THE ROLE OF TRAFFIC CIRCLES IN CONSTRAINED URBAN ENVIRONMENTS

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ABSTRACT

National and international literature generally promotes traffic circles (roundabouts) as safe, efficient and cost effective alternatives to priority and signalised intersections. Research was conducted in eThekwini to evaluate the role of traffic circles in constrained urban environments. When priority intersections start experiencing high delays, local authorities are typically faced with the choice of replacing these intersections with traffic circles or traffic signals. The objective of the research was to quantify and compare the costs, environmental impacts (emissions), safety record and capacity of traffic circles versus traffic signals when the ability to expropriate additional land is both expensive and difficult. In such a scenario, are traffic circles able to be a competitive alternative to traffic signals? The research shows that, surprisingly, based on the above mentioned evaluation criteria, traffic signals still seem to offer both a safer and more cost effective option than traffic circles once the intersection reaches the traffic volumes that would warrant traffic signals.

Introduction

The role of traffic signals has come under scrutiny in eThekwini. Apart from consuming electricity (which is currently an important consideration), they also have a number of disadvantages.

(i) Firstly, when the power supply fails (due to vandalism, load shedding, and general power failures) they revert to four-way stops, which is very inefficient. The resultant congestion results in higher greenhouse gas emissions from vehicles. However, it needs to be noted that these circumstances occur only for a very small percentage of the time.

(ii) Secondly, traffic signals mainly solve morning and evening peak hour congestion problems. During the morning and afternoon valley periods, at night and on most of a weekend, they are essentially not required. During these times, there may be more efficient form of intersection control, such as traffic circles.

(iii) Thirdly, the maintenance of traffic signals is onerous and expensive, especially in a culture of rampant vandalism.

While it is simply not possible to move away from installing traffic signals at intersections, eThekwini has had a renewed interest in traffic circles. Traffic circles have the inherent advantages of consuming no power for operations and being relatively low maintenance intersections.

When priority intersections start experiencing high delays, local authorities are typically faced with the choice of replacing these intersections with traffic circles or traffic signals. The objective of the research was to quantify and compare the costs, environmental impacts (emissions), safety record and capacity of traffic circles versus traffic signals when the ability to expropriate additional land is both expensive and difficult.

This paper is therefore aimed at evaluating the role of traffic circles in relation to traffic signals in eThekwini in constrained urban environments.

In this paper, the term "traffic circle" has been retained due to its widespread usage in South Africa, even though Sampson and Meijer (2000:1) note that internationally "roundabout" is more popular. It is critical to note, however, that, generally speaking, the traffic circles investigated in this paper were recently designed and conform to the design standards of modern roundabouts. These design standards include:

(i) Tight entry radius to reduce speed
(ii) Flared exit radius to allow for faster exit
(iii) Raised islands between entry and exit lanes
(iv) Analysing capacity on gap-acceptance principles as opposed to weaving principles
(v) The approaching traffic has to yield to vehicles already in the circle (Sampson and Meijer, 2000:2; Hakkert, Mahalel and Asante, 1991:93-106).

As will be seen later, the two, high volume traffic circles that display significantly high accident rates conform very well to these standards.

It is important to note that small "mini-circles" that operate on a "first-come, first-serve" basis are not in view, as generally speaking, their capacities are significantly lower and they would not be an appropriate alternative to signalised intersections.

1. BRIEF LITERATURE REVIEW

Mandaville, Russell and Rys (2003:2-3) list a better safety record, lower fuel usage (and consequent greenhouse gas emissions), and aesthetics as advantages of circles over signals. Some of these advantages are also noted by Sampson and Meijer (2000:4-6), who also add lower construction and maintenance costs. Government Departments also list these advantages (see for example Minnesota Department of Transport; Seattle Department of Transport). In addition, writing from a South African perspective, Krogscheepers (1997:1-2) also notes the following advantages:

(i) When signals are damaged or vandalised, they pose a higher accident risk than circles, which are essentially vandal proof.
(ii) Circles have traffic flow advantages, such as ease of u-turns and automatically accommodating fluctuating demand. Signals need to be specifically set up to respond to fluctuating demand, and that at an increased cost.
(iii) Circles tend to be self-enforcing, whereas signals require active enforcement.

