Roundabouts along Rural Arterials in South Africa

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ABSTRACT
The use of roundabouts in both an urban and rural context have been gaining ground over the past twenty years not only in South Africa, but also in many other parts of the world. Apart from the geometric design details and the operational characteristics of roundabouts there is also no clear guidance in terms of the spacing of roundabouts, specifically when it comes to using them along a high order road. Often the spacing requirements for signals along arterials are being used as a guideline to determine the spacing of roundabouts.

This paper explores the practical use of roundabouts along arterials and specifically along high speed rural arterials with relatively high commuter traffic volumes. This is done for a rural arterial in the Western Cape, South Africa. The focus of the evaluation is specifically done in the context of operational efficiencies, access management and future capacity requirements of the arterial.

The operational efficiencies of the roundabouts along the corridor, currently and under future higher demand scenarios, was evaluated using micro-simulation analysis where roundabout control is compared with traffic signal control. The comparison of the simulation results clearly highlights the operational advantages of using roundabouts, but is also illustrates possible future capacity constraints for the roundabout scenarios. Based on the simulation results it is evident that roundabouts could play a role in the rural arterial context, not only operationally but also in terms of safety and future capacity expansions.

INTRODUCTION
Over the past decade, roundabouts have been considered increasingly as an important type of intersection control at major intersections. Mostly because of the low average delay to vehicles when considered for the full day and also because of the many safety advantages. As part of the development of an Arterial Management Plan for the R304 that connects the town of Stellenbosch in the Western Cape with the N1 and Malmesbury further to the north, the question was raised how to deal with the major intersections along the route (1). Although the route runs mostly through a rural area, the demand for direct access off the R304 is steadily increasing due to the number of wine farms along the route and the owners that are looking to increase the tourist potential of the properties. Not only is there a demand for direct access to individual properties, but there are a number of current and planned future roads that are and will be intersecting with the R204. Most of the intersections, except one that is currently signalised, are stop controlled on the minor approaches or even stop controlled on all approaches. The R304 is a strategic north-south link between the N7 through Malmesbury via the N1 and Stellenbosch to the N2 in Somerset West. The locality of the route is shown in the following figure.

Primary Objectives
The objective of this study was firstly to evaluate the operational impacts of roundabouts as the primary intersection control along a rural arterial and to compare that with other types of intersection control, specifically traffic signals. Secondly, the objective was to evaluate the spacing requirements of roundabouts when compared to that of traffic signalised intersections, specifically in the light of existing guidelines which are mostly silent on the spacing requirements of roundabouts (2). The safety and other benefits of roundabouts are widely publicised and are not considered specifically in this study (3,4).

Study Roadway
The study roadway includes the R304 or Provincial Main Road 174 (MR 174) between the N1 Freeway and the town of Stellenbosch. The study only covered the southern section of the R304 between KM 47.0 and KM 60.0, i.e. approximately 13.0 kilometres. There are six major intersections along the study roadway as well as many direct property accesses. For the purposes of this study only the six major intersections were included. The actual distances between the intersections are illustrated in Figure 1 and vary from 560 metres to nearly 5 kilometres.
STUDY APPROACH

The study investigated the operational efficiencies of traffic signals and roundabouts at the major intersections along this rural arterial. The Paramics micro-simulation model was used to simulate operations during a typical weekday (5). A typical daily demand profile was used as input to the model and a 24-hour period was modelled. The model was validated to ensure that the modelled volumes, queue lengths and average speeds were similar to the existing. The following traffic volume scenarios were evaluated:

- Short Term Scenario: Existing traffic plus 20% growth (4-5 year horizon)
- Medium Term Scenario: Existing traffic plus 40% growth (8-12 year scenario)
- Long Term Scenario: Existing traffic plus 60% growth (15-20 year scenario)

The traffic control and actual lane configuration at the intersections were adjusted with the increase in volumes to ensure realistic capacities for the intersections. For the roundabout options, this was only done up to a double lane roundabout with left-turn slip lanes where necessary.

