Approaches to Managing Mobility on High Order Urban Arterials

A.D. Abrahamson[1] and M.L. Watters[2]

[1]A3 Transportation Engineers, P.O. Box 771, Rondebosch, Cape Town, 7701; South Africa; tony@a3.co.za
[2]Western Cape Government, P.O. Box 2603, Cape Town, 8000, South Africa; malcolm.watters@westerncape.gov.za

ABSTRACT: In revising the Western Cape Province's Road Access Guidelines of 2002 and replacing it with the Western Cape Province's Access Management Guidelines of 2016 (1), several new approaches have been adopted to ensure that at-grade high order arterials are planned and managed to maintain mobility while allowing accesses to adjacent land developments. This paper explores the concept of flexible intersection spacings and forms of intersection, based on the preservation of arterial level of service as defined and measured as average travel speed in the Transportation Research Board's Highway Capacity Manual. By ensuring high quality travel along the arterial, arterial mobility management may be attained through a range of techniques, from the classic two-way signal progression, to one-way progression or allowing for alternating or intermittent roundabouts at major intersections.

INTRODUCTION

The objectives of this paper are to consider whether the traditional method used by transportation and road planners to determine the appropriate spacing of major intersections on Class 2 and 3 urban arterials is appropriate in all contexts. The traditional method used is to calculate the spacing based on the provision of signal control at all major intersections and the achievement of two-way "green wave" progression. In this paper, options to the traditional methodology are considered where two-way progression cannot be achieved, and where roundabouts replace signal control at some major intersections. Conclusions are reached on where the alternative strategies may be more appropriate that the traditional strategy.

At-grade Classes 2 and 3 urban arterial roads are the focus of this paper. These are the major arterials which perform the mobility function in the road hierarchy and where access to adjacent land developments is strictly controlled. It is these arterials along which vehicles travel relatively long distances in proportion to the total journey distance using various classes of roads (the trip chain usually being local – collector – arterial – freeway – arterial – collector – local) at relatively high average speeds. Classes 2 and 3 mobility routes are expected to allow drivers to travel without the need for excessive stopping and delays. Of the total number of vehicle-km of travel on all classes of roads on the network, 83% takes place on Classes 1, 2 and 3 roads, while their total length is only 13% of the total length. The remaining 17% of vehicle-km of travel takes place on the remaining 87% of the total road network, these being the Class 4 and 5 collector and local roads. See Table 1.

Table 1. Vehicle-km and road length by Class

Class	Vehicle-km	Road length
1	55%	2%
2		4%
3	28%	7%
4	12%	13%
5	5%	75%

Class 1 roads are generally built to freeway standards and are by definition limited access roads, allowing free flow on the main carriageways and accesses only by means of on and off ramps. The design standards of freeways are universally applied in most countries according to these basic parameters. Conversely, Classes 2 and 3 arterial roads generally have at-grade intersections and accesses, and are often poorly managed with respect to access management. This applies to a variety of attributes of the road, the most important being the spacing of major intersections. Where major intersections are too closely spaced, or intersection control is poorly managed, the mobility of the road can be compromised.

CURRENT GUIDELINES FOR SPACING OF MAJOR INTERSECTIONS

Conventional basis for major intersection spacing

Recommended practice in the USA, as reflected in the Access Management Manual 2014 (2), is that an 800m (½ mile) distance between major signalised intersections is the optimum spacing for urban arterial roads. The ½ mile rule is based on the experience that long and uniform signal spacing allows for signal timing plans that can accommodate varying traffic conditions as are experienced during off peak and peak periods of the day. The Manual compares the efficiency and capacity of arterials with ¼ mile spacing with those that have ½ mile spacing, and concludes that the arterials with ½ mile spacing are better able to cope with traffic at higher speeds and have lower crash rates.

The USA's Manual for Uniform Traffic Control Devices (3) also gives a general ½ mile recommendation for spacing of major signalised intersections. It states: "Traffic control signals within ½ mile of one another along a major route or in a network of intersecting major routes should be coordinated, preferably with interconnected controller units."

