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EXPERIENCE OF USING FLUSH MEDIANS IN AUCKLAND CITY

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ABSTRACT

This paper summarises research carried out to determine the safety implications of flush medians at 50 Auckland City sites – the flush median implementation dates varied from 1988 to 1994 for which at least five years of recorded crashes were analysed. The before and after crash study showed that large crash cost savings have been achieved with flush median implementation despite small overall savings in frequency. Flush medians decreased fatal, serious and non-injury crashes while increasing minor injury crashes at the study sites. Crash types were affected differently by flush medians, with major savings seen in turning versus same direction (GD), 'pedestrian' (NA and NB) and 'loss of control' crashes (BF, DA, DB) and large increases seen in some rear end (FD) crashes and the turning crashes (JA, JB, HA). Crash reductions were observed to be greatest during night-time periods, with increases in crash costs observed in peak periods. Both narrow and wide medians produced crash savings highlighting the benefit of installing narrow medians where carriageway width restrictions apply. Preliminary guidelines have been developed to ensure flush medians result in crash savings, as half the sites in Auckland City experienced crash increases. Remedial measures have been included to address crashes at pedestrian refuge islands on flush medians.

1. INTRODUCTION

1.1 HISTORICAL OVERVIEW

Flush medians have been introduced extensively in Auckland over the last 10 years. This wide spread implementation followed their perceived successful introduction in Australia one to two years earlier. However, no crash statistics were available at the times of implementation, to support any claims regarding safety improvements.

Flush medians were not introduced in Auckland City specifically as a treatment for problem crash sites, rather they were installed at sites where it was believed operational and safety improvements would result. These flush medians were not the result of black spot, crash route or other detailed studies into crash history or capacity.

The first national study on the safety of flush medians was undertaken by the Land Transport Safety Authority (LTSA) in 1995. The flush medians in the LTSA database were all installed as a result of crash studies where they were recommended as a remedial measure. This study suggested that injury crash savings of 19% could be obtained through implementation of flush medians on undivided roadway sections – therefore, the use of flush medians was further encouraged in Auckland City.

In 1998, *CITY* DESIGN however, produced a report showing much lower crash savings for the 54 Auckland City sites where flush medians had been implemented (Jurisich 1998). It was found that injury crash savings of only 1% had been achieved, with up to 50% of sites having crash increases. This was the first significant study on the safety of flush medians for Auckland. It is believed that the difference observed in the two studies may be explained by the method by which flush medians were introduced in Auckland City. Sites in Auckland City were chosen as stated above, where, as the LTSA sites were problem crash routes where flush medians were suggested as part of the remedial measures to be implemented.

1.2 INVESTIGATION APPROACH

To investigate flush median safety, this project used an observational 'before' and 'after' study of the vehicle and pedestrian crashes. The crash data was obtained from the LTSA Crash Analysis System (CAS) and transferred to a Microsoft Excel spreadsheet for analysis. The historical data for the 54 flush median sites previously studied by *CITY* DESIGN (Jurisich 1998) was collected and grouped into periods of 'before' and 'after' flush median implementation. The flush median implementation dates varied from 1988 to 1994 and at least five years of recorded crashes were analysed. The raw crash data was then 'cleansed' of anomalies such as, sites where road marking had changed, and crashes where patterns had developed for reasons other than flush median implementation. This left 50 sites with 1609 injury and 3447 non-injury crashes.

Two methods of crash analysis were undertaken. The first used historical crash trends to convert crash counts from the period 'before' implementation into estimated crash counts for the 'after' implementation period. This estimate of crashes that would have occurred had no flush median been installed was then compared to the actual counts. A second method used Generalised Linear Modelling (GLM) of crashes, where sites were grouped according to implementation date and compared to a historical control. Differences in trend from 'before' to 'after' provided estimates of the safety effects.

The analysis of crashes was broken up into 5 categories:

1. Assessment of the impact that the implementation of flush medians has had on crash severity;
2. Assessment of the impact that the implementation of flush medians has had on night-time, daytime, peak and off-peak crashes;
3. Assessment of the impact that the width of flush medians has had on safety;
4. Identification of the types of major crash changes;
5. Investigation of the effects of implementation of pedestrian refuge islands on flush median safety

This paper summarises a study undertaken as part of the Transfund research programme - more details are available in Transfund Research Report No. 233 (Segedin et al, 2002).

1.3 ANALYSIS LIMITATIONS

Several difficulties arose in the statistical assessment of the crash data. The most significant involved the formation of a crash control. The choice of control has a significant impact on reductions observed, therefore careful consideration of the regression to mean phenomena, road class selection and remedial site omission was required. In this undertaking, a balance was required between refinement of control and maintaining significant numbers of crashes.

Observational 'before' and 'after' studies also have inherent uncertainties involved (Hauer 1997). Unlike a designed experiment, no control can be exercised in data collection techniques, maintaining an unchanging environment, and treatment application to sites. Therefore careful consideration of influencing factors was required and the associated uncertainty recognised (Hauer 1997).

1.4 FLUSH MEDIANS AS USED IN AUCKLAND CITY

Figure 1.1 illustrates how flush medians are used in New Zealand to separate conflicting streams of traffic and to assist in right turn manoeuvres. Vehicles may use the flush median when turning right onto another road or access way or when turning right onto a road marked with a flush median. The flush median is not allowed to be used for overtaking another vehicle.

