force for over 20 years. Each record contains comprehensive information such as accident time and date, vehicle type, accident location, speed limit and road type, which are valuable for scientific road safety investigation. To cover a reasonable time scope, accident records from the years 1989 to 2004 were extracted for the analysis, providing the focus data for this study.

4.5 Comparison group establishment

In non-experimental observational before-after study, a “comparison” group and “case study” group need to be established. The establishment was based on two factors, i.e. accident location and accident time. First, the accident location was used to filter out the records where the accidents happened outside the study area. However, according to the validating study by Loo (2006), the correct rate of accident location documented in TRADS is about 65 to 80%. This figure is broadly comparable to the United Kingdom, where the correct rate is between 80 and 90% (Austin, 1995). Spatial information validation is thus required before the group establishment. In this regard, additional information including coordinates (i.e. Easting and Northing), brief descriptions of accidents and chainage were used to help with the filtering process.

Owing to the fair quality location records in TRADS, it is hard to distinguish the traffic lanes that the accidents took place, i.e. whether the accidents occurred on bus lane or non-bus lanes. Therefore, no sub-division for the accidents on bus lanes or non-bus lanes was carried out. This inclusion can be considered as an assumption that the operation of bus lane would probably influence traffic flow, driving behavior and so occurrence of traffic accidents on all the traffic lanes. It could also be taken as a measure to account for both the changes of accident occurrences on bus lanes and non-bus lanes after the implementations.

Second, accident time was used. The records where the accidents happened on road with bus lane and during the operation hours were categorized as the “case study” group; while the accidents happened on the road with bus lane but outside the operation hours were categorized as the “comparison” group. According to the Empirical Bayes method defined by Hauer (1997), the site taken into the “comparison” group shall be qualified to have homogeneous accident trend in the “before” period with the site taken into the “case study” group.

In the past practices, a corridor with similar traffic conditions and road layouts, or another segment at downstream or upstream location of the site studied was generally taken as the comparison subject. In which, the site did not receive any treatments within the interested period. In this study, however, the same road at the time outside the operation hours was taken. This is because the downstream or upstream segment of the interested road, or another corridor has different road layouts and traffic conditions that could otherwise influence the occurrence of traffic accidents and hence the reliability of the investigation results. Bus lanes on Prince Edward Road East and Gloucester Road are operated for 24 hours, upstream and downstream sections of the bus lanes along the roads were used as comparison groups in the analysis; the length of the comparison sections are taken as half that of the bus lanes.

As was initially stated, there is a need to know as if the BOL system has had significant impact on accident severity of the two interested vehicle categories. The groups were thus finally established as accidents involving Public buses and Other Vehicles and by fatal, serious and slight (FSS) as well as fatal and serious (FS) accidents. Albeit Bull and Roberts (1972) suggested that the number of slight accident can very often be over- or under-reported, the phenomenon is expected to be similar on the roads in the “case study” and “comparison” groups and hence the corresponding accident records were not excluded.

Lastly, there is a concern of the accident migration problem as was suggested by Skowronek et al. (1997). By the prior experiences, in order to offer a comprehensive review of the safety implications of a treatment, the above migration problem should be sought. In this study, however, the question of whether some accidents may have migrated to or from other roads as a result of non-bus traffic diversions cannot be addressed. This is because the relevant information regarding the diverting traffic to or from the studied roads and the roads nearby in the “before” and the “after” periods is not available.

4.6 Results

4.6.1 Odds ratio test

Table 4-2 and Table 4-3 show the Odds ratio test results for fatal, serious and slight (FSS) as well as fatal and serious (FS) accidents of each studied bus lane of the two vehicle categories, i.e. Public Buses and Other Vehicles.

With the exceptions of the bus-only lanes that were of no accident record either in the “comparison” or “case study” group in the “before” period, as well as the candidate of Gloucester Road under the category of FSS accident, all the bus lanes passed the Odds ratio test. That means most of the comparison sites were suitable for estimating the accident counts that the investigation sites would have in the "after" period by the methods described in Chapter 2. They were then taken for accident count and safety implication estimations, the results are shown in the following section.

Table 4-2 Results of the Odds ratio tests for fatal, serious and slight (FSS) accidents

Road Name	Vehicle Category	Years (from – to)	Odds ratio	95% CIs	
Wong Chuk Hang Rd	Public Buses	1991 – 1996	-0.224	0.274	-0.274
	Other Vehicles		0.056	0.105	-0.105
Nathan Rd	Public Buses		-0.150	0.587	-0.587
	Other Vehicles		-0.096	0.124	-0.124
Prince Edward Rd East	Public Buses		0.098	0.505	-0.505
	Other Vehicles		-0.118	0.156	-0.156
Gloucester Rd	Public Buses		0.245	0.858	-0.858
	Other Vehicles*		-0.254	0.165	-0.165
Hennessy Rd (A)	Public Buses		-0.092	0.307	-0.307
	Other Vehicles		0.133	0.196	-0.196
Hennessy Rd (B)	Public Buses		-0.116	0.529	-0.529
	Other Vehicles		-0.102	0.597	-0.597
Tuen Mun Rd	Public Buses	1989 - 1994	-0.150	0.587	-0.587
	Other Vehicles		-0.096	0.124	-0.124

* Fail to pass the Odds ratio test at the 5% significance level

Table 4-3 Results of the Odds ratio tests for fatal and serious (FS) accidents

Road Name	Vehicle Category	Years (from – to)	Odds ratio	95% CIs	
Wong Chuk Hang Rd	Public Buses	1991 – 1996	0.124	0.618	-0.618
	Other Vehicles		0.000	0.405	-0.405
Nathan Rd	Public Buses		0.264	0.350	-0.350
	Other Vehicles		-0.023	0.180	-0.180
Prince Edward Rd East	Public Buses		0.082	1.017	-1.017
	Other Vehicles		0.020	0.260	-0.260
Gloucester Rd	Public Buses		-	-	-
	Other Vehicles		-0.294	0.497	-0.497
Hennessy Rd (A)	Public Buses		-	-	-
	Other Vehicles		0.212	0.709	-0.709
Hennessy Rd (B)	Public Buses		-	-	-
	Other Vehicles		-0.061	0.720	-0.720
Tuen Mun Rd	Public Buses	1989 - 1994	-	-	-
	Other Vehicles		0.022	0.329	-0.329

- Odds ratio cannot be determined because there is no accident records over the specified time period in the "comparison" or "case study" group.

4.6.2 Safety implication estimation

Of the seven bus-only lanes considered in the individual analysis, all reported to have decreases in the number of FSS accidents for Public Buses. However, only the results of the two study sites, Gloucester Road and Wong Chuk Hang Road, which had 31.5% and 33.3% decreases after implementation, were statistically significant at the 5% level as shown in Table 4-4. For the impacts on Other Vehicles, similar changes in accident occurrences were found; all but one of the study sites had decreases on the FSS accidents.

Impacts of the bus-only lanes on the FS accidents to the Public Buses and Other Vehicles were evaluated. The results shown in Table 4-5 reveal that there were all decreases in the number of Public Buses FS accidents, except the sites that were not analyzed due to methodological reasons. Whilst, for the Other Vehicles, only two of the study sites had reported of decreases in the number of FS accidents; the rest even had reported of increases after the bus lane operation. Nevertheless, results for the changes in FSS and FS accidents owing to the operation of bus-only lanes are of relatively low significances.

Furthermore, a pooled analysis taking all the bus-only lanes into consideration was conducted to address the concern of bias assessment on individual sites. The results of the two vehicle categories, i.e. the Public Buses and Other Vehicles obtained by the CG and an alternative method are shown in Table 4-6. Much like the previous assessment, it has no clear indication that bus-only lanes bring negative impacts on road safety. Of which, only 10 to 20% changes, which were not statistically significant at the 5% level, were reported in the occurrences of both the FSS and FS accidents.

