Left Turn Treatments at Signalised Intersections
A balance between safety and efficiency

Author: **Marisha Jaglal (Presenter) BE Civil, MEngSt (Transport), GIPENZ**
Project Engineer, GHD Limited
marisha.jaglal@ghd.com

Dr Douglas James Wilson NZCE, BE Civil (Hons), PhD, MIPENZ, PIARC, REAAA
Senior Lecturer, the University of Auckland
dj.wilson@auckland.ac.nz

Acknowledgements The authors would like to acknowledge Peter Evans (NZ Transport Agency) and Tim Booth (GHD Limited) for their guidance and support during the course of this research.

ABSTRACT

In order to transform our cities into more liveable areas, it is becoming increasingly common for local authorities to change road user hierarchy in favour of pedestrians to ensure that their needs are fully considered in all road schemes. This is a fundamental shift in the engineering culture, which traditionally has focused on reducing delays and improving safety for vehicles, and is very much driven by urban design aspirations and an assumption of improved safety rather than robust and scientific understanding of the actual effects.

In Auckland, two such strategies being implemented to improve priority for pedestrians at signalised intersections include:

- the elimination of slip lanes, and
- the increased use of left turn red arrow protection.

Although these treatments are aimed at benefiting pedestrians, careful consideration needs to be given to the overall effects on intersection safety and efficiency, which may far outweigh the initial safety benefits expected.

Presently, there is minimal research on evaluating the performance of these strategies and little guidance on the selection of the most appropriate treatment. This paper provides a summary of the results obtained from a Masters Research Project undertaken in collaboration with the University of Auckland on nine intersections in the greater Auckland area. One of the nine intersections, Mayoral Drive / Wakefield Street which is located in Auckland's central business district, has been used as a case study for this paper to highlight to practitioners the full effect of these treatments on intersection safety and efficiency.

The results of the study demonstrated that intersections should be evaluated individually on a 'case by case basis' as opposed to adopting 'blanket' use of the above treatments in the interest of pedestrian safety.

INTRODUCTION

Background

The elimination of left turn slip lanes and the increased use of left turn red arrow protection are fast becoming requirements at most signalised intersections in the Auckland area, in a bid to transform the City into more pedestrian-friendly urban centres.

Although these treatments are aimed at benefiting pedestrians, they can result in longer pedestrian crossing clearances and increased cycle times which can have detrimental effects for both pedestrians and motorists. Careful consideration thus needs to be given to the overall effects this may have on intersection safety and efficiency, which may far outweigh the initial safety benefits expected.

Research Motivation

The primary motivation for this research paper was to highlight to transport professionals the full effect of the elimination of left turn slip lanes and the increased use of left turn red arrow protection treatments at signalised intersections on the overall safety and performance of an intersection and its users. This is to enable more informed decisions to be made on effective pedestrian safety improvements. Another motivation was to provide some practical guidance concerning the appropriate use of left turn policies in an urban signalised intersection context.

For example, left turn slip lanes may be removed at an intersection because it is assumed that pedestrians are safer on a single protected crossing, however this results in a wider intersection area with longer pedestrian crossing distances and increased pedestrian crossing clearance times. The consequences of this are greater pedestrian exposure to traffic as well as extended cycle times which results in more delay for vehicles subsequently leading to driver frustration and increased potential for red light running. In addition, pedestrians arriving at the end of a crossing phase will have a lengthy wait often encouraging non-compliant behaviour.

Whilst the removal of slip lanes and even the use of increased red arrow protection may be duly warranted at sites where there are high volumes of children crossing or at other situations where it would be unsafe not to do so, this paper is more concerned with the “blanket” use of such policies.

Although the intention is to improve pedestrian safety and amenity, the consequential effects of some of these restrictive measures results in a negation of the initial safety benefits anticipated.

Research Objectives

The purpose of this study was to measure and provide factual understanding of the effects of the removal of left turn slip lanes and the use of increased left turn red arrow protection for parallel pedestrian movements at signalised intersections.

Firstly, the effect of these measures on the operational efficiency of an intersection was assessed by undertaking a comparison of the basic intersection performance measures with and without the treatment. Secondly, the effect of the treatment on pedestrian safety and amenity was also assessed as well as the consequential effect of longer crossing distances and cycle times at intersections.

The decision to remove slip lanes or implement pedestrian protection for periods longer than the commonly used 6 seconds is considered to be a significant change in the fundamentals of signalised intersection design. Thus it was anticipated that this study would provide a clear understanding of the trade-offs between pedestrian safety and vehicle efficiency to better guide transport authorities in the design and operation of their urban intersections. The results from this study were then translated into a guideline for the application of left turn treatments at signalised intersections to assist engineers and policy makers with making more informed decisions when selecting best practices and strategies for pedestrian safety and vehicle efficiency.