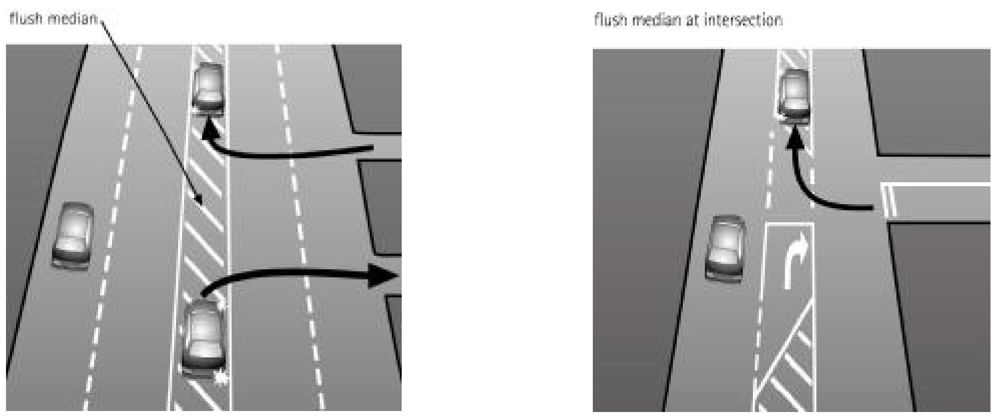

Figure 1.1 Flush Median Operation (Land Transport Safety Authority 2002)

The "flush median" can be marked out differently in other countries. In Great Britain they are called Ghost Islands. In the USA they are effectively Two-Way Left-Turn Lanes.

1.5 BENEFIT / COST EVALUATION

Benefit cost analysis was used to evaluate the reduction in accidents as it is the most direct crash performance indicator (Nicholson 2002) of crash severity. Assessment of all costs provides a more useful tool for comparison of reductions than crash frequency alone.

As noted earlier, the B/C analyses undertaken throughout the research study followed the Project Evaluation Procedures (Transfund 2002), namely, a 25-year time period and a 10% discount rate.

2. CRASH ANALYSIS

2.1 METHODOLOGY

For the 50 sites investigated, crashes at each site were separated into severity classes and 'before' and 'after' periods. The expected number of 'after' crashes was then estimated for individual sites. 'Before' crashes at a site for a severity class were multiplied by a control factor accounting for time trends and time period differences. The observed 'after' crashes at individual sites were summed together and the estimated expected 'after' crashes combined. The percentage change in crashes was then estimated for the group of sites.

The calculation involved is as follows:

$$\text{Percentage change in crashes} = -\frac{(\text{sum of 'expected'} - \text{sum of 'after'}) \times 100}{\text{sum of 'expected'}}$$

where

'expected' is the estimated number of 'after' crashes at a site during the 'after' period, assuming the treatment had no effect.

'after' is the observed number of crashes that occurred in the 'after' period.

2.1.1 Database Formation

A database of 54 Auckland City flush median sections was formed by the Land Transport Safety Authority in 1998 and this data was used by Jurisich (1998). An updated version of this database has been investigated in this current study. The flush median sections chosen were some of the first sites converted in Auckland City and therefore provided the greatest 'after' time periods. Implementation dates for these sites ranged from 1988 to 1994.

Flush medians during this period were usually installed on main roads where it was believed operational and safety benefits would result.

Five year 'before' and 'after' periods were chosen for analysis based on previous LTSA studies. It is held by the Land Transport Safety Authority (1995) that use of significant study periods is a satisfactory estimate of the underlying true crash rate, thus also reducing any possible regression to the mean effect.

Only those crashes that could be affected by flush medians were required in the database, therefore those crashes believed to be non-target were removed. The target crash group was defined by expert opinion and as a result only signalised intersections and their approaches were omitted from the database. No other crash type, period or light condition could be isolated from the potential effects of flush medians.

Further cleansing was undertaken in order to remove locations where problems developed as a result of influences other than flush median implementation.

Using these cost estimates, benefit cost analyses were undertaken for each aspect of the investigation. The analyses followed Transfund's procedures as is outlined in the Transfund Project Evaluation Manual (Transfund New Zealand 2002). Evaluations were undertaken using a spreadsheet program developed by *CITY* DESIGN and accepted by Transfund New Zealand for B/C analysis.

2.1.2 Control Design

One of the most important tasks in crash analysis is to "separate the effect of the treatment from the effect of other factors" (Hauer 1997). This study has attempted to achieve this through use of a control group. The most important assumption in the selection of a control group is, that the change in the factors influencing safety is similar in the treatment and control groups (the compatibility assumption).

This study has made use of a modified LTSA control for crash analysis. In the LTSA control group, all crashes in Auckland City for individual months are summed together. Total crashes are then calculated for a range of five year 'before' and 'after' periods matching the study sites. 'After' crashes are then divided by the 'before' crashes to form a 'control' value. Thus the control value will vary with changing implementation dates. This control group excludes any traffic safety investigation sites, such as black spots, as these may significantly distort the control.

For this study, modifications were made to this control group through the removal of additional road sections. Local roads were excluded from the control group, as flush medians were almost exclusively implemented on collector or arterial roads. This will strengthen the compatibility assumption of the control group, as crash trends at arterial and collector roads could be significantly different to those on local roads. The Auckland City Road Assessment Maintenance Management database (RAMM) of collector and arterial roads was used in order to identify control road sections. Sections of road where flush medians were installed were also removed from the control group, as their inclusion would minimise any differences observed from the 'before' to 'after' periods.

Further refinement of the control group was made by using crash severity to analyse the crash data. In previous LTSA studies, all injury crashes have been combined for controls. However when analysing crash severity, using an all or general injury type for the control group could lead to distortions. Historical trends varied for the four severity classes. Therefore to further increase accuracy, separate control values were formulated for the three crash severity classes. The LTSA method of control used for all injury crashes, tends to overestimate both the reduction in fatal and serious injury crashes and the increase of minor injury crashes.

