THE IMPACT OF ROAD SHOULDERS ON URBAN FREEWAYS: A CASE STUDY IN DURBAN, SOUTH AFRICA

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ABSTRACT

The growing need to improve transport systems and maximise traffic-flow, efficiency and capacities, particularly those of mobility routes such as urban freeways, has seen some innovations and new trends in terms of urban freeway design in South Africa. They have all aimed at seeking more efficient means of moving passengers, reducing travel and delay time, and improve safety by introducing one or a combination of transport operating strategies such as Bus Rapid Transport (BRT's), Integrated Rapid Transport (IRT's), High Occupancy Vehicle lanes (HOV's), among others. The majority of metropolitan cities have adopted these strategies through a combination of features such as physical transport infrastructure restructuring, together with technologies such as Intelligent Transport Systems (ITS), Variable Message Signs (VMS) and Closed-Circuit Television (CCTV), among others. The study aims to evaluate the impact of this growing trend of restructuring urban freeways, thereby reducing or totally removing road shoulders for the purpose of introducing public transport lanes. Through the static experiment, "before-and-after" analysis, "with-and-without" analysis and other analytical studies and observational methods, a number of interesting findings were concluded. Study results have shown a 4% decline in crash rates after the restructuring of urban freeways. However, in terms of efficiency and traffic flow, major delays are evident when there are minor incidents or crashes on the freeway. It was concluded that while non-shoulder urban freeways do not have the worst crash rates, they also vulnerable to challenges in terms of efficiency, travelling costs, time lost and vehicle operating costs.

1. INTRODUCTION

1.1 Background

This study investigated the importance of road shoulders on urban freeways in South Africa. Road shoulders, particularly their width, are among the roadside features that were developed for their vital role in the safety and operational capacity of highways. Shoulder widths, particularly the outer shoulder (right-hand side for most European countries), are commonly recognized for their instrumental role in road safety. They are fundamentally valued for their forgiving role during recovery. Too wide road shoulders can lead to counter effects with an increase in crashes, especially when they are wider than 3 metres. (Stamatiadis, Lord, Pigman, Sacksteder & Ruff, 2009).

Each country has its own design criteria for road shoulder width for different road classes. In South Africa, shoulder width varies per road category. A shoulder width of 3.0m is often recommended for all higher order roads such as freeways and highways. The South African geometric design guidelines define a road shoulder as the usable area alongside the travel lane that must be kept clear of all obstructions including the mounting of guardrails (CSIR, 2000). For stopped vehicles, the Red Book clearly stipulates a wide enough shoulder to accommodate a stalled vehicle without causing any congestion by forcing lane change (CSIR, 2000). Contrary to the aforementioned South African standard, a new trend has been established in which road shoulders, their width and their functions in terms of safety and capacity are neglected in favour of other transport objectives such as prioritizing public transport and high occupancy vehicles (HOV's). In recent times in South Africa, additional public transport lanes and HOV's lanes have seen road shoulders drastically reduced and in some instances totally eliminated, more especially in urban freeways around the country.

1.2 Purpose of the Study

This research presents a safety and capacity analysis, carried out to compare the functionality and safety of shoulder versus non-shoulder roads on urban freeways in Durban, South Africa. The main objectives are:

- To evaluate the impact of new public transport strategies on urban freeways in South Africa, particularly the utilisation of existing road shoulders.
- To assess implications of reduced shoulder width in terms of highway capacity, highway traffic characteristics and safety.

1.3 Context of the Study

Within South Africa there has been a growing trend of introducing Transportation Demand Management (TDM) strategies in the form of HOV lanes and express lanes, as well as dedicated public transport lanes. According to 'Moving South Africa', dedicated road facilities such as express lanes, public transport lanes, HOV lanes and integrated rapid transport (IRT's) have the potential to reduce road users operating costs by between 5% and 20% (MSA, 1998). In addition, traffic-flow could improve by almost 25% in congested highways (Pillay & Seedat, 2007).