In the South African Road Classification and Access Management Manual of 2012 (TRH 26) (4) the major intersection spacing guidelines are based on traffic signal co-ordination allowing vehicle progression in both directions of travel. Other reasons given are safety considerations and to allow sufficient decision and reaction time for drivers to negotiate downstream intersections. TRH 26 advises that the standard 800m spacing is the requirement on urban Class 2 arterials, while a 600 m spacing between intersections is allowed on urban Class 3 arterials as a concession. The concession is based on an inference that Class 3 arterials generally have a lower operating speed. Traffic signal progression requirements determine an intersection spacing of around 800m, as this spacing will allow a two-way progression speed of between 60 and 80 km/h. At a spacing of 600 m, the progression speed is reduced to between 50 and 70 km/h.

In the Road Access Guidelines of 2002 (5) the spacing of major intersections were also based on signal progression in both directions of travel – yielding the theoretical spacings using calculations based on travel speed and bandwidth of platoons. See Figure 1 showing the principles on which the spacing between signalised intersections that allow for two-way progression are based.

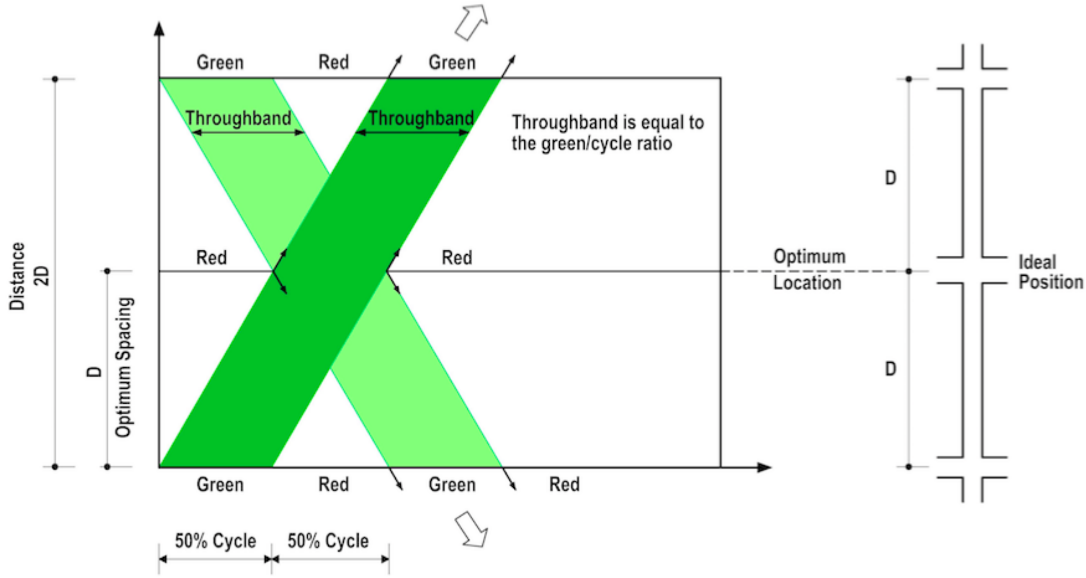

Fig. 1. Time-space diagram of signalised spacing for two-way progression

The assumed operating speeds on mobility arterials for each urban roadside development environment in urban areas are given in Table 2, as extracted from the Road Access Guidelines of 2002. This yields the spacing guidelines for traffic signals for each of these road classes for the different roadside development environments, as are also given in Table 2. (The term “roadside development environment” is a measure of the density of development and assumes lower operating speeds on roads passing through high density urban development environments and higher operating speeds on roads through low density urban development environments.) The spacing distances are based on an analysis giving two-way progression for the given operating speed and assuming cycle length. Bandwidths on the through route range between 25% and 40% of the cycle length, allowing platoons to largely clear every signal without being stopped on red signal phases.

The values in Table 2 suggest that a 780m (effectively ½ mile) spacing is appropriate for Class 2 arterials in low density suburban development environments, while for the same class of arterial in CBD development environments a 420m (effectively ¼ mile) spacing would suffice.

