Traffic Crashes and Traffic Flow Conditions On Auckland's SH1 Southern Motorway

Authors:
Rabia Zafar,
The University of Auckland
Email: rzaf001@aucklanduni.ac.nz

Dr Douglas Wilson, PhD, BE(Civil, Hons), NZCE, MIPENZ, PIARC
Senior Lecturer, Dept. of Civil and Environmental Engineering, University of Auckland
Phone: 64 9 373 7599 ext 87948
Email: dj.wilson@auckland.ac.nz

Presenter:
Rabia Zafar

Abstract

Motorway crashes are critical from a traffic safety as well as an operational point of view. They not only impact traffic safety but also cause non-recurrent congestion. The probability of a crash is significantly affected by traffic flow and environmental weather conditions that sometimes change adversely. This paper will discuss the detailed analysis of road crash data with varying traffic flow. A case study using data collected over 11.28 km section of Auckland's Southern Motorway (SH1) identified factors that included time periods, weather, lighting conditions, week day/week end and others that were over representative. V/C ratios, LOS and trafic regimes under which higher crash rates ocurred are identified. Thirty sec loop detectors' data from the Sydney Coordinated Adaptive Traffic System (SCATS) and Crash data from the New Zealand Transport Agency (NZTA) Crash Analysis System (CAS) database over one year (1st June 2009 to 31st May 2010) were obtained and analysed. This post graduate research study has been undertaken by The University of Auckland in conjunction with the Auckland Motorway Alliance(AMA). The results of this study demonstrated that the highest frequency of crashes occurred in the PM peak period when traffic flow was heavy between 3600 to 4788 vehicles per hour. The crash rates on this motorway section generally increased with increasing traffic volume to capacity (v/c) ratio conditions, up to a maximum of 27.8 crashes per 100 Million Vehicle Kilometres Travelled (MVKT) at 0.7 v/c ratio (corresponding to a Level of Service (LOS) of "D"). This crash rate was more than double the crash rate at 0.5 v/c ratio. The research also surprisingly showed that the crash rate then decreases from this maximum rate to 8 crashes per 100MVK at capacity conditions (v/c ratio = 1.0) being approximately the same crash rate as a v/c ratio of 0.4. Most of the crashes occurred during day time peak and shoulder peak periods and were mostly rear end movement type crashes.

Key words: Crashes; traffic flow; motorways

1. Introduction

The total length of motorways across New Zealand is 365 kms from a total of approximately 94,000kms of road. However this relatively small proportion (0.4%) of motorways carries a disproportionate 3,500 million vehicle kilometres travelled (MVKT). In comparison to other road types, motorways are considered the safest road based travel facility as recently rated 4 stars out of 5 by the KiwiRAP assessment programme (NZAA, 2010); the highest rated roads in New Zealand. However, the social crash cost risk on motorway facilities is still 3.4 cents per vehicle kilometre travelled (NZ MoT, 2003). Being one of the busiest sections of Auckland's Southern Motorway (State Highway 1) crashes (road trauma) are relatively frequent, although in terms of crash rates per 100MVKT it is reasonably low. The southern motorway is the most congested motorway on New Zealand's road network especially in the morning and evening peak periods when the flow is relatively high. The Road safety issues report for Auckland Motorways published by New Zealand Transport Agency for the 2004-2008 period, shows 521 injury crashes and 1806 non-injury crashes in 2008 alone (NZTA, June 2009).

Rear end crashes were found to be of the highest proportions on Auckland Motorways when compared with other motorways in New Zealand. Rear end crashes are to be more expected on divided motorway sections as at grade intersections and opposing traffic are removed and traffic flow is usually more 'event free'. However, as traffic volumes approach capacity with corresponding slower speeds, queues form that can move back along motorway sections that can catch drivers unaware that follow too closely. The large relative speed differences mean that often there is not enough headway distance to allow a vehicle to safely break and slow down or stop prior to hitting the vehicle in front causing a rear end crash. These crash types are often not fatal crashes as the relative speeds at impact are often significantly reduced, and furthermore as the safety devices of the average vehicle fleet increases with time the crash injury severity reduces. This is shown in the numbers of crashes involving minor injuries that has been gradually increasing on Auckland's Motorways in the last decade with complementary reduction of serious injury crashes.

Among the 20 worst black spots (in terms of crash frequency) with 3 or more fatal or serious crashes and 21 or more injury crashes in the Auckland region, 5 are found on the Southern Motorway SH1 2010 (MOT, July 2010). This research paper reports upon a case study of 11.28 km section of Auckland's Southern motorway (State highway 1) outside of recent construction events with relatively good geometric sections. The section starts from St Mark's Road overbridge and ends near the relatively new Highbrook interchange.