The Government of South Africa, through the National Treasury Office and National Department of Transport, embarked on a multibillion project to revamp and restructure public transport systems and the associated infrastructure in the major metropolitan areas of the country. This initiative has seen the introduction of the Integrated Rapid Transport (IRT's) and Bus Rapid Transport (BRT's) in major cities. In many cities, road reserves are fully occupied to such an extent that no additional infrastructure can be accommodated without reshuffling the existing configuration, or employing an expensive expropriation approach. The use of existing shoulder for the purpose of Right of Way (R.O.W) and the changing of lanes to either public transport lanes or HOV lanes are some of the strategies adopted to fit the IRT's and BRT's in urban freeways in South .Africa. Some of these transport initiatives are tabulated in Table 1.

Table 1: Summary of Public Transport Systems in South Africa

No.	City Name	Strategy adopted	Name of the system
1	City of Cape Town	HOV and IRT	MyCiti
2	Durban (eThekwini Municipality)	IRPTN	Go!Durban
3	City of Johannesburg	HOV and BRT	ReaVaya
4	Port Elizabeth (Nelson Mandela Bay Municipality)	IPTS	Bongolethu
5	City of Tshwane (Tshwane Municipality)	TRT (BRT)	A ReYeng

Figures 1 and 2: Public Transport Lanes in Pretoria (Google Earth) and eThekwini Municipality N3 Freeway (eThekwini Municipality)

2. LITERATURE REVIEW

2.1 Early Research on Hard Shoulders

The use of shoulders and narrow lanes on freeway or expressway type facilities dates back to construction of the first facilities. The earliest urban freeways or their equivalent (such as the East River Drive and West side highway in New York City) were generally constructed with narrow lanes and with little or no shoulder width (Curren, 1995). Through strategies such as Active Traffic Management (ATM), Netherlands permits the right shoulder usage on a temporal bases; the use of left shoulder is also permitted during highly congested periods. Operational, when levels reach a certain threshold (traffic volume), the plus lanes are activated. Figure 3 and 4 below presents a typical ATM strategy called Bus on Shoulder (BOS).

Figures 3 and 4: Bus on Shoulder (BOS) strategy (Curren, 1995)

In the 1960s, congestion had reached such significant levels on some freeways in Los Angeles so that road shoulders and narrow lanes were converted to provide more capacity on facilities originally constructed with wider shoulders and 3.7m wide lanes (Curren,1995). Primarily, the United States of America implemented road shoulders purely for safety reason, to provide a refuge space. Exemptions were made, however, for special road users such as transit vehicles.

2.2 Road Safety

A road shoulder is expected to perform several functions. These include providing a refuge area for emergency stops, act as a pull off bay, and play the vital role of forgiving run-off cars (Stamatiadis *et al.*, 2009). Matson, et al in Curren (1995), cited a Californian study of crashes on highways without shoulders, indicated that 15% of all crashes involved vehicles parked on the travelled way (Curren, 1995). When rush–hour lanes were introduced in The Netherlands (between 2005 and 2007), the number of injury type crashes reduced by 13% (Veld, 2009). Rush-hour lanes are additional lanes or emergency lanes that are opened for the peak directional flow.

In another study, shoulders over 2.4m were found to have experienced significantly more crashes than those of 0.9m to 1.2m (Zegeer et al., 1980). In a study by Rinde (1977, in Dewar & Olson, 2001), 37 two-way roads in each direction in California were assessed. The roads were classified according to shoulder width with a range of three shoulder width classes (0.6, 1.3 and 2.5m). The study revealed that narrow shoulders turn to cause drivers to drive closer to the road centre line. This has a direct implication of causing head-to-head (head on) crashes.

3. METHODOLOGY

3.1 Site Description

This study was conducted on the M4 Southern Freeway (Ruth First Freeway) in Durban, South Africa. The M4 Southern Freeway connects the City Centre to the N2 national road. To aid analysis and achieve the study objectives, the M4 Southern Freeway was divided into two segments of homogenous characteristics - the *altered section* of about 8.4km which is the active study section, and the *unaltered section* of about 4.2km which functions here as the control section of the experiment. The altered section starts immediately north of the Quality Street interchange and ends 500m before the City Centre (northbound). The rest of the M4 South from Quality Street to the N2/M4 interchange is defined as the unaltered section in this study.

The alterations that were constructed through the *altered* section consisted of the introduction of a central bus lane alongside a concrete central barrier, and reducing the lane widths from 3.5m to 3.4m in some instances. The changes also meant that the hard shoulder was reduced from an average of 1.5m to 0.4m. The speed limit remained at 100km/h in both sections. An aerial plan of the study area plus two sections (altered and unaltered sections) can be seen on Figures 5, 6 and 7 below.