In summary, the key objectives of the research were as follows:

- To confirm the effects of the removal of left turn slip lanes and the use of red arrow protection at signalised intersections. This was undertaken through analytical traffic modelling and observational techniques that focused on the interaction between left turning drivers and parallel pedestrian movements,
- To develop a "toolbox" of typical intersection scenarios and appropriate left turn treatments at signalised intersections based on road user characteristics and the surrounding environs. This included an investigation into alternative ways of improving pedestrian safety and amenity, and
- To highlight to industry professionals the urban design influence on engineering principles and the desire to achieve a more balanced user hierarchy.

LITERATURE REVIEW

Introduction

To date, past research offers at best minimal evaluation of the various left turn treatments at signalised intersections (Dixon et al. 1999). This lack of attention was evident in the initial literature review conducted in the course of this study. Much of the focus has been on evaluating the safety effects of right turn movements as these involve more conflicting movements than left turns (Perez, R. 1995). Furthermore, of the limited literature available on left turns at signalised intersections, much of it evaluates the safety and operational effects of primarily channelised left turn lanes and does not particularly focus on non-channelised lanes.

Hence there is little research that actually tests the effectiveness of some of the current pedestrian improvements being employed at non-channelised left turn lanes. Treatments such as the removal of slip lanes and the increased use of red arrow protection result in longer cycle times. It is hypothesised in this paper that increased cycle times result in a decrease in safety for not only vehicles but pedestrians. Longer cycle times are also correlated with increased delays and consequently increased driver frustration and pedestrian non-compliance.

This literature review thus focuses on previous studies that attempt to demonstrate and support this hypothesis. To accomplish the objective for this literature review a summary of both NZ and international studies that particularly focus on the interaction between pedestrians and vehicles at signalised intersections was undertaken. In addition, a look at some of the best practices for left turn treatments overseas (or right turn treatments for countries that drive on the right) was reviewed to determine if these could be applied to intersections locally.

In summary, the main findings of this literature review were as follows:

- The literature review revealed the overall lack of knowledge about the operational and safety aspects of some of the pedestrian strategies adopted at left turn lanes explaining, to a large extent, the lack of guidance in practice,
- The study further highlighted the need for further research on the operational and safety aspects of these left turn treatments at signalised intersections,
- The literature review also identified the need to develop a design guideline for the application of the various left turn treatments to effectively determine when they would be best applied. It is anticipated that this literature review and essentially the results of this study will provide the impetus for further research in this area.

The Safety of Channelised vs. Non-channelised Left Turn Lanes

Various studies have been undertaken to demonstrate the beneficial safety effects of channelised left turn lanes with some studies reporting a 50% decrease in left turn collisions (Agent et al. 1996) and between a 20 – 40% reduction of all accidents at intersections (Ogden 1996). According to Elvik et al. (2004) channelised left turning lanes reduce injury accidents at four arm or X-intersections with a 19% decrease of all crashes. Another American study undertaken by Dixon et al. (1999) for the Cobb County Department of Transportation in Georgia also evaluated the safety effects of various left turn configurations at signalised intersections and showed that non-channelised shared left turn lanes had the highest number of right-angle collisions i.e. 50% of all crashes compared to the other configurations. The literature review confirmed that channelised left turn lanes or slip lanes improve safety for motorists to a higher degree than non-channelised lanes. This is predominantly due to the following:

- Slip lanes assist with making the intention of the left turning driver more conspicuous to other road users and can thus result in a much safer intersection layout, and
- It reduces the total number of conflicting movements within the signalised intersection area.

The topic of pedestrian safety at left turns however is not specifically addressed in much of the published literature. It is implied though that channelised lanes may decrease pedestrian safety because of the largely interrupted flow of vehicle traffic and the high speeds at which they travel (Al-Kaisy and Roefaro, 2010; Potts et al. 2005; Fitzpatrick et al, 2006; Kerr and Cheung, 2010) but there is no data to strongly support this. Whilst pedestrian crossings at slip lanes can be hazardous for visually impaired pedestrians (Schroeder et al. 2011), design standards today provide guidance for designing slip lanes where the geometry can assist with lowering vehicle approach speeds and where they can be retrofitted with other treatments such as raised tables to enhance pedestrian amenity. A pedestrian crossing at a slip lane is also only exposed to a single lane of traffic and because the crossing distances are short, exposure to traffic is also very short i.e. 3 to 5 seconds (Evans, 2006).

In Auckland's central business district (CBD), policies such as the removal of channelised turn lanes are being carried out in a bid to improve safety for pedestrians. Danish architect and urban designer Jan Gehl promotes the removal of free left turn slip lanes to help achieve a more pedestrian friendly street layout with improved accessibility at crossings. Whilst this approach may be warranted in high pedestrian activity areas such as the CBD, it becomes quite concerning when these urban design inspired treatments are "blanketly" applied across intersections outside of the city.