ROAD NETWORK AND INTERSECTION CONTROL

The R304 is currently a two-lane two-way roadway for most of its length with turning lanes at some of the intersections. There are many passing opportunities since the topography is mainly flat and many slower motorists allow faster vehicles to pass by moving to the shoulder. The roadway cross-section consist of what is defined as a Class 1 type by the Western Cape Government and which typically consist of two 3.7-metre travel lanes with 2.0 metre shoulders on both directions (Refer to Figure 2).
All the intersections are currently unsignalised with stop control on the minor approaches, i.e. free flow along the R304. The only exceptions are the Bottelary Road intersection, which is signalised with dedicated turning lanes and the Welgevonden Intersection which was recently signalised. The latter happened after this study was completed. Many of the intersections are experiencing capacity constraints and with an increase in traffic volumes, this situation will naturally deteriorate to a point where another type of control will be required like a traffic signal or a roundabout. Many of the direct accesses to farms and other uses do not have dedicated turning lanes and turning vehicles have to stop in the through lane to wait for an acceptable gap in the opposing traffic to turn. From previous work, it has already been established that the road will require dualling within the near future to ensure that acceptable levels of service are maintained, not only along the mainline sections, but also at the intersections. For the purposes of the evaluation, it was assumed that the road would remain a single lane roadway, but that the intersections will be upgraded to allow the maximum capacity at the intersections within the constraints of a single lane arterial.

**TRAFFIC VOLUMES**

The current daily volumes vary from less than 10 000 vehicles per day north of the N1 Interchange to approximately 20 000 vehicles per day south of Bottelary Road. The volumes between the interchange and Bottelary road vary around 15 000 vehicles per day. The variation in traffic volumes over a typical day along the section north of Bottelary Road where the daily volumes vary around 15 000 vehicles is illustrated in Figure 3. The morning and evening peak hour volumes of between 1 300 and 1 500 vehicles per hour are typically between 8.5 and 9.5 percent of the AADT. The traffic volumes during the evening peak are slightly higher than during the morning peak.
The variation in traffic volumes as modelled over a typical day was increased with the following
percentages to replicate future demand scenarios:

- 20% Increase = 3 – 4 percent growth per annum over 4 to 5 year period [Short Term]
- 40% Increase = 3 – 4 percent growth per annum over 9 to 12 year period [Medium Term]
- 60% Increase = 3 – 4 percent growth per annum over 12 to 16 year period [Long Term]

MODELLING

The network that was included in the modelling was a collapsed version of the actual network as
illustrated in Figure 1. The long distances between the Old Paarl and Bottelary Road intersections as
well as between the Bottelary Road and Welgevonden Road intersections were reduced from 4.84 km
to 1.76 km and from 3.99 km to 500 metres respectively. This was done to reduce the modelling time
and to create a more compact network. The more compact network should be an advantage to the traffic
signal control scenario since it supports synchronisation of signal timings. However, once intersections
are spaced more than 1.0 km apart, the efficiency of synchronisation disappears since platoons disperse
to the extent that arrivals can be considered random. The signal timings of the individual intersections
were optimised for the different demand scenarios and also synchronised as far as possible.

For the purposes of this exercise, the model was built using the recommended default values available
for the variables in Paramics. It was then visually checked to ensure that the queues that develop at the
control intersections correspond with what is observed in the field. The modelled speeds and volumes
were also checked against the actual counted volumes and the observed free flow speeds. There are no
locally available calibration parameters for simulating driver behaviour in Paramics, specifically such
as gap acceptance at roundabouts. The simulation model results, specifically the queue lengths were
compared against estimates provided by the analytical HCM and Sidra methodologies.

The Paramics model is based on the assigning of vehicular trips between origin and destination zones.
The OD-matrices for both alternatives were exactly the same in terms of the volume as well as the
variation over the hour and the day. The model was setup to run a short warm-up time before the actual
demand files were introduced. However, since the whole day was modelled from early morning when
the network is essentially empty to late evening, the impact of the warm-up period on the modelling
results was negligible. Each of the scenarios was simulated with at least five different seed numbers and
an average of the five runs was used for comparison of the results.

RESULTS

For the purposes of this study the following network performance measures were used:

- Average speeds of all vehicles in the system
- Standard deviation of the speeds of all the vehicles in the system
- Average delay per vehicle in the system
- Average travel times between defined origins and destinations
- The time-space movement of selected individual vehicles.

Average Speeds

The average speeds for all vehicles in the network and for the two alternatives are illustrated in Figure
4 and Figure 5. In Figure 4, the average speed is shown for each minute interval over a normal weekday,
while in Figure 5 these speeds were averaged for the specific demand period and in addition to the
average speeds, the standard deviation during a demand period is also illustrated. These results are only
for the first demand scenario with 20 percent growth. It is evident from both figures that in general, the
average system speeds for the roundabout option are higher than those of the signal control alternative.
The difference in average speeds is significantly more during the off- and evening periods where it is
generally 50 percent higher for the roundabout option. During the peak hours the average speeds for the
roundabout option are nearly 30 percent higher. As the demand increases the difference in average
speeds during the off-peak hours remain more or less similar to the 20 percent scenario. However, during
the peak hours, the average speeds for the roundabout options decrease to the point where, during the p.m. peak hour with a 60 percent increase in demand, the average speed for the roundabout option becomes less than that for the traffic signal option. The decrease in speeds for the roundabout option is essentially due to the capacity constraints of the Bottelary intersection where the 60 percent increase in demand scenario will result in the capacity of the roundabout being exceeded.