The primary aim of this research was to develop a better understanding of the complex relationship between traffic flows and crashes and how changes in varying traffic flow conditions can affect the likelihood of crashes on Auckland Motorway Networks.

The objectives of this study were to:

1) Determine the influence of traffic volume on crash characteristics e.g. crash type and severity.
2) Identify over-represented traffic characteristics that may lead to crashes.
3) Identify over-represented crash time periods of the day
4) Analyse the performance indicators at different time periods and their effect on crashes.
5) Identify the road environment conditions that lead to higher crash numbers.
6) Identify secondary crashes and their specific characteristics.

2. Literature Review

Research prior to 2000 (Aljanahi, Rhodes, & Metcalfe, 1998; e.g.Ceder & Livneh, 1982; Dickerson, Peirson, & Vickerman, 2000; Frantzeskakis & Iordanis, 1987; Garber & Gadiraju, 1989; Hall & Pendleton, 1989; Sandhu & Al-Kazily, 1996; Edward C. Sullivan, 1990; E. C. Sullivan & Hsu, 1988; Zhou & Sisiopiku, 1997) found a strong relationship between accident rates and traffic flows. More recent research relating traffic crashes and traffic flow has been summarised below.

Martin (2002) studied the relationship between crash incidence rate and hourly traffic volume using a collective approach to crash data analysis, elaborating on the effect of traffic on crash severity by taking into account all types of crashes using data for 2000km of French interurban motorways over 2 years. Martin found higher crash rates for property damage only crashes and injury crashes when traffic conditions were the lightest. Furthermore, he found that in the light traffic conditions, crashes were higher on 3 lane motorways than 2 lane motorways and they were also higher during the weekends.

A series of studies (Golob, Recker, & Pavlis, 2008; Golob & Recker, 2003, 2004; Golob, Recker, & Alvarez, 2004) illustrated the relationship between crashes and traffic flow using an individual crash approach under different weather and lighting conditions. The authors developed a tool to assess the changes in traffic safety tendency resulting from changes in traffic flows. They found that under controlled weather and lighting conditions, accident severity is more influenced by traffic volume as compared to speed and noted 21 traffic flow regimes that were dependent upon weather patterns and time of day.

A few researchers have also examined the relationship between crashes and some performance measures e.g volume to capacity (v/c) ratio and Level of Service (LOS). Persaud and Nguyen (1998a) found that crash rates and number of crashes both increase when LOS decreases from A to F. Vizioli and Manar (2002) also studied v/c ratio and its impacts on crashes. Lord et al.(2005) studied the relationship between crashes and traffic volume and found that that not only traffic volume but vehicle density and v/c ratio have a direct influence on the probability and severity of crashes.

3. Study Design

This study is based on traffic and crash data collected for a 11.28 km section of Auckland's southern motorway (State Highway 1) section from St Marks' Road to Highbrook interchange over a one year period from 1st June 2009 to 31st May 2010. Previous researchers have used either a collective (aggregated) crash analysis approach or an individual (disaggregated) approach depending upon the availability of traffic data. Readers are referred to Abdel and Pande (2007) for additional information and an evaluation of the advantages and disadvantages of these two approaches. Both aggregated and disaggregated approaches have been applied in this research. After an investigation into the available traffic flow data on Auckland's Motorways, it was found that the best time period for which the traffic flow data was available in 5min intervals was from June 2009 onwards. Hence, the 1st June 2009 to 31st May, 2010 was selected as the study period for a detailed analysis of traffic flow and crash data.

The principle aim of this study was to determine whether there was a relationship between crashes and traffic flow conditions on Auckland's Southern motorway. Where possible, crash variables outside the scope of this research were managed or controlled by making the following assumptions:

i. Traffic flow can be effected by road geometry and design factors, horizontal curve radii, lane widths, junction ramps etc. To eliminate the influence of merging and diverging traffic at junctions, only traffic flow and crash data on the main motorway carriageway were analysed and all other data related to ramps were discarded.

ii. It was assumed that there were no significant changes in road way cross sectional characteristics for this section e.g. pavement width, shoulder width, length of sections during the analysed time period. This ensured a comparable base for the data.

4. The Data

Crash Data:

Crash data from the New Zealand Transport Agency (NZTA) Crash Analysis System (CAS) database was retrieved for one year (June 2009 to May 2010). The data contains the crashes which are reported to the New Zealand Police. There were 393 police reported crashes that occurred during the selected study period. Table 1 below shows the characteristics of crashes for this motorway section and study period. All injury related and non-injury (property damage only) crashes were analysed in this study.