Figure 1: Intersection of Queen Street and Mayoral Drive Before and After Removal of Slip Lane (Auckland Council's Public Life Survey Document, 2010)

Issues Associated with Long Pedestrian Crossings

The removal of slip lanes resulting in longer pedestrian crossing distances can be problematic for pedestrians as it increases exposure of pedestrians to traffic potentially reducing safety for them. Similarly, longer crossings require longer pedestrian phases which result in increased cycle times and consequently longer delays for both motorists and pedestrians. Literature on some of the direct effects that result from increasing pedestrian crossing distances as well as increasing pedestrian crossing clearance times at urban intersections is summarised in this section.

Long cycle times:
A complete sequence of signal phases is called a signal cycle (Akcelik, R. 1995) and is defined as:
$c = \Sigma\ (I + G)$

where

c = cycle time
I = Intergreen time
G = the displayed green time for a phase

In NZ, there is no specified acceptable maximum cycle time with some intersections in Auckland having cycle times that range between 100 sec and 150 sec. The HCM 2000 however does provide default cycle length values for signalised intersections in urban areas.

Table 1 Default cycle lengths by area (exhibit 10-16, HCM 2000)

Area	Type Default (sec)
CBD	70
Other	100

Transport for London's (TfL) *SQA-0064 Design Standards for Signal Schemes in London* specifies that the maximum cycle time for a signalised intersection in London should be no greater than 90 seconds – refer to clause 3.4.11.2 below:

At junctions with pedestrian crossing facilities, cycle times should only exceptionally be longer than 90 seconds. Cycle times greater than 120 seconds are deprecated and only acceptable in certain special cases such as at junctions on high speed roads, MOVA sites and where green periods appear twice in a cycle.

Research has shown that increasing the cycle time beyond the default values result in poorer compliance by pedestrians primarily because pedestrians become frustrated as their waiting times become longer (refer Figure 2). Any factor that increases the possibility of pedestrians crossing on the red will negatively impact on their safety. Studies undertaken by both Catchpole (2003) and Keegan and O'Mahony (2003) have confirmed this.

Figure 2: Impatient Pedestrian Crossing on Red (images taken from recorded video footage at Queen St/Mayoral Dr Intersection, Auckland)

Recent research undertaken by Singh et al. (2011) on the safety impacts of different intersection features on cyclists and pedestrians demonstrated that shorter cycle times resulted in an improvement in pedestrian safety. The paper focused on the effects of signal phasing and geometry on the crash risk faced by various road user groups at traffic signals. The study collected data from 238 three-arm and four-arm intersections (corresponding to 889 approaches) from Auckland, Wellington, Christchurch, Hamilton and Dunedin in New Zealand and from Melbourne in Australia and established that increasing the cycle time was shown to result in an increase in pedestrian crashes.

Vallyon et al. (2011) also carried out investigations into a number of intersections in the Auckland, Wellington and Christchurch areas recently with a focus on reducing pedestrian delays. This was achieved by developing and analysing micro-simulation models to model pedestrian and vehicle delays during pedestrian peak or 'lunchtime' hours. Vallyon states that "*a primary means of improving the desirability and safety of pedestrian trips in urban environments is to reduce delays created by traffic signals"*. His study investigated lower cost measures such as operational changes to increase performance rather than expensive infrastructure improvements. It was found during the modelling that extending the green time for pedestrians provided less improvement than reducing the cycle time. This is because extending the green time only benefitted those pedestrians that arrived during the extended phase whereas a reduction in cycle times benefitted everyone arriving outside of the "Walk" interval as they had less time to wait until the next "Walk" phase.

<u>*Increased Pedestrian Waiting Times*</u>

Significant waiting times at intersections can deter pedestrians from walking or lead to unsafe crossing behaviour (Vallyon et al., 2011). In NZ, the Pedestrian Planning and Design Guide recommends an average waiting time of 30 seconds at intersections. Waiting times above this should be avoided as pedestrians may then choose their own gap and try to cross the roadway against the signal. The 30 second average wait time for pedestrians has also been confirmed by studies undertaken by the Transportation Research Laboratory (TRL) in the UK; and by Kaiser, (1994). Care however should be taken when applying average waiting times from other countries to NZ as waiting times depend on a number of factors including weather and lighting conditions as well as traffic and pedestrian volumes.

Vallyon determined in his study that pedestrians in NZ waited an average of 53, 45 and 25 seconds in Auckland, Wellington and Christchurch respectively demonstrating that in Auckland and Wellington pedestrians accepted waiting times greater than the recommended 30 seconds. HCM 2000 also acknowledges that when pedestrians experience delays greater than 30 seconds they become more impatient and engage in more risk-taking behaviour. The higher the delay the more likely it is that pedestrians will cross against the signal. The likelihood of pedestrian non-compliance based on the delay experienced at signalised intersections is shown in the table below.