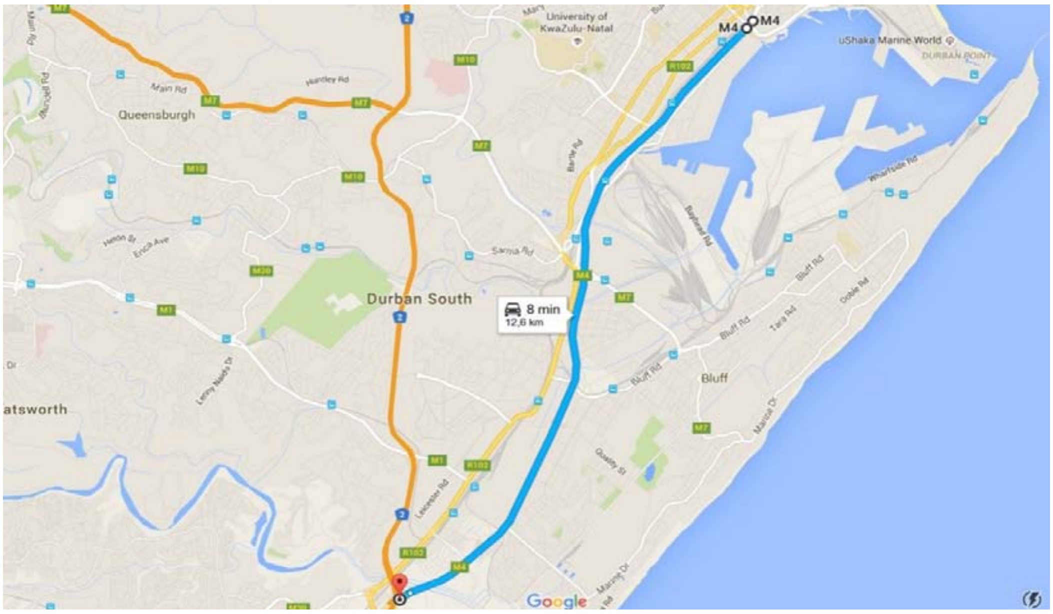

Figure 5: Areal plan of the study area (Google Earth)

Figure 6: Unaltered section, typical layout

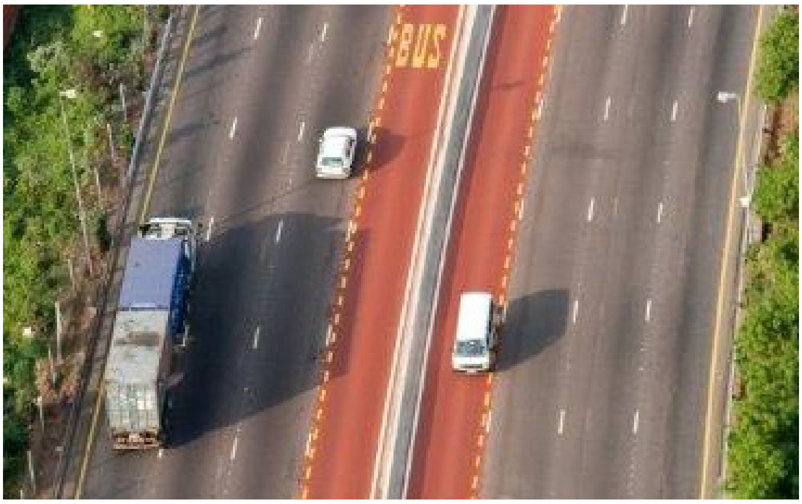

Figure 7: Altered section, typical layout

Table 2: Study area - Details

Section	No. of lanes (per dir.)	Total length (both dir.) (km)	Separator detail	Ave Acc (per year)	Posted Speed (km/h)	Acc Stats	Aver. Lane Width	ADT	Average shoulder width (m)
Altered	4	16.8	Concrete Barrier	440	100	440	3.5	67116	0.4
Un-altered	3	8.4	Back-to-back Guard rail	227	100	27	3.5	89729	1.5

3.2 The Experiment

One of the key stages in the research was the conducting of an experiment into the effect of a traffic 'incident' on traffic flow in both altered and unaltered sections of the freeway. The experiment involved setting up a vehicle with an assumed flat tyre, in the hard shoulder. Warning triangles were set up in advance of the vehicle. The impact of this obstruction on the hard shoulder to the remainder of the traffic was measured, in terms of both time delay for passing vehicles and safety implications. Figures 8 and 9 below presents a typical experiment set-up.

