THE SAFETY OF TRAFFIC CIRCLES IN ETHEKWINI

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ABSTRACT

National and international literature and research generally indicate that traffic circles (roundabouts) have a much better safety record than stop controlled and signalised intersections, especially when the severity of accidents are taken into account. A comprehensive investigation was done in eThekwini to evaluate the safety of traffic circles. Thirteen traffic circles were evaluated from a safety point of view, and compared to the safety record of twenty one traffic signals and ten stop controlled intersections. The intersections were chosen to cover a wide range of traffic volumes, so that accident rates could be plotted against average daily traffic for all three intersection types. Both accident rates and accident severity rates were analysed. Contrary to what is found in the literature, results showed that many traffic circles had higher accident rates and accident severity rates than traffic signals for the same average daily traffic. For higher daily traffic volumes (above 20 000 vehicles per day), traffic circles were found to have an alarmingly high accident rate compared to what is found in the literature. Possible reasons for the high accident rate at high volume circles are given, and the applicability of the research to the rest of South Africa is noted.

Introduction

The international literature almost universally credits traffic circles with a better safety record than signalised intersections. This is primarily due to traffic circles having slower approach speeds (if correctly designed) and the elimination of some of the conflicts that occur at stop controlled or signalised intersections.

Flannery and Elefteriadou (2001:3-4) indicated that, based on studies from the United States of America and Europe, roundabouts have consistently reduced the accident rates. Even when studies did not find a reduction in the number of accidents, the severity was invariably reduced (Volpe, Lewko and Batra, 2003:57).

Sampson and Meijer (2005:4) indicated that traffic circles show a 30-50% reduction in accident rate and severity when compared to signalised intersections. Even pedestrian and cyclist accidents are no worse than at signalised intersections. Two main features of circles contribute to this safety, the first being lower speeds, and the second a reduction in conflict points due to the one-way circulation.

Nambisan and Parimi (2007) evaluated 5 years of accident data for circles, stop controlled and signalised intersections in the Las Vegas Metropolitan area. The traffic circles were classified as minor (less than 10 000 vehicles per day), medium (10 000 to 20 000 vehicles per day) and major (greater than 20 000 vehicles per day). Their findings were as follows:

(i) Minor traffic circles showed substantially lower accident rates than stop controlled intersections.
(ii) Medium traffic circles also experienced lower accident rates than stop controlled intersections.
(iii) Contrary to the above results, major traffic circles had a higher accident rate than signalised intersections. However, when accident severity was introduced, traffic circles and signalised intersections were comparable.
(iv) They concluded that some geometric modifications would make the major traffic circles with three circulating lanes safer (Nambisan and Parimi, 2007:22-23).

Nambisan and Parimi (2007:22, 24) acknowledged that their findings were contrary to the findings in Europe where traffic circles proved safer for all traffic volumes. They also noted the importance of comparing similar sized intersections based on average daily traffic. Interestingly, Gross, Lyon, Persaud, and Srinivasan (2012:239-240) found that replacing signalised intersections with traffic circles resulted in a reduction in both the number of accidents and their severity. However, they found that crash modification factors (CMF) reduced with increasing average annual daily traffic. A CMF is a factor that can be multiplied by the current number of accidents to predict the expected number of accidents when a particular countermeasure is introduced.

The Livingston County Road Commission indicated that circles are safer even for pedestrians and cyclists. They indicated that the following aspects of traffic circles enhance the safety of pedestrians:

(i) The number of vehicle-pedestrian conflicts is reduced at traffic circles.
(ii) At stop controlled intersections (and to a lesser extent at traffic signals) pedestrian crossings are placed in front of drivers who need to simultaneously look for gaps in traffic as well as pedestrian activity. At traffic circles, the pedestrian crossing points are typically placed behind the entry point for vehicles at the circle.
(iii) Deflection angles for vehicles entering the circle reduces speed, which is a critical factor in the severity of pedestrian accidents.
(iv) Curbed islands between entry and exit lanes provide a refuge for pedestrians (Livingston County Road Commission).

In 2013 the eThekwini Transport Authority investigated and analysed the safety record for some twenty one traffic signals and thirteen traffic circles, representing the most comprehensive accident assessment for circles to date in eThekwini.

For the sake of comparison, a 3 year accident record (2009-2011) was used for each intersection. Counts that ranged from the years 2007 to 2013 were used, and factored up or down to a 2010 base year. Counts that were older than 2007 were recounted to ensure accuracy of the results. These counts were either increased or decreased to the year 2010 at 4% p.a., and then used to generate accident rates for each intersection. The counts were all twelve hour counts, and these were converted to an average daily traffic count (ADT) using eThekwini Transport Authority (ETA) approved factors.