The exact time of each crash cannot be known with precision. Presumably, the time of crash documented by the police in the Traffic Crash Report (TCR), is obtained from the witness or driver or assumed by the attending Police Officer. The collected data from CAS reveals that 65 percent of crashes have a reported time in minutes that falls exactly on twelve 5min intervals of the hour. To reduce this reporting bias, the time of a crash was rounded to the nearest 5min interval.

Traffic Flow Data:

The traffic flow data was drawn from the Motorway Sydney Coordinated Adaptive Traffic System (SCATS) 30 sec loop detectors. There were 22 detectors on different locations on the motorway section from St Mark's Road to Highbrook Interchange. For the disaggregate analysis method, flow data was collected at the time of each crash occurrence. Volumes varied from 5 to 550 vehicles per 5 minute period (Equivalent to approximately 60 to 6600 vehicles per hour ignoring any peak hour factors).

The traffic flow periods were assigned the following flow range categories for further analysis:

- Very Light flow (0-1199 vph),
- Light flow (1200 to 2399 vph),
- Medium Flow 2400 to 3599 vph),
- Heavy Flow (3600 to 4799 vph, near capacity),
- Very Heavy Flow (4800 to 5999 vph at capacity)
- Flow above capacity (6000 to 6300)

Table 1. Crash Characteristics for the study section (1st June -31st May 2010)

Crash Description	Sample (%)	Crash Description	Sample (%)
By crash severity		**By Road condition**	
Fatal	0.5*	Dry	80
Serious	7.5	Wet	20
Minor	20		
Property Damage only	72		
*There were two fatal crashes over the study period.			
By crash movement type		**By Lighting condition**	
Rear End/Obstruction	69	Light/Overcast	76
Overtaking Crashes	20	Dark/Twilight	24
Lost Control	10		
Other	1		
By day/period			
Weekday	88		
Weekend	12		

Fusion of crash and traffic data:

The traffic volume from the detector closest to the crash location was collected at the time that matched with the crash occurrence time. Instead of taking just one value of traffic flow at the time of the crash, the flow data for the 30mins before a crash occurrence was also archived and the mean of those 6 x 5min values was calculated to take out any unusual peak 5min traffic inconsistencies.

16% of the total crashes were subsequently discarded from further crash analysis as the traffic loop detectors that count the number of vehicles were at the time showing an error with data missing for the time at which the crash occurred. From these, a remaining sample of 328 crashes were selected for further analysis based on having sufficient corresponding valid loop detector data.

5. Exploratory Analysis and Results:

This section discusses the exploratory analysis conducted on the traffic and crash data. A descriptive overview of crash characteristics was presented in Table 1. The summary results found during the study period are herein described.

Effect of Flow on Crash Severity:

During the study period on the section being considered there were two fatal injury crashes, four serious injury and 79 minor injury crashes, the rest being non injury crashes. To study the effect of the traffic flow period on crash severity and the effect of a crash on the corresponding downstream traffic flow, two crashes from each injury severity type that occurred on different sections were selected for a case study. It was found that both fatal injury crashes occurred in the north bound direction on dry roads and the casualties in both crashes were passengers not drivers. The motorway section remained closed or blocked for normal traffic for more than two hours (based on detailed study of the Traffic Crash Reports from CAS) due to the Police having as a legal requirement to isolate the road section to enable a Serious Crash Unit (SCU) investigation. The times of the two fatal crashes were night off peak and am peak occurring in light to medium traffic flow ranges. The social cost of the crashes both in terms of human tragedy and economic effect, not only in loss of economic productivity of the casualty itself and their families, but those caught up in the congestion following is often not fully taken into account.

Similarly the flow data for a sample of the serious, minor and non-injury (property damage only) crashes were studied and it was found that the injury severity of crashes was higher in light to medium traffic flows due most likely to the higher relative impact speeds.

However, in congested and heavy traffic flow periods, the frequency of crashes was higher but less severe and more likely to be property damage only crashes. Moreover, the severe injury crashes are more responsible for blocking downstream traffic and a higher loss of productivity as they have in this case taken more time for traffic to resume to normal. Figure 1 and 2 shows the sudden drop in traffic flow in the lane where the crash occurred and how long it took traffic flow to recover for a fatal crash in the AM peak and for a serious injury crash in the PM peak respectively.