Table 2. Signal spacing by class and speed for two-way signal progression

Roadside development environment	**Class 2**		**Class 3**	
	Operating speed	Signal spacing	Operating speed	Signal spacing
CBD	50 kph	420m	40 kph	300m
Intermediate	60 kph	580m	50 kph	420m
Suburban	70 kph	780m	60 kph	580m

Questioning the principles behind two-way progression

In developing the Access Management Guidelines of 2016 questions were raised about the conventional basis for decisions on the spacing of signals along mobility arterials, and whether the standard ½ mile guidelines according to the USA's Access Management Manual, the 600m or 800m spacing recommended by TRH 26 or the variable spacing developed for Road Access Guidelines of 2002 are still relevant in the South African context. These questions related to a variety of practical circumstances.

Firstly, many road authorities in the Western Cape Province and other part of South Africa no longer make any attempt to attain two-way progression along arterials. This is often due to the historical placement of traffic signals that are inappropriately spaced and this does not allow for two-way progression. In addition, many road authorities in South Africa simply do not have the technical capabilities to manage the large number of signalised intersections under their control and provide two-way progression to the sophistication required for them to be effective. The result is that two-way progression is rarely used with significant impact on the arterial road networks of South African towns and cities, and most signals operate as stand-alone systems.

Secondly, where signal coordination is pursued, a significant advantage over stand-alone signal systems can be attained simply by linking signals to obtain one-way progression. This provides adequately for the tidal flow behaviour on many arterials whereby the predominant flow occurs in one period of the day and the reverse flow occurs in another part of the day. In this way the delay to the major flow is minimised by providing one-way bandwidths. The strategy of managing arterials using one-way progression does not require signalised intersections to be located at uniform intervals and can accommodate irregular spaced intersections and those that are relatively closely spaced.

Thirdly, the substitution of major signalised intersections by roundabouts is gaining popularity with many road authorities in South Africa. Currently, when a previously unsignalised intersection with priority given to the through route is being considered for full intersection control on all approaches, road authorities are advised to consider a roundabout as a first option. The viability of a roundabout depends on space available and the volume of traffic being accommodated on the through route and the side road, but if suitable the advantages can outweigh those of a signalised intersection. Roundabouts do not require signals that must be maintained or are a danger during power outages, and when crashes occur they are generally less severe due to lower operating speeds in advance of and through the roundabout itself.

Roundabouts, in spite of these advantages, are an antithesis to vehicle progression, either two-way or one-way, as platooning breaks up at a roundabout and vehicles emerging on the downstream side depart at random intervals due to the queuing on the approach and the yielding to vehicles in the rotary. Thus, situating a roundabout in place of a signalised intersection within a string of signalised intersections will result in the fragmentation of platoons, and have a negative impact on any progression strategy.

ALTERNATIVE STRATEGY FOR SPACING OF MAJOR INTERSECTIONS

The growing popularity of roundabouts as a substitute for signal control at major intersections requires a rethink of the gold standard ½ mile rule, especially where signalised intersections and roundabouts alternate. In these circumstances, no longer can progression be the sole empirical rationale for major intersection spacing.

What alternative spacing strategy should transportation engineers adopt?

The answer lies in the principle that users of the road system want as efficient a journey as possible from origin to destination. Considering the trip sequence: local-collector-arterial-freeway-arterial-collector-local, the longer part of the trip is usually on the at-grade arterial and freeway systems, and just as users expect a high speed limited access experience on the freeway system, so they expect a reasonably high level of average travel speed on the at-grade arterial system. Hence there is a need to manage the at-grade arterial system with a view to preserving the average travel speed.

The Highway Capacity Manual 2000 put this concept forward in Chapter 15 on Urban Streets Methodology, in which the Level of Service for urban streets was introduced. The Level of Service measure of effectiveness considers the average travel speed on urban arterials of different classes.

The principle of maintaining acceptable average travels speeds on arterials has been adapted for use in the Access Management Guidelines of 2016. By selecting a reasonably high Level of Service as the target for Classes 2 and 3 arterials, a high average travel speed can be attained.

Applying mobility standards on urban arterial roads

When the standards of mobility on arterials are based on targeted average travel speeds, the efficiency of travel along the length of the arterial is maximised, given the interruptions imposed by signalised intersections, roundabouts and other forms of access along the route.

Table 3 provides mobility standards adapted from the Highway Capacity Manual for Classes 2 and 3 at-grade arterials that are associated with Levels of Service A to Level of Service F, where Level of Service A represents free flow conditions, and where the motor vehicle can travel unconstrained. Level of Service F applies to periods where excessive queuing and delays normally prevalent during commuter peaks occur.