Figure 8: Experimental set-up, altered section (morning- peak)

Figure 9: Experimental set-up unaltered section (afternoon-peak)

<u>3.3 Consent and Institutional Permission</u>

Local authorities including City Metro police and road authorities were informed and granted their consent before the experiment commenced. The study primary participants (research team) were fully trained and thereafter their consent was attained. No consent was attained from the secondary participants. All potential risks were identified and mitigated against before the study commenced.

Table 3: Conducted study surveys and experiments

Survey no.	Method	Description and objectives	Location	
			Altered	Unaltered
1	Static experiment set-up	The experiment was conducted to observe the speed and traffic flow variations due to an obstruction on the slow lane	Yes	Yes
2	Direct time delay analysis	To analyze the direct time delays due to obstruction on the slow lane.	Yes	No
3	Safety analysis	Before and after approach. To compare crash statistics and analyze results.	Yes	Yes

3.4 Data Collection

3.4.1 Data Collection (Safety Evaluation)

Crash data for both the altered and unaltered sections were obtained from the 2004–2014 eThekwini Municipality – Road System Management – Traffic Safety Department files. The *before* period covered four years from 2004 to 2008, while the *after* period extended from 2011 to2014. The two years between 2009 and 2010 represented the construction period and therefore was not significant to the purpose or the results of this study.

3.4.2 Data Collection (Traffic-Flow Analysis)

Traffic data such as hourly volume, operating speed and free-flow speed data were collected electronically via the two eThekwini Municipal automatic traffic survey devices that were identified along the study area. Himalayas and Dalbridge traffic survey devices formed part of the series of traffic management devices that were implemented by the eThekwini Municipality for the purpose of traffic and transportation management. The Himalayas Traffic Survey device is located further south within the unaltered section of the study area, whereas the Dalbridge Traffic Survey device is located at the altered section of the study area. Table 4 below presents a typical survey device output that was extracted from the server.

Table 4: Typical peak hour survey information

Un-Altered section (HIMALAYAS SITE) - a.m. Peak												
Time Slot	Lane 01 Av Speed	Lane 02 Av Speed	Lane 03 Av Speed	Lane 04 Av Speed	Lane 05 Av Speed	Lane 06 Av Speed	Total Vehicles	Mean Speed kph	Standard Deviation	% Exceeding	50th Percentile	85th Percentile
06:30	63	71	77	88	106	91	1,548	80	18.71	9.8%	75	85
06:45	65	69	75	88	105	87	1,658	79	18.50	10.4%	75	85
07:00	63	67	71	88	104	86	1,687	77	19.60	9.3%	65	85
07:15	63	68	73	89	107	91	1,601	79	18.26	10.4%	75	85
Average	**63**	**69**	**74**	**88**	**106**	**89**	**6,494**	**79**	**19**	**0**	**73**	**85**

3.5 Apparatus

The apparatus used in the experiment included three (3) vehicles, vehicle spare wheel, tyre changing kit, warning triangle and 2 video cameras.

4. RESULTS AND DISCUSSION

4.1 Altered Section

4.1.1 Morning-Peak Hour Analysis and Results

The study experiment was conducted on the altered section during the morning- peak, with the experiment set-up on Lane no.1. Results are shown in Figure 10. The morning peak hour analysis started exactly at 06h30 on the inbound carriageway and lasted until 07h30.

As illustrated in Figure 10, speed results during this experiment shows a major impact on the freeway mean-speed on the inbound stream (Lanes 1, 2, 3 and 4). Serious congestion in the traffic stream was observed and the above results illustrate the change in traffic-flow. In terms of numbers, average mean-speed dropped from 69km/h (no experiment) to 58 km/h (experiment).