1. SELECTION OF ACCIDENT STATISTICS AND CALCULATIONS

The Federal Highway Administration (FHWA) notes the following safety assessment methods:

- Accident Frequency: number of accidents per site per annum.
- Accident Rate: number of accidents per annum/annual traffic.
- Combined Accident Frequency and Rate: a combination of the above two.
- Accident Severity: more severe accidents are weighted higher.
- Critical Accident Rate: a critical accident rate for each intersection type is determined.
- Risk Analysis Methods: accident risks are determined using accident rates and volumes.
- Safety Performance Functions: equations are developed representing the relationships between accident frequency, volumes, and intersection types.
- Empirical Bayes Method: calculates expected accident frequencies based on past and estimated accident rates (FHWA, 2004: 118-123).

For the analysis that follows, the accident frequency, accident rate and accident severity were used as a comparative assessment of signalised intersections versus circles. As discussed later, stop controlled intersections were also included to broaden the relevance of the results.

The accident frequency used three consecutive years of accident data to account for random fluctuations in year-to-year accident numbers.

$$Accident\ frequency = Accidents/_{Year} = \frac{\sum Accidents\ over\ 3\ years}{3\ years} \qquad \text{(Equation 1)}$$

In order to determine the accident rate both the accident frequency obtained from the above formula and the estimated annual traffic were taken into account:

$$Accident\ rate = Accidents/_{Million\ Vehicle} = \frac{Accident\ Frequency \times million}{12\ hr\ count \times 1{,}2 \times 300} \qquad \text{(Equation 2)}$$

The accident frequency, however, does not take into account the severity of the accidents. For this reason, to assess accident severity, the above formulas were used, except that the accident values were replaced by “injury” accident values which weigh the accidents as shown in Table 1. This equivalent accident number (EAN) is a factor based on the cost of the accident type. For example, as can be seen in Table 1, a fatal accident is weighted twelve times relative to a non-injury accident.

Table 1: Equivalent accident numbers (EAN) (ETA, 2004:4)

Severity	EAN
Fatal	12
Serious	8
Slight	3
No injury	1

2. INTERSECTION ANALYSIS

3.1 Traffic signals

The detailed accident records and traffic volumes used for this analysis are too extensive to be listed in this paper. A number of signalised intersections with the respective ADT and accident rates are listed in Table 2. The above mentioned formulas were used to calculate accident statistics.

Table 2: Accident rates for signalised intersections in eThekwini

intersection	type	ADT	Ave freq	ave rate	ave sev freq	ave sev rate
Marianhill / Sarel celliers	signal	14501	1,33	0,31	1,33	0,31
Bartle / Sphiwe Zuma	signal	16713	15,67	3,12	26,33	5,25
Tara / Lighthouse	signal	18026	10,33	1,91	16,00	2,96
URD / Longwoods	signal	18781	5,67	1,01	5,67	1,01
Rick Turner / Bartle	signal	19455	9,33	1,60	15,00	2,57
Anderson / Kings	signal	19720	13,00	2,20	17,33	2,93
Bluff / Beacon	signal	22767	8,67	1,27	13,00	1,90
Bluff / Lighthouse	signal	23316	14,00	2,00	18,33	2,62
Caversham /Waering	signal	23560	5,33	0,75	5,33	0,75
URD / Sagewood	signal	24000	6,33	0,88	6,33	0,88
St James / Link	signal	26290	11,33	1,44	16,00	2,03
Swapo / Adelaide Tambo	signal	27192	11,67	1,43	17,33	2,12
Attercliffe / Buckingham Terrace	signal	27271	16,67	2,04	22,33	2,73
Qashana Khuzwayo / Escom	signal	29288	15,67	1,78	17,67	2,01
Qashana Khuzwayo / Broadway	signal	30752	5,33	0,58	7,33	0,79
Kenneth Kkaunda / Old mill	signal	31411	11,00	1,17	16,67	1,77
Old Mission / Bluff	signal	36999	20,67	1,86	37,33	3,36
MY Ave / Athlone	signal	39540	32,33	2,73	48,67	4,10
Underwood / Caversham	signal	47367	37,33	2,63	48,33	3,40
MY Ave / Somtsue	signal	47875	42,67	2,97	63,33	4,41
Anderson / Josiah Gumede	signal	50870	67,30	4,41	91,67	6,01