2.2 RESULTS

2.2.1 Crash Severity

The results are shown in the table below.

Table 2.1 Crash changes by severity

Severity Class	Before Crash	After Crash	Crash Differences	Exp After	% Change	$ Change (million)
Fatal Inj	24	13	-5.1	18.1	-28	-26
Serious inj	226	120	-11.2	131.2	-9	-10.4
Minor Inj	612	565	+37.8	527.2	+7	+2.5
Total Inj	**862**	**698**	+21.5	**676.5**	**+3**	**-33.5**
Non-Inj	1324	1875	-76	1951.3	-4	-1.2
Total	**2186**	**2573**	-54	**2627.8**	**-2**	**-35.2**

* Significant at (0.05)

An overall B/C ratio of 30.2 with 25-year crash savings of $35.2 million was calculated for the implementation of flush medians at the 50 study sites.

The majority of the projected savings for the design life of the flush medians have been in the fatal ($26 million) or serious ($10.4 million) injury accidents costs whereas there have only been a small change in the minor and non-injury accident costs.

2.2.2 'Night-time' and 'Daytime' Crashes

Table 2.2 'Night-time' and 'daytime' crash changes by severity

Sev Class	Time of Day	Before Crash	After Crash	Crash Differences	Exp After	% Change	$ Change ($mill)
Fatal Inj	Night	12	5	-4.1	9.1	-45	-20.7
	Day	12	8	-1.0	9.0	-11	-5.3
Serious Inj	Night	103	52	-8.1	60.1	-13	-7.5
	Day	123	68	-3.1	71.1	-4	-2.9
Minor Inj	Night	216	189	+3.4	185.6	+2	+0.2
	Day	396	376	+34.4	341.6	+10	+2.3
Total Inj	**Night**	**331**	**246**	-8.8	**254.8**	**-3**	**-28.0**
	Day	**531**	**452**	+30.3	**421.7**	**+7**	**-5.9**
Non-Inj	Night	431	612	-21.3	633.3	-3	-0.3
	Day	893	1263	-55	1318.0	-4	-0.9
Total	**Night**	**762**	**858**	-30.1	**888.1**	**-3**	**-28.3**
	Day	**1424**	**1715**	-24.7	**1739.7**	**-1**	**-6.8**

* Significant at (0.05)

The largest crash cost savings were observed in the night-time crashes despite total crashes in this group being much lower than those during the day. From the results, design life crash cost savings of $28.3 million is achieved for night-time crashes and $18.9 million for daytime crashes. The fatal and serious injury crashes have made up most of the crash cost savings observed in both periods, with minor and non-injury crashes contributing relatively low savings.

Flushes seem to be most beneficial in saving accidents at night rather than in the daytime. Again, if you have a night-time accident problem, flush medians are great for reducing night-time accidents.

2.2.3 'Peak' and 'Off-peak' Crashes

The effect of flush medians on peak and off-peak crashes was calculated after separating these two groups. The a.m. peak period was between 7:00

to 9:00 a.m. and the p.m. peak between 4:00 to 6:00 p.m., Monday to Friday. The results of this analysis are listed in Table 2.3.

Table 2.3 'Peak' and 'off-peak' crash changes by severity class

Severity Class	Time of Day	Before Crash	After Crash	Crash Differences	Exp After	% Change	$ Change ($mill)
Fatal Inj	Peak	4	4	+0.8	3.2	+24	+3.7
	Off	20	9	-5.9	14.9	-40	-30.5
Serious Inj	Peak	46	26	-0.5	26.5	-2	-0.5
	Off	180	94	-0.7	104.7	-10	-9.9
Minor Inj	Peak	164	141	-1.1	142.1	-1	-0.1
	Off	448	424	+38.8	385.2	+11	+2.6
Total Inj	**Peak**	**214**	**171**	-0.8	**171.8**	**0**	**+3.1**
	Off-	**648**	**527**	+22.2	**504.8**	**+4**	**-37.8**
Non-Inj	Peak	299	485	+48	437.0	+11	+0.8
	Off	1025	1390	-124	1514.3	-8	-2.0
Total	**Peak**	**513**	**656**	+47	**608.8**	**+7**	**+4.0**
	Off-	**1673**	**1917**	-102	**2019.1**	**-5**	**-39.8**

* Significance at (0.05) level

Cost analysis showed that large cost ($39.8 million) savings occurred in the off-peak period, but the peak period had a small cost ($4 million).

This shows that flush medians are very good in reducing accidents in the off-peak periods but not effective in peak periods.

2.2.4 Median Width

The effect of median width on crash savings was determined by dividing crash sites into widths narrower than 2 m (10 sites) and widths greater or equal to 2 m (40 sites). Table 2.4 summarises the results of the investigation into median width. Median width had a large impact on non-injury crashes. A reduction of 20% was found in non-injury crashes with medians less than two metres wide, compared to an increase of 2% with wider medians.