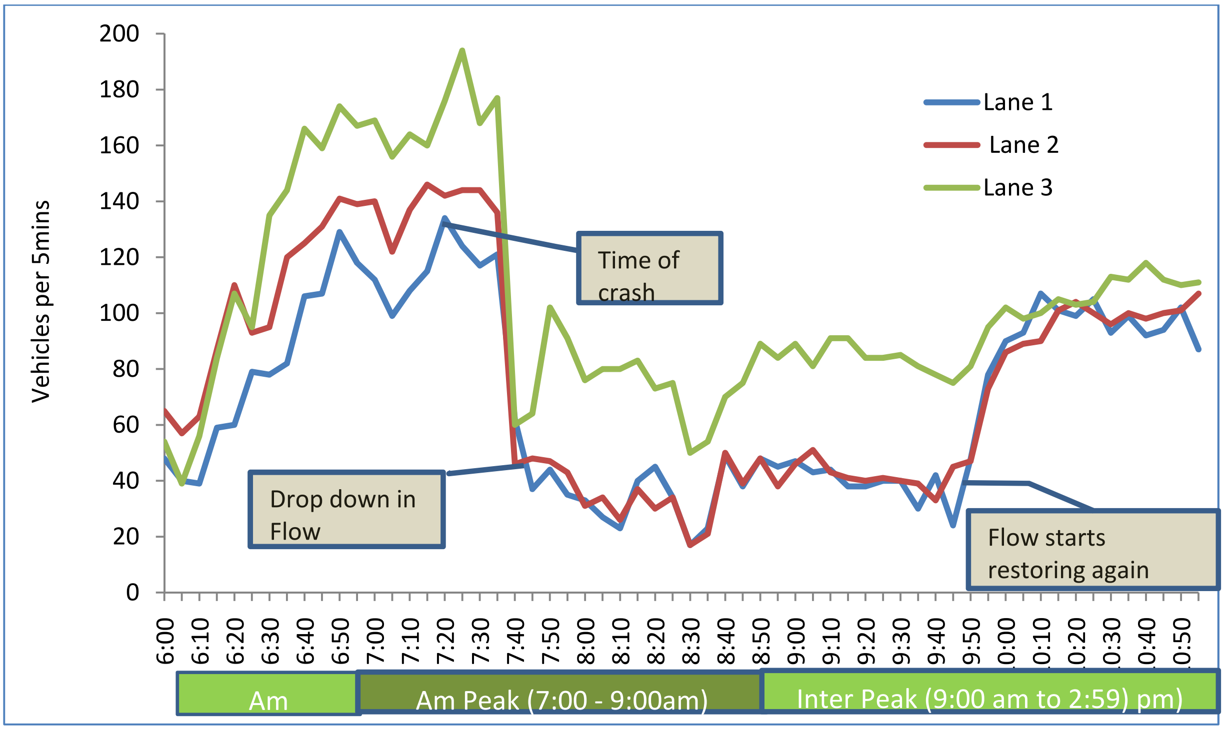

Figure 1: The effect of a fatal crash on Traffic flow on Auckland's Southern Motorway in the AM Peak

Figure 1 above shows that the fatal crash in the AM peak took approximately 2.5hrs for the vehicle and injured to be cleared and for the traffic flow to recover. However, the traffic flow rate did not recover to the same flow rate as the flow conditions prior to the crash, although the flow period was then well into what would normally be described as the inter-peak period. The traffic flow rate of lane 3 was less affected than lanes 1 and 2.