Ave freq = average accident frequency
Ave rate = average accident rate (accidents / million vehicles)
Ave sev freq = average severity frequency
Ave sev rate = average severity accident rate (EAN / million vehicles)

3.2 Traffic circles

Thirteen traffic circles were evaluated from a safety point of view. As noted above, three years of accident data (2009-2011 inclusive) were obtained, together with recent traffic counts. Five of the traffic circles had counts older than 2007 and these were updated by the eThekwini Transport Authority. All counts were either factored up and down to get a 2010 count. The following results were obtained:

Table 3: Accident rates for traffic circles in eThekwini

intersection	type	ADT	Ave freq	ave rate	ave sev freq	ave sev rate
Anderson/Roselle	circle	5473	0,67	0,41	1,33	0,81
Old mission / Zinto Cele	circle	12983	1,33	0,34	1,33	0,34
Old Main / Villiage	circle	13820	14,00	3,38	14,67	3,54
Underwood / Maurice Nichols	circle	14000	3,33	0,79	3,33	0,79
Swapo / Ennisdale	circle	14090	3,00	0,71	3,00	0,71
Margaret M / Adelaide T	circle	14170	3,00	0,71	3,67	0,86
Sphiwe Zuma / ZK Matthews	circle	15200	11,33	2,49	12,67	2,78
Swapo / St Andrews	circle	15792	2,67	0,56	2,67	0,56
Ruth First / North Beach	circle	16504	9,33	1,89	12,67	2,56
Ruth First / South Beach	circle	16847	7,00	1,38	10,33	2,04
Ruth First / Ushukela Dr	circle	17819	14,00	2,62	18,67	3,49
URD / Herwood	circle	30417	33,33	3,65	37,33	4,09
URD / Armstrong	circle	44813	65,33	4,68	76,00	5,65

Ave freq = average accident frequency
Ave rate = average accident rate (accidents / million vehicles)
Ave sev freq = average severity frequency
Ave sev rate = average severity accident rate (EAN / million vehicles)

3.3 Stop controlled intersections

Stop controlled intersections were included to contextualise the safety evaluation of the circles and signals. The stop controlled intersections that were analysed are listed in Table 4.

Table 4 Accident rates for stop controlled intersections

intersection	type	ADT	Ave freq	ave rate	ave sev freq	ave sev rate
Avondale / Clarence	stop	8078	11,67	4,81	16,33	6,74
JG Champion / Brookdale	stop	12411	15,67	4,21	24,67	6,63
Kenyon Howden / Radcliffe	stop	14018	12,33	2,93	16,00	3,80
Chris Hani / Sneezewood	stop	14093	14,67	3,47	17,33	4,10
John Zikhali / Currie	stop	14847	20,33	4,57	26,00	5,84
Moss Kolnick / Blazeway	stop	17358	11,00	2,11	16,67	3,20
Old SCR / Mahes	stop	17418	4,33	0,83	4,33	0,83
Stella / Ridley Park	stop	19459	21,00	3,60	25,00	4,28
RD Naidu / D'Aintree	stop	21294	8,33	1,30	14,00	2,19
URD/ Margaret Maytom	stop	21947	14,00	2,13	19,67	2,99

Ave freq = average accident frequency
Ave rate = average accident rate (accidents / million vehicles)
Ave sev freq = average severity frequency
Ave sev rate = average severity accident rate (EAN / million vehicles)

RESULTS

4.1 Accident rates and accident severity rates for full range of ADT

Figures 1 and 2 show the ADT plotted against the average accident rates and the average accident severity rates respectively.

