LYNNWOOD ROAD ARTERIAL STUDY
The effect of intersection spacing on arterial operation

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1 INTRODUCTION

The desirable spacing of intersections on provincial arterial roads in Gauteng is 600 to 800m. In exceptional circumstances, the Gauteng Department of Transport and Public Works (Gautrans) will allow a spacing of 550m minimum. Although these standards are well established to ensure proper traffic mobility, the provincial authorities often receive requests for these standards to be relaxed. In these requests, the need for the high mobility provided by the large spacing of intersections along the arterial is usually disputed, and it is often argued that the spacing between intersections should be reduced to improve the access function of the road.

The questioning of existing standards, coupled with the current issue of access control on arterial roads, has led to this investigation to determine the effect of intersection spacing on the traffic operation on arterial roads.

2 EXISTING POLICY FOR SPACING OF INTERSECTIONS

It is accepted that provincial roads serving an arterial function will eventually become dual carriageway roads consisting of at least 4 lanes. Traffic growth along these roads will eventually require the installation of traffic signals at all intersections. Therefore, the Gautrans policy for the spacing of intersections on these roads is based on considerations for signalised intersections. The motivation for this policy is primarily based on the findings of NCHRP Report 93. The motivation can be grouped according to mobility, accessibility and safety considerations.

2.1 Mobility

- The main function of provincial arterial roads is the provision of mobility for through-traffic. Mobility on signal controlled roads is improved by using coordinated traffic signals which increase operational efficiency through reducing vehicular stops and delays.
- Coordinated traffic signals allow vehicles on the main road to maintain a reasonably high speed through the progressive flow of platoons of vehicles.
- Intersections need to be spaced at regular intervals to allow two-way progression that will minimise overall travel time.
- The maximum through-capacity is achieved by using longer signal cycle lengths, typically between 60 to 120 seconds per cycle.
- Depending on the cycle time of traffic signals, progression speeds of between 60 and 90 km/h can be achieved with intersection spacing in the range of 500 to 600m.

2.2 Accessibility

Access to the arterial is controlled to reduce traffic interference and facilitate through-movement. Generally, the longer the spacing between intersections, the less interference to through-traffic, and the higher the speeds on the arterial.

On the other hand, the disadvantages of longer spacing between intersections are:

- Longer travel distances for side road traffic entering or leaving the arterial.
- Platoon formations of vehicles travelling on the arterial tend to break up, thereby reducing even progression.
- Generally, the longer the spacing, the larger the volume of side road traffic concentrated at each intersection.

2.3 Safety

Traffic safety and accidents are related to the number of intersections on a road:

- Collision rates on arterial roads generally increase with the number of signalised intersections per kilometre.

2.4 Practical standards

On the strength of the considerations above, the desirable access spacing has been determined by Gautrans as 600m to 800m, with 550m as the absolute minimum distance.

3 PROBLEM STATEMENT

The functional road system provides for a graduation of traffic flow from the mobility function to the access function. The classification in such a system is based on a trade-off between mobility and access. For example, freeways operate at very high speeds with full control of access, whereas local residential streets provide full, unrestricted access, but operate at very low speeds. In the road hierarchy, the arterial roads are intended to operate at high speeds, with access being restricted to at-grade intersections spaced at large distances.

The effect of this trade-off between mobility and access on the traffic operation of signalised arterial roads is not obvious, and is the subject of this investigation.

3.1 Accessibility affected by spacing

As intersection spacing is decreased, the number of access points to the arterial increase. This improves accessibility for side road traffic, in two ways:

- Opportunity for more vehicles to enter or exit the arterial.
- Shorter travel distance between local destinations and arterial.

3.2 Mobility affected by intersection spacing and traffic flows

At low traffic flows, the longer spacing between intersections improves mobility of through-traffic in two ways:

- higher two-way progression speeds are possible for through-traffic
- fewer intersections at which through-traffic is delayed.

At high flows the situation is reversed; a longer spacing of intersections will generally concentrate more side road traffic at fewer intersections. High side road volumes require a larger portion of green time in the signal cycle, thereby reducing the green time available for the main arterial movements, which increases delay to through-traffic. In such conditions, a shorter spacing allows the distribution of the local traffic to more intersections, thereby avoiding extreme congestion, and reducing overall delay.

3.3 Variability of traffic flows

Traffic flows clearly affect mobility and arterial operation:

- Large spacing of intersections is suitable for low concentrations of side road traffic and allows high mobility for through-traffic.
- Smaller spacing of intersections is suitable for higher concentrations of side road traffic, but provides lower mobility for through-traffic.