Some of these additional advantages reflect the current context of transport infrastructure in South Africa, where incidents of vandalism are high, and driver behaviour is less than desirable.

2.1 Costs

It is commonly argued that construction costs for traffic circles are much more than traffic signals. This argument is not always true. Sampson and Meijer (2000:5-6) note that intersection costs need to be disaggregated to reflect road user costs (such as fuel, time and accidents), construction costs and maintenance costs. Sampson and Meijer (2000:5-6) claim that construction costs to convert and intersection to a circle can be lower than to convert it to a signal, and the accident and maintenance costs are also substantially lower. They also conclude that even where signals are eventually required, the maintenance, safety and road user savings from a traffic circle would have been worthwhile, and the intersection would have most likely required widening in any event to accommodate the signals.

2.2 Safety

Internationally, circles are touted as a form of traffic control that lowers the number and severity of accidents when compared to priority intersections (Sathyanarayanan, Russell and Rys, 2002:31, 109) and signalised intersections (Seattle Department of Transport).

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

(i) The number of vehicle-pedestrian conflicts are reduced at traffic circles
(ii) At priority 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)

Flannery and Elefteriadou (s.a.:3-4) indicate that roundabouts have consistently reduced the accident rates from studies in the United States of America and Europe. 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) indicate that traffic circles show a 30-50% reduction in accident rates and severity when compared to signals. 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 being reduction in conflict points due to the one-way circulation.

2.3 Fuel usage and vehicular emissions

Emissions and environmental concerns are becoming a primary consideration in choosing between alternatives in any project. Mandavilli, Russell and Rys (2003:2) note the growing popularity of roundabouts both in the USA and the United Kingdom (UK) for a variety of reasons, such as safety, noise reduction and emissions. In particular, they report that roundabouts, in almost all circumstances, have lower fuel usage and emission rates than signals.

El-Fadel, Najm and Sbayti (2000:92-93) show the marked increase in emissions with a vehicle having to come to a stop as opposed moving through an intersection at a low but steady speed. Roundabouts therefore reduce emissions substantially in off-peak conditions compared to traffic signals, as traffic signals always bring some of the vehicles to a stop all the time (Mandavilli, Russell and Rys, 2003:3). It is only in exceptional circumstances that traffic signals have lower emissions than roundabouts.

2.4 Capacity

Sampson and Meijer (2000:3) note that while circles do not have the ultimate capacity that traffic signals have, they can still function well at intersections that would otherwise require signalisation. They indicate the following capacities for circles.

Table 1: Traffic circle capacities (Sampson and Meijer, 2000:3)

	Total capacity of all approaches	**Single lane approach capacity**	**Daily capacity**
	(veh/hr)	**(veh/hr)**	**(ADT)**
Single lane	1 500 comfortable 2 500 capacity	0- 1 500 depending on circulating volume	15 000 to 25 000
Two lane	3 600 practical capacity 4 000 ultimate capacity	1 400 (Germany)	30 000 to 40 000
Multi lane roundabouts	4 000 – 6 000 7 500 max claimed	-	-

Sampson and Meijer (2000:6) do advise that circles should not be installed where signals will soon be required.

2. EVALUATION OF TRAFFIC CIRCLES VERSUS TRAFFIC SIGNALS IN ETHEKWINI

3.1 Construction, maintenance and operating costs

It is critical to note the context of this cost comparison. The evaluation of traffic circles with traffic signals was in the context of constrained urban environments. Generally, when upgrading intersections, Municipalities will, if at all possible, work within the existing road reserves to avoid the time and cost of expropriation. In this evaluation, therefore, it was assumed that the physical roadwork costs for signal and circles would be similar. This was considered reasonable, as with the installation of signals, slip lanes and turning slots are usually required, which would approximate the costs of installing a circle within the road reserve. Importantly, this assumption was maintained when doing the capacity analysis – the traffic circles were sized to fit within the existing road reserves and kerb lines of the traffic signal layout. This meant that the only installation and maintenance costs that needed to be calculated were for the traffic signal equipment. The maintenance costs for the physical roadworks (kerbs, storm water etc) were assumed to be similar for the traffic signal and traffic circle.