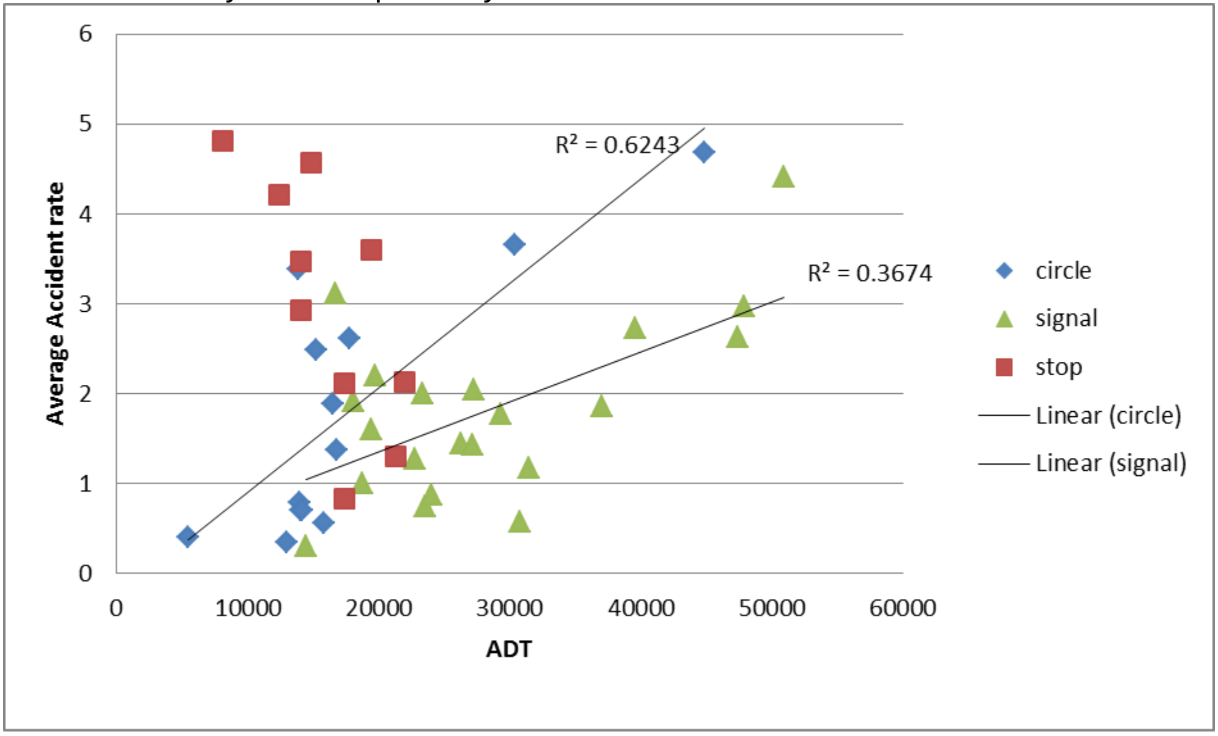

Figure 1: Average accident rates versus ADT for traffic circles, stop controlled and traffic signals