Traffic flows on both the arterial road, and on the side roads do not remain constant throughout the day, but vary from high flows during peak periods to very low flows during off-peak periods. This leads to the following questions:

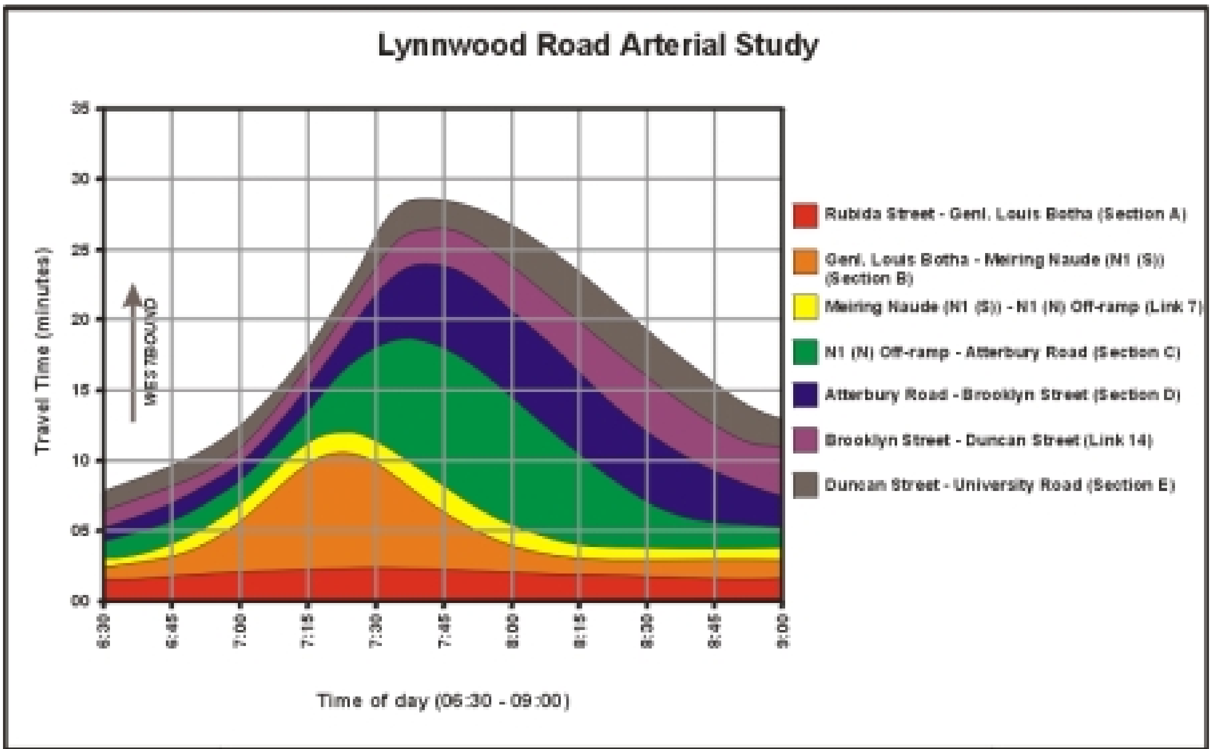
- *What uniform spacing of coordinated signals provides the best overall operation for both the through-traffic on the arterial road, as well as the local traffic entering the arterial from the side roads?*
- *What uniform spacing of signals is best suited for peak periods, when the arterial is congested?*
- *What uniform spacing of signals is best suited for off-peak periods when the arterial is not congested?*
- *What uniform spacing of signals is best suited to accommodate the full variation of traffic flows during a normal day?*

4 TRAFFIC SURVEYS ON LYNNWOOD ROAD

An eight km long section of Lynnwood Road in Pretoria between Rubida Street in a suburban setting, to University Road near the CBD was used for the case study. This section of Lynnwood Road connects different land uses, and has different standards along its length, ranging from dual carriageway to undivided multilane sections.

There are 19 signalised intersections along the selected route. The average spacing between signalised intersections is 500m. Average daily traffic volumes vary from 26 000 to 35 000 vehicles per day along the route. Peak two-way flows are in the order of 2 500 vehicles per hour.

The traffic operation on Lynnwood Road was first measured through field studies. Teams travelling by car measured travel times between sections at different times of the day. Figure 1.1 shows how the travel times increased over different sections along the route during the morning peak period.



A.M. Travel Time from Rubida Street to University Road (Westbound) Figure 1.1

The graph shows that travel times during the peak period increased considerably on certain sections of the road. These increases were mostly attributable to congestion at intersections where through-traffic lanes were being blocked by queues of vehicles waiting to turn at the intersection. This had a two-fold effect in reducing the through-capacity, and increasing overall delay.

The survey showed that the major factor influencing the arterial operation during peak periods is delay at individual intersections, and the congestion due to blocked through-traffic lanes tended to overshadow the effect of intersection spacing on travel times.