A comprehensive financial analysis was done for eThekwini's 2010 budget, and actual costs for the installation and maintenance of traffic signals were determined.

3.1.1 Construction and installation costs

Three signal installations were costed in detail in the year 2010. These signals represent small to medium sized signalised intersections, and would typically be the size that would be installed at an intersection where a circle may be an option. These three intersections are listed in Table 2. The costs include equipment (poles, cables, signal heads etc), labour, installation, pole painting, the electricity connection and transport.

Table 2: Installation costs for three typical intersections in eThekwini

	Brighton / Grays Inn Rds	Attercliffe / Jan Hofmeyer Rds	Bartle / Hillier Rds
TOTAL (incl VAT)	R242 512	R 256 970	R 236 974

This yielded an average intersection installation cost of R 245 000. As can be seen from the above figures, the variation between individual intersection installations costs was low, and the estimate is therefore considered suitably accurate to represent a small to medium installation.

3.1.2 Maintenance costs

Traffic signal maintenance costs were collated for eThekwini for 2010. These included both contractor costs and internal municipal costs. The internal municipal costs include both electrical / electronic maintenance costs, as well as costs to keep the signals well-timed. It therefore includes full costs of internal staff, communication costs, vehicle fleet costs and materials. However, associated costs such as restoration of electricity supply were borne by the Electricity Department, and have not been included. Due to space constraints, the full breakdown could not be given here.

It was found that the total annual maintenance cost was R64 071 per annum per signal.

The above costs do not include repairs to surfacing, kerbs, drainage, traffic signs or line markings. These costs should be comparable for both signal and circles, and therefore excluded from the comparison.

3.1.3 Operating costs

In terms of operational costs, only electricity costs needed to be further considered. The following electricity usage and costs are relevant for a medium sized signal with LEDs:

Average electricity usage- normal signal: 350W/hr
Average annual power consumption: 3,066 MW
Cost /kWhr: R 0,970 (supplied by eThekwini Electricity for 2010)
Cost per annum per intersection: R 2 974

In summary, traffic signals have the following additional installation, maintenance and operating costs (at 2010 prices):
<u>Installation</u>: R245 000.
<u>Maintenance and operating</u>: R67 000 pa.a

3.2 Emissions

Two intersections were modelled to compare emissions:

- Old Mill Way / Sackville Place
- Moss Kolnick / Ashgate Roads

These intersections were modelled on SIDRA using the standard eThekwini default gap acceptance and follow-up headway values. The morning peak, evening peak, average daily hour and average night hour were modelled in order to establish a twenty four hour assessment of the comparative emissions of circles versus signals at both these sites.

Due to space limitations, and the fact that the two intersections yielded very similar results, only the results of the one intersection will be given here.

At Moss Kolnick / Ashgate Roads, the following results were obtained for CO_2 emissions:

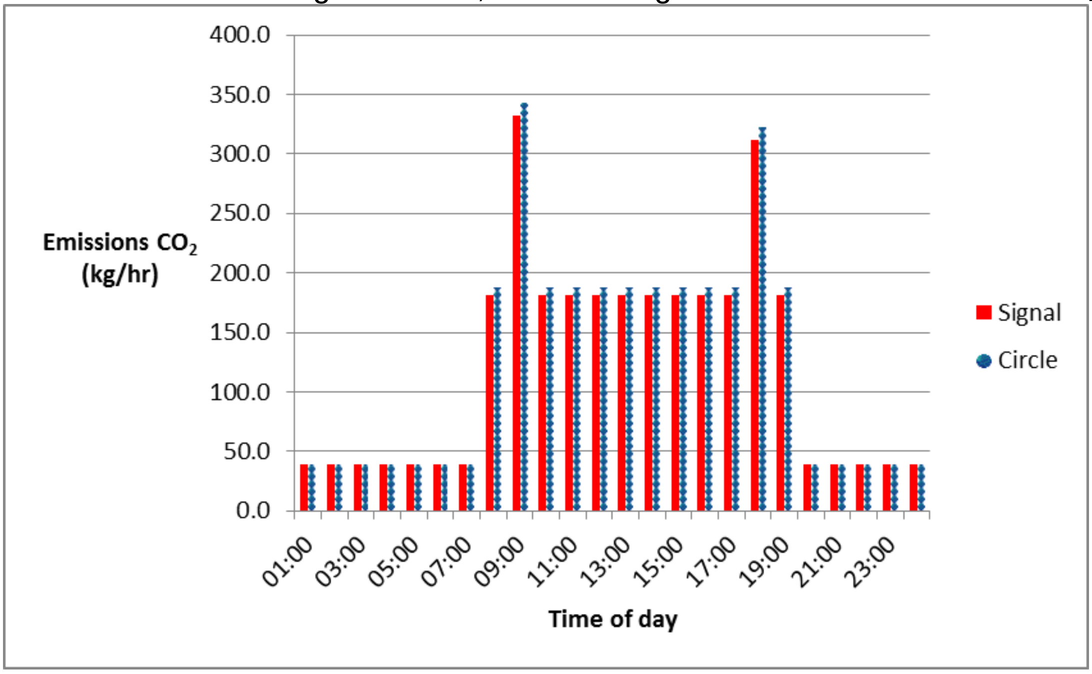

Figure 2: Comparative CO_2 emissions: Moss Kolnick / Ashgate Roads

Emissions were very close for traffic circles and signals, as shown in Table 5.

Table 5: Twenty-four hour CO2 emissions for Moss Kolnick / Ashgate Roads

	24 hour CO2 emissions (kg)
Signals	2922,80
Circle	3009,90

As can be seen, the values are within 3% of each other. A similar result was obtained for the emissions of NOx, CO and HC, as can be seen in Table 6.

Table 6: Twenty-four hour emissions for Moss Kolnick / Ashgate Roads

	NO_x emissions (kg)	CO emissions (kg)	HC emissions (kg)
Signals	6,935	225,98	4,692
Circle	7,446	248,20	4,868
% difference	-7,3%	-9,8%	-3,7%

The lack of local emission data in South Africa means that the SIDRA models for eThekwini cannot be considered to be extremely accurate with regard to vehicular emissions. This meant that if the emissions results for signals and circles were relatively close, no definitive conclusion could be reached as to which is more efficient in terms of emissions. More accurate base data may in fact produce modelled results that agree with the international research.

3.3 Safety

The eThekwini Transport Authority is in the fortunate position of having one of the most accurate and reliable accident databases in South Africa. The safety record for some fifteen traffic signals, thirteen priority intersections and ten traffic circles were compared, representing a comprehensive accident assessment for circles in eThekwini.

For the sake of comparison, a 3 year accident record (2009-2011) was used for each intersection. Counts between 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.