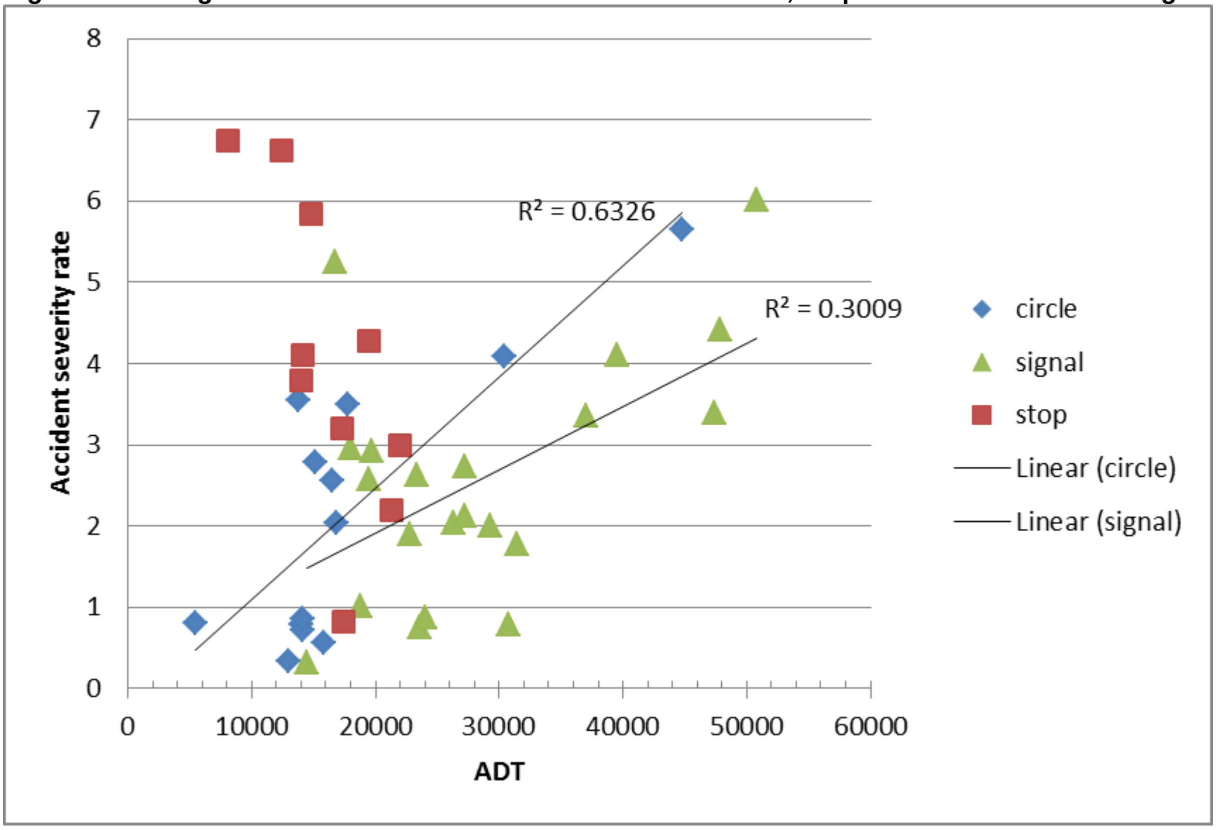

Figure 2: Average severity accident rates versus ADT for traffic circles, stop controlled and traffic signals

Linear regression analysis was done for both the traffic circles and signals, with their corresponding coefficient of determination (R^2). A high value for R^2 indicates a strong correlation, while a low value indicates a weak correlation. For example, coefficient of determination of 0,81 indicates that 81% of the total variations in the Y value occurs due to the independent X variable (Jain and Aggarwal, 2010:61-62).

As can be seen from Figures 1 and 2, they both indicate that traffic circles show a higher accident rate and accident severity rate for corresponding ADT. Although the traffic circles data only had two data points above 20 000 ADT, it had a relatively good correlation. In order to investigate the relationship between traffic circles and traffic signals further, linear regression was also done for accident frequency (Figure 3) and accident severity frequency (Figure 4).

Figures 3 and 4 yielded similar results to Figures 1 and 2. However, the R2 values were much better, showing strong correlation. In particular, the R2 values for the traffic circles show exceptionally strong correlation, much higher than for signalised intersections. This was to be expected, as at similar ADT, traffic signals can have vastly different turning movement proportions, and hence different accident rates. With traffic circles, however, the turning movement volumes are channelled into the same entry point and one-way directional flow, irrespective of where they exit. The scatter of accident frequency with increasing ADT would therefore generally be less (and the correlation better) than for circles. The R2 values for the traffic signal could be marginally increased by fitting a second order polynomial. However, the result remains that traffic circles exhibit a higher accident rate.