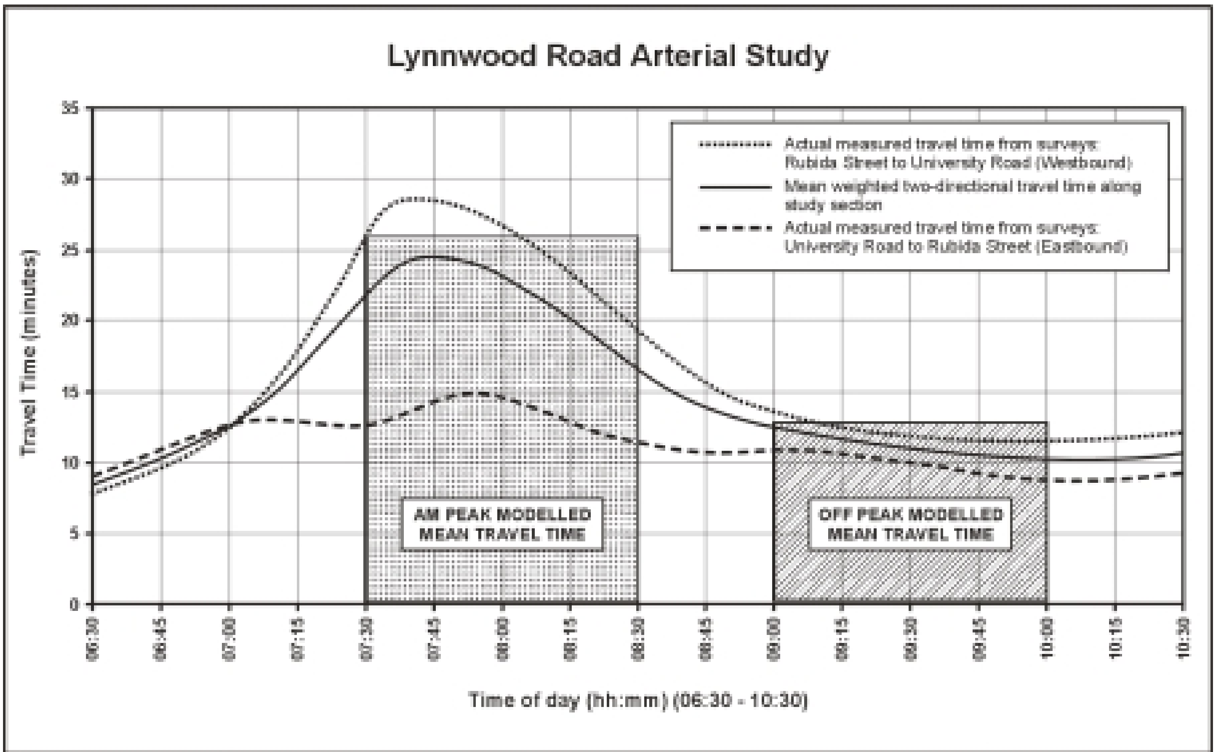
5 MODELLING STUDY

The next step was to use traffic modelling to investigate the relationship between intersection spacing and traffic operation. The TRANSYT 8 model was selected to model the study section of the Lynnwood Road arterial. TRANSYT uses macro simulation to model traffic operation on arterial roads with signalised intersections. It takes into account the travel of platoons of vehicles between intersections, and calculates the arrival and departure of vehicles at intersections. The model optimises signal settings to minimise total delay to traffic. The output of the model provides various measures of effectiveness, such as average travel speeds and total delay.

6 CALIBRATION - TESTING THE ACTUAL TRAVEL TIMES

The total 8,0 km length of the Lynnwood Road study section was used to test the accuracy of the TRANSYT model. The modelled travel times were compared against the actual travel times obtained from the traffic surveys. Two time periods with different traffic flows were tested; the morning peak between 07:30 and 08:30, and the off-peak period between 09:00 and 10:00. For the test, the actual intersection layouts, traffic flows and spacing between intersections was used.

The result of the test is shown on Figure 2. Although the measured travel times over the study section increased considerably during the peak period, the model provided a close correlation between the actual and predicted average travel times for both peak and off-peak flow conditions.



	A.M. Travel Time from Rubida Street to University Road (Westbound) and from University Road to Rubida Street (Eastbound) compared with Transyt modelling results	Figure 2

It was concluded from the good correlation obtained, that the model would be suitable to test the influence of intersection spacing and traffic flows on the average overall travel time.

7 UNIFORM SPACING OF INTERSECTIONS

The effect of intersection spacing on arterial performance was investigated through the modelling of Lynnwood Road as an idealized four lane arterial road with uniformly spaced signalised intersections. All intersections were improved to the Gauteng provincial standard for dual carriageway roads. The standard provides two dedicated through lanes together with a separate right- and left-turn lane on the arterial road at each approach.

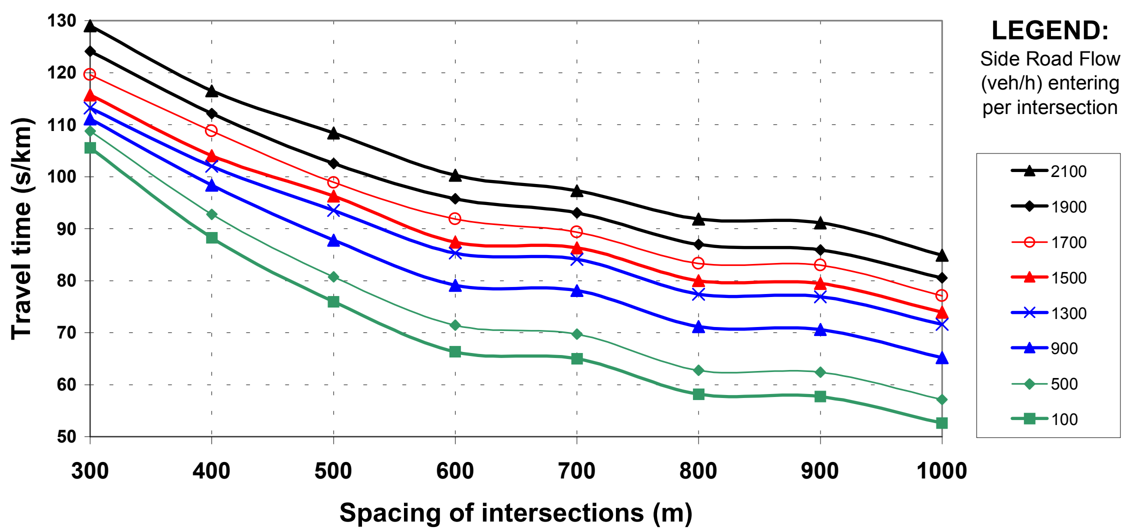
The actual sequence and type of intersections along Lynnwood Road, ie T-junction or four legged were retained and used for the model layout. Furthermore, a similar set of traffic flows was used at each intersection. The traffic flows on the main road approach, and the side road approaches were varied independently for various uniform spacings along the main road:

- Uniform spacing of intersections tested from 300 to 1000m in increments of 100.
- On the Main Road flows tested between 1000 and 4000 vehicles per hour (two-way) in increments of 500.
- On the Side Roads the total approach flows entering each intersection were varied between 100 and 2100 vehicles per hour in increments of 200.

The results from the modelling showed that traffic operation will improve with increased spacing of intersections for constant main road and side road volumes. The measure of effectiveness used to evaluate traffic operation in the modelling is the average travel time per kilometre for all vehicles, i.e. both side road and main traffic.

The travel time per kilometre decreases throughout with increasing spacing of intersections. The highest travel times occur at a spacing of 300m. It can be seen from Figure 2.1 that increasing the spacing from 300m to 600m results in a large decrease in the travel time, whereas increasing the spacing beyond 600m results in relative small reductions in travel time.

Figure 2.1
Total travel time at Main Road flow of 2000 veh/h



The graph also shows that the average travel time on the arterial is affected by the volume of side road traffic, higher side road traffic volumes will increase travel time on the arterial.

8 SIDE ROAD VOLUMES PER KILOMETRE LENGTH

The modelling has shown that for constant main and side road flows, the average travel time decreases with increased spacing of intersections. However, the large spacing of intersections could lead to greater concentrations of side road traffic at individual intersections. An increase in the side road traffic at each intersection could increase average travel time.

The possible concentration of traffic is illustrated by way of the following example:

> A certain land-use next to an arterial road will generate a peak demand of 2000 vehicles per hour along each kilometre length of the arterial. It would be possible to provide intersections spaced at either 1000 or 500m spacing. The side road traffic demand of 2000 vehicles per kilometre length could be accommodated as follows:
>
> 1 Side road traffic demand of 2000 vehicles/h is accommodated at 1 intersection every 1000m along an arterial road. Each intersection carries 2000 veh/h on the side road.

2 Side road traffic demand of 2000 vehicles/h is divided between 2 intersections spaced at 500m along the arterial road. Each intersection carries 1000 veh/h on the side road.

On the one hand, the larger spacing between intersections will decrease average travel time, but this could be outweighed by the larger concentration of side road traffic per intersection that will tend to increase average travel time. The question is which arterial spacing system will provide the best operation in terms of lowest overall travel time for both side road and arterial traffic.

In general terms the question is:

"*For a constant main road volume on the arterial, and a constant side road volume per kilometre length of arterial, what intersection spacing provides the optimum arterial operation in terms of average travel time per vehicle?*"

In order to investigate the effect of intersection spacing at constant side road volumes per kilometre length of arterial, the model was used to determine the average travel time per vehicle (s/km) for main and side road traffic. The traffic volumes and spacing were varied as follows:

- Intersection spacing of 500 to 1000m in increments of 100m
- Main road volumes of 1000 to 4000 veh/h in increments of 500 veh/h
- Side road volumes of 500 to 4000 veh/h <u>per kilometre length of arterial</u>, in increments of 500.