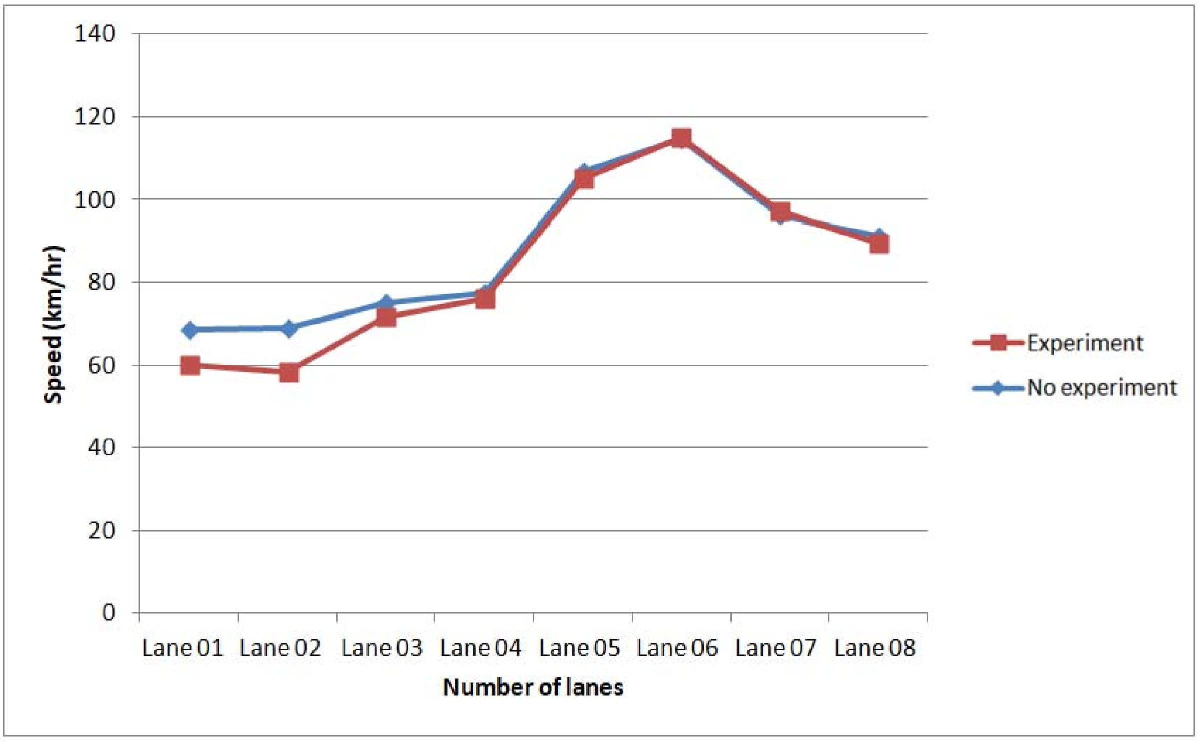

Figure 10: Graphical presentation of the morning- peak speed survey results (Altered Section)

4.1.2 Evening Peak Hour Analysis and Results

Figure 11 presents the evening results of the experiment on the altered section (outbound). The speed dropped significantly during the evening peak hour from an average mean-speed of 87km/h to 55km/h. Out of four lanes (Lanes 5, 6, 7 and 8 – outbound carriageway), three mixed-use lanes dropped from 87km/h, 87km/h and 98km/h to 69km/h, 55km/h and 56 km/h, respectively.