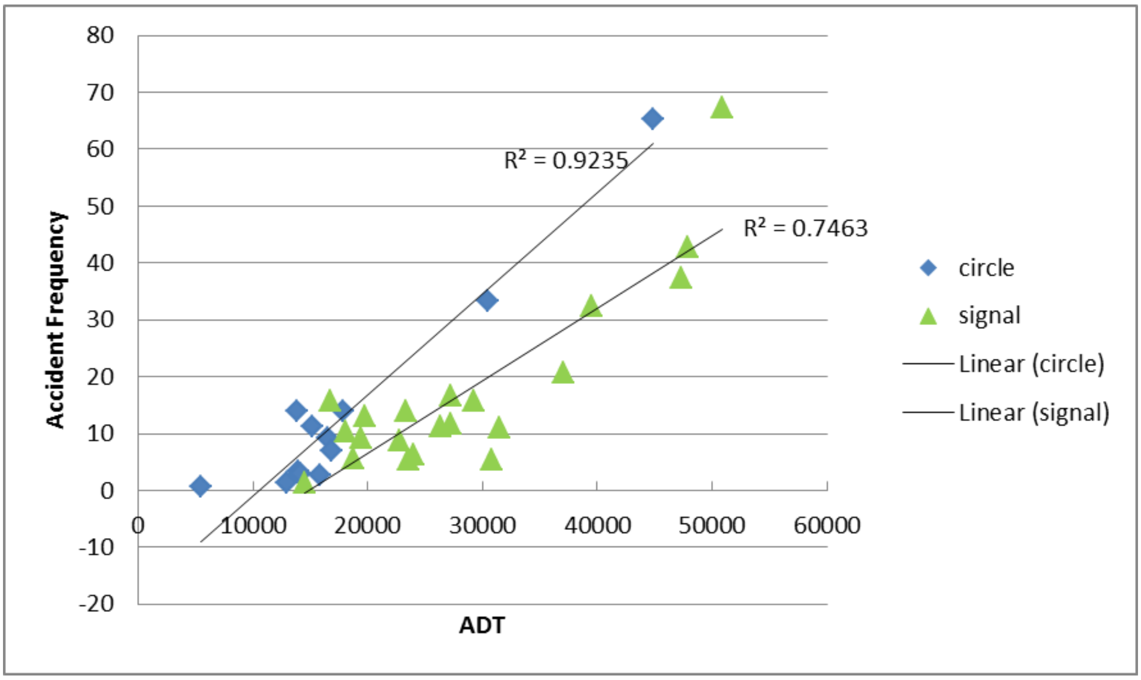

Figure 3: Average accident frequency versus ADT for traffic circles and traffic signals

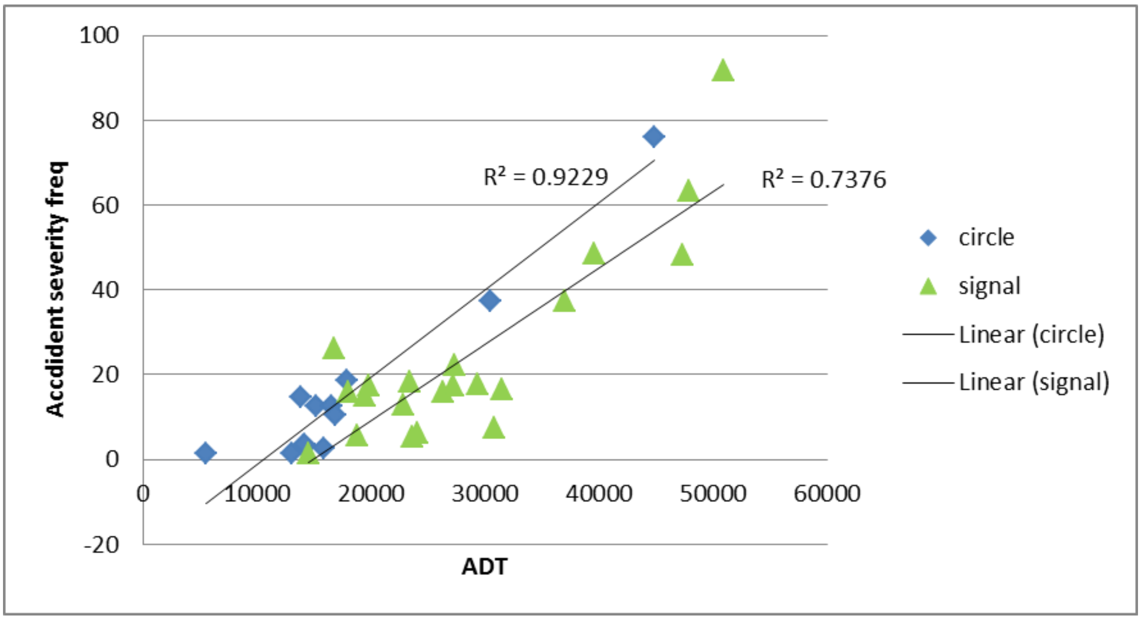

Figure 4: Average severity frequency rates versus ADT for traffic circles and traffic signals

Nevertheless, all four graphs consistently indicate that traffic circles display higher accident rates and frequencies compared to traffic signals, even when severity is taken into account.

A few points need to be noted from the above graphs:

(i) The ADT boundary for the signal warrants lies between 17 000 and 22 000 vehicles per day. The Mariannhill Rd / Sarel Celliers Rd intersection does not meet the warrants, although signalised.

(ii) The accident severity rate for traffic circles increases above that of signals approximately in the boundary for the signal warrants

(iii) The average accident severity rate for traffic circles and signals is substantially lower than stop controlled intersections in the 10 000 – 20 000 vehicles per day range of intersections.

(iv) A comparison of the accident rates and the accident severity rates (Figures 2 and 4) shows that when severity is considered, the linear regression equations for traffic circles and signals do not diverge as much, indicating that circles do tend to reduce the overall severity of accidents when compared to signals. In other words, the higher accident rates for traffic circles when compared to signals are largely due to the increased number of accidents and not an increase in the severity of the accidents.

(v) If the two high volume traffic circle data points are ignored (i.e. the data points are limited to the ADT range of 10 00 to 20 000), traffic circles still do not display the safety benefits over signals that were noted in the international literature.