Table 2.4 Flush median width effect on crash changes by severity class

Severity Class	Median Width	Before Crashes	After Crashes	Expected After	Crash Differences	% Change	$ Change ($mill)
Fatal Inj	<2 m	7	3	5.4	-2.4	-44	-11.9
	≥2 m	17	10	12.7	-2.7	-21	-14.1
Serious Inj	<2 m	63	36	37.5	-1.5	-4	-1.4
	≥2 m	163	84	93.7	-10	-10	-9.1
Minor Inj	<2 m	149	136	126.7	+10.7	+7	+0.6
	≥2 m	463	429	400.6	+29	+7	+1.9
Total Inj	**<2 m**	**219**	**175**	**169.6**	+56	**+3**	**-12.7**
	≥2 m	**643**	**523**	**507.0**	+16	**+3**	**+21.3**
Non-Inj	<2 m	373	402	503.3	-101	-20*	-1.8
	≥2 m	951	1473	1448.0	+25	+2	+0.4
Total	**<2 m**	**592**	**577**	**672.9**	-96	**-14***	**-14.4**
	≥2 m	**1594**	**1996**	**1955.0**	+41	**+2**	**-20.9**

*Significant at 0.05 level

For flush medians less than 2 m wide, the greatest savings have been observed in the fatal crashes while for the wider medians, this has been in the serious injury crashes. A B/C ratio of 55.8 is achieved where flush medians less than two metres wide have been installed with 25-year crash savings of $14.4 million. While a ratio of 24.0 and savings of $20.9 million have been calculated where flush medians greater than two metres have been installed.

2.2.5 Crash Types

Figure 2.2 shows the major changes in crash types. Crash analysis found that the largest reductions occurred with turning versus same direction (GD) crashes, where all three crash severity classes experienced very large savings (>74%). Loss of control crashes (BF, CB, CC, DA, and DB) generally occurred less frequently at flush median sites. Only CC and CB crashes showed some increases in the serious and non-injury classes respectively. Pedestrian crashes (NA and NB) were observed to have reduced in all but the minor injury class. A very large increase was seen in the minor injury category of the FD class (rear end crashes at queues) and consistent increases were observed in all categories for some right turn manoeuvres (JA and LB). No obvious trends were found for the remaining crash types.

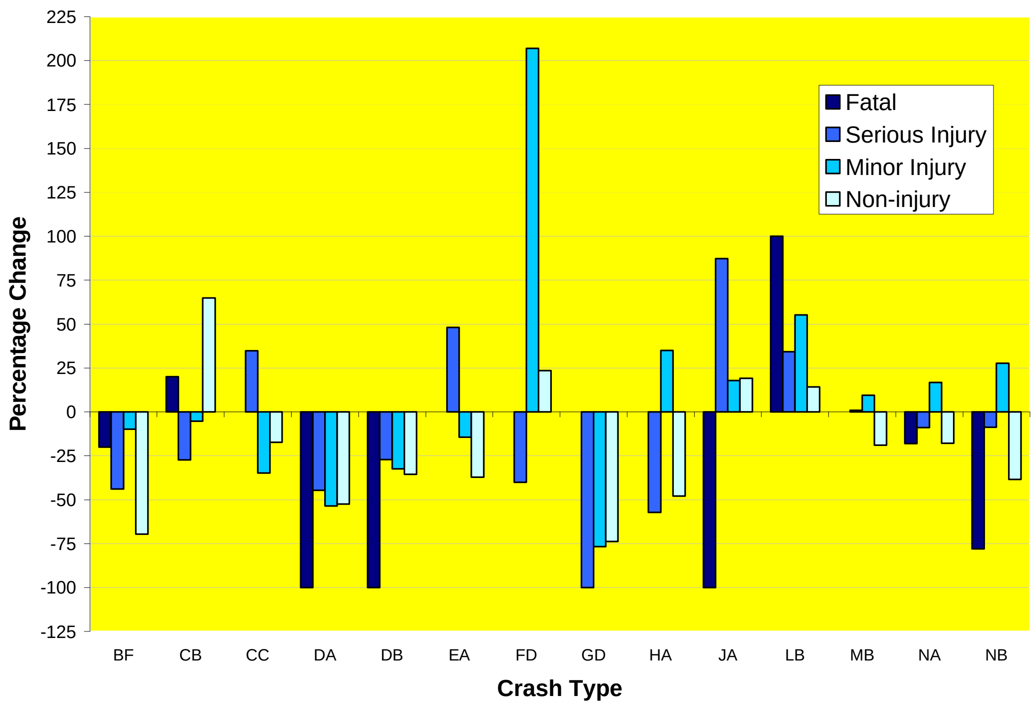

Figure 2.2 Percentage crash changes by crash type

Table 2.5 shows the crash statistics by accident type and highlights the significance of the reductions in frequency through calculation of predicted crash cost savings. The major crash cost savings are seen in the group comprising of 'loss of control' on bends and 'head on' crashes on bends (DA, DB, and BF). Consistent reductions in these crashes resulted in a combined $28.9 million projected saving in fatal, serious, minor and non-injury crashes for the 50 sites studied.

The next largest saving was seen in pedestrian crashes (NA and NB) which resulted in combined projected savings of $15.2 million. The large savings observed has resulted from the reduction in fatal crashes. These two movements made up 11 of the 24 fatals in the 'before' period at the 50 sites.

Rear end type crashes showed some variability within the group. The major saving observed was in the 'rear end near centre line' crashes with projected design life savings of $6.8 million. A small saving was also observed in U-turn crashes (MB). However both 'rear end hitting parked vehicles' (EA) and rear end at queues (FD) showed increases.

'Crossing and turning' crashes resulted in a combined projected increase in costs of $9.3 million. A$1.5 million saving was observed in HA 'right angle' crashes while a combined $10.8 million increase was observed in 'right turning' crashes (JA and LB).