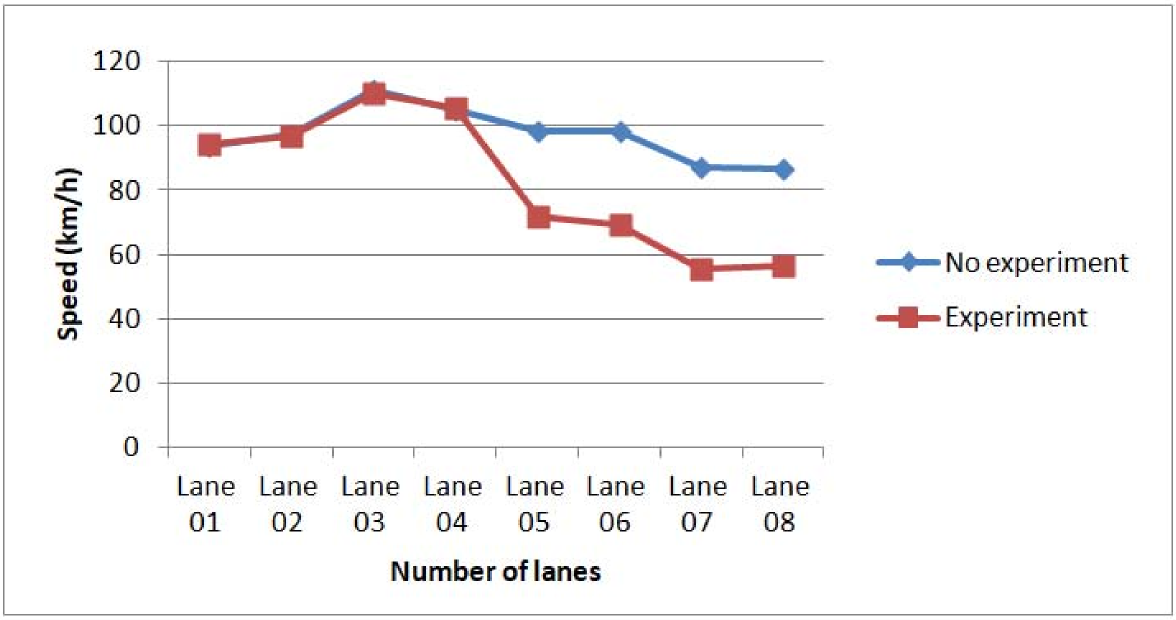

Figure 11: Graphical presentation of the evening speed strip results (Altered Section)

4.2 Unaltered Section

4.2.1 Morning Peak Hour Analysis and Results

Of interest in Figure 12 is the insignificant but consistent variation in speed between the normal flow and the flow during the experiment, in the unaltered section of the freeway. This experiment was set-up on the shoulder, adjacent to Lane no.1. A slightly reduced average speed was recorded during the duration of the experiment – at its maximum, the average mean-speed reduced from 69km/h to 66km/h.

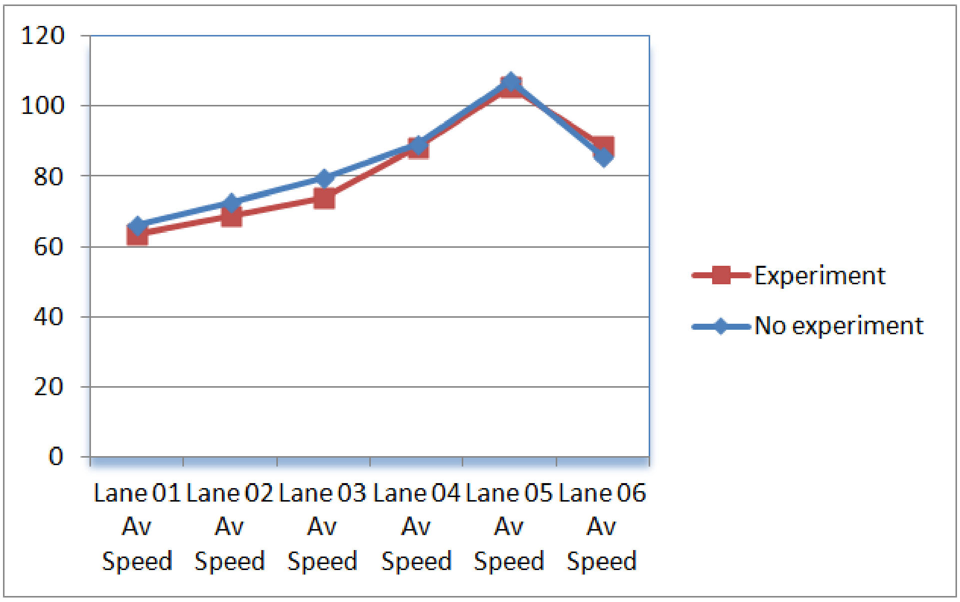

Figure 12: Graphical presentation of the morning peak results (Unaltered Section)

4.2.2 Afternoon Peak Hour Analysis and Results

Similar to the morning peak, the evening experiment was conducted on the 2.5m shoulder next to the slow lane (Lane no. 6). From the above result, an insignificant reduction in average mean-speed was observed at maximum, average mean-speed dropped from 89km/h to 84km/h during the experiment.