4.2 Average accident severity rates for specific ADT ranges

The average severity accident rates for circles, signals and stop controlled intersections if strictly limited to the ADT range of 10 000 to 20 000 vehicles are as listed in Table 5.

Table 5: Average severity rates for types of intersections

	Average severity accident rate in the general range of 10 000 – 20 000 ADT
Circles	1,77
Signals	2,51
Stop controlled	4,10

The above table indicates that, taking purely an average severity rate for the 10 000 to 20 000 ADT range, circles generally show a lower accident rate. However, as noted above, this can be misleading. As soon as the ADT increases, circles become less safe relative to signals.

For ADT greater than 20 000, Table 6 shows the average severity accident rates.

Table 6: Average severity rates for types of intersections

	Average severity accident rate in the general range > 20 000 ADT
Circles	4,87 (two intersections analysed)
Signals	2,59 (fifteen intersections analysed)

4.3 Detailed comparative analysis of low and high accident rate circles

The four traffic circles that exhibit high accident severity rates (above 3,0) are:

- (i) Umhlanga Rock Drive / Armstrong
- (ii) Umhlanga Rocks Drive / Herwood
- (iii) Old Main / Village Rd
- (iv) Ruth First / Ushukela Drive

A detailed, comparative analysis of the traffic circles with high accident rates compared to those of low accident rates as shown in Figures 5 and 6 was required to better understand these high accident traffic circles. It should be noted that, while the actual accident numbers and their severity are deemed to be very accurate, the actual accident coding for circles could be improved. For example, there should be no "right turn opposing" accidents. Also, the differentiation between "right-angle straight," "right angle-turn" and "right turn same" is meaningless in the context of a traffic circle. These types of accidents are basically describing the accident between vehicles entering the circle and colliding with vehicles circulating within the traffic circle, and have been designated as "right angle entry" accidents.