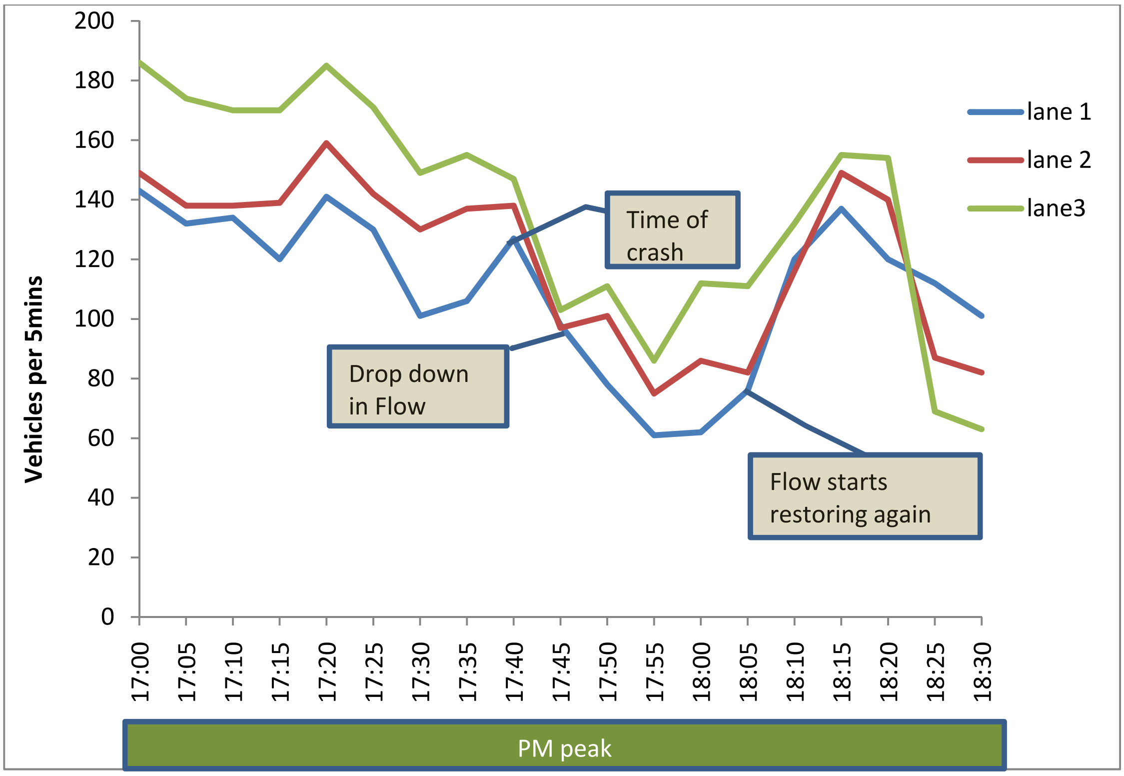

Figure 2: The effect of a Serious Injury crash on Traffic flow on Auckland's Southern Motorway in the PM Peak

Figure 2 shows the effect of a serious injury crash that occurred in the PM peak where the traffic flow was significantly affected for 25 minutes before the traffic flow began recovering. It then took a further 10minutes to recover back to the flow rate experienced prior to the crash. The traffic flow rate of lane 3 was also less effected than lanes 1 and 2.

Effect of Flow in Different Time Periods of the Day on Crashes

To analyse in detail the different time periods which were over represented during crashes, categories were assigned to all time periods of the day. These categories were made by setting one day as a base line. The category allocated for time and the number of crashes that occurred in these time categories are summarised in Table 2.

Table 2. Categories for time periods (24 hours of a day)

Time category	Variables assigned	Hours in each category	Number of crashes in %
Night Off Peak	T_1	0:00 to 4:59 AM	3
Shoulder AM peak	T_2	5:00 to 6:59 AM	2.5
AM Peak	T_3	7:00 to 8:59 AM	11.4
Inter Peak	T_4	9:00 to 14:59 PM	27.2
PM Peak	T_5	15:00 to 17:59 PM	37.1
PM Shoulder Peak	T_6	18:00 to 19:59 PM	12.9
Late Evening off Peak	T_7	20:00 to 23:59 PM	5.8

It was found that the highest frequency of crashes occurred in the PM peak when the traffic flow was heavy between 3600 to 4788 vehicles per hour. Crash rates related to v/c ratio and LOS will be discussed in the following sections.

Crash Movement Type and Traffic Flow

Rear end and over taking crashes were the majority of the crash movement types found during the study period. The data analysis revealed that 90% of total crashes were rear end (damage only) crashes that primarily occurred in the congested traffic flow periods when vehicles were following too closely (headways were too small).

Crashes by Week Day and Weekend

Monday 5AM to Friday 5:59PM was defined as a week day and Friday 6PM to Sunday 04:59PM was defined as a weekend. 42% of crashes occurred on week days during PM peak hours whilst 28% of week end crashes occurred during inter peak and PM shoulder peak hours.

Weather and Lighting Conditions

Crashes are categorised by Police Officers and coded in the CAS database into four types of lighting conditions being bright sun, dark, overcast and twilight.

As would be expected due to higher traffic volumes most of the crashes occurred during day time hours. There is no evidence found confirming any relationship between crash severities with day or night time crash types. Crashes that occurred in fine weather were much higher in proportion than heavy or light rain. The percentage of crashes in wet road surface conditions was 20%. No clear evidence is found for crashes related to weather on the type and frequency of crashes.

Crashes by Traffic Regimes

In order to find traffic regimes in which crashes were more frequent, an analysis sheet was prepared by assigning a unique code to each variable of crash and traffic flow data. A statistical analysis of this data was undertaken using MATLAB (matrix laboratory) as a statistical tool. Out of many combinations of conditions (regimes), the top nine regimes where crashes were identified as being the most frequent were determined and these are summarised in Table 3.