The results are shown in figures 3.1 to 3.4

Figure 3.1
Total travel time at Main Road flow of 1000 veh/h

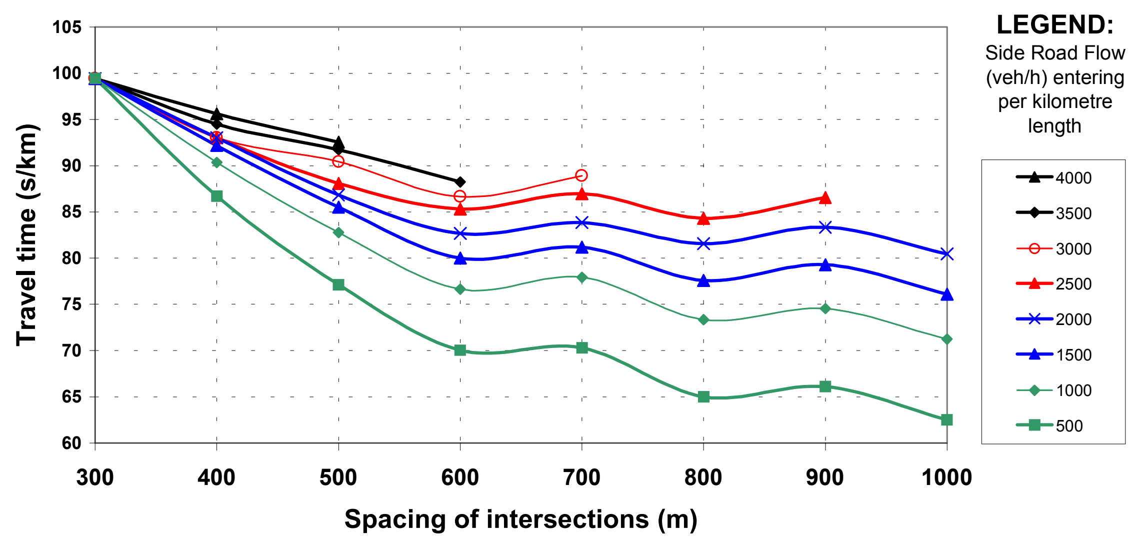


Figure 3.2
Total travel time at Main Road flow of 2000 veh/h

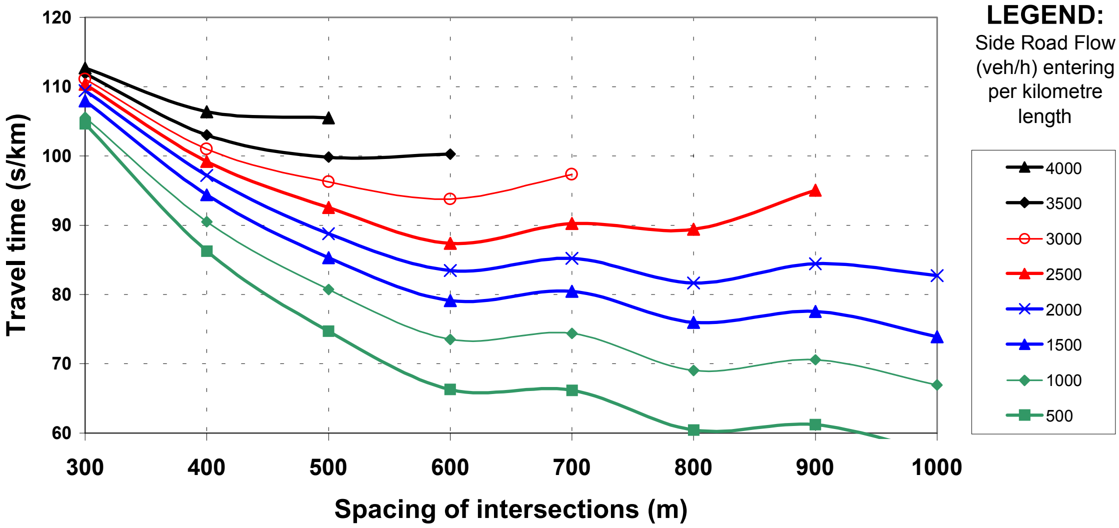


Figure 3.3
Total travel time at Main Road flow of 3000 veh/h

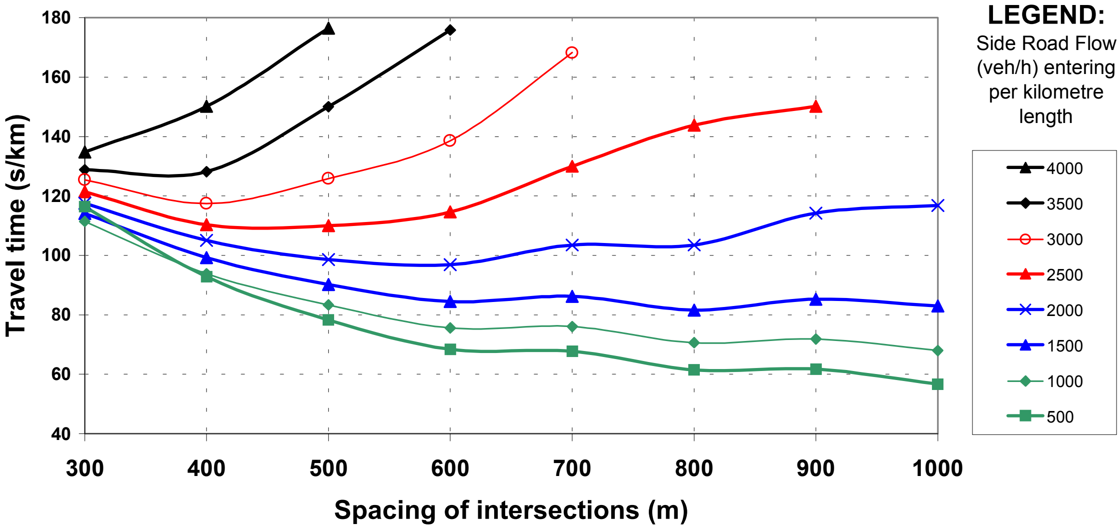
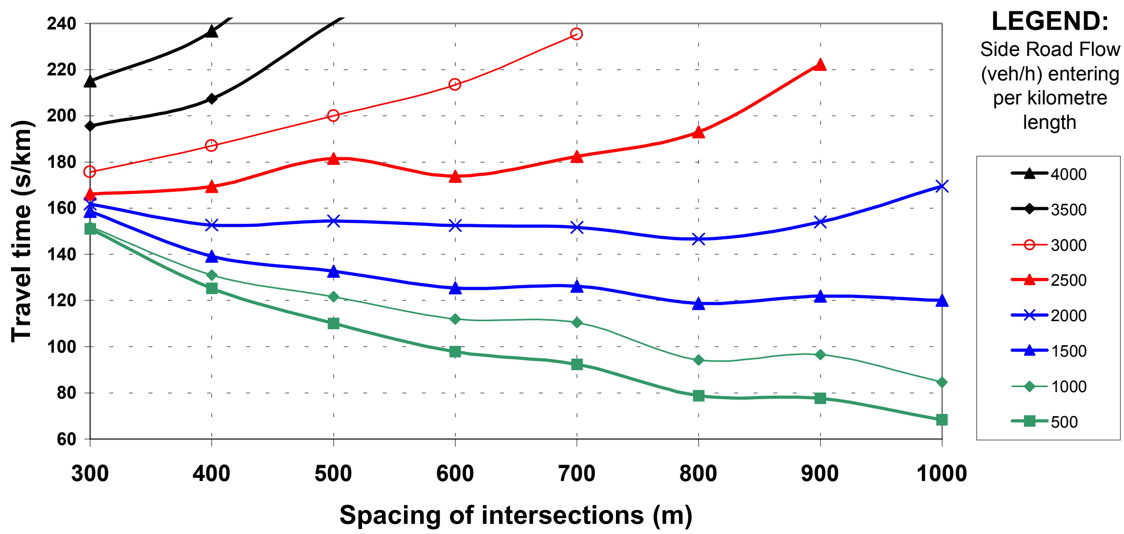


Figure 3.4
Total travel time at Main Road flow of 4000 veh/h