Table 2.5 Crash statistics by accident type

	Crash Type	Severity	Before Crash	After Crash	Expected After	Change % (Number of accidents)	$ Change (million)
Straight – Lost	CB	Fatal	2	2	2	-	-
Control / Head	Off roadway	Serious	14	6	8	-27	-2.2
On	to left	Minor	21	17	18	-5	-0.1
	-$0.3 million	Non-injury	32	77	47	(30) 65*	0.5
	CC	Fatal	0	0	0	-	-
$0.18 million	Off roadway to	Serious	5	4	3	35	0.9
	Right	Minor	18	10	15	(-5) -35*	-0.4
	+$0.4 million	Non-injury	21	25	30	(-5) -17	-0.1
Bend – Lost	BF	Fatal	3	2	2	-20	-1.9
Control / Head	Lost control on	Serious	12	4	7	-44	-3.6
on	Curve	Minor	13	10	11	-10	-0.1
	-$6.2 million	Non-injury	21	8	26	(-18) -70*	-0.6
	DA	Fatal	2	0	1	-100	-6.5
-$28.88 million	Lost control	Serious	12	4	7	-45	-3.1
	turning right	Minor	45	18	39	(-21) -53*	-1.4
	-$12.2 million	Non-injury	90	56	118	(-62) -52*	-1.2
	DB	Fatal	2	0	1	-100	-7.4
	Lost control	Serious	14	6	8	-27	-2.2
	turning left	Minor	26	15	22	-32	-0.5
	-$10.6 million	Non-injury	53	44	68	(-24) -36*	-0.5
Rear End -	EA	Fatal	0	1	0	100	1.7
Obstruction	Parked vehicle	Serious	7	6	4	48	1.6
		Minor	38	28	33	-14	-0.3
	+$2.6 million	Non-injury	103	95	151	(-56) -37*	-0.4
-$1.96 million	FD	Fatal	0	0	0	-	-
	Queue	Serious	3	1	2	-40	-0.6
		Minor	18	49	16	(+33) 207*	2.3
	+$2.3 million	Non-injury	105	198	160	23	0.6
	GD	Fatal	0	0	0	-	-
	Near centre line	Serious	6	0	3	-100	-3.0
		Minor	40	8	34	(-26) -77*	-1.9
	-$6.8 million	Non-injury	93	38	145	(-107) -74*	-1.9
	MB	Fatal	0	0	0	-	-
	U-turn	Serious	12	7	7	1	0.1
		Minor	48	45	41	10	0.2
	-$0.1 million	Non-injury	112	141	174	-19	-0.4
Crossing /	HA	Fatal	0	0	0	-	-
Turning	Right angle	Serious	4	1	2	-57	-1.2
	(70° to 110°)	Minor	20	23	17	35	0.4
	-$1.4 million	Non-injury	52	36	69	(-33) -48*	-0.6
$9.34 million	JA	Fatal	1	0	1	-100	-2.5
	Right turn	Serious	13	14	7	(+7) 87*	6.0
	right side	Minor	63	64	54	18	0.6
	+$4.7 million	Non-injury	160	289	242	18	0.6
	LB	Fatal	0	1	0	100	2.3
	Making turn	Serious	13	10	7	34	2.2
		Minor	45	61	39	(22) 55*	1.3
	+$6.0 million	Non-injury	81	135	118	14	0.2
Pedestrian vs	NA	Fatal	5	3	4	-18	-3.6

	Crash Type	Severity	Before Crash	After Crash	Expected After	Change % (Number of accidents)	$ Change (million)
Vehicle	Left side	Serious	38	20	22	-9	-1.6
		Minor	56	56	48	(+8) 17	0.4
	-$4.8 million	Non-injury	7	9	11	-18	0.0
-$15.19 million	NB	Fatal	6	1	5	(-4) -78*	-9.7
	Right side	Serious	21	11	12	-9	-1.0
		Minor	27	30	24	28	0.3
	-$10.4 million	Non-injury	6	6	10	-38	0.0

*Significant at (0.05)

2.3 DISCUSSION

2.3.1 Severity

The implementation of flush medians at 50 Auckland sites has been found to reduce fatal, serious and non-injury crashes by 28%, 7% and 10% respectively (GLM) while resulting in a 7% increase in minor injury crashes. The associated B/C of 30.2 and a predicted design life crash savings of $35.2 million illustrates that flush median implementation has achieved a very significant economic safety benefit.

Analysis of total crash frequency has resulted in an observed decrease of 2% and analysis of crash severity has found large savings of $35.2 million in crash cost.

The implementation of flush medians has possibly created a calming effect and slowing of traffic. The increased separation of opposing flows and the constricting of lane widths resulting from flush median implementation may have shifted usually serious and fatal injury crashes into the minor injury class. Flush medians have also improved driver discipline, thus taking away uncertainty by drivers' actions.

The difference in crash reductions between severity classes with flush median implementation may also have resulted from the different observed savings in crash type. As seen in section 2.2.5, rear end' (FD) crashes increased dramatically. Historically, a large proportion of these type of crashes have resulted in less serious crashes with the whole 'rear end' group of crashes only making up 2.8% of fatal crashes and 7.6% of injury crashes in New Zealand in 1999 (Land Transport Safety Authority 2002b). This crash migration between severity classes hypothesis is also supported by the result of the historically more severe 'loss of control' group of crashes generally observed reductions. Loss of control crashes on straight sections and loss of control when cornering made up a total of 32.5% of fatal crashes and 30.5% of injury crashes in New Zealand in 1999 (Land Transport Safety Authority 2002). This demonstrates that analysis of crash types along with severity analysis is important when investigating the benefits of traffic safety devices.

2.3.2 Night / Day

The implementation of flush medians has had more impact in reducing night-time crashes (crash saving of $27.8 million) than they do during the day (crash savings of $18.9 million). The difference in savings is significant as night-time crash numbers are approximately half that of those during the day.

The analysis of night and day crashes has again followed the general patterns observed in the severity analysis. The largest reductions were observed in fatal and serious crashes during the night periods. This could be attributed to high vehicle speeds at night being reduced upon flush median implementation due to constriction in lane width and increased delineation.