Table 3. Standards for mobility – arterial Level of Service by road class

	Class 2	**Class 3**
Typical free flow speed	65kph	55kph
Level of Service	**Average travel speed**	
A	>59kph	>50
B	>46 – 59kph	>39 – 50kph
C	>33 – 46kph	>28 – 39kph
D	>26 – 33kph	>22 – 28kph
E	>21 – 26kph	>17 – 22kph
F	<21kph	<17kph

For the purpose of considering the desired spacing of major intersections along an at-grade arterial route, an arterial Level of Service C should be aimed for. This represents a good standard of mobility for the length of the arterial during daytime inter-peak periods of operation. During peak periods where traffic is congested, average travel speeds of Level of Service C are unlikely to be achieved and for these periods of the day it is accepted that average travel speeds will be substandard.

In the Access Management Guidelines of 2016 standards of mobility are applied when a major intersection (signalised intersection or a roundabout) is to be introduced on a section of route where traffic flow on the arterial was previously uninterrupted at that location. The introduction of a major intersection will always reduce average travel speed on that section of road relative to the free flow speed; in the case of a signalised intersection some vehicles will need to stop on the red phase; in the case of a roundabout, vehicles will pass through the roundabout at slower speeds and may be delayed in queues upstream of the entrance to the roundabout. The average travel speeds to be achieved for different classes of mobility arterial and in different roadside development environments to achieve the Level of Service C standard are given in Table 4.

Table 4. Average travel speed by class and roadside development environment

	Class 2	**Class 3**
Roadside development environment	**Average travel speed Level of Service C**	
CDB	>40kph	>35kph
Intermediate	>48kph	>40kph
Suburban	>56kph	>48kph
Semi-rural	>64kph	>56kph

A mobility analysis using the appropriate average travel speed standards in Table 4 is undertaken to determine the effect that a new signal-controlled intersection or roundabout would have on the average travel speed of vehicles for a reasonable length of route upstream and downstream of the new controlled intersection. In urban roadside development environments a distance of 1.0 km on each side of the proposed intersection in question is considered. The analysis considers the implications of the installation of the intersection, taking into account the projected traffic demands and the traffic design of the intersection. The analysis should ensure that a Level of Service C would be attained for the 2.0 km section of arterial during inter-peak periods on implementation of the intersection or roundabout. See Fig. 2.

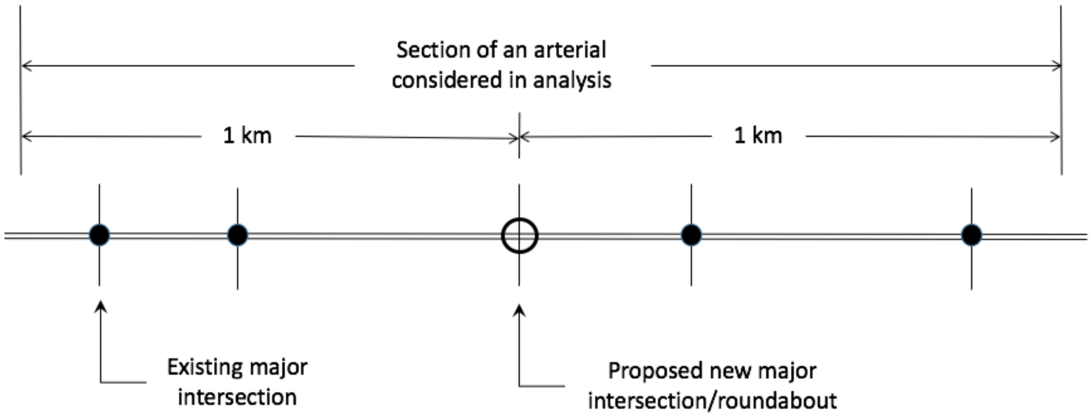

Fig. 2. Average travel speed – section of arterial to be considered

Determining the spacing when 2-way progression is not contemplated

To determine the spacing between major intersections in the absence of the ½ mile rule or the spacing dimensions given in Table 2, alternative principles related to the operational safety of vehicles on the arterial must be considered. These principles rest on two operational spacing criteria for determining the distance between an intersection and a downstream intersection: functional boundary distance and left-turn criterion.