Table 4-4 Results of each studied bus lane by the Comparison Group method under the category of fatal, serious and slight (FSS) accident

Road Name	Vehicle Category	Observed accident count	Expected accident count	Estimated accident changing factor	95% CIs
Wong Chuk Hang Rd	Public Buses	16	44.2	0.333*	0.08 , 0.585
	Other Vehicles	131	126.5	0.993	0.353 , 1.736
Nathan Rd	Public Buses	442	382.4	0.780	0 , 1.844
	Other Vehicles	456	367.6	1.180	0.645 , 1.714
Prince Edward Rd East	Public Buses	14	16.8	0.737	0.084 , 1.39
	Other Vehicles	108	94.0	0.926	0.019 , 1.833
Gloucester Rd	Public Buses	25	61.1	0.305*	0 , 0.674
	Other Vehicles[a]	-	-	-	-
Hennessy Rd (A)	Public Buses	98	101.9	0.770	0 , 1.539
	Other Vehicles	139	147.0	0.827	0.197 , 1.456
Hennessy Rd (B)	Public Buses	20.1	22.0	0.821	0.174 , 1.468
	Other Vehicles	24	19.5	1.155	0.404 , 1.906
Tuen Mun Rd	Public Buses	18	20	0.756	0.007 , 1.505
	Other Vehicles	81	86	0.827	0.203 , 1.45

* Significant at the 5% level; [a] No estimation was done due to the non-qualified road in the “comparison” group

Table 4-5 Results of each studied bus lane by the Comparison Group method under the category of fatal and serious (FS) accident

Road Name	Vehicle Category	Observed accident count	Expected accident count	Estimated accident changing factor	95% CIs
Wong Chuk Hang Rd	Public Buses	5	7.3	0.521	0 , 1.267
	Other Vehicles	23	15.0	1.200	0 , 2.541
Nathan Rd	Public Buses	70	74.9	0.796	0.119 , 1.474
	Other Vehicles	74	50.2	1.109	0 , 2.38
Prince Edward Rd East	Public Buses	3	3.0	0.591	0 , 1.776
	Other Vehicles	22	13.6	1.363	0.069 , 2.658
Gloucester Rd	Public Buses[a]	-	-	-	-
	Other Vehicles	40	47.8	0.759	0.228 , 1.29
Hennessy Rd (A)	Public Buses[a]	-	-	-	-
	Other Vehicles	29	16.0	1.380	0 , 2.978
Hennessy Rd (B)	Public Buses[a]	-	-	-	-
	Other Vehicles	3	5.0	0.498	0 , 1.239
Tuen Mun Rd	Public Buses[a]	-	-	-	-
	Other Vehicles	29	22	1.201	0.319 , 2.083

[a] No estimation was done due to the non-qualified road in the "comparison" group

Table 4-6 Results of the pooled analysis by the Comparison Group and Second-best methods

Public Buses	Comparison Group method		Second-best method	
	FSS accident	FS accident	FSS accident	FS accident
Number of studied bus lanes	7	3	7	3
Pooled number of accidents (Observed)	633	78	633	78
Pooled number of accidents (Expected)	739.8	85.2	936.2	96.9
Pooled estimate of accident changing factor / safety effect	0.786	0.807	0.797	0.826
95% Confidence Intervals	0.324 , 1.249	0.194 , 1.42	0.595 , 1.068	0.35 , 1.949

Other Vehicles	Comparison Group method		Second-best method	
	FSS accident	FS accident	FSS accident	FS accident
Number of studied bus lanes	6	7	6	7
Pooled number of accidents (Observed)	939	220	939	220
Pooled number of accidents (Expected)	893.7	185.0	965.4	199.8
Pooled estimate of accident changing factor / safety effect	1.045	1.169	1.090	1.205
95% Confidence Intervals	0.877 , 1.212	0.827, 1.511	0.9 , 1.288	0.853 , 1.703

4.7 Discussions

In both the individual and pooled analyses, virtually all the sites with bus-only lane operated had changes in the FSS and FS accidents to buses and the non-bus traffic after implementation. However, only the changes in two of the study sites, i.e. Gloucester Road and Wong Chuk Hang Road, are of relatively high significance (at 0.05 level). The evidence may be weak to assert that bus-only lanes would deteriorate traffic safety to the either vehicle category during operation. Else, the question whether bus-only lanes can provide an extra safe condition for buses could not be addressed. Nonetheless, the two significant reductions in the numbers of bus FSS accidents create a positive view to the extension of the bus-only lane system. It basically has no strong views onto the system leading adverse impact to buses or even have been benefited from the reservation of nearside traffic lanes, whereas the original purpose of the system was to relieve the congestion problem of buses in urban areas.

In the literature, Chimba et al. (2010), for instance, concluded that at the times when a bus is approaching or departing a bus stop, protection for buses from interacting with general traffic might be required as for safety. af Wahlberg (2002; 2004a) also reached a similar conclusion that an endemic safety problem of buses may be associated with the conflicts prone situation at the areas near bus stops and close proximity of buses with the non-bus traffic. For any exclusive runway, which is analogous to the bus-only lane system in Hong Kong, could be pragmatic to provide an extra safety condition for the targeted vehicles by offering less congested environment and so fewer interaction with the rest of the road users and probably, lower risks in having traffic accidents.

Of the seven bus lanes studied, increases in the FS and FSS accidents were only reported under the category of Other Vehicles. The result even though was weak in scientific view, there is a possibility that the bus-only lanes jeopardize safety levels of the non-bus traffic. The adverse impacts may be attributed to the following situations. First, an even faster traffic -flow speed could be induced when buses are on the exclusive runways. Drivers of the non-bus traffic may drive faster under reduced interactions with the slow running buses that could otherwise increase their accident occurrences (Yau et al., 2006). Indeed, Wong et al. (2005) reported in an observational study that numbers of fatal and seriously injured accidents were raised as a result of faster operating speeds on roads after speed limit was relaxed. Second, when buses are prioritized under an exclusive traffic lane, the non-bus traffic has been squeezed onto the remaining traffic lanes. More frequent interactions among vehicles are expected and that increases of traffic accidents might be simply due to the more congested roadway conditions to them.

Regardless of low statistical significance of the results which was less than certain levels, e.g. 0.05, safety impacts to non-bus traffic may worth further attentions in the future bus-only lanes. The increases in accident occurrences found in the study sites could be attributed to their complex traffic conditions. Nathan Road, for instance, which is a heavily trafficked urban thoroughfare. Vehicles there exercise frequent stop-and-go movement as a result of temporary parking and so congestion. The parking problem, in particular, on nearside traffic lane is severe, as which the public light bus and taxi drivers temporarily take the place for board/alight passengers and load/unload freights. Once the bus-only lane is occupied, road spaces for general traffic are further reduced especially when buses are operated onto the non-bus lanes. Subject to such a special condition, accident occurrences of the buses and non-bus traffic might be affected (Lord et al., 2005; Kockelman and Ma, 2007).

In this observational study, the results consistently reflect that under the operation of bus-only lanes, there have been no adverse impacts on road safety to buses or non-bus traffic. As such, it would be worthwhile for the Hong Kong government to extend the bus-only lane network to improve the services of public buses, particular in the areas where traffic congestion is commonplace and without worries of safety implications. In fact, there are numbers of heavily trafficked corridors and inter-district links have yet been adopted such a road-space rationalization policy to improve bus service reliability and efficiency of the entire public transport system.

4.8 Summary

In this chapter, the seven selected bus-only lanes in Hong Kong were first scrutinized by the Odds Ratio test. Their accident counts and safety implications within the study period, from years 1989 to 2004 were then estimated by the two observational Before-After study techniques. The objective to evaluate influences of the ECBL on numbers of fatal, serious and slight as well as fatal and serious accidents involving the Public Buses and the Other Vehicles was achieved. Suitability of the use of bus-only lanes on the study sites regarding the road layouts, traffic conditions and operation features were discussed.