Table 3. Traffic Regimes with higher numbers of crashes in descending priority order

Regime	Flow	No. of lanes	Weekday/ Weekend	Time	Crash Type	Road Condition	Lighting Condition	Weather	Severity
1	Heavy Flow	3	weekday	T5	Rear end	Dry	Bright Sun	fine	PDO
2	Congested Flow	3	weekday	T5	Rear end	Dry	Bright Sun	fine	PDO
3	Congested Flow	3	weekday	T4	Rear end	Dry	Bright Sun	fine	PDO
4	Congested Flow	3	weekday	T4	Rear end	Dry	Bright Sun	fine	Minor
5	Heavy Flow	3	weekday	T3	Rear end	Dry	Bright Sun	fine	PDO
6	Congested Flow	3	weekday	T3	Rear end	Dry	Bright Sun	fine	PDO
7	Heavy Flow	3	weekday	T4	Rear end	Dry	Bright Sun	fine	PDO
8	Heavy Flow	3	weekday	T5	Overtaking	Dry	Bright Sun	fine	PDO
9	Medium Flow	3	weekday	T4	Rear End	Dry	Bright Sun	fine	Minor

Crashes and V/C Ratio

To calculate the volume to capacity (v/c) ratios, the capacity of the motorway section first had to be determined. The basic capacity for motorways from the US Highway capacity manual (HCM, 2000) is 2300 passenger car units per hour per lane. An adjustment factor was applied for the percentage of heavy vehicles to determine the actual theoretical capacity of the project section which came out to 2000pcu per lane per hour i.e 167 vehicles per lane per 5 min period. This value of traffic capacity has also been confirmed with Auckland Motorway Alliance (AMA) staff in the field and the v/c ratio at the time of each crash was then calculated. Figure 3 below compares the crash rate (crashes per 100million vehicle kilometres travelled) with the calculated volume to capacity (v/c) ratio.

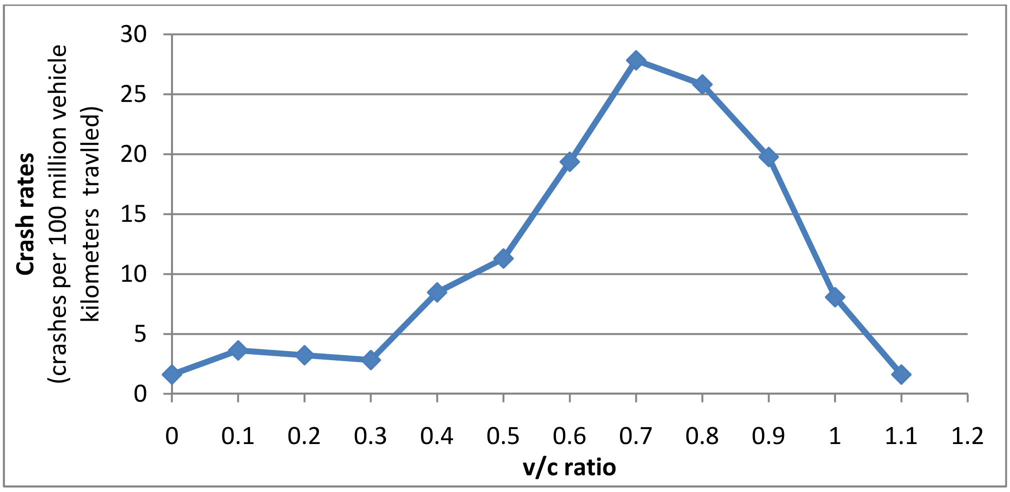

Figure 3: Crash rate in comparison to v/c Ratio

The corresponding v/c ratio when crashes occurred varied from 0.1 to 1.05. It was noted that the highest proportion of crashes occurred where the v/c ratio ranged from 0.6 to 0.95 (refer to Figure 3) with the peak crash rate of 27.8 crashes per 100 MVKT coinciding at 0.7 v/c ratio. This traffic flow period could be described as the shoulder peak periods and is when the greatest difference in relative speeds are most likely. Once the traffic conditions increase past a v/c ratio of 0.7 the crash rate then decreases down to a similar crash rate that occurs at a v/c ratio of 0.4 at a v/c ratio of 1.0.

Level of Service

The v/c ratio has been taken as an indicator of the level of service (LOS) at the time of crash. Using the HCM as a guide line the LOS has been determined at the time of each crash. The LOS varied from A to F. The bar chart in Figure 4 shows that the highest number of crashes (37%) occurred when the motorway was functioning in LOS D conditions.