Table 2 LOS criteria for pedestrians at signalised intersections (exhibit 18-9, HCM 2000)

LOS	Pedestrian Delay (s/p)	Likelihood of Noncompliance
A	<10	Low
B	10-20	
C	20-30	Moderate
D	30-40	
E	40-60	High
F	>60	Very High

Based on the table above, the level of service (LOS) on average for pedestrians waiting at signalised intersections in Auckland is poor i.e. LOS E, with the likelihood of pedestrian non-compliance being high.

<u>*Longer Pedestrian Crossing Distances*</u>

The removal of slip lanes and the inclusion of left turning lanes within the signalised intersection area can result in wider intersection approaches (refer Figure 3) and longer pedestrian crossing distances for pedestrians which can be hazardous. This is because long crossings increase pedestrian exposure to traffic and thus potentially reduce pedestrian safety (Tao et al., 2009). Longer crossings can also make it more difficult for the elderly and mobility-impaired pedestrians to cross within the allocated pedestrian green times.

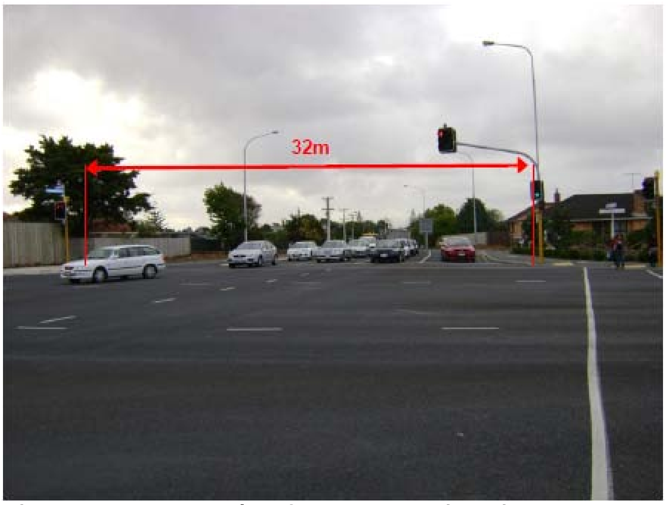

Figure 3: Example of a Long Pedestrian Crosswalk
(Richardson Road / Maioro Street / SH20, Auckland)

Austroads recommends that if a pedestrian crosswalk is greater than 25m in length an additional set of median lanterns be provided as beyond this distance visibility of the pedestrian lanterns on either end of the crossing is compromised. Crossings distances and hence the amount of time that pedestrians are exposed to traffic can be shortened by installing kerb extensions or median islands.

SITE SELECTION, DATA COLLECTION AND METHODOLOGY

Site Selection

As the focus of this paper is on the two previously noted left turning treatments at signalised intersections, the study involved conducting a before/after analysis on intersections that had three lane approaches and that previously had left turn slip lanes. These slip lanes must have been removed and replaced with signalised left turn lanes controlled by red arrows. The intersection configuration under study is illustrated below in Figure 4:

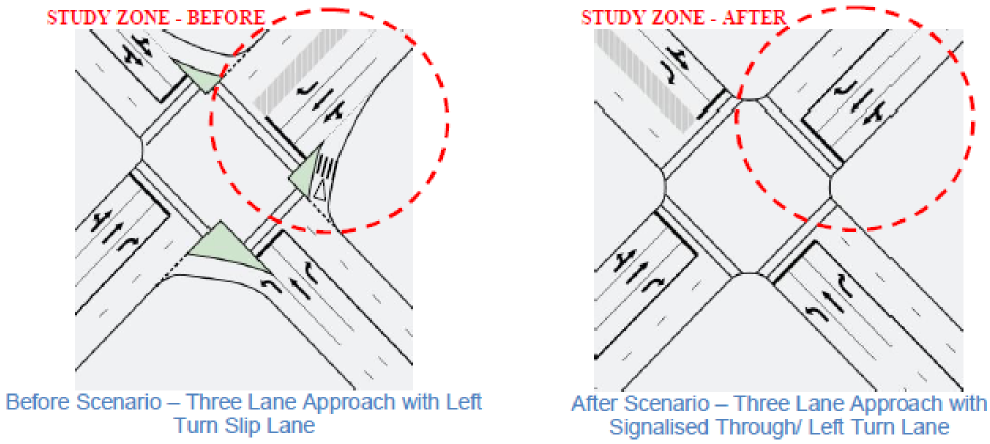

Figure 4: Typical Intersection Configuration

The intersection of Mayoral Drive and Wakefield Street met the above criteria. This intersection is located at the heart of Auckland's CBD area. In the immediate vicinity of the intersection is the

Auckland University of Technology (AUT), a council car park, high-rise apartment blocks and offices. The nature of this surrounding environment generates high numbers of pedestrians throughout the day. In late 2009, the intersection was upgraded which resulted in the existing left turn slip lanes on Mayoral Drive East and both the Wakefield Street approaches being removed and replaced with signalised left turn lanes. Photos of the intersection with and without left turn slip lanes are shown in Figure 5 below.