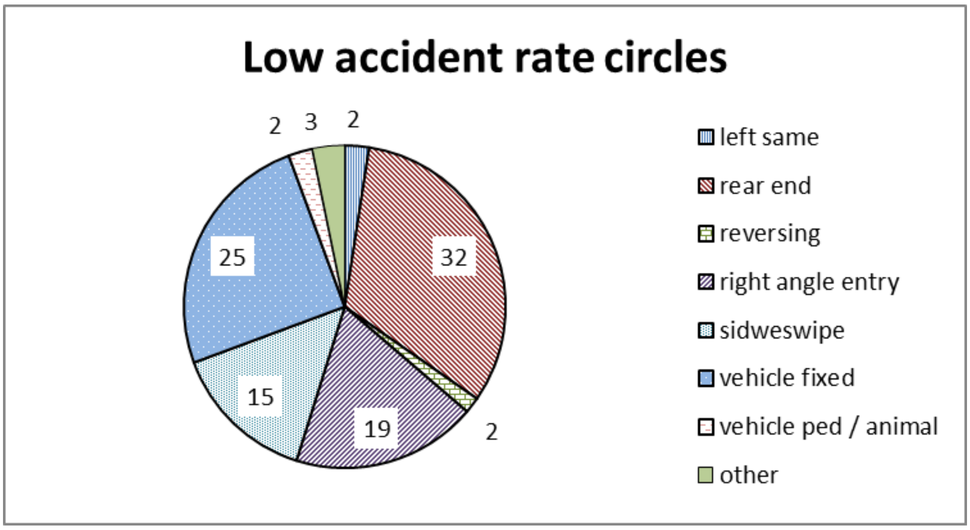

Figure 5: Classification of accidents for low accident rate circles

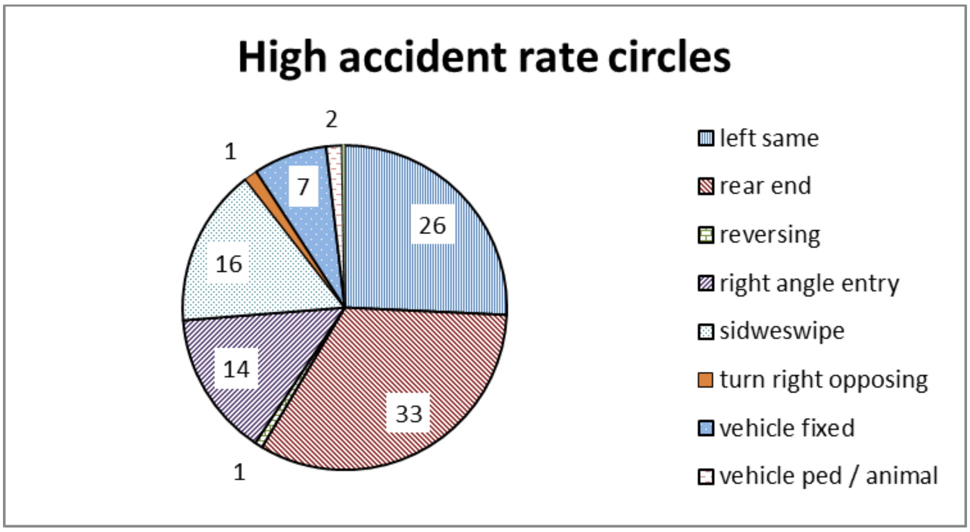

Figure 6: Classification of accidents for high accident rate circles

It can be seen from the above two graphs that the proportion of accident types were similar, except for:

- The "left same" accident proportion are much higher for the high accident rate circles. This accident type arises almost exclusively from the two lane circles in Umhlanga Rocks Drive. This indicates that there is a problem with vehicles exiting from two lanes circles, most likely due to incorrect lane selection.
- The low accident rate circles have a much higher proportion of fixed object accidents. A significant contributor to this statistic was the Ruth First / North Beach circle. This was possibly due to the fact that the Ruth First Highway effectively functions as a major arterial or freeway with very good geometric design standards, and hence allows for higher speeds to be achieved approaching the traffic circle.

A more detailed evaluation of the accidents for all circles revealed that rear end accidents at the entrances were the highest proportion of accident types at all circles (both high and low accident rate circles, 33 and 32% respectively).

3. DISCUSSION AND CONCLUSIONS

It is beyond the scope of this paper to do a detailed geometric investigation into all high accident rate circles to establish if they have been correctly designed. However, a number of conclusions are warranted:

- Firstly, from a safety point of view, there is no indication from the data analysed that circles provide a safer solution to signals once the current signal warrant range has been reached. This is similar to the *trend* from the research Nambisan and Parimi (2007:22-23) which indicated that for major intersections with an ADT greater than 20 000, circles, although still a safer option, showed decreasing safety relative to signals as ADT increased.

- Secondly, however, there is a strong case to be made for utilising traffic circles in place of stop controlled intersections up to the 20 000 ADT range. Table 5 above indicates that a traffic circle generally has a 57 per cent accident severity reduction over stop controlled intersections. This is in line with international research, which indicates that traffic circles invariably reduce accidents at stop-controlled intersections (see for example Sathyanarayanan, Russell and Rys, 2002:31, 109). A more comprehensive study would need to be done in this regard, as the space requirements for a traffic circle at an existing stop controlled intersection is higher.

- Thirdly, further research in the form of a detailed investigation into the high accident rates at high ADT traffic circles is necessary. The two traffic circles in Umhlanga Rocks with high ADT affect the linear regression, and contribute to produce results that are at variance with international research which consistently attributes lower accident severity rates for traffic circles.

- Fourthly, the accident severity rates for traffic circles in the 10 000 to 20 000 ADT range is also surprising. These rates range from 0,34 to 3,49 EAN/million vehicles with five of the traffic circles having accidents rates above 2,0 EAN/million vehicles. This also requires further investigation. The most likely explanation is that there is a general problem with the design of traffic circles in eThekwini. The following aspects, among others, need to be examined, as noted in the literature review:

    - Size of the internal diameter.
    - Deflection angles of the approaches.
    - Curvature of the approach lanes to be similar to that of the curvature within the circle, and also to be tangential to the internal circle (see Montella, 2011:1453-1454).

Another possible explanation for the high accident rates at circles in eThekwini is the generally poor driver behaviour found in South Africa. Poor driver behaviour has the result that drivers take unacceptably high risks when left to their own discretion. Stop controlled intersections would therefore exhibit the worst accident rates. Traffic circles would improve the accident rates when compared to stop controlled intersections, as they are essentially a merge with one-way traffic, and the right turn across conflicting flows is removed. Two circulating lanes in the larger traffic circles seem to generate increased accidents rates, as driver discretion is again required for correct lane selection. Traffic signals similarly reduce much of the discretionary movements from the side road. However, as ADT increases, signals tend to get additional, exclusive phases to deal with high volume conflicting movements, largely removing the discretionary gap acceptance from the drivers. Therefore, in a culture of poor driving discipline and high-risk behaviour, the ability of traffic signals using exclusive phases to remove much of the driver discretion for high risk movements is a safer option than multi-lane traffic circles. This explanation needs to be tested.

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