As for further improving the bus-only lane system in safety aspect, the following might require further investigations in Hong Kong and elsewhere, in which the bus-only lane systems are in similar form, i.e. the ECBL. First, public buses on the sites considered in this study appear to be the only beneficiary from the bus lane operation. The positive impacts on crash frequencies and severity of the system require stronger evidences to support and validate the assertion. Second, insignificant increases in the FSS and FS accidents to Other Vehicles on the majority sites might be an indication of the safety problems of the bus-only lane system. Albeit there is no clear indication showing bus-only lane system has brought adverse impacts on road safety to the buses or the non-bus traffic, road safety should always be a major consideration in the design of a new bus lane introduced.

CHAPTER 5

BEHAVIORAL EVALUATIONS OF BUS DRIVERS AT SIGNALIZED JUNCTION

5.1 Introduction

In this chapter, the question whether public buses have been safely operating at signalized junctions is addressed. Unlike the past practices in modeling accident occurrences at particular locations (e.g. Yau, 2004; Yau et al., 2006), the investigation here was set to be more specific. It aimed to analyze the bus driver behavior at a signalized junction. The focus was on driver approaching maneuver at the times near the end of green signal and their Stop/Go decision-making behavior at amber. In which these two aspects have been broadly discussed in the literature concerning the Dilemma Zone (DZ) problem and junction safety.

5.2 The Dilemma Zone (DZ) problem

In urban areas, signal control junctions have been popularly used at the locations where there are complex traffic patterns and high demand of intersecting traffic. This is because the design is commonly expected to have systematic control over conflicting traffic and so preventing road users from crashes. However, a substantial amount of accidents has still been reported at signalized junctions. This high accident risk at junction appears to indicate that the design may not be as conductive to safety as was initially anticipated. The flaw of minimizing accident at junctions has been widely discussed with a general conclusion that red-light running is the leading cause of the problem (e.g. Lum and Wong, 2003a and 2003b; Fitzsimmons et al., 2009; Archer and Young, 2009; Liu, 2009).

Despite the widespread analysis on red-light running, there has been another opinion in regard to the flaw of maintaining operation safety of signalized junctions. Since Gazis et al. (1960), efforts on reviewing traffic signal setting have begun. The discussion centers on the improperly time amber duration problem which make drivers feel dilemma in response to to the start of amber phase while approaching. In particular, if they are too close to the junction to stop or too far away from it to pass through the stop line. This context has been broadly known as the Dilemma Zone (DZ) problem. For this, a formulation was set to determine the minimum amber duration, namely the Gazis, Herman and Maradudin model. It was claimed that the response dilemma of drivers could be relieved if amber signal is designed in accordance with the requirement governed by the model.

Other than modeling, efforts have been exerted on assessing drivers' junction approaching behavior at amber. For instance, El-Shawarby et al. (2010) undertook an on-road experiment to examine the influences of age, platooning condition and junction gradient on driver reaction time at amber. They found that female and old drivers (i.e. aged over 60) took longer reaction time than male and young drivers do when making Stop/Go decision. Variations of driver reaction time under different platooning conditions or at junctions with different gradients were also reported.

In another study, the changes of drivers' approaching speed and final

Stop/Go decision at amber under wet pavement conditions caused by raining or snowing were studied (Sharma et al., 2010). It was found that drivers attempted to adjust their speed choices and decisions for the wet pavement, but the changes were not proportionate to the degradation of pavement friction. That means the drivers being observed in the study were not able to make appropriate adjustments as were required.

By those experiences, whether drivers can make proper response to amber signal at junctions appears to be associated with the occurrence of the DZ problem. One might then question whether driving behavior is also contributory to this, as to some extent the behavior of drivers is correlated with their driving abilities. The signalized junctions in Greece, for instance, where there has had serious speeding and red-light running problem. Papaioannou (2007) examined the relationship among driving behavior, the occurrences of DZ problem and red-light running. Its study qualitatively classified drivers into three categories by their approaching speeds and final Stop/Go decision at amber. That drivers approached the junction with high operating speeds and made aggressive Go decision at amber represented a high proportion in the study site. Owing to this, the drivers there were more likely to confront response dilemma at amber and that would probably explain why the rates of red-light running and crashes there remained high.

To date, various issues regarding engineering designs and behavior of drivers have been greatly discussed. The question as if public buses, which are less maneuverable due to the large vehicle size, are more risky at junctions during amber has not been adequately considered. If this is true, the bus drivers might require special care at signalized junctions as to relieve their dilemma in deciding Stop/Go at amber. The investigation here therefore aimed to address this issue by assessing the behavior of bus drivers at a junction. Approaching maneuvers of drivers at the times near the start of amber phase and their final Stop/Go decisions at amber were analyzed. Then, the results were compared with other road users, aiming to evaluate their behavioral differences with respect to the bus drivers at the junction during the study period.

5.3 Study design

5.3.1 Study site

A signalized T-junction of two through lanes and one right-turning lane with design speed limit 50 kph was selected for the investigation of this study. This junction is situated in a highly populated residential area in Kowloon peninsula in Hong Kong. Near the junction, there are eight 40 storey residential buildings, one primary and five secondary schools as well as a football playground. A roundabout and signalized T-junction is 700 m and 450 m, respectively, apart at upstream direction. An offline bus stop for public service vehicles to board/alight passengers is 50 m apart at downstream direction.

In this junction, vehicular and pedestrian traffic is coordinated by means of traffic signal with an average of 9,060 vehicles running across it every year (HKTD, 2010). The 4-stage phase diagram shown in Figure 5-1 illustrates the movements and intervals of the junction studied. It should be noticed that this signal phase setting has been commonly adopted at signalized T-junctions in Hong Kong, especially at intersections with right turning movement from a major road to a minor road. The green signal including stages 1 and 2, amber signal and cycle length of this junction is 70, 3 and 130 seconds, respectively.

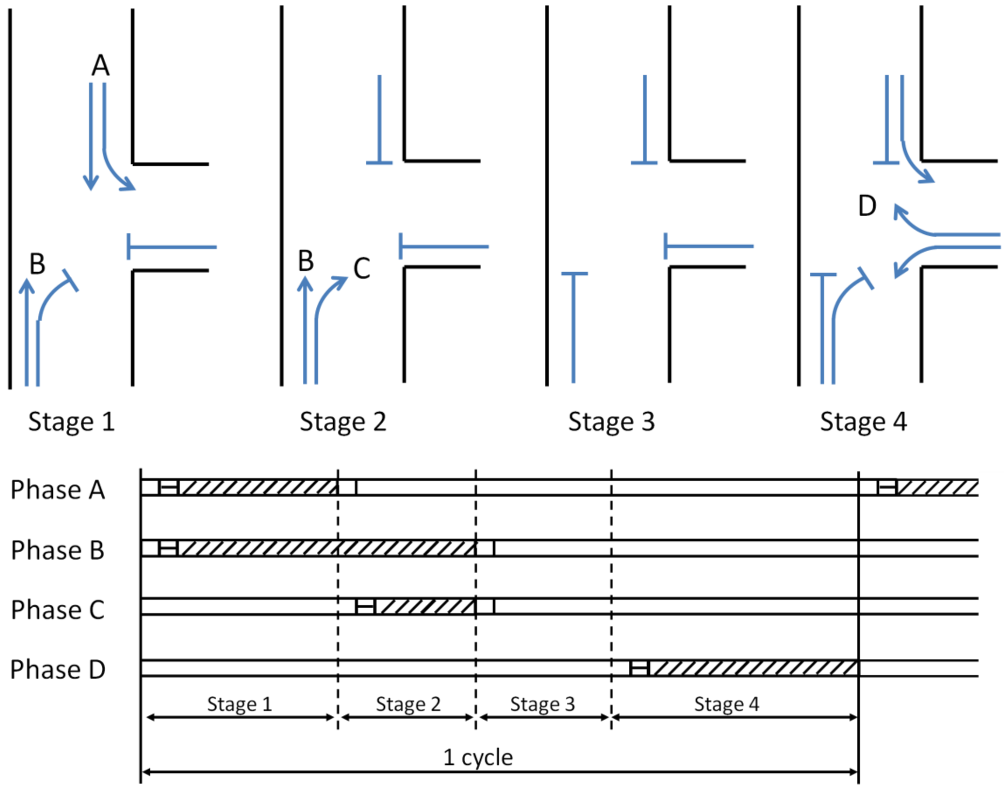


Figure 5-1 Phase diagram of the studied junction

According to the Transport Department Road Safety and Standards Division, this junction was listed as a junction Blacksite in quarter three year 2010. That means at the times while investigations were conducted, two or more fatal accidents were reported in the past 5 years, or nine or more seriously injured accidents were reported in the past 12 months. This study site though reported to have large numbers of serious injuries or fatalities resulting from crashes; no speeding camera, red-light camera or signal countdown devices was installed. The historic accident records of this junction in the past five years are shown in Table 5-1.