Figure 5: Mayoral Drive / Wakefield Street – Before and after the removal of slip lanes

Data Collection

There are many types of data that can be collected at signalised intersections however the information gathering part of this study included focusing on the following five types of data:

- Video Survey Footage;
- Pedestrian and Traffic Volume Data;
- SCATs CIS and IDM (Intersection Diagnostic Monitor) Data;
- Geometric Data; and
- Crash Data.

Methodology

The methodology adopted for this paper aimed to provide information to practitioners based on a comprehensive numerical analysis of the data.

To achieve this, data analysis was undertaken in three parts:

1. *A theoretical before / after analysis of the pedestrian improvement measure on the performance of the intersection*

This was undertaken using the traffic modelling software package SIDRA Intersection 5.0 using traffic and pedestrian count data measured in the field. SIDRA models were developed and calibrated as a starting point to replicate how the existing intersection was performing. The base or existing models were then modified to determine how removal of a slip lane or the introduction of red arrow protection (i.e. partial or full pedestrian protection) impacted on the performance of the intersection.

2. *An analysis of the observational data on an approach by approach basis to determine pedestrian and vehicle compliance*
   This was undertaken by analysing video survey data collected during the AM and PM peak periods.

3. *An analysis of the historic crash data for sites where left turn slip lanes have been removed*
   A detailed investigation of the crash history using New Zealand Transport Agency's Crash Analysis System was undertaken to understand whether in fact slip lanes are hazardous to pedestrians.

RESULTS

Theoretical Before / After Analysis – Intersection Performance

Four SIDRA models were developed, using traffic count data and queue length survey information obtained in the field. The models were developed to compare the operation of the intersection with the before and after conditions i.e. with and without slip lanes. The four models developed are as follows:

1. Model 1A – 2007 Existing Base Intersection model with slip lanes
2. Model 1B – 2007 Upgraded Intersection model with slip lanes removed
   Models 1A and 1B simulate the operation of the intersection in late 2007/2008, before the intersection was upgraded, using traffic count and vehicle queue length data collected on Tuesday 4 December 2007.
3. Model 2A – 2011 Existing Base Intersection model with signalised left turn lanes
4. Model 2B – 2011 Option Model with slip lanes
   Models 2A and 2B simulate the current operation of the intersection using traffic count and vehicle queue length data collected on Wednesday 27 April 2011. It was decided to run Model 2B to determine whether the inclusion of left turn slip lanes at the intersection would improve its performance, based on the current 2011 traffic flows.

The results of the models are included below in Tables 3 to Table 7 for the standard 6 signalised intersection measures of performance (average delay, level of service, cycle time, 95% percentile back of the queue, degree of saturation and total CO2 emissions):

Table 3: Comparison of Average Delay and Level of Service (LOS)

	2007/2008 Conditions		2011 Conditions	
	Model 1A (Slip)	**Model 1B (No Slip)**	**Model 2A (No Slip)**	**Model 2B (Slip)**
AM Peak	24.8 sec (C)	48.9 sec (D)	48.4sec(D)	40.1sec (D)
PM Peak	23.2sec (C)	40.4sec (D)	67.3sec (E)	38.9sec(D)

Table 4: Comparison of Practical Cycle Time

	2007/2008 Conditions		**2011 Conditions**	
	Model 1A (Slip)	**Model 1B (No Slip)**	**Model 2A (No Slip)**	**Model 2B (Slip)**
AM Peak	70 sec	110 sec	120 sec	110 sec
PM Peak	70 sec	100 sec	150 sec	110 sec

Table 5: Comparison of 95 Percentile Back of Queue

	2007/2008 Conditions		**2011 Conditions**	
	Model 1A (Slip)	**Model 1B (No Slip)**	**Model 2A (No Slip)**	**Model 2B (Slip)**
AM Peak	77.6 m (Mayoral Dr West)	127.2 m (Mayoral Dr East)	93.8 m(Mayoral Dr East)	73.9 m ((Mayoral Dr West)
PM Peak	50.9 m ((Mayoral Dr West)	81.2 m (Mayoral Dr East)	198.4 m (Mayoral Dr East)	85.9m (Mayoral Dr East)

Table 6: Comparison of Degree of Saturation

	2007/2008 Conditions		**2011 Conditions**	
	Model 1A (Slip)	**Model 1B (No Slip)**	**Model 2A (No Slip)**	**Model 2B (Slip)**
AM Peak	0.678	0.893	0.642	0.799
PM Peak	0.520	0.713	0.982	0.700