2.3.3 Peak / Off-peak

That flush medians are most beneficial in reducing crashes during off-peak periods. Predictive crash savings of $49.5 million were calculated for 'off-peak' periods while a $4.5 million increase was observed for 'peak' periods. This is expected as it has already been established that flush medians are effective in addressing night-time (off-peak) crashes. This is again probably due to high vehicle speeds and alcohol being contributing factors in these crashes.

The off-peak period represents three times the number of crashes compared to those in the peak periods.

The absence of significant savings of any class in the peak period is consistent with more congestion and slower moving vehicles. Auckland has considerable congestion in the peak periods with long slow moving vehicles along its roads. It is not uncommon for queues to extend the whole block length. This would then reduce the number of serious and minor injury crashes but probably increase 'turning' crashes and 'rear end' crashes, which are prevalent in peak periods.

2.3.4 Median Width

The width of flush medians influences the difficulty and speed with which vehicles can leave the adjacent through traffic lane. The results show that median width causes no obvious difference in crash changes within the injury classes. The most obvious difference between median widths was in the non-injury class with median widths less than 2 m showing a large saving. As indicated in the B/C analysis, narrow medians achieve twice the B/C ratio of the wider medians. The majority of this benefit is attributed to savings in fatal crashes.

These results, therefore, show that it is better to use narrow medians as opposed to wider ones. It is believed the increased benefit at narrow medians is due to driver perception. The driver perceives it as more dangerous to use a narrow flush median, therefore, uses it with caution. On narrow medians even though turning vehicles can not be fully removed from the traffic stream, vehicles will still be able to pass on the inside. Encroaching on the traffic stream may result in more caution being taken by the passing driver, which may explain the large saving.

2.3.5 Crash Types

It is observed from the results that flush medians have different effects on different crash types. By highlighting the changes in the major crash types, assessment of future benefits from implementation at potential flush median sites can be achieved.

The largest increase in crash percentage has been observed in 'rear end' crashes at queues (FD). The FD group of crashes resulted in a $2.3 million increase in crash costs. Implementation of flush medians has frequently resulted in a reduction in the number of lanes at a site. This has therefore decreased headways and reduced capacity. As a result queues at major intersections may have been extended, providing more opportunity for rear end crashes. The dramatic increase in crashes may also have resulted as in the 'before' period queues were contained within the approaches to signalised intersections and were consequently removed from the study cordon. Following flush median implementation and the resulting increase in queue lengths, the crash types may have been pushed into the study cordon.

In contrast, rear end crashes involving right turning vehicles (GD) have been observed to have the largest percentage reduction and achieved savings of $4.8 million. With the implementation of flush medians right turning vehicles are removed from the through traffic stream, therefore taking away the opportunity for such crashes.

The largest crash cost savings was seen in 'loss of control' crashes and 'head on' crashes on bends ($28.8 million). Savings were observed in all crash severity classes for these crash types. Importantly, this category contained seven of the 'before' period fatal crashes, and only two 'after' crashes. This apparent reduction in fatalities has contributed to the larger crash cost savings observed. It is believed that the savings observed with flush median implementation could result from the increased constriction perceived by drivers resulting in more caution and lower vehicle speeds. Flush medians also provide better delineation than a centre lane alone, which may have also assisted in reducing these types of crashes. Flush median installation also moves the tracking path of vehicles further to the left where the camber may be better for vehicle stability. The increased separation of traffic flows probably accounts for the reduction in head on crashes.

Large savings are also achieved for the pedestrian related crashes NA and NB ($15.2 million). These categories observed 11 fatal crashes in the 'before' period while only 4 in the 'after' period. Implementation of a flush median provides protection to pedestrians and reduces the conflict area for potential crashes. Implementation of pedestrian refuge islands would also have contributed to the observed savings. Again, reduction in severity may be attributed to lower vehicle speeds resulting from constriction in lane width and better delineation.

Finally, right turning crashes (JA and LB) were observed to consistently increase over the three severity classes analysed resulting in an increased crash cost of $9.3 million. The JA type (right turn right side) may have resulted from a reduction in visibility, as the centre line and lane lines will have been shifted further toward the kerb side following flush median implementation. Flush median installation may also have encouraged previously undesirable manoeuvres possibly increasing these types of crashes. Therefore if JA problems are identified, visibility should be investigated and increased if required through the restriction or prohibition of adjacent parking. If a number of JA or LB crashes are identified at an intersection investigation should be made into installation of high friction grip surfacing on the problem approach.

2.3.6 Future Implementation

The analyses of 50 Auckland City sites, where flush medians have been implemented, have overall achieved a significant economic benefit in safety. However, the concern still is that crashes increased at some of the sites:

- Fatal crashes increased at 11 sites;
- Serious injury crashes increased at 19 sites;
- Minor injury crashes increased at 27 sites; and
- Non-injury crashes increased at 18 sites.

Assessment of crash types provides the strongest means of ensuring successful implementation of flush medians. This study has identified several target crash types, which have been significantly influenced. Assessment of the numbers and proportions of these crashes should be undertaken at the preliminary assessment stage of flush median implementation in order to identify:

1. Whether a flush median is appropriate at a site; and
2. What should be incorporated in the design to ensure crashes do not increase?

In order to achieve this, a preliminary guideline for the safer use of flush medians has been included in Transfund Research Report No. 233 Appendix, 1 (Segedin et al, 2002).