Table 5-1 Fatal and serious accident records of the study junction

Year	Private car	Goods vehicle*	Taxi
2010	-	2	-
2009	1	-	-
2008	-	3	-
2007	-	1	-
2006	-	-	1
Total	1	6	1

* Goods vehicle includes light goods vehicle and medium goods vehicle

5.3.2 Roadside observation

Much like the previous work done in the literature, roadside video based observation method was adopted to record the approaching and decision-making behavior of drivers at the studied junction. To avoid interference on drivers and hence validity of the observation, equipment used for video recording was mounted on podium level of a residential building, which is about 60m from the stop line.

Factors like vehicle approaching speed and distance from stop line at the instances of the start of amber were extracted by replaying the video records thereafter. As for the ease of data extraction, pairs of benchmark were placed along the road kerbs in every 5 m interval from the stop line. Figure 5-2 depicts the overhead view of the studied junction from video camera with the 5 m interval lines overlaid on it.

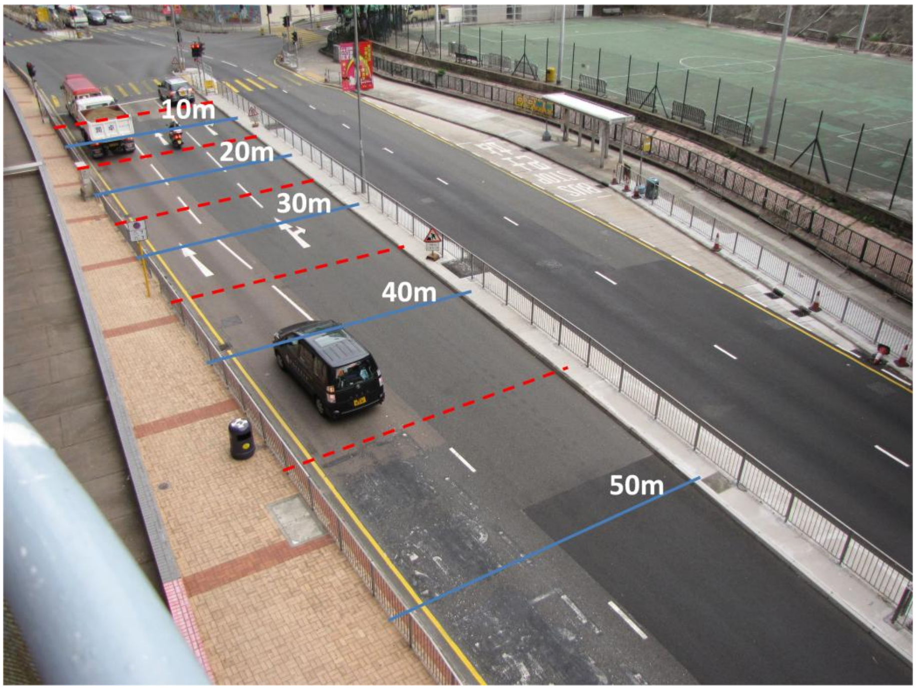


Figure 5-2 Overhead view of the studied signalized junction

5.3.3 Evaluation of approaching maneuver

In general, drivers should not know the remaining time of signal phases at signalized junctions unless a countdown device is implemented. However, the findings of a laboratory study by Hamaoka et al. (2010) pull against this expectation. By acquisitioning information from a pedestrian signal, drivers' response time to the start of amber signal reported to shorten. Some of them were even able to make early Stop/Go decisions just after the change of signal phase.

Of the junction selected in this study, the situation is similar to that under the laboratory setting. The phase diagram shown in Figure 5-1 depicts that the signal phase C was started in the middle of and ended concurrently with the signal phase B. Such an associated arrangement in traffic signal might give proxy information to the drivers who are heading towards the junction. That the drivers might perceive the start of right turning movement is an indication of the impending end of green traffic signal of the junction. It then leads to a question whether the drivers attempt to slow down or speed up their vehicles while approaching as to avoid confronting decision dilemma at amber based on the signal change information.

In this regard, a hypothesis was set as if the bus drivers observed in the studied junction had different approaching behavior at the times near the end of green phases. Albeit bus drivers are the main focus of this study, the rest of the drivers who might not be able to exercise such a skill demanding practice due to lacking experience are also considered. In fact, their records were taken as comparative subjects in the analysis to evaluate their behavioural differences with respect to the bus drivers during the study period. Their records can also be taken as references to the findings of previous studies, in which private cars had been generally considered as the main focus of the investigation.

To evaluate the behavioural differences of drivers, their approaching speeds at 55 to 50 m, 50 to 45 m, and 45 to 40 m from stop line at the times green traffic signal was going to end in five seconds were recorded. As this study aimed at decision dilemma situation at signalized junctions, only the records that the drivers faced the start of amber before reaching the stop line were used. Under this strict requirement, 301 records were obtained in which 54 of them are public buses.

These records were then used to establish pairs of control and case study groups for the evaluation of bus driver behaviour at junction. The grouping method was that taking green remaining time as the cut-off. Vehicles that entered the study area within the specified time intervals, their records were categorized into the case study group. Starting from the green remaining time in less than 1 second with an increment by 0.5 seconds for each group, a total of eight case study groups were obtained. Having this grouping idea is because the investigation aimed to obtain an overall assessment on the presence of different approaching behaviour of drivers in this junction at the time intervals specified in this study. It was about 5 seconds to the start of the amber phase.

In case there reported significant differences in approaching speed from 2 seconds onward, the investigation will then specifically focus on the approaching manoeuvre of drivers at that particular time interval. In addition, to obtain data samples for establishing the control group, 113 more vehicles running across the studied junction at the times prior to the start of signal phase C were recorded. They were all categorized into a single control group to form comparison pairs for the hypothesis set up in this study. The summary of observation records under the case study and control groups is shown in Table 5-2.

Table 5-2 Summary of the data under the case study and control groups

	Factors	Attributes	Count	Mean / std
Case study group (N = 301)	*Green remaining time less than*	*1 second*	*30*	
		1.5 seconds	*60*	
		2 seconds	*99*	
		2.5 seconds	*135*	
		3 seconds	*162*	
		3.5 seconds	*177*	
		4 seconds	*190*	
		4.5 seconds	*301*	
	Approaching speed (kph)	*55 to 50 m*		*44.2 / 10.25*
		50 to 45 m		*43.7 / 10.10*
		45 to 40 m		*43.1 / 9.66*
	Vehicle type	*Private car*	*65*	
		Public bus	*54*	
		Public light bus	*63*	
		Taxi	*47*	
		Goods vehicle	*72*	
Control group (N = 113)	*Approaching speed (kph)*	*55 to 50 m*		*44.4 / 7.64*
		50 to 45 m		*44.1 / 7.16*
		45 to 40 m		*43.9 / 7.11*
	Vehicle type	*Private car*	*26*	
		Public bus	*20*	
		Public light bus	*20*	
		Taxi	*20*	
		Goods vehicle	*27*	

5.3.4 Modeling of decision-making behavior

Under the situation that a driver approaches a signalized junction and faces the start of amber, s/he has to decide either making a full stop at the stop line or passing through the junction. The problem albeit was discussed and resolved by Gazis et al. (1960) with a deterministic model, Zegeer and Deen (1978) attempted to redefine the dichotomous context in a new perspective. They used the Logistic regression model to figure out the area where drivers are likely to confront the response dilemma at junction while facing amber.