The graphs show that the average travel time is influenced by all three variables

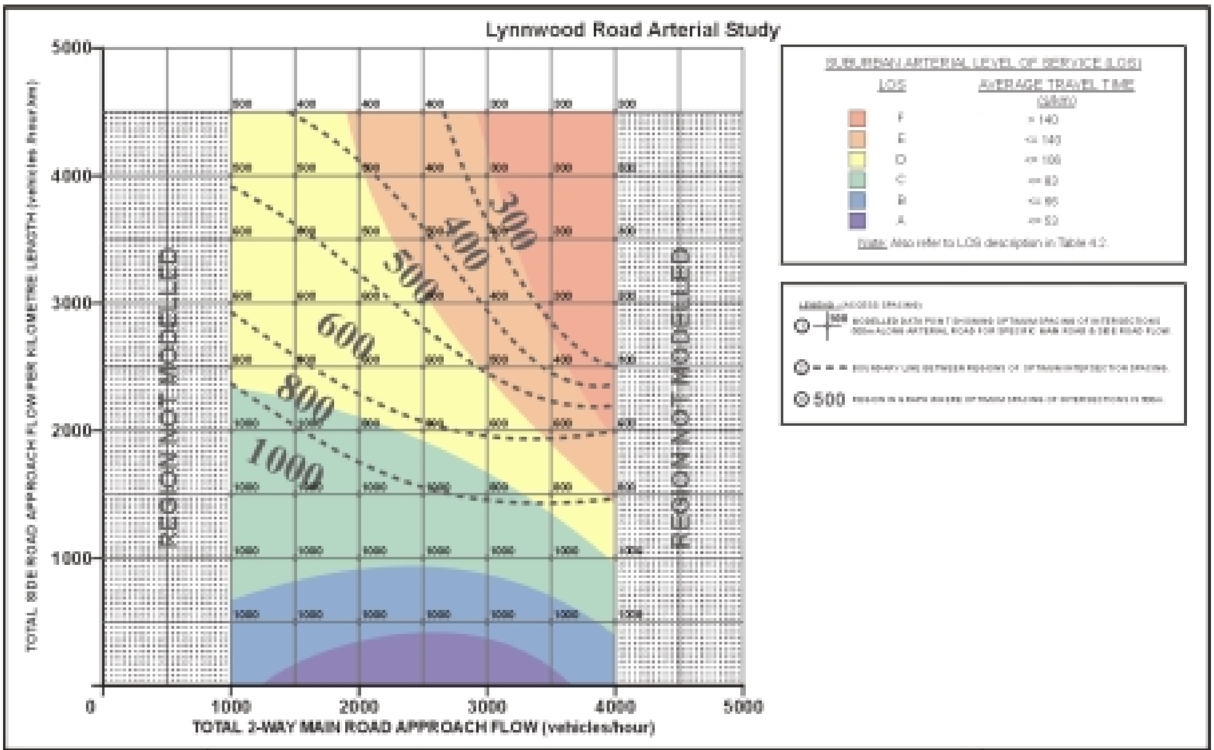
- side road traffic volumes per km length
- main road traffic flows
- intersection spacing

At low main road and side road volumes per kilometre, the minimum overall travel time is provided at large spacing of intersection, generally 600-1000m. As side road and main road volumes increase, the optimum travel time is obtained at shorter intersection spacings.