Figure 4: Average Speeds of All Vehicles (20% Increase in Volumes) per minute of a weekday

Figure 5: Average Speeds and Speeds within one Standard Deviation per demand period of a weekday (20% Increase in Volumes)

Apart from the average speed per time interval as simulated, the variation in the average speeds from time interval to interval should be noted. The impact of the delay of a single vehicle during a time interval with low demand is more significant during a low demand interval, compared to when there are several vehicles during the interval. The variation during the low demand periods is similar for both alternatives, but during the peak hours and the midday period, the variation in average speeds is much more significant for the traffic signal option than for the roundabout option. The variation in average speeds for the traffic signal option is due to the impact of the traffic signal phasing. During intervals when the signals are red and the majority of the vehicles are stopped, the average speed will be low, while during a green interval the average speeds will be high. The signals were coordinated with red and greens at all signals displayed in a constant pattern. The phasing was optimised to ensure that the optimum cycle length and phasing was used for the current demand during all hours, except during the midday peak period, where a longer cycle length (80 seconds) was used compared to that used in the off-peak hours (60 seconds). The demand during the off-peaks and midday period was similar. The longer cycle length during the midday peak period resulted in higher average speeds, but also in much more variation in average speeds.
It is evident from these comparisons that the roundabouts option will ensure higher average speeds during most times of the day and also more reliable travel times for all vehicles. Under the traffic signal control option, some drivers can experience relatively low speeds and long travel times when having to stop at red signals compared to other vehicles who might encounter mostly green signal phases resulting in higher average speeds and shorter travel times. As the demand increases to levels where the capacity of the roundabouts are approached, the average speeds on the capacity constrained approaches will impact the average speeds of the system.

**Average Delay**

The average delay per vehicle over the entire simulation day is illustrated in Figure 6 for the 20 percent demand scenario.

![Figure 6: Average delay per vehicle (20% Increase in Volumes) over a normal weekday](image)

For the 20 percent demand scenario, the average delay per vehicle during the off-peak hours is similar (120 seconds per vehicle) for the two scenarios, although it is slightly lower for the roundabout control scenario. Once the peak hours start and the higher volumes are introduced the average delay per vehicle for the traffic signal scenarios increases to more than 140 seconds while for the roundabout scenario it increases to less than 130 seconds. As the demand volumes increase to more than 60 percent of the current demand, the delay per vehicle for the two options is similar for most of the day until the p.m. peak period. During the latter period, the demand at the Bottelary Road intersection exceeds the capacity of the two-lane roundabout, resulting in significantly higher delays for the roundabout option compared to the signal option. The comparison of the average delays clearly indicates that the delay per vehicle for the roundabout options is generally lower than the traffic signal option, until the capacity of one or more of the roundabouts is exceeded.

**Average Travel Times between Major Origins and Destinations**

The average travel times and average delay per vehicle discussed in the above sections, report on a system-wide measure which includes data for all vehicles in the system and from all origins to all destinations for a specific time interval. A more detailed evaluation of the traffic operations between the major origins and destinations was also done and specifically between the N1 and Stellenbosch, and between Bottelary Road and Stellenbosch. The results of the evaluation are summarized in Figure 7 for the scenario with a 20 percent increase in demand. The graph shows the difference in travel times for the specific origin-destination pair indicated on the x-axis of the graph. A positive number indicates that the traffic signal control option resulted in shorter travel times, while a negative number indicates that the roundabout option resulted in the shorter travel time.
For the scenario with a 20 percent increase in demand, the roundabout option resulted in shorter travel time for all the O-D pairs and for all times of the day, except for the N1 to Stellenbosch and back during the off-peak hours. This means that during these low speed periods, it is possible to travel faster through the system along the R304 and on average arrive at the traffic signals on green without having to stop.

As the traffic volumes increase with 40 and 60 percent, the benefits of the roundabout option decrease with a relatively smaller difference in travel speed when comparing the two alternatives. This is the case for all time periods, except during the p.m. peak hour where it is evident that the demand at one or more of the roundabouts reached the capacity of the roundabout/s with the associated impact on travel time. The capacities of the roundabouts were not increased beyond that of the two-lane roundabout which is obviously not sufficient when compared to that of the signal controlled option. More detailed investigation revealed that the constraint occurred at different roundabouts depending on the time of day.
From the above figure it is evident that the roundabout scenario is optimal even with a 60 percent increase in demand for all the major origin-and-destination pairs except for the following:

- During the a.m. peak period for vehicles travelling from the N1 to Stellenbosch
- During the p.m. peak period for vehicles leaving Stellenbosch to both N1 and Bottelary.