Since then, the probabilistic approach has been viewed by many as a more practical tool to simulate the decision-making behavior of drivers at amber and for the evaluation of DZ problem. By using this technique, the relationship among drivers' Stop/Go decisions, approaching speeds, vehicle distances from stop line at amber, and variants like time-of-day and vehicle type could be linked (Gates and Noyce, 2010). This practice has thus been broadly adopted to evaluate the drivers decision-making behaviour at junctions at amber and so the investigation of this study.

In the prior studies, the Logistic regression model has been widely adopted as was originally defined. The regression model, however, might not be appropriate in examining the probability of occurrences of binary choices. Thus, the binary logit model, which is an alternative method to simulate dichotomous situations, is adopted. The calibrated model was then used to simulate the probability of drivers making Stop/Go decision at amber and figure out the area where there is a higher tendency to confront the decision dilemma problem.

However, there is a problem that the parameters obtained from the video records cannot be used to form attributes of the two choices. In this regard, a parameter termed generalized distance that was previously proposed to overcome the captioned problem was deployed (Tse et al., 2011). Beside the aim to take up the binary logit model, this parameter has an extra function. It can be used to quantify the satisfaction levels of drivers in making Stop and Go decisions at amber. The idea is similar to that of quantifying the satisfaction levels of travellers in deciding modal choices in a transport system. In the following paragraphs, formulations of the parameter and how it applies in quantifying the decision-making behavior of drivers are described.

As was proposed, the parameter is formulated on the basis of the GHM model (Gazis et al., 1960). The satisfaction level of a driver making Stop decision while the amber phase commences, termed gen_dist_{stop} is determined by the subtraction of vehicle distance from stop line and its minimum safe stopping distance. In case the driver opts to Go at amber, the parameter termed gen_dist_{go} is determined by the subtraction of its maximum safe passing distance and vehicle distance from stop line as follows,

$$gen\_dist_{stop} = D - X_c = D - \left(v_o \delta_{stop} + v_o^2 / 2a_{stop}\right) \qquad \text{Eq. 5-1}$$

$$gen\_dist_{go} = X_o - D = \left[v_o \tau + 0.5 a_{go} \left(\tau - \delta_{go}\right)^2\right] - D \qquad \text{Eq. 5-2}$$

where

τ is amber time of the signalized junction, i.e. 3 seconds;

v_o is vehicle approaching speed (m/s);

X_c, X_o, D is maximum safe passing distance, minimum safe stopping distance and vehicle distance from stop line at amber onset (m);

$\delta_{stop}, \delta_{go}$ is driver reaction time to make STOP/GO decision while facing amber, 1 second (e.g. Bonsall et al., 2005; Papaioannou, 2007);

a_{stop}, a_{go} is maximum deceleration rate for stopping 5-0.213v_o m/s^2 and maximum acceleration rate for passing 5 m/s^2 (Gazis et al., 1960; Traffic Detector Handbook, 2006; Wei et al., 2009; Li et al., 2010).

The numerical example below illustrates how the variables gen_dist_{stop} and gen_dist_{go} apply in quantifying drivers' satisfaction levels in making Stop and Go decisions at amber. Assuming that a driver with operating speed 45 kph approaches a junction and faces the start of amber at 20 m from stop line, its satisfaction levels in choosing the two alternatives, i.e. gen_dist_{stop} and gen_dist_{go} are given as follows,

$$gen\_dist_{stop} = 20 - (45/3.6)^2/2/[5 - 0.213 \times (45/3.6)] \\ -(45/3.6) \times 1.0 = -25.9m$$

$$gen\_dist_{go} = [(45/3.6) \times 3 + 0.5 \times 5 \times (3-1)^2] - 20 = 27.5m$$

Regarding the results, the positivity indicates the appropriateness of the corresponding decision. In addition, the magnitude is a metric unit showing the degree of appropriateness of taking that particular decision at amber. In case a driver approaches the junction with the same speed but faces the start of amber at 20 more meters from stop line, the value of gen_dist_{go} becomes 7.5 m instead. Its satisfaction level in making Go decision is thus dropped remarkably, even though the gen_dist_{go} remains as positive. In such a way, the propensities of drivers in making Stop/Go decision at amber could be quantified; their behavior can be compared in a numerical sense.

To obtain the model of drivers' Stop/Go decision-making behavior at amber, a total of 20-hour video was filmed during weekdays at daytime and nighttime at the junction. On top of the 301 records obtained in the previous analysis, an extra 210 records were obtained as to enlarge the sample size for modeling. Parameters describing the traffic conditions of subject vehicles at the times amber signal commences including vehicle speed, distance from stop line, and variants like vehicle type and vehicle platooning condition were obtained.

Of the 511 records, 275 of them opted to clear the junction at amber with grand mean speed 45 kph. It is imperative to highlight that there were 190 drivers maneuvering over design speed limit while approaching, in which 119 of them cleared the junction finally. Table 5-3 shows the summary of data used for the model calibration with the utility function as follows,

$$U_{stop} = C + \beta_{stop} \times ln(gen\_dist_{stop}) \qquad \text{Eq. 5-3}$$

$$U_{go} = \beta_{go} \times ln(gen\_dist_{go}) \qquad \text{Eq. 5-4}$$

Table 5-3 Summary of data collected at the studied junction at amber

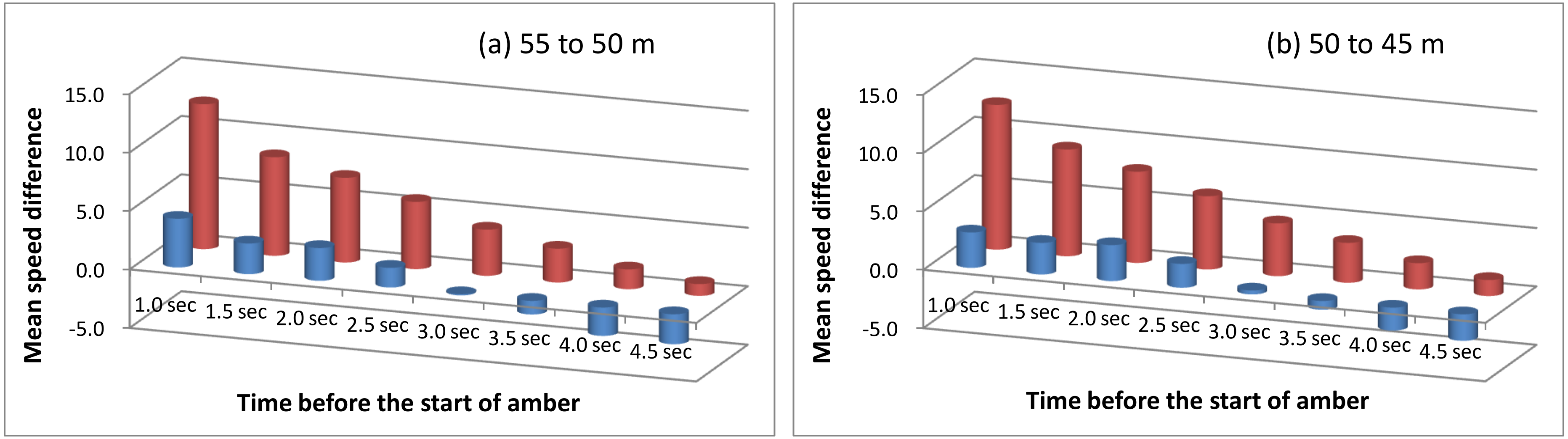
Factors	Attributes	Count
Decision	*GO*	*275*
	STOP	*236*
Speed (kph)		*Mean = 45.6 kph*
		Std = 14.57 kph
Speeding	*1 = Yes*	*190*
	0 = No	*321*
Distance (m)		*Mean = 26.9 m*
		Std = 14.67 m
Ln(gen_dist) (m)	*GO*	*Mean = 2.478 m*
		Std = 1.577 m
	STOP	*Mean = -2.129 m*
		Std = 2.787 m
Vehicle type	*Private car*	*104*
	Public bus	*90*
	Public light bus	*107*
	Taxi	*66*
	Goods vehicle	*144*
Vehicle platooning	*Leading*	*79*
	Following	*81*
	Individual	*262*
	Adjacent	*89*
Pedestrian waiting to cross the junction	*1 = Yes*	*407*
	0 = No	*104*