9 OPTIMUM SPACING FOR ARTERIAL OPERATION

9.1 Peak period

The optimum intersection spacing providing the lowest overall travel time, depends on the main road volumes and side road flow per kilometre. The optimum intersection spacing for each set of side road flows per kilometre length and main road flows, was obtained from the modelling and plotted in Figure 4.



	OPTIMUM SPACING OF INTERSECTIONS FOR PEAK FLOW CONDITIONS	Figure 4

The figure shows the flow regions of optimum intersection spacing, together with the associated Level of Service in terms of average travel times:

- Intersection spacings of 600m and more provide the optimum operation for low to medium flows generally in the range of LOS A to D.
- Intersection spacings of 500 to 400m appear to be suited for medium to high flows associated with LOS E.
- Short intersection spacing less than 400m appears to be only suited for combinations of very high main and side road flows associated with extreme congestion at LOS F.

9.2 Analysis for full day

Traffic flows are not constant, but vary throughout the full 24 hours of a typical day. The two peak periods of a normal weekday account for approximately 20% of the full daily flow over a 24 hour period. Therefore, 80% of the total daily traffic flows are low volume flows occurring outside the peak hours.

The typical pattern of traffic variation of suburban roads in Johannesburg for a full 24 hour period is shown in Figure 5. This variation is expressed as the % of Average Daily Traffic (ADT) for each of the 24 hours of a normal weekday. The use of this relationship allowed the expansion of the peak hour volumes to all the hours within a day.