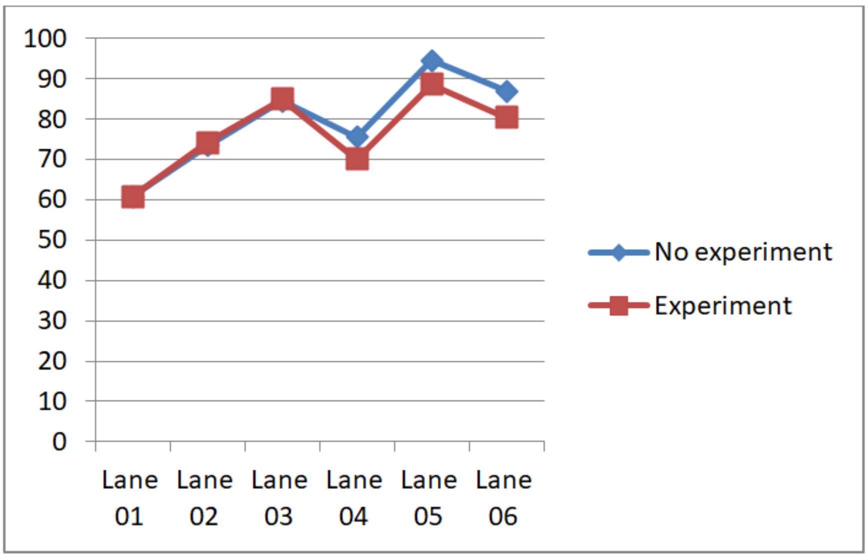

Figure 13: Graphical presentation of the afternoon peak results (Unaltered section)

4.3 Safety Implications

4.3.1 "Before-and-After" Results (by Vehicle Type)

From the statistical presentation, it is evident that the public transport mode realised more benefits in terms of safety from the implementation of a public transport lane (express lane). Accidents involving both buses and taxis have dropped quite remarkably on the altered section. Other vehicle type accidents including accidents involving cars and Light Duty Vehicles have followed the same trend with the exception of accidents involving heavy vehicles and motor cycles. The slight increase in accidents involving heavy vehicles can be attributed to the new lane configuration due to the fact that this type of accident has decreased on the un-altered section.

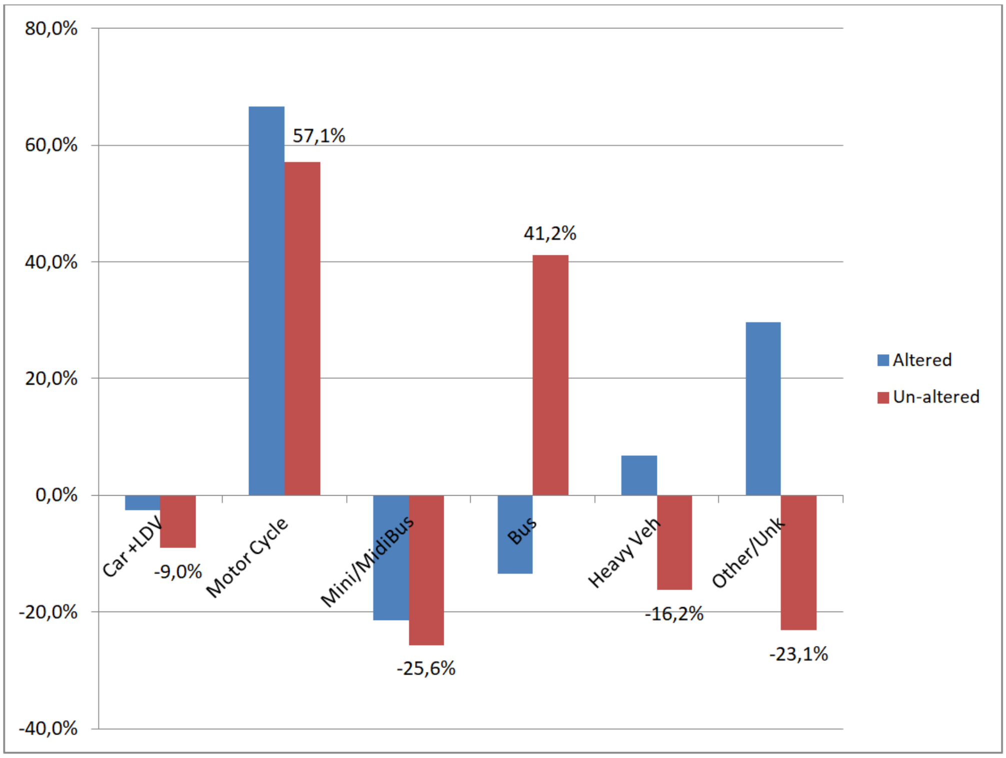

Figure 14: Accident statistics by vehicle type (Altered versus Unaltered)

4.3.2 "Before-and-After" Results (Altered Section)

Results illustrated in Table 5, have shown a slight reduction when comparing a period before freeway alterations to a period after alterations. Crashes reduced from 420 per annum to 411 per annum.