5.4 Results

5.4.1 Approaching maneuver

At first, an overall evaluation on the differences in mean approaching speeds between the case study and control groups was conducted. The results of eight comparison pairs, i.e. five seconds to the start of amber, were depicted in Figure 5-3. It was found that with respect to the drivers observed during signal phase B, drivers tended to approach the junction with an even faster operating speed, particularly at 2.5 seconds prior to the start of amber. The speed differences, however, became statistically insignificant after 3 seconds.

After the behavioural difference of drivers was confirmed, the focus moved onto the five individual driver groups. Their approaching speeds under the 2.5 seconds case study group were compared to those under the control samples. Table 5-4 shows the results of the estimated mean speed differences and the 95% confidence intervals of each group. With respect to the time in the middle of signal phase B, taxi and public light bus drivers found to have significant approaching speed changes at the time 2.5 seconds to the start of amber. The public bus drivers, which are the main focus of this investigation, also reported to have some changes in approaching speed, but neither of them was statistically significant at the 5% level. Goods vehicle drivers which have been generally reported as reckless in driving, however, had slight changes in approaching speed at the interested time.



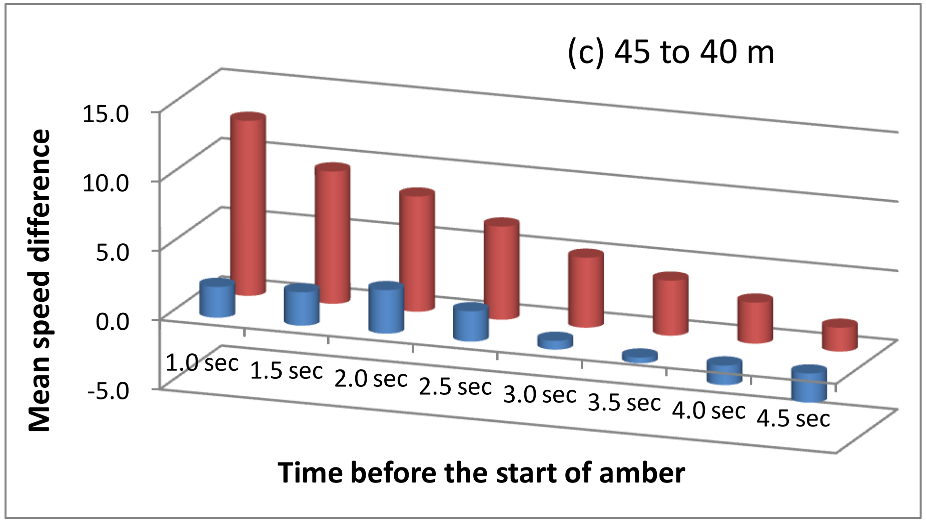


Figure 5-3 95% Confident Intervals of mean difference in approaching speed between control and case study groups at (a) 55 to 50 m; (b) 50 to 45 m; and (c) 45 to 40 m from stop line.

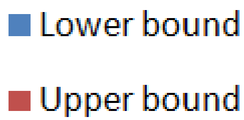


Table 5-4 Mean approaching speed differences between the case study and control groups of individual groups of drivers

	Public bus				Taxi			
At…	*Est diff*	*95% CIs*		*P-value*	*Est diff*	*95% CIs*		*P-value*
55 to 50 m	*6.95*	*-2.32*	*16.22*	*0.116*	*7.80*	*2.42*	*13.17*	*0.005*
50 to 45 m	*5.46*	*-3.95*	*14.86*	*0.205*	*7.28*	*2.01*	*12.55*	*0.008*
45 to 40 m	*5.89*	*-4.17*	*15.94*	*0.202*	*6.74*	*1.43*	*12.06*	*0.014*

	Public light bus				Goods vehicle			
At…	*Est diff*	*95% CIs*		*P-value*	*Est diff*	*95% CIs*		*P-value*
55 to 50 m	*4.59*	*1.55*	*7.62*	*0.004*	*0.61*	*-3.32*	*4.55*	*0.756*
50 to 45 m	*5.23*	*1.86*	*8.60*	*0.003*	*0.99*	*-3.04*	*5.02*	*0.625*
45 to 40 m	*5.40*	*1.70*	*9.10*	*0.005*	*1.10*	*-3.50*	*5.71*	*0.633*

	Private car			
At…	*Est diff*	*95% CIs*		*P-value*
55 to 50 m	*2.40*	*-1.60*	*6.40*	*0.234*
50 to 45 m	*4.15*	*-0.31*	*8.61*	*0.068*
45 to 40 m	*5.48*	*0.55*	*10.41*	*0.030*

In the above hypothesis, private car, taxi and public light bus drivers reported of significant changes in approaching speed at the impending end of green signal. One might then question as if the reported changes were merely the practices of the minority of drivers in junction, leading to a large variation of speed, i.e. a large variance within the focus group. To address the issue, an F-test was conducted with the conclusion that the variances of approaching speeds between the control and case study groups are not differing from each other at the 5% level. That means the changes would not be contributed by the minority of drivers, who use to drive aggressively at the junction studied.

5.4.2 Stop/Go decision-making

Second, a total of five binary logit models regarding drivers' Stop/Go decision-making behavior at amber at the junction were obtained. The calibration results are shown in Table 5-5.

Table 5-5 Results of the calibrated binary logit models

	β_{go}	β_{stop}	C	Adj Rho sq.	N
Public bus	*42.5*	*-5.77*	*13.8 **	*0.490*	*90*
Taxi	*22.6*	*-4.87*	*5.78*	*0.276*	*66*
Public light bus	*22.4*	*-5.00*	*5.38*	*0.400*	*107*
Goods vehicle	*22.0*	*-2.18*	*7.10*	*0.398*	*144*
Private car	*24.1*	*-0.651*	*8.34* [#]	*0.383*	*104*

All of the coefficients are significant at the 5% level unless specified; * significant at 10% level; [#] significant at 20% level.

As for easing the comparison, probabilities of drivers in making Stop decision at amber against vehicle distance from stop line are depicted in Figure 5-4. The slope of the stopping curves reveal that public bus, public light bus and taxi drivers had comparatively high consistencies in making stop/go decision at amber in the study junction. They are thus expected to have lower chances to confront response dilemma when they face the start of amber phase while approaching the junction.

According to the definition by Zegeer and Dean (1978), DZ boundary is an area where a driver has 10% to 90% chance to make a stop at the stop line or clear the junction while it faces amber light. For the junction considered in this study, the DZ boundaries of taxi and public light bus drivers were about 45 to 50 m. The DZ boundaries of public bus, goods vehicle and private car drivers were about 41 to 45 m, 32 to 48 m and 23 to 44 m, respectively. The longest boundary reported in this junction, i.e. the boundary of private car driver, was about 1.6 to 3.1 seconds estimate travel time to the intersection (TTI). Comparing to the results reported in the literature and in the US, for instance, Li et al. (2010) which was 3.2 to 5.3 seconds estimate TTI. The dilemma response problem in the junction studied in Hong Kong appears to be less severe. It should be noticed that the signalized junction studied in the US was with design speed limit of 50 mph i.e. 80 kph and with amber duration of 4.5 seconds differing the one in this study.