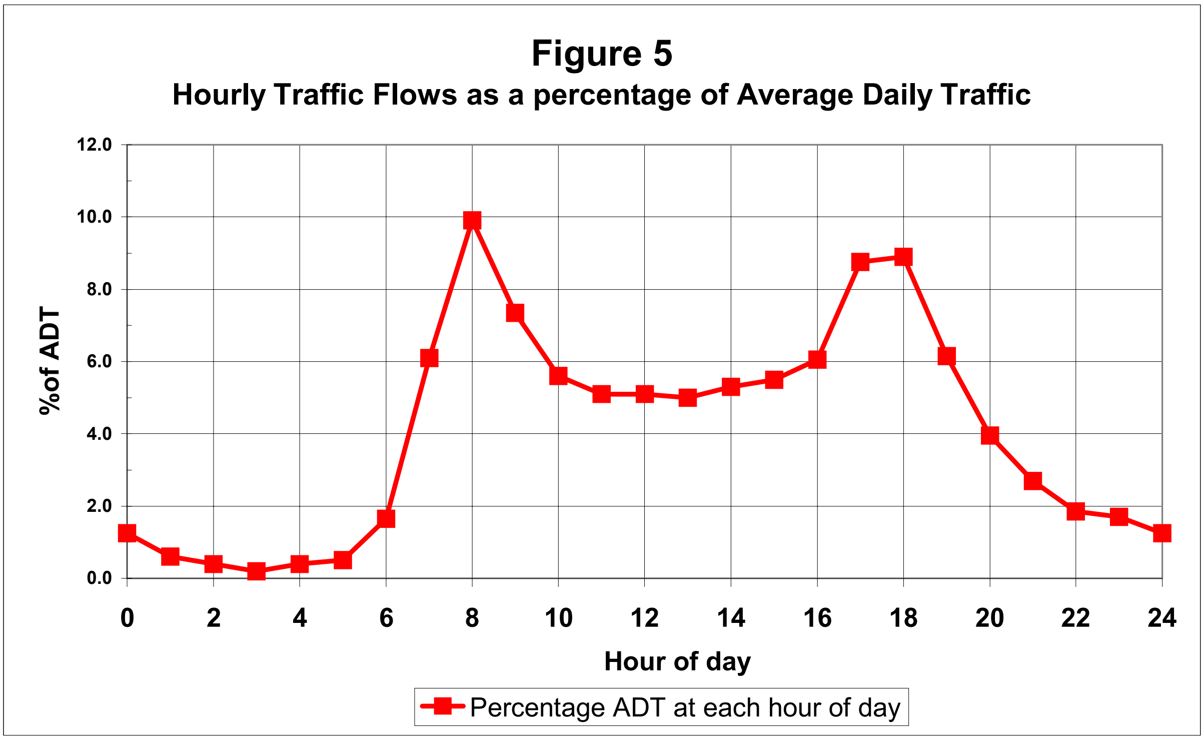


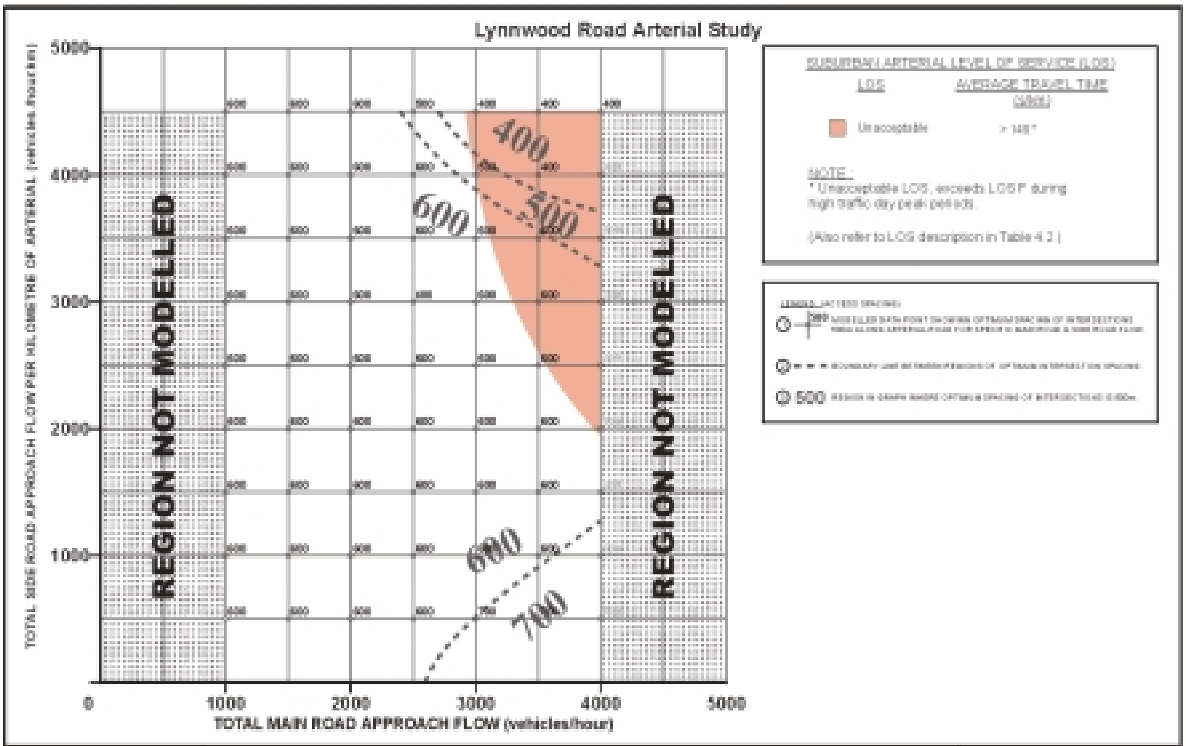
Figure 6 shows the optimum spacing between intersections when traffic flows during all 24 hours of the day is taken into account. The 600m spacing provides the lowest overall travel time per km during a full day for the widest range of main road and side road peak traffic flows

10 CONCLUSION

1. The traffic surveys have shown that most of the delay to traffic on arterial roads occurs at signalised intersections.

2. The modelling shows that for constant main road and side road traffic volumes, traffic operation in terms of average travel time per kilometre improves with increased spacing of intersections.

3. For a constant level of access to the arterial road, maintained through a constant side road approach volume per kilometer length, the optimum traffic operation is provided at the following intersection spacings:
   - Spacings of 600m and more for side road traffic volumes up to 2500 to 3000 vehicles per kilometre length of arterial
   - Spacings of 400 to 500m for high side road flows in excess of 3000 vehicles per kilometre length of arterial
   - Spacings of 300m for very high flows associated with extreme congestion.



OPTIMUM SPACING OF INTERSECTIONS FOR FULL 24 HOUR PERIOD

Figure 6

4. The 600m spacing of intersections provides near optimum mobility during peak traffic conditions associated with high traffic flows. However, it is best suited for the wide range of flow conditions that occur during a full day, and will provide the lowest overall travel time per vehicle of all intersection spacings investigated.

5. It is concluded that the results of the study confirm the existing access spacing policy of Gautrans, namely that the desirable access spacing on arterial roads should be in the range of 600 to 800m, with 550m as the absolute minimum distance.

11 REFERENCES

TRB, *Guidelines for Medial and Marginal Access Control on Major Roadways.* National Cooperative Highway Research Program, NCHRP Report 93. Transportation Research Board, National Research Council, Washington DC, 1970.

Sampson, J.D. Traffic flow variations in urban areas, Proceedings of the Annual Transportation Convention, Pretoria, 1983

PWV Consortium, Lynnwood Road Arterial Study, Draft document, January 2000.

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Curriculum Vitae
Andries Johannes Joubert

Education:	BSc Eng (Civil)	University of Pretoria	1978
	M Eng (Transportation)	University of Pretoria	1995

Geometric design experience with Jeffares & Green Inc. invarious types of roads which range from low volume rural roads to urban arterials and freeways. Road network planning for PWV area and transportation studies as part of working group for PWV Consortium since 1985. Network planning experience for regions outside PWV area include previous regions such as KwaNdebele, Bophutaswana. More lately North West Roads Master Plan.

Extensive traffic counting experience in the PWV area, Kwa Ndebele, Bophuthatswana and Botswana. Traffic studies for access, parking and sizing requirements. Capacity and analysis of various projects ranging from isolated intersections to arterial roads and freeway interchanges.

Since 1990 Executive Associate with Jeffares & Green.