Table 7: Comparison of Total CO2 Emissions

	2007/2008 Conditions		2011 Conditions	
	Model 1A (Slip)	**Model 1B (No Slip)**	**Model 2A (No Slip)**	**Model 2B (Slip)**
AM Peak	494.6 kg/h	546.5 kg/h	411.9 kg/h	400.5 kg/h
PM Peak	447.9 kg/h	481.5 kg/h	478.6 kg/h	427.0 kg/h

The 2007/2008 Sidra model results of the Group 1 – High Traffic / High Pedestrian Volume site, Mayoral Drive/ Wakefield Street intersection, indicates that all six measures of performance worsened when the slip lanes were removed and the left turning movements were signalised. This is similar for the 2011 models except for one parameter, degree of saturation, which increased during the AM Peak period. Based on the results, the models generally indicate that the intersection performs less efficiently once the slip lanes are removed and results in increased vehicle delays and decreased intersection capacity.

It should be noted that traffic volumes on Mayoral Drive / Wakefield Street have since decreased from the 2007/2008 volumes. The Sidra models also indicate that the current level of demand at the intersection have since decreased from the time when the slip lanes were removed. This is probably due to the collective pedestrian measures that have been implemented by the local council in the CBD, which aims to shift priority from vehicles to pedestrians. However, the concern with the removal of the slip lanes in high pedestrian volume areas such as the CBD is that although the intention may be to provide priority to pedestrians, resulting in increased delays to vehicles this is likely to cause frustration to drivers and cause them to violate the signals thus increasing the potential for crashes.

Observational Data Analysis

The observational data analysis was carried out in two parts:

- An analysis of pedestrian compliance; and
- An analysis of left turning vehicle compliance.

Pedestrian Compliance

Video survey recordings were undertaken at the intersection and the pedestrian crossing movements were observed and classified during both the AM peak and PM peak periods as follows:

- Compliers: Compliers were classed as pedestrians that waited for the “Walk” interval to begin their crossing movement and completed crossing within the allocated time i.e. they **complied** with the signals.
- Flashers: Flashers were categorised as pedestrians that commenced their crossing movement after the "Walk" interval had expired and during the **flashing** "Clearance" interval but were still able to complete their crossing movement within the allocated crossing time.
- Violator (Type 1): Violators (Type 1) were pedestrians that did not call the phase / press the push button, but looked for an available gap and crossed the road in **violation** of the signal.
- Violator (Type 2): Violators (Type 2) were pedestrians that called the phase / pressed the push button but became tired of waiting for the “Walk” interval and crossed the road in **violation** of the signal.
- Leavers: Leavers were categorised as pedestrians that called the phase / pressed the push button but **left** and had no intention of crossing at the respective crosswalk.

- Dawdlers: Dawdlers were pedestrians that could not complete their crossing movement within the allocated time either because they are too slow i.e. **dawdling** along / started crossing too late toward the end of the flashing “Clearance” interval.

Figure 6 below shows the average pedestrian compliance rate during the AM and PM peak periods.

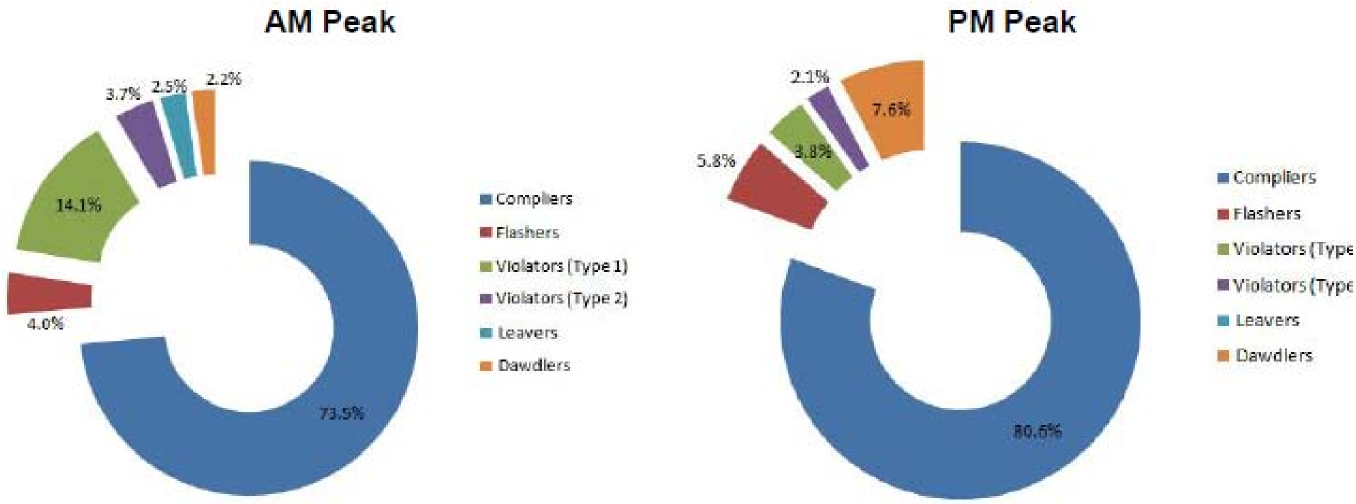

Figure 6: Average Pedestrian Compliance

<u>Vehicle Compliance</u>

Left turning drivers were classified into the following three categories:

- Compliers: Compliers were classed as left turning drivers that waited behind the limit line and only commenced turning once the red arrow had expired i.e. they complied with the red arrow.
- Encroachers: Encroachers were classified as left turning drivers that significantly encroached over the limit line, whilst the red arrow was displayed.
- Red Light Runners: Red light runners were left turning drivers that ran the red arrow i.e. they turned left whilst the arrow was still displayed.

Figure 7 below shows the average vehicle compliance rate during the AM and PM peak periods.

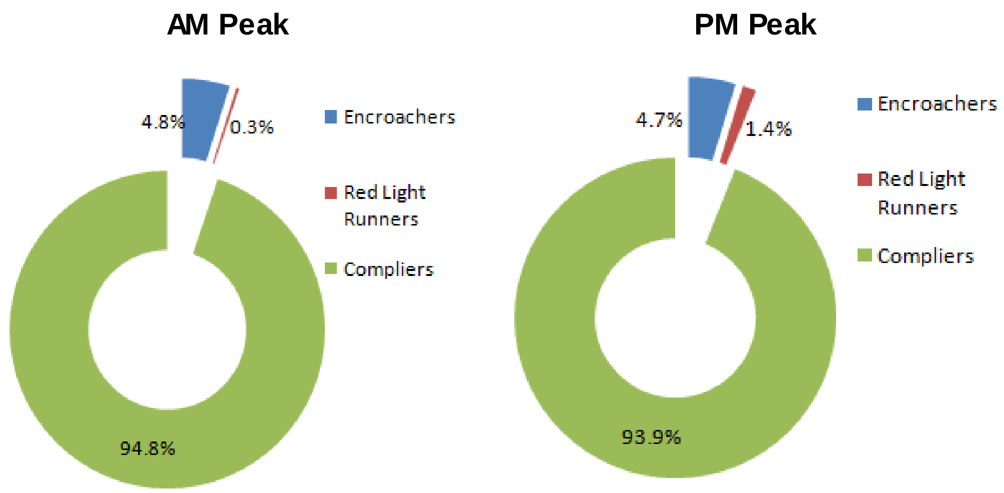

Figure 7: Average Vehicle Compliance

Crash Data Analysis

A 10 year crash history from 2001 to 2010 was analysed for this intersection. The crash results show that in the period before the slip lanes were removed a total of 6 pedestrian crashes occurred at the intersection. An investigation into the traffic crash reports (TCRs) revealed that only one of the six crashes involved a pedestrian crossing at a slip lane and this was attributed to negligence by the pedestrian. The majority of the crashes involved pedestrians crossing outside of the crosswalk lines and against the signal. The data above indicates that a high number of pedestrian crashes is not necessarily related to the slip lane reducing safety of the intersection. There have been no reported pedestrian crashes during the after period, however given that the slip lanes were removed in late 2009 there is insufficient crash information to determine whether removal of the slip lanes have resulted in a safer environment for pedestrians.

CONCLUSIONS AND RECOMMENDATIONS

This study investigated the following two pedestrian improvement strategies at signalised intersections in the Auckland area:

- the elimination of left turn slip lanes; and
- the increased use of left turn red arrow protection.

There is concern that the above treatments although aimed at benefiting pedestrians can result in longer pedestrian crossing clearances and increased cycle times which can actually negate the initial safety benefits expected. It was hypothesised in this paper that the above treatments may have adverse effects on intersection safety and efficiency.

A sample of nine intersections across the Auckland area in both the CBD and suburban areas were analysed as part of a Masters of Engineering Studies (Transportation) Research project to determine if this hypothesis was true. However, only one intersection, Mayoral Drive / Wakefield Street, was used as a case study for this paper. It was noted that there is limited research and guidance in this area in NZ and internationally.

The main study found that there were general trends between extended cycle times and pedestrian and driver non-compliance at signalised intersections indicating that the delay caused by longer cycle times cause increased driver frustration and the potential for greater red light running. It also encourages non-compliant behaviour in pedestrians. Generally, it was found that pedestrians comply with the traffic signals at a rate of 74% and 81% for the AM and PM peaks respectively. On the other hand vehicle compliance was found to be very high, approximately 95% for both peak periods.