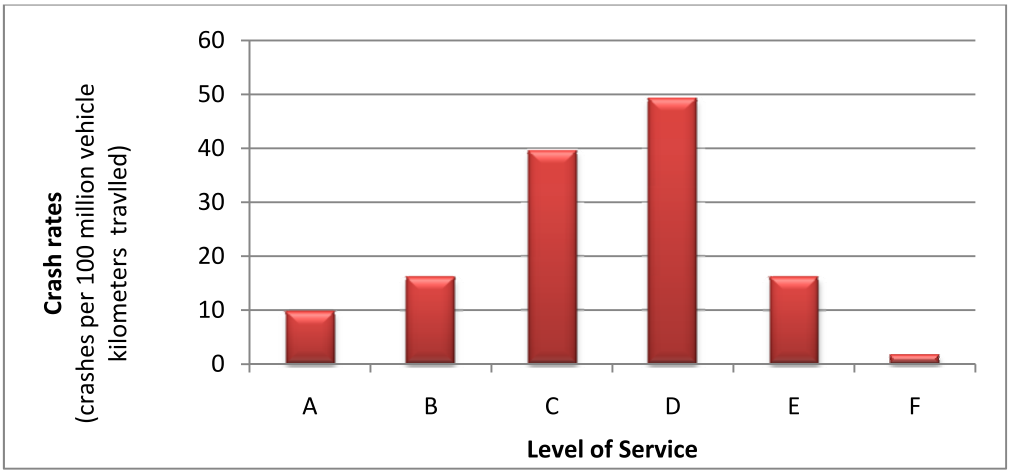

Figure 4: Crash rates in comparison to varying level of service (LOS).

Identification of Secondary Crashes

The analysis of crash times revealed that 3% of the total crashes occurred in the queue that was formed because of a previously occurred crash. The crashes that occurred within 20mins of a previous crash or the distance was no more than 1km away in the same direction of travel were identified in this study as being potential secondary crashes. The traffic crash report (TCR) was then also examined as part of a more detailed investigation of these types of crashes. It was noticed that all of the identified secondary crashes occurred during PM peak hours in the queue formed because of primary crashes and they occurred when a primary crash in the same vicinity distracted the drivers. The secondary crashes were found to be less severe than primary ones.

6. Discussion and Conclusions

This research has provided a better understanding of the impacts of traffic flow on crashes associated with Auckland's Southern Motorway (SH1). An effort has been made to highlight the different time periods of the day and traffic flow conditions that are over represented in crashes in comparison to others. The results obtained show:

a) Non-injury (property damage only) crashes are higher when traffic volumes are higher.

b) A case study demonstrated that fatal crashes can affect traffic flow for approximately 2.5 hours after the crash, whilst serious injury crashes for approximately 30 minutes.

c) The crash rate increases when the v/c ratio increases from 0.3 to a maximum crash rate of 27.8 crashes per 100 MVKT at a v/c ratio of 0.7. The peak crash rate at a v/c ratio of 0.7 is more than double the crash rate with a v/c ratio of 0.5.

d) The crash rates also increases as the LOS decreases from A to D with the crash rate of LOS D being approximately five times greater than LOS A. The crash rate in LOS E being described as in congested conditions drops significantly to being roughly equivalent to LOS B.

e) It was found that predominantly rear end non injury crashes occurred during the PM peak hours when the motorway was operating in congested conditions (LOS D and E). These rear end crashes occurred generally because of stop and go conditions called 'traffic oscillation'.

These results confirm that as traffic flow conditions decrease in level of service, crash rates increase up to a v/c ratio of 0.7. These conditions often occur on the shoulder peak periods. Once the traffic conditions increase past a v/c ratio of 0.7 the crash rate then decreases down to a similar crash rate that occurs at a v/c ratio of 0.4 at a v/c ratio of 1.0. These crashes cause significant social costs to the wider community and economy and are not only directly from the vehicles involved in the crash itself but those that are also caught up in the 'wake' of the crash and the loss of economic productivity to the region / nation. This research demonstrates that crash rates depend upon the time of crash occurrence and/or traffic flow conditions.