3. PEDESTRIAN REFUGE ISLANDS

3.1 INTRODUCTION

Pedestrian refuge implementation on flush medians in Auckland City began in the mid-1990s in an effort to improve pedestrian safety. Since then they have been installed in numerous locations throughout Auckland City. Pedestrian refuge islands have been installed for a variety of reasons, which did not have a systematic or analytical basis, however suggestions have been made for future systematic implementation on all flush medians. This raises concerns, as the impact of pedestrian refuge islands on pedestrian and vehicle safety is unknown. Therefore, a preliminary investigation has been made into crashes following which, possible remedial measures to address those crashes have been discussed. As a result of this research, it was intended that guidelines would be produced making suggestions on how to improve the safety of pedestrian refuge islands.

3.2 PROCEDURE

Crash types possibly related to pedestrian refuge islands were identified and the corresponding TCRs reviewed. The following target crash types were investigated:

- F type crashes (Rear end);
- GD type crashes (Turning versus same direction);

- N and P type crashes (Pedestrian);
- JA, KB, LA and LB type crashes (Turning);
- AO, EC and EO type crashes (Collision with objects).

Pedestrian refuge island placement is restricted by the minimum vehicle turning curve allowed into or out of an adjacent access point. The minimum separation of pedestrian refuge islands from access points was investigated for several typical carriageway widths and for two refuge island design types (shown in Appendix F in Segedin et al, 2002) using the Auckland City District Plan 99 percentile car turning circles. These were then site tested to ensure accuracy.

3.3 RESULTS

3.3.1 Pedestrian Refuge Crashes

A total of 23 crashes involving pedestrian refuge islands on flush medians have been identified. These crashes can be broken up into five general types of crashes.

Vehicles hitting pedestrian refuge islands have resulted in two crashes. Sun strike was identified as the contributing factor in one of these crashes. The other involved a vehicle overtaking on a flush median. However it is believed that this type of crash has a very low reporting rate. Maintenance records of RG-17 “Keep Left” signs at pedestrian refuge islands indicate a significantly higher under-reporting rate than is suggested in the Project Evaluation Manual (Transfund New Zealand 1997/2000). For example, within the Auckland City area, approximately 140 signs were replaced on the pedestrian refuge islands during 2001.

Vehicles stopping for pedestrians at refuge islands have resulted in seven reported crashes. Driver obligation at pedestrian refuge island, as opposed to zebra crossings has created confusion in these crashes. Cars have stopped to allow or encourage pedestrians to cross the road. This has then created rear end crashes, with following vehicles unable to stop (three crashes), or, in multilane situations, following vehicles passing on the kerbside lane have hit the pedestrians (four crashes). Three of the four crashes where pedestrians were hit involved children crossing the road.

Pedestrians walking in front of traffic without looking have resulted in 10 crashes at refuge islands. Five pedestrians have been hit moving off the central island and four moving from the kerbside to cross. A rear end crash has also resulted from a pedestrian stepping in front of a car. Five of the crashes have involved child pedestrians. Four children have been hit moving off central refuge islands. Only one of the crashes has been at night.

Three crashes involving vehicles right turning to and from access points may have involved substandard island design. GIS aerial photographs have shown that insufficient separation of raised islands from access points has not allowed right turning vehicles to move onto the flush median. This has resulted in rear end crashes.

One crash has resulted when a vehicle travelling in the kerbside lane has hit a child pedestrian walking off a refuge island through a centre lane queue. This highlights a more general concern of pedestrians walking through queuing traffic.

3.3.2 Minimum Separation from Access Points

Minimum separation distances were formed using turning circles. The minimum requirement for the distance from the further most kerbside of the access point to the end of the pedestrian refuge island was 11 m for type 1 pedestrian refuge islands and 10 m for type 2 islands. Values for different carriageway widths can be found in Appendix F of Segedin et al (2002). The separations detailed are minimum requirements only and typical vehicle through speeds and number of turning movements generated by access points should be considered in the design.

3.4 DISCUSSION

Pedestrian inattention and driver confusion has caused the majority of the crashes identified at pedestrian refuge islands. The first step in addressing these crashes is through education, in order to help both parties better understand pedestrian refuge island operation. Children in particular must be taught the different obligations at refuge islands and zebra crossings. Current school curriculum involving traffic safety should include the operation of pedestrian refuge islands.

Design improvements have also been identified that may help to address some of the crashes reported. Pedestrians walking in front of traffic have resulted in a number of crashes. These crashes may have been influenced by sight lines at the kerbsides and at the pedestrian refuge islands.

It is critical that Approach Site Distance (ASD) and Crossing Sight Distance (CSD) as described in AUSTROADS (1994), is achieved. Parking adjacent the pedestrian refuge islands may need to be removed to achieve CSD. AUSTROADS (1994) also highlights that the line of sight should not be obstructed by "street furniture, such as poles, mailboxes, telephone booths, trees, decorative planters etc, however minor obstructions, such as posts, poles and tree trunks, less than 200 mm diameter within the line of sight may be ignored." An audit of existing islands should be undertaken to ensure adequate sight distances have been achieved and remedial steps undertaken if islands are found to be substandard.

The majority of the crashes involving pedestrians walking off central refuge islands have involved children. It is thought that children may be hidden from the view of drivers by the RG-17 'Keep Left' signs on the islands. This concern is also highlighted by AUSTROADS (1994). It is therefore recommended that a 300 mm by 600 mm RG-17.1 'Keep Left' sign be used to replace the existing 600mm RG-17 at islands with high child pedestrian use. These should be positioned at least 600 mm from the left kerb of the island (for approaching drivers). This will maximise the visibility of pedestrians waiting to cross from the island.

Pedestrian refuge island proximity to access points has also been identified as a concern. Turning vehicles access to the flush median can be restricted by placement of the islands, leaving the vehicles encroaching on the through traffic lane. This can then result in rear end crashes. Appendix F in Segedin et al (2002) shows tables and diagrams detailing minimum distances that have been developed to address this problem. Vehicle tracking should also be investigated for all movements where pedestrian refuge islands are being implemented in the vicinity of intersections. Design should also ensure appropriate manoeuvre speeds can be achieved for the site environment.