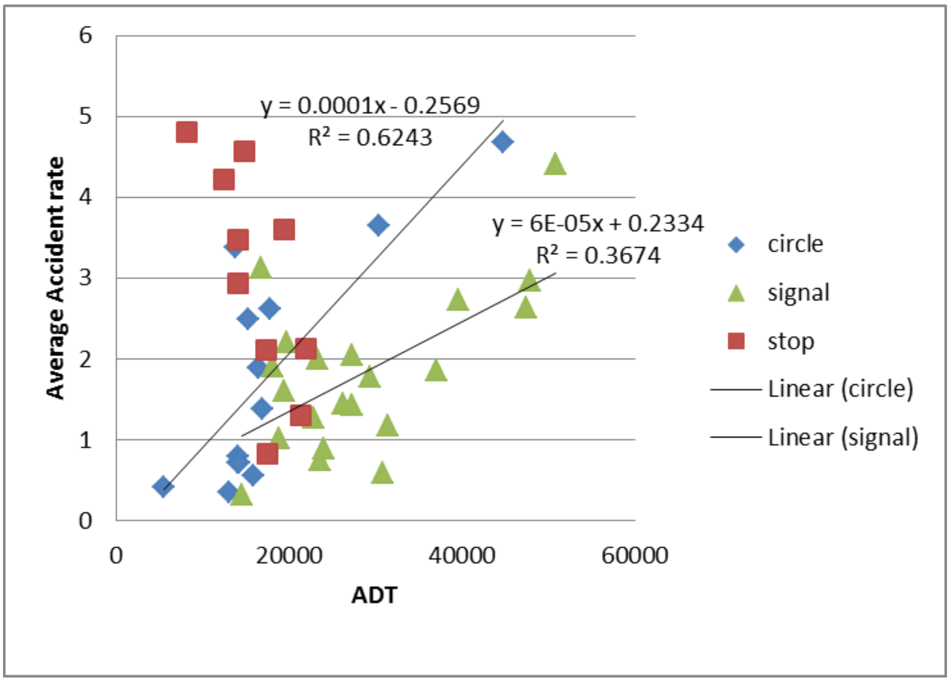

Figure 3: Average accident rates versus ADT for traffic circles, priority and traffic signals

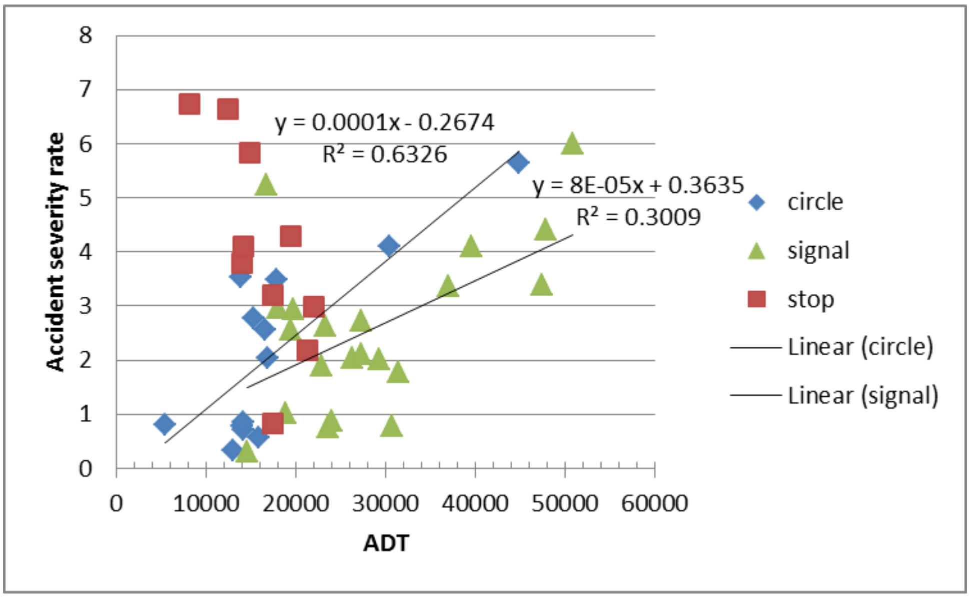

Figure 4: Average severity accident rates versus ADT for traffic circles, priority and traffic signals

Linear regression analysis was done for both the traffic circles and signals, with their corresponding coefficient of determination (R^2). A value for R^2 greater than 0,64 indicates a strong correlation, while a value of less than 0,25 indicates a weak correlation.

As can be seen from Figures 3 and 4, the results 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. It can also be seen from the graphs that eThekwni's signal warrants start from around 17 000 ADT.

Accident frequency and accident severity frequency versus ADT were also plotted for traffic circle and traffic signals. They gave similar results to those above, with improved R^2 values.

These results were surprising and contrary to international literature. A comparison of the accident and accident severity rates for a significant sample of traffic circles and signals have shown that:

(i) For traffic circles within the 10 000 to 20 000 ADT range, there is a significant proportion of traffic circles with accident severity rates above 2,0 EAN/million vehicles. A few traffic circles have a rate above 3,0 EAN/million vehicles.
(ii) For the 10 000 to 20 000 ADT range, based purely on an average accident rate, traffic circles have a lower accident rate than traffic signals. This statistic, however, can be misleading, as the linear regression for the accident severity rates for traffic circles and signals show that even in this range, traffic signals are comparable and could even be safer than many traffic circles.
(iii) For traffic circles with a ADT greater than 20 000, the accident rate increases to over 4,0 EAN/million vehicles, significantly higher than traffic signals. *It is critical to note that these two traffic circles conform very well to the design standards of modern roundabouts (see Introduction).*

The regression analysis for the accident rates and accident severity rates indicate that from the range where signals are warranted (around 17 000 to 20 000 ADT), traffic signals in fact provide a safer accident record.