The findings of this research are especially significant, relevant and important to the NZTA, the Auckland Motorway Alliance and road safety engineers in the Auckland Region (although also relevant to some other parts of New Zealand and congested networks internationally). Currently, levels of congestion on the Southern Motorway mean that the crash rates are lower due to the significant periods of the day that traffic travels in traffic conditions that relate to a v/c ratio greater than 0.8. When the alternative western ring route that includes the SH20 Waterview project is completed and network congestion levels even out, it is likely (at least for a while) that greater time periods of the day for the southern SH1 motorway will operate in less congested conditions (i.e. v/c ratio will decrease to approximately 0.7 for greater periods of the day). This will have the adverse effect that road crashes and likely crash injury severity (without further intervention) will increase during these periods thereby increasing crash frequency and aggregated crash rates for the Auckland Southern Motorway. Given that this will go against current Ministry of Transport Safer Journey targets specific road safety countermeasures will need to be employed (e.g. greater use of Intelligent Transport Systems) to counter this effect.

Acknowledgements

This research was made possible with generous assistance and cooperation of staff of the New Zealand Transport Agency (NZTA) & the Auckland Motorway Alliance (AMA). The authors would like to say our special thanks to Mr. Gary See from the Traffic Management Unit (TMU) for providing the access to the required data.

References

Aljanahi, A. A. M., Rhodes, A. H., & Metcalfe, A. V. (1998). Speed, speed limits and road traffic accidents under free flow conditions. *Accident Analysis and Prevention, 31*(1-2), 161-168.

Ceder, A., & Livneh, M. (1982). Relationships between road accidents and hourly traffic flow. I. Analyses and interpretation. *Accident Analysis and Prevention, 14*(1), 19-34.

Dickerson, A., Peirson, J., & Vickerman, R. (2000). Road accidents and traffic flows: An econometric investigation. *Economica, 67*(265), 101-121.

Frantzeskakis, J. M., & Iordanis, D. I. (1987). VOLUME-TO-CAPACITY RATIO AND TRAFFIC ACCIDENTS ON INTERURBAN FOUR-LANE HIGHWAYS IN GREECE. *Transportation Research Record*, 29-38.

Garber, N. J., & Gadiraju, R. (1989). Factors affecting speed variance and its influence on accidents. *Transportation Research Record*(1213), 64-71.

Golob, T. F., Recker, W., & Pavlis, Y. (2008). Probabilistic models of freeway safety performance using traffic flow data as predictors. *Safety Science, 46*(9), 1306-1333.

Golob, T. F., & Recker, W. W. (2003). Relationships among urban freeway accidents, traffic flow, weather, and lighting conditions. *Journal of Transportation Engineering, 129*(4), 342-353.

Golob, T. F., & Recker, W. W. (2004). A method for relating type of crash to traffic flow characteristics on urban freeways. *Transportation Research Part A: Policy and Practice, 38*(1), 53-80.

Golob, T. F., Recker, W. W., & Alvarez, V. M. (2004). Tool to evaluate safety effects of changes in freeway traffic flow. *Journal of Transportation Engineering, 130*(2), 222-230.

Hall, J. W., & Pendleton, O. J. (1989). Relationship between V/C ratios and accident rates. *Relationship between V/C Ratios and Accident Rates*.

Lord, D., Manar, A., & Vizioli, A. (2005). Modeling crash-flow-density and crash-flow-V/C ratio relationships for rural and urban freeway segments. *Accident Analysis and Prevention, 37*(1), 185-199.

Martin, J.-L. (2002). Relationship between crash rate and hourly traffic flow on interurban motorways. *Accident Analysis and Prevention, 34*(Compendex), 619-629.

MOT. Retrieved 12thJuly 2010, from http://www.transport.govt.nz/research/Pages/Crashblackspots.aspx

New Zealand Ministry of Transport (2003), 'Government's Road Safety to 2010 strategy'.

NZTA. (June 2009). briefing notes-Road Safety Issues Auckland Motorways. Retrieved 14th July, 2010, from http://www.nzta.govt.nz/resources/road-safety-issues/auckland-motorways/motorways-2009.pdf

Persuad, N. (1998 a). *Safety consideration and capacity analysis.* Paper presented at the Proceedings of the third international Symposius on Highway Capacity, Copenhagen,Denmark.

Sandhu, B., & Al-Kazily, J. (1996). Safety impacts of freeway traffic congestion. *Annual Meeting of Transportation Research Board*.

Sullivan, E. C. (1990). Estimating accident benefits of reduced freeway congestion. *Journal of Transportation Engineering, 116*(2), 167-180.

Sullivan, E. C., & Hsu, C. I. (1988). Accident rates along congested freeways. *Research Rep. UCB-ITS-RR-88-6*.

Vizioli , M. (2002). *Analyse macroscoppique et microscopique de la relation entre le taux d'accidents et la densite'*. Paper presented at the 37th Annual meeting of the AQTR.

Zhou, M., & Sisiopiku, V. P. (1997) Relationship between volume-to-capacity ratios and accident rates. (pp. 47-52).