Maintenance records have indicated that vehicles hitting refuge islands is also a concern. It is thought that this could be a predominantly overtaking problem possibly occurring with more frequency at night. In order to address these crashes, a yellow reflectorised no overtaking line should be installed for a length on the approaches to pedestrian refuge islands. It should also be ensured that lighting levels at the islands are in accordance with the values described in the Australian/New Zealand Standards for Road Lighting (AS/NZS 1158.1.1:1997 and AS/NZS 1158.3.1:1999). To further increase the visibility of the pedestrian refuge islands at night, yellow mono-directional raised reflectorised pavement markers (rrpms) should be installed at one metre intervals on the no overtaking lines approaching the pedestrian refuge islands. Installation of rrpms at close spacings will also increase driver recognition during the night and day through their physical impact when vehicles cross the flush median edge line. At sites where high numbers of collisions are occurring, additional white bi-directional rrpms should be installed at half metre spacings on the diagonal flush median bars to further increase driver recognition of the potential hazard.

Education of drivers and pedestrians combined with the implementation of the described design measures should reduce pedestrian refuge island related crashes. The measures recommended are low cost and can be implemented easily.

4. CONCLUSIONS

The main results from this research, which are more fully described in Segedin et al (2002), are summarised below. As noted earlier, the resulting cost savings and B/C ratios are based on Project Evaluation Manual procedures (Transfund 2002), namely, a 25-year period and a 10% discount factor.

Crash Severity

- Overall saving of $35.2 million with a B/C of 30.2 has been achieved with the implementation of flush medians at 50 Auckland City sites studied using the GLM analysis method.
- Flush medians have clearly reduced the severity of crashes with reduction in fatal, serious and non-injury crashes costs of $26 million, $10.4 million and $1.2 million respectively with an increase of $2.5 million in minor injury crashes.
- There was only a 2% saving in total crash frequency with an increase 3% in injury and a 4% decrease in non-injury crashes.
- Flush medians appear to have had a calming effect that has reduced the severity of crashes. This could be related to a slowing down of vehicle speed with a better defined and constricted route, which has also resulted in improved driver discipline.
- There has been an increase in crashes at some of the 50 flush median sites:
  - 11 sites fatal crashes increased;
  - 19 sites serious injury crashes increased;
  - 27 sites minor injury crashes increased;
  - 18 sites non-injury crashes increased.

Night-time / Daytime

- Flush medians have reduced the severity of crashes at night more than during the daytime. There has been a $20.7 million and $7.5 million reduction in fatal and serious crashes at night, but only a $2.83 million and $2.9 million reduction during the day (GLM analysis method).
- Greater cost savings have been achieved in night-time crashes despite significantly less crash numbers than those during the daytime.
- The reduction in night-time crashes is mostly due to reductions in the 'loss of control' and 'head-on' crashes.

Peak and Off-peak Crashes

- There has been an increase in the cost of crashes ($4.5 million) in the 'peak' periods, with a significant saving in the 'off-peak' periods ($49.5 million).
- In the 'peak' period, crashes have decreased in all crash severity classes except for fatal crashes.
- In the 'off-peak' periods, crash frequencies have decreased in the fatal, serious and non-injury classes, while increasing in the minor injury.

Median Width

- Narrow flush medians have resulted in crash savings of $14.4 million (10 sites) with a B/C of 55.8 while wider medians have resulted in crash savings of $20.9 million and a B/C of 24.0.
- Narrow flush medians made up approximately 28% of crashes however resulted in 40% of the total cost saving.
- Greater crash saving for narrow medians may be related to driver perception – drivers may perceive them to be less safe and therefore use them with caution resulting in higher crash savings.

Crash Types

Flush medians resulted in major crash cost savings in 7 crash types.
The largest cost savings occurred as follows:

- Bend loss of control
  - turn to left (DA) $12.21 million
  - turning left (DB) $10.6 million
  - head on (BF) $6.2 million
- Pedestrian
  - right side (NB) $10.4 million
  - left side (NA) $4.8 million
- Rear end / object
  - near centreline (GD) $6.8 million
- Crossing
  - right angles (HA) $1.4 million

Flush median implementation has greatly reduced fatal crashes in the 'bend loss of control' and 'pedestrian' crash types. Eighteen of the total 24 fatal crashes in the 'before' implementation period were observed in these groups while only 6 in the 'after' period.

The largest cost increases occurred in the following crash types:

- Turning - right turn right side (JA) $4.7 million
  - making turn (LB) $6 million
- Rear end obstruction - queue (FD) $2.3 million

Turning

- The greatest increase in crash cost occurred for turning crashes (JA and LB) type.
- The reduction in visibility by moving traffic lanes closer to the kerb with the implementation of flush medians could be contributing to the increase in turning crashes.
- It is believed that by improving the friction of the pavement (e.g. friction grip) and improving visibility (e.g. removing obstructions etc.) that most of the turning safety problems will be reduced.

Pedestrian

- Flush medians appear to have reduced the severity of pedestrian crashes.
- It is considered that pedestrian refuge islands may make it safer for pedestrians.
- Design guidelines have been developed for improved pedestrian refuge islands.
- Maintenance records have shown that there are a significant number of non-reported crashes where signs have been knocked down at pedestrian refuge islands.
- Most of the pedestrian savings have been achieved in pedestrians being hit from the left (NA type crashes). Parked cars obstructing visibility could be the major contributing factor in these crashes.

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