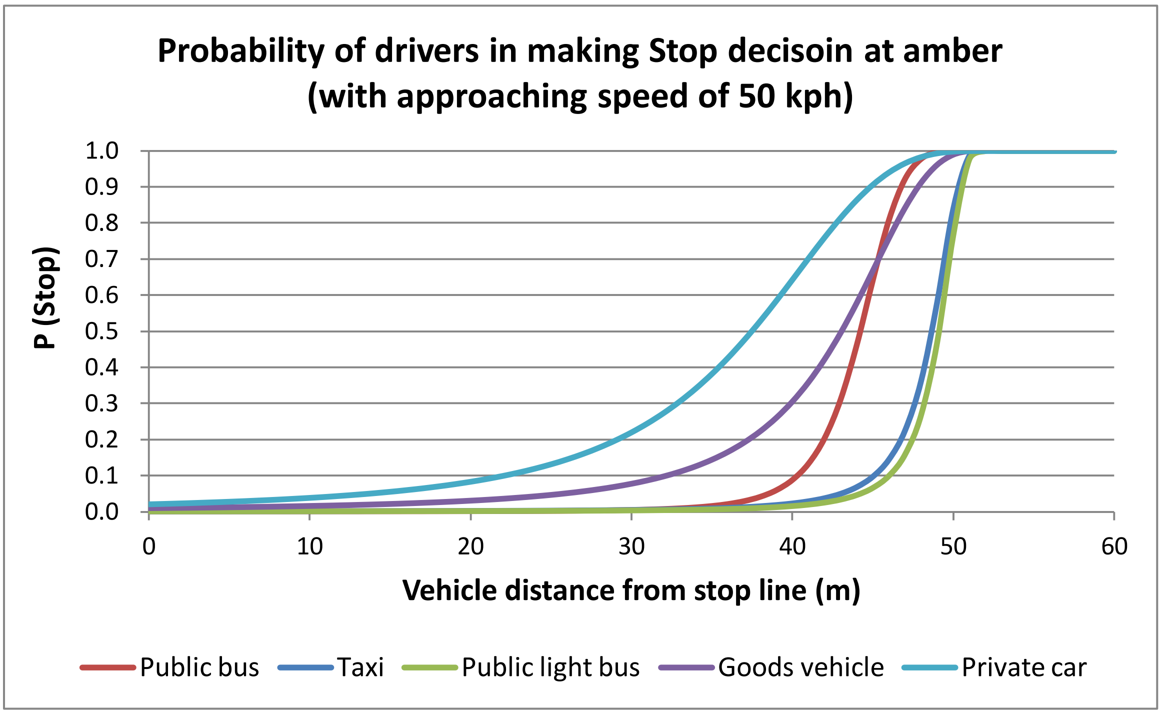


Figure 5-4 Probability of drivers in making Stop decision at amber by vehicle type (with approaching speed of 50 kph)

5.5 Discussions

From the evaluation of bus drivers junction approaching manoeuvre to modeling of Stop/Go decision making, the results consistently indicate that bus drivers had comparatively well performance regarding safety at the study junction. Having comparatively slow approaching speed (which was at or below the design speed limit) and high consistency in decision-making at amber were concluded as good practice to tackle the dilemma response problem and maintain operation safety at junctions (Gazis et al., 1960).

Furthermore, by the experiences of drivers behavioral research, such kind of speedy maneuver would probably raise accident occurrences and worsen crash severity once it happens (Wong et al., 2007; Papaioannou, 2007; Liu, 2007). From the observations in this study, bus drivers appear to be maneuvering at the study junction with appropriately safe manner that the public expects.

Nevertheless, there could be safety concern on the rest of road users. The private car drivers, for instance, attempted to speed up their vehicles while approaching the junction at the time near the end of green signal. Because of this, they might be suffering from a higher degree of decision dilemma problem or even running red-light (Gates et al., 2007; Wei et al., 2009; Hamaoka et al., 2010a and 2010b). Their risky behavior could then affect accident occurrences of the buses when they closely interact with each other in the form of vehicle platoons, which is very common in the high dense road networks in Hong Kong.

In another perspective, the calibrated logit models could be used for revealing the propensity of drivers in making Stop/Go decision at amber. For the case shown in Figure 5-4, an explicit deviation between stopping behaviour of bus drivers and theoretical safe stopping distance, which is 35m from stop line, was revealed. The inconsistency with junction design, to some extent, is an indication showing the need to have pressing effort in reviewing their driving practice on roads. The tendencies in clearing signalized junction at amber should be rectified, as they could subject to higher risks in running red-light or having accidents (Papaioannou, 2007; Retting et al., 2008; Archer and Young, 2009; Elmitiny, 2010).

In Hong Kong, being a bus driver has to fulfill several requirements: (1) holder of driving licence at minimum 3 years; (2) good driving records in safety; and (3) get pass in the pre-job training. However, being a taxi or public light bus driver is far less restricted. The candidate is only required to hold a relevant and valid driving licence, as which these two business are generally operated in personal basis or by small-scaled organizations. Hence, the drivers are seldom selected based upon their abilities, leading to a concern on road safety (Hamed et al., 1998; Albertsson and Falkmer, 2005; Wong et al., 2008). In this study, albeit there was no specific effort exert onto the relationship between employment criteria and bus safety, it is reasonable to believe that the strict selection criteria are imperative to the operators to ascertain the suitability of candidates. Divers who can pass intake tests are surely having better driving skills and hence able to maneuver on roads safely as required.

In fact, the results of this study somewhat support the assertion that bus drivers surpass the others in consistently making Stop/Go decision at amber at the study junction, though their incongruous practice reported with respect to the signal design could be a concern. In which bus drivers could be over confident with their driving skills at the places where they are familiar or feel secure, result in higher risk in accidents. Nevertheless, the great tendencies of bus drivers observed worth attention onto why buses had no accidents in the past five years at the junction, whereas the other drivers, in particular, goods vehicle drivers had a total of six serious and fatal accidents.

For future studies considering the DZ problem, it is recommended to extend the scope of observation have comprehensive investigation onto approaching maneuver of drivers in every signal cycle. This is because in the prior practices, study foci were merely paid onto the times between amber and red phases. This may overlook the correlation between driver speed choice while approaching and their final stop/go decision at amber. In fact, of the 99 record of drivers in the case study group, over 90% with operating speeds higher than that of control samples, opted to clear the junction. This possible relationship seems to infer that drivers might start to think about their Stop/Go decisions at the times before amber, even if there is no signal countdown clock operated on roads (Chiou and Chang, 2005; Hamaoka et al., 2010; Ma et al., 2010). Once the above relation is proven, further efforts should be exerted as to re-define the dilemma response problem may be needed, as it was originally assumed that drivers begin to think about their decisions since they start seeing the amber light. In other words, drivers decision may not be solely a reaction to the change of traffic signal, they may react to an anticipation of the change derived from personal experiences or unique behavior in driving.

5.6 Summary

In this chapter, the initial concern that as if public bus drivers require special care at signal control junctions due to the low manoeuvrability of large-sized buses was addressed. Evaluations of approaching maneuvers and Stop/Go decision-making behavior at amber were done. In order to offer a comprehensive review, the rest of the road users observed in the studied junction were also taken. The records were used as references to compare with the findings in the literature and to figure out behavioral difference of bus drivers to the others during the observation.