Functional boundary distance is the measure used to allow sufficient distance for a driver to perceive, react and undertake a braking or lane-changing manoeuver on the approach to a major intersection where the driver must choose between left, right and straight through movements. The upstream point from which the functional boundary distance is measured is the previous driveway or intersection. Only after passing it is the driver able to give priority to the next task. Queue lengths in advance of a signalised intersection must be factored in, as well as a queue on a dedicated right-turning lane. In the case of a roundabout the preceding area of influence or the queue length must be used, whichever is greater. The recommended dimensions for functional boundary distance are given in Table 5.

Left-turn conflict distance is the measure used to allow for adequate distance from an intersection to a downstream left-in left-out driveway. It ensures that the vehicle on the through route is able to perceive and slow down to take evasive action to prevent it from colliding with a vehicle turning left in or left out of a downstream driveway. The recommended dimensions for left-turn conflict distance are given in Table 5.

Table 5. Functional boundary and left turn conflict distances

Operating speed	Functional boundary distance	Left-turn conflict distance
40kph	155m	40m
50kph	190m	60m
60kph	235m	82m
70kph	270m	107m
80kph	305m	135m

An example of the application of the alternative strategy

Fig. 3 illustrates an example of how the determination of the spacing between major intersections is undertaken where a signalised intersection is followed to the east of it by a roundabout. The example assumes that the roundabout is being considered where no controlled intersection existed previously. In this case the total distance between the signalised intersection in the west and the roundabout in the east is determined by considering the eastbound direction of travel. The westbound direction must also be considered before finality can be reached on the total spacing.

The example also illustrates the manner in which a left-in left-out driveway on the eastbound carriageway is taken into consideration, as it must be located at a distance downstream of the signalised intersection greater than the left-turn conflict distance. A further distance east of the driveway greater or equal to the functional boundary distance between the driveway and the roundabout must also be provided. The total distance between the signalised intersection and the roundabout is the sum of the left-turn conflict distance, the functional boundary distance and the roundabout area. For a Class 3 road in a suburban roadside development environment where the operating speed is 60kph, the distance would equate to 82m + 235m + 30m = 347m assuming a roundabout area of 30m.

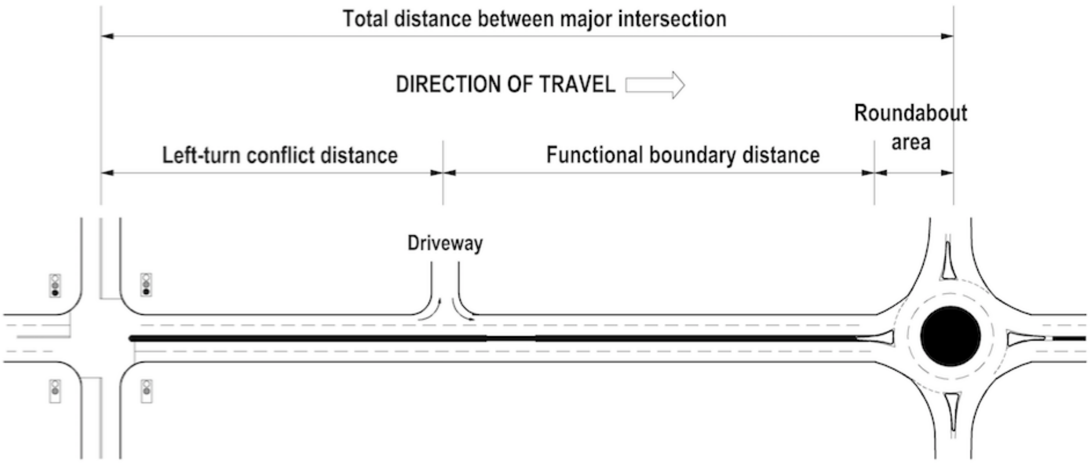

Fig. 3. Example of determination of spacing of major intersections where two-way progression is not planned

A similar procedure of analysis must be undertaken for the spacing between the roundabout and the next major intersection to the east of the roundabout. In addition, as illustrated in Fig.2, it is necessary to consider the section of the arterial for a full 2km section, 1km to the west of the roundabout and 1km to the east of the roundabout, to ensure that the average travel speed of at least 48kph given in Table 4 is achievable.