Table 5: Crash statistics by severity (Altered section)

By Severity - Altered Section				
Crashes	**Before**	**Construction**	**After**	**% Change**
Total Crashes	420	539	411	-2.1%
Fatal Crashes	13	13	8	-38.0%
Injury Crashes	90	101	78	-12.8%
EAN	821	975	750	-8.6%

4.3.3 “Altered Versus Unaltered” Section

An important point to note in Figure 15 is the total decline in fatal crashes on the altered section of the road. A significant portion of this improvement could potentially be attributed to the total eradication of opposite direction crashes on the altered section of the road, as guardrails were replaced by a concrete barrier on the altered section.

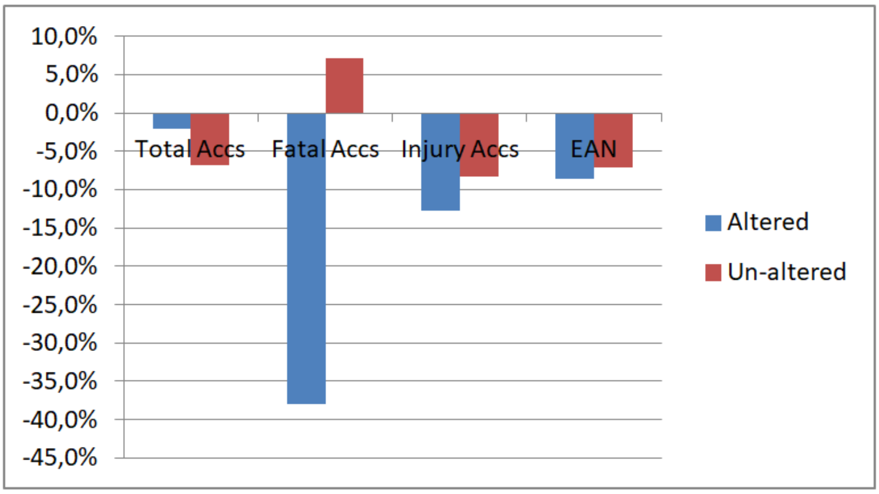

Figure 15: Crash statistics by severity (Altered versus Unaltered)

5. CONCLUSION

The conducted analysis presented evidence to show that reducing the shoulder width along eThekwini’s M4 Freeway, in order to add a public transport lane, has not worsened freeway safety conditions. In fact, the overall crash rate has decreased significantly since the changes were made.

Based on the available data, crash costs have decreased to approximately 40% less than the crash cost before the implementation of a Public Transport Lane. These results could be used to justify more investment on similar public transport projects, more especially with regard to safety.

However, results from the site observations have shown drastic reduction in the time mean-speed due to a stationary vehicle on the altered portion of the road. This has a direct negative impact on traffic flow when incidents occur. On average, a minor incident (broken vehicle on the slow lane) could result in an overall reduction in speed of about 35.8%.

While the public transport lane was implemented, primarily to prioritise public transport and avoid delays during times when there is congestion on urban freeway, all four lanes (including the public transport lanes) were heavily and uniformly affected during the period of experiment, defeating the initial investment objective and efficiency benefits.

While the study results have shown no negative impact in terms of safety, the negative impacts in terms of efficiency and traffic flow cannot be underestimated.

Maintaining the minimum shoulder width, particularly on urban freeways, could help alleviate some of these problems.

From an efficiency point of view, it is recommended that at least a 1.5m wide road shoulder be maintained on urban freeways to avoid delays, inconveniences, frustrations and possible crashes; and to maintain a better freeway traffic flow condition. This was proven in this experiment where vehicles stalled on the road without a wide enough hard shoulder has resulted into serious congestion and delays.

Both safety and efficiency are of highest importance on any major road serving both the accessibility and mobility functions, however, if anything, road safety must remain a priority in every decision to be taken.

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