The cost of accidents at traffic circles as opposed to traffic signals at the 20 000 ADT can be calculated:
Traffic circles at 20 000 ADT = 2,5 EAN/ million vehicles (average)
Traffic signals at 20 000 ADT = 1,9 EAN/ million vehicles (average)
This equates to a 24% reduction in accident severity rate.

The average cost of accidents for the three traffic circles close to the 20 000 ADT is R 537 408 p.a. A twenty-four per cent reduction in accidents equates to a saving of R129 000 p.a. Using the values for the installation of the traffic signals, and the annual maintenance and electricity costs for signals, this means that within 4 years the savings in accident costs for signals will outweigh the additional installation and operating costs relative to traffic circles

This means that the cost savings for signals in terms of accidents relative to traffic circles is significant, and outweighs the additional installation and maintenance costs. From a safety point of view, then, until the eThekwini Transport Authority can address the high accident rate at traffic circles, signals are a more cost effective option when priority intersections start reaching the traffic signal warrant levels.

4.4 Capacity and delay

Two priority intersections that were experiencing high delays were analysed to test the capacities and design life of both a traffic signal and traffic circle solution. The general approach was to design a traffic signal with the required slip lanes and turning slots. A traffic circle that generally “fitted” within the road reserve and traffic signal kerb-lines was designed. Both were analysed with SIDRA, to test their capacities, level of service and design lives.

Due to space limitation, and the fact that very similar results were obtained for both intersections, only the results of one of the intersections will be given.

Figure 5 shows the relative reductions in average control delay at the intersection using a traffic circle and traffic signal. As can be seen, the reductions in delay are very similar, with the traffic circle offering slightly better levels of service than the traffic signal in the PM peak. For the current situation, both the traffic circle and the traffic signal offer acceptable solutions, with both taking up similar land space.

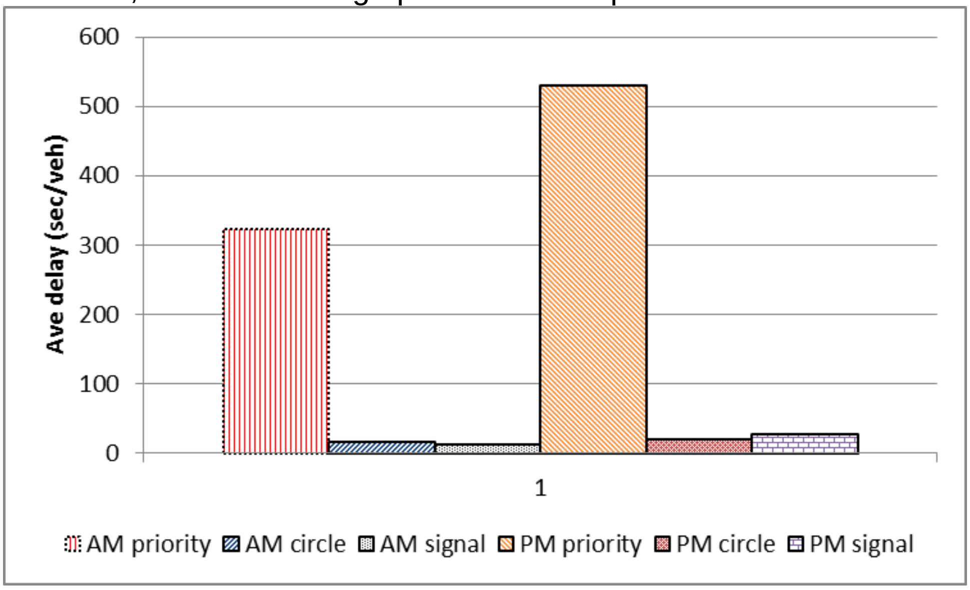

Figure 5: Relative average control delay for Armstrong / Ridge Rds

However, in terms of the design life of the solutions, Figure 6 shows that after 4% traffic growth the traffic circle experiences significantly increased average control delay relative to the traffic signal.