From the evaluation, there was an interesting observation that some of the drivers attempted to speed up their vehicles while approaching at the times near the end of green traffic signal, but the bus drivers did not. In addition, the binary logit model was calibrated as for simulating bus drivers' decision-making behavior at amber. Their probabilities in making a stop at amber against operating speed and vehicle distance from stop line was obtained. The curve was then used to identify the areas where the bus drivers are likely to confront the decision dilemma problem while facing amber.

According to the findings of this study, there are two issues that may worth extra attention in the future safety studies on signalized junctions. First, the interesting phenomenon found in this study and its possible relation with driver stop/go decision at amber requires more evidences to support and validate. Its transferability to the other signalized junction is a critical question to answer.

Second, in the evaluation of drivers’ decision making at amber, there was an explicit deviation between stopping behavior and theoretical safe stopping distance, which is 35m from the stop line. The correlation of the drivers' behavior identified in this study to the red-light running or large numbers of fatal and serious accident reported would be critical in improving road safety at signalized junctions.

CHAPTER 6

CONCLUSIONS

In this chapter, the study findings are summarized. Its contributions to the literature, limitations of the research work and recommendations for further investigations considering operation safety of public buses are given.

6.1 Summary of Findings

As initially stated, two major issues regarding the operation safety of buses on the bus-only lane and at signalized junction were addressed. This study evaluated road safety implication resulting from the operation of bus-only lane system and bus drivers' response in dilemma zone at signalized junctions.

A review of the past research studies indicates that public buses may not be safe as we anticipated. In particular, at urban thoroughfare and signalized junctions, where there is a high possibility to have frequent interactions with other road users. Conflicts or even collisions are more likely to happen especially under heavily trafficked situations, buses may then subject to higher accident risks than elsewhere.

To cope with the safety concern of buses, the investigation reported in Chapter 4 intended to examine whether the reservation of nearside traffic lane for buses improves their operation safety under the system usage. The first study issue was addressed by examining the hypothesis whether bus-only lanes affect road safety level after the implementation.

It was done by the well-acknowledged observational before-after study technique with the main findings as follows:

- Of the bus-only lanes studied, the bus-only lane system appears to bring decreases in FSS and FS accidents involving public buses. Albeit the system was not originally designed for safety purpose, it may provide an extra safe operation environment for buses by the provision of exclusive traffic lanes for them.
- For the non-bus traffic, there reported insignificant increases in the FSS and FS accidents. The possible negative safety effect was attributed to their even faster operating speed on roads under the operation of bus-only lane. This is because while buses were designated to the exclusive traffic lanes, vehicles on non-bus lanes may have fewer interactions with them. The free flow condition could consequently encourage drivers to maneuver faster, which could then affect accident occurrences or even crash severity.
- In both the individual and pooled analyses, there is generally no strong evidence that the implementations of bus-only lane have deteriorated safety levels of either buses or the non-bus traffic. Except two sites, Wong Chuk Hand Road and Gloucester Road in which significant reductions in bus related accidents were found under bus lane operations. As such, bus-only lane network should be extended with no worry of safety implicatoins if there is demand on such a road-space rationalization policy for buses or even public light buses at the areas where congestion is an

issue.

Chapter 5 evaluated public bus drivers' approaching behavior at a signalized junction, where large numbers of seriously injured or fatal accidents were reported. Their records were analyzed and compared with the rest of drivers observed in the studied junction. The question whether public bus drivers required special care at signalized junctions was answered by assessing their changes in speed near the end of green light and Stop/Go decision-making behavior at amber. The main findings are listed as follows:

- The evaluations of bus drivers' junction approaching manoeuvre at amber signal indicate that bus drivers had comparatively well performance regarding safety at junction. Having comparatively slow operating speed and high consistency in stop/go decision -making at amber, bus drivers have been exercising good driving practice.
- For road users other than buses, there were significant changes in approaching speed at an impending end of green traffic signal, in which has been questioned deriving from their anticipation of amber signal. This anticipation may cause the drivers had higher tendencies to clearing the junction, leading to high occurrences of red-light running and crashes at signal control junctions.
- At the signal control junction studied, bus drivers might not be able to stop within the theoretical safe stopping distance. Their great tendencies in clearing the junction at amber signal require further attention in road safety studies regarding junctions, as it

may lead to red-light running problem.

6.2 Contributions to the literature

Major contributions of this research study are summarized as follows:

- This research study identified the operation safety issues of buses on roads with bus-only lanes and at signalized junction, in which the issues were not adequately considered by the local researchers.
- The evaluation of the bus-only lane system gives an insight into the way of protecting buses from traffic accidents. If the side effect on non-bus traffic regarding safety can be resolved, the system would be a good choice to enhance both service reliability and operation safety of buses.
- In order to make the future bus-only lanes be more conductive to improve safety, the suitability of having such a road rationalization measure should be sought beforehand. Design consideration of the system may include operation hours, future road layouts, presence of illegal/temporary parking as well as complexity of traffic, which were discussed in this study.
- The safe accident records at junction and the well performances of bus drivers provide a new perspective to resolve the situation of dilemma response at signalized junctions during amber. The drivers may make use of the indirect information on site helping

them to make pre-decision while approaching. It somewhat gives a support to the discussions on the cause of decision dilemma problem. The problem seems to be partly attributed to engineering design, i.e. the improperly timed amber duration and the behaviour of drivers (Papaioannou, 2007; Sharma et al., 2010; El-Shawarby et al., 2010).

- In Hong Kong, public bus operators have established strict criteria and systematic trainings for new bus drivers. It aims to ensure their capabilities of operating large-sized buses. The well performance of bus drivers and their safety accident records at the studied junction would probably derived from that. If the correlation is true, there is a need to promote the same recruitment practice for new taxi and public light bus drivers. The policy extension is expected to raise the overall standing of new drivers in regard safety, and it may finally ascertain safe operation of the entire public road transport system.

6.3 Limitations and Recommendations

In every single research work, there should encounter some constraints during the progress and this study is no exception. The limitations and their corresponding recommendations are listed as follows:

- In Chapter 4, creditable information regarding the system launching date is required for evaluating the safety implication brought by the bus-only lane system. However, as documented by the government, only half of the bus-only lanes' records have been kept. This study, albeit making use of all the available records, the results may not be conclusive to reflect the actual safety impact of the exclusive busway system. Hence, it is suggested that the size of study samples including number of site and interested type of accident should be as large as possible when considering a similar topic in future investigations. This is because larger sizes of study samples are expected to minimize the possibility of having bias estimation in some study areas, where only small numbers of accidents were recorded.
- According to the estimation, accident frequencies of non-bus traffic were increased under the operation of bus-only lane. There is thus a pressing need to figure out why they had not been benefited or even had been harmed from that. However, owing to the time constraint and complexity of observing and analyzing traffic conditions on roads with and without the bus-only lane

system, further exploration was not undertaken here. In case the Hong Kong government decides to upgrade the bus-only lane network, this particular type of work has to be done in the design stage as to identify the possible impact on non-bus traffic in regard safety and to figure out the means to resolve the reported safety problems.

- In Chapter 5, the hypothesis as if bus drivers had anticipation to the end of green signal was checked by inferring their behavioral changes at one single junction. Albeit some significant changes in operating speed were reported at the times 2.5 seconds to the start of amber, the results might not be generalized to represent their usual practices around Hong Kong. So, to ascertain the special approaching practice of drivers at signalized junctions, study sites with various signal time settings, road layouts and traffic patterns should be considered. The influences of unobserved attributes like driving behavioral differences at and outside urban areas can thus be distinguished and controlled for in the investigation.
- Furthermore, there is a possibility that the behavioral changes of bus drivers at the signalized junction might not be totally derived from their anticipations to the change of traffic signal. In order to validate the assumption, follow up interviews with drivers who found to have behavioral changes while approaching or laboratory study by the use of driving simulator would be required. This aims to identify how and why the drivers had such differences in

approaching maneuver at the times near the end of green traffic signal.

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