Arterial management plans – a recommended practise

A mobility analysis procedure must always form part of undertaking an arterial management plan to determine the position and form of control of the major intersections on Class 2 and 3 urban mobility arterials. Once positions are confirmed, these may be reserved for upgrading to their final form in a phased manner. Retrofitting of an arterial will similarly yield a plan for the conversion of an arterial that determines the final location of major intersections. A mobility analysis must also be undertaken when, in the absence of an arterial management plan, a location that is currently uncontrolled is to be replaced by a signalised intersection or by a roundabout.

The Access Management Guidelines 2016 recommends the following strategies for establishing locations of major intersections:

- 2-way progression strategy: The adoption of the two-way signal progression principle wherever locations of major intersections are being considered for a new planned arterial. This policy should also be adopted for an existing arterial where the spacing of existing signalised intersections may not be compliant with two-way progression, but the objective is feasible and can be achieved over time.
- 1-way progression strategy: In cases where the road authority undertakes an arterial management plan of an existing arterial where the spacings of existing signalised intersections are not and cannot reasonably be made compliant with the standards set out for the achievement of two-way progression, a strategy that provides for one-way progression according to tidal flows may be considered.
- No progression strategy: A strategy where neither two-way progression nor one-way progression is feasible may be considered in special circumstances, such as where an arterial is short in length, all or most major intersections are roundabouts, or where there is a justifiable need to provided for a greater number of major intersections than the guidelines for two-way progression can provide.

In adopting any of the three strategies above, the average travel speeds must be attained for the entire length of the arterial and major intersections spaced to allow for safe and efficient operations on intersection approaches.

CONCLUSIONS

Spacing of major intersections on urban arterials is traditionally based on the ½ mile rule contained in most road design and access management manuals, which usually also recommend that spacing should allow for two-way progression. This objective is not always feasible, particularly in the South African context where road authorities are often unable due to scarce resources to establish functioning coordinated signal control systems. Furthermore, the popularity of roundabouts as a substitute for signal controlled major intersections has the effect of breaking up platoons and casting a doubt on the logic of the traditional ½ mile rule.

Using as a measure of effectiveness the attainment of average travel speed on Class 2 and 3 urban arterials with at-grade major intersections, it is concluded that the spacing between major intersections can be more flexible where it is decided that two-way progression is not a suitable criterion for setting spacing. The alternative strategy can be applied when one-way signal progression is considered appropriate, or where roundabouts replace major intersections.

ACKNOWLEDGMENTS

This paper is based on content of the Western Cape's Access Management Guidelines 2016. The authors wish to acknowledge the members of the project team responsible for the compilation of the Western Cape Access Management Guidelines 2016, specifically Cecil Rose PrEng, Lynn Pretorius PrEng, Simon Nicks, SACTRP, Roy Tyndall PrEng and Bertie Phillips PrTechEng.

REFERENCES

1. Western Cape Government, Department of Transport and Public Works. *"Draft Access Management Guidelines".* 2016.
2. Transportation Research Board USA (2014). *"Access Management Manual", Second Edition.* 2014.
3. Federal Highway Administration USA. *"Manual on Uniform Traffic Control Devices".* 2009 Edition.
4. Committee of Transport Officials. *"TRH 26 South African Road Classification and Access Management Manual", Version 1.0.* 2012.
5. Provincial Administration Western Cape, Department of Economic Affairs, Agriculture & Tourism, Transport Branch. *"Road Access Guidelines", Second Edition.* 2002.
6. Transportation Research Board USA. *"Highway Capacity Manual".* 2010 Edition.
7. Watters, M.L., Abrahamson A.D., Rose C.A. *"The Evolution of Access Management at the Southern Tip of Africa".* The Transportation Research Board Annual Meeting, Washington DC. 2012.
8. Watters, M.L., Tyndall, G.R. *"The Development Guidelines for the Western Cape Government, South Africa".* The Second International Conference on Access Management, Shanghai, China. 2014.