**Travel Times of Individual Vehicles**

To understand the reason for the change in average travel times with an increase in demand as outlined above, the path of individual vehicles were tracked through the network and specifically from the N1 to Stellenbosch and back. The simulated vehicles were selected randomly and the time-distance profiles are presented in several graphs. The profiles for the a.m. and p.m. peak period and for the scenario with a 20 percent increase in demand are illustrated in Figure 9 and Figure 10, respectively. These figures illustrate the time on the y-axis that it takes to cover a specific distance (x-axis) for different randomly selected vehicles and for the two control scenarios. The blue paths are vehicles tracked through the roundabout scenario and the red paths are for vehicles tracked through the traffic signal scenario. The paths for both directions of travel are plotted with the traffic signal phasing indicated at each of the intersections. The signal timing is obviously only relevant to the traffic signal scenario. The vehicle paths start at time zero and increase over time as the vehicle travels along the route. The steeper the gradient of the path the slower the vehicle moves, with a vertical line indicating a stationary vehicle.

From these profiles the following are evident for the 20 percent increase in demand scenario:

- Vehicles generally travel along the arterial at a constant speed except for slower speeds at the roundabouts and zero speeds whenever they stop at a signal.
- Whenever vehicles are not stopped by the red phases the travel times are shorter than that of the roundabout option. However, it generally just takes one stop to increase the travel time to more than that of the roundabout option.
- The larger variation in travel times for the traffic signal option is evident when compared to the roundabout option, with some vehicles stopping on red and others not.

![](image)  
**Figure 9: Time-Distance profiles of Individual Vehicles - AM Peak (20% increase in demand)**
In Figures 11 and 12 are illustrated the vehicle paths for the scenario where there is an increase in demand of 60 percent, again for the a.m. and p.m. peak periods. The paths are significantly different from the 20 percent increase in demand scenario and it is evident that:

- During the a.m. peak period, the roundabout at Bottelary Road cannot accommodate the eastbound demand resulting in long delays for vehicles travelling from the N1 to Stellenbosch.
- The remainder of the network operates acceptably during the a.m. peak period for both the roundabout and traffic signal control scenarios.
- During the p.m. peak period, the constraint is the intersection at Welgevonden Road, specifically the westbound direction through the roundabouts but to some extent for the signal option also.
- The remainder of the network operates acceptably, with the roundabout options outperforming the signal option in terms of travel times.

It is evident from the modelling results that roundabouts offer various benefits compared to traffic signal control:

- More predictable travel times, i.e. less variation in travel times and delays
- Less delay and faster travel times for most times of the day and for a variation in traffic demand.

On the other hand it is also evident that the capacities of some of the two-lane roundabouts (used in the simulation) were reached at lower levels of demand than when compared with that of the traffic signal option. These capacities were reached with an increase in demand of approximately 60 percent beyond current levels, which represents a design life of 12 to 16 years depending on the actual growth in traffic.
Figure 11: Time-Distance profiles of Individual Vehicles - AM Peak (60% increase in demand)

Figure 12: Time-Distance profiles of Individual Vehicles - PM Peak (60% increase in demand)
CONCLUSIONS

The aim of this study was to evaluate the operational impacts of roundabouts as the primary intersection control along a rural arterial and to compare that with specifically traffic signals. From the results of the study it can be concluded that:

- Roundabouts offer significant operational benefits when compared with traffic signals even along high volume major arterials.
- Roundabouts could result in more reliable average travel times and speeds when compared to traffic signals.
- Roundabouts are self-regulating and the operations are directly impacted by the presence of other vehicles, which is specifically evident during low demand periods. Low demand periods exist for a large part of the normal day.
- The operational benefits throughout the day when roundabouts are used compared to traffic signals, should emphasize the use of roundabouts along arterials. Note that this is concluded based on the specific scenarios evaluated as part of this study and should not be applied blindly without a detailed engineering evaluation.
- The safety benefits of roundabouts for all road users are widely reported, and combined with the operational benefits outlined in this study, make a compelling case for the use of roundabouts even along high volume arterials.
- Roundabouts have less capacity than traffic signals and could result in worse operating conditions during some of the peak periods of the day when compared to traffic signals. This holds specifically for two lane roundabouts compared to traffic signals with four lanes per approach, i.e. turning lanes and through lanes.
- The possible capacity constraints need to be considered during the design and evaluation process, while also bearing in mind future upgrade alternatives such as grade separation and/or the possible conversion to traffic signals.

REFERENCES