A traffic signal is therefore more efficient in handling the traffic growth if the traffic circle is limited to the general land-take of the traffic signal. A significantly larger traffic circle would be required to match the capacity of the traffic signal at these higher volumes.

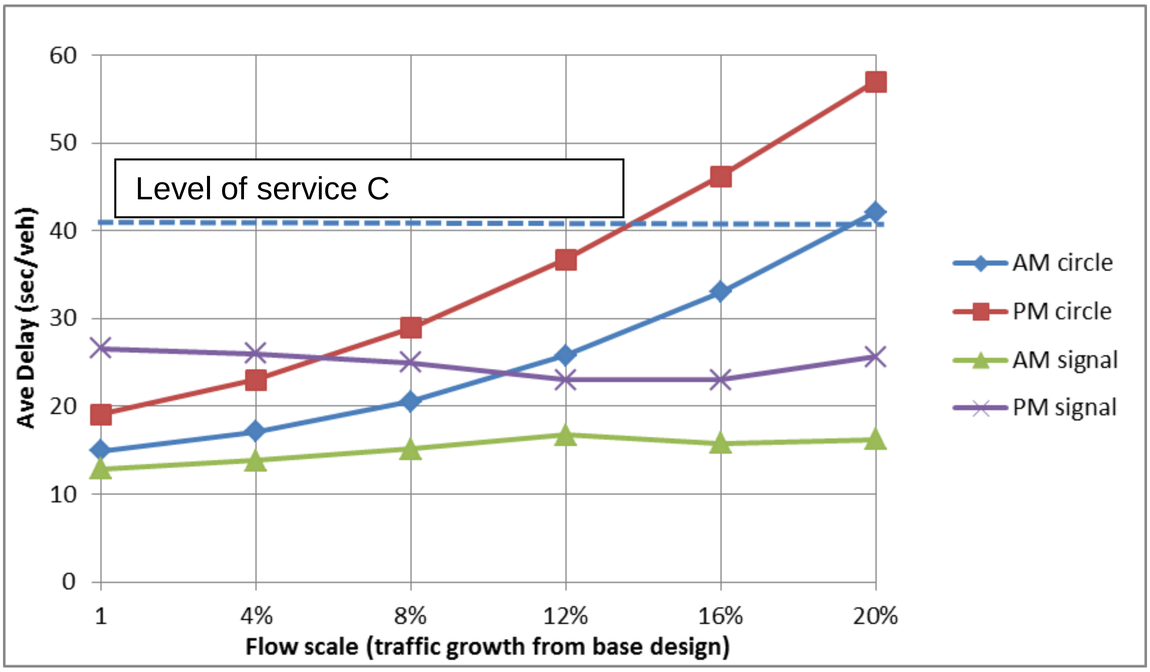

Figure 6: Design life of alternatives

3. CONCLUSIONS

The following conclusions are warranted for the role of traffic circles versus traffic signals in built up, urban areas where availability of land is problematic:

(i) The current signal warrant which takes effects in the range of 17 000 to 20 000 ADT seems to be appropriate.

(ii) When signals are warranted, they have a lower accident rate than traffic circles, and these accident costs savings relative to traffic circles outweigh the additional installation and maintenance costs of the signals within four years. This conclusion is contrary to international norms, and eThekwini needs to urgently investigate the reason for the higher accident rate at traffic circles. In this regard, as noted earlier, the traffic circles investigated generally conform to the design standards of modern roundabouts. The two, high volume traffic circles that show very high accident rates in particular conform closely to these design standards.

(iii) From a capacity and delay point of view, traffic signals show a much higher design life than traffic circles in built up, urban areas where land is constrained.

(iv) Many traffic circles in eThekwini indicate much higher accident rates than international norms.

(v) There is a significant accident reduction when comparing priority intersections with traffic circles. Replacing high accident priority intersections (which are well below signal warrants) with traffic circles will significantly reduce the accident rates at these intersections.

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