Investigations were also carried out on the removal of slip lanes and even the use of increased red arrow protection on the performance of an intersection. It was found that as the level of protection increased or if a slip lane was removed, the average delays at the intersection worsened. In general, most intersection parameters worsened however this was not the case for all, probably indicating that refinement of the Sidra models is required. It could also indicate limitations in the Sidra models or that that further investigations into a larger sample size is required.

Lastly, an investigation into the crash data for the case study intersection was carried out to determine if slip lanes as previously designed and implemented were in fact hazardous. The analysis revealed that there were no inherent safety problems associated with the slip lanes and therefore the removal of the lanes were most probably undertaken on the basis of an assumed safety benefit.

Finally, the learnings from the study enabled a preliminary design guide to be developed to provide guidance to practitioners when selecting the most appropriate left turn treatment. However, it is stressed that good engineering judgement is always required when making this decision. It is recommended in this study that further research be undertaken to confirm the effects of the elimination of left turn slip lanes and the increased use of left turn red arrow protection, with a larger sample database of information.

PRELIMINARY DESIGN GUIDE FOR PEDESTRIAN IMPROVEMENT STRATEGIES FOR LEFT TURNS AT SIGNALISED INTERSECTIONS

A draft preliminary design guide has been developed that brings together the findings of this study. The design guide is intended to highlight to practitioners what pedestrian improvement measures at left turn treatments are appropriate for varying intersection scenarios in the urban environment. When reviewing this guideline, it should be remembered that every intersection has different features and thus the decision to implement a left turn treatment should be based on the site specific characteristics and should not be made based solely on blanket rules or on a checklist.

The following table provides a starting point for practitioners when selecting the appropriate left turn treatment however further research and data is required to support the guidance:

Table 8: Preliminary Design Guideline for Pedestrian Strategies for Left Turns

Typical Scenario	Guidance	Refer to:
Intersections with high volumes of left turning traffic and low volumes of pedestrians.	Provide slip lanes with high entry angles. As a minimum ensure that pram crossings are provided for pedestrians. If warrant criteria met, mark a zebra crossing on the slip lane.	Austroads, MOTSAM and PPDG
Intersections with high volumes of left turning traffic and low volumes of pedestrians (enhanced facility)	Provide slip lanes with high entry angles and zebra crossing atop a raised table. To enhance the facility high friction surfacing in a bright colour can be installed on the slip lane on the approach to the crossing. If high numbers of vulnerable road users are expected, consideration can also be given to the use of part-time signals.	Austroads, MOTSAM and PPDG
Intersections with low volumes of left turning traffic and high volumes of pedestrians.	Consider the use of partial pedestrian protection with Walk + ½ Clearance.	Austroads and TMU Manuals
Intersections with high volumes of left turning traffic and high volumes of pedestrians (enhanced pedestrian protection)	Consider the use of partial pedestrian protection for the Walk. A late start can also be considered. This type of treatment would be suitable for CBD areas and at areas where high numbers of pedestrians are expected e.g. at shopping centres, universities etc. It is not necessary to delay drivers for the Walk +½ Clearance interval as they are already in a heightened sense of alert due the high activity area. Safety in numbers concept also means risk of collisions reduces as pedestrian numbers increase.	Austroads and TMU Manuals Practitioners experience

REFERENCES

1. *Akçelik*, R., (*1995*).Traffic Signals: Capacity and Timing Analysis, Research Report *ARR 123.* Transport Research Ltd
2. Al-Kaisy, A., Roefaro, S., (2010). Channelized Right-Turn Lanes at Signalized Intersection.
3. Auckland City Council, Liveable Arterials Plan.
4. Auckland Traffic Management Unit, (2005). National Traffic Signal Specification.
5. Austroads, (2009). Guide to Road Design Part 4A: Unsignalised and Signalised
6. Dixon, K., Hibbard, J., Nyman, H., (1999). Right-Turn Treatment for Signalised Intersections. TRB Circular E-C019: Urban Street Symposium, Dallas, Texas, 28-30 June, 1999.
7. Elvik, R., Hoye, A., Truls, V., Sorenson, M., (2009). The Handbook of Road Safety Measures, Second Edition.
8. Highway Capacity Manual (2010), Fifth Edition. Transportation Research Board.
9. Land Transport New Zealand (2007). Pedestrian Planning and Design Guide.
10. Kaiser, S. H., (1994). Urban Intersections that Work for Pedestrians: A New Definition for Level of Service. The 73rd Annual Meeting of the Transportation Research Board, Washington, D.C., 1994.
11. Singh, R.; Turner, S. A.; Hughes, T.; Nates, G. D., (2011). Safety at Traffic Signals For Cyclists and Pedestrians. IPENZ Transportation Group Conference, Auckland, March 2011.
12. Vallyon, C., Turner, S., (2011). Reducing Pedestrian Delay at Traffic Signals. NZ Transport Agency Research Report 440.