DESIGN GUIDELINES AND TRAFFIC OPERATION ANALYSIS OF ONE-WAY COUPLETS

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1 INTRODUCTION

One-way roads have been used in urban areas where high traffic demand exists and where access to properties requires closely spaced traffic signals, in order to simplify traffic operations and to improve capacity of the road network.

Although the operational benefits of one way roads with particular reference to traffic progression along signalised corridors and unopposed right turn manoeuvres are well known, limited work has been done both locally and internationally on traffic and operational benefits of closely spaced one-way road pairs often referred to as one-way couplets. An international search indicated that although a couple of road projects which include one-way couplets are being undertaken by local authorities in particular in the United States of America, little information is available on issues such as operational benefits, design criteria such as spacing of one-way pairs, traffic signal operation, access to adjacent properties, accommodation of pedestrians and public transport.

Comments from developers, town planners and urban designers have indicated that the typical boulevard type dual carriageway arterial roads with an intersection spacing of 600 m is not conducive to urban development within the framework of current town planning principles.

The purpose of this paper is to analyse the operational benefits, and to develop design criteria for one-way couplet roads.

2 ROAD HIERARCHY

The functional classification of the road network is one of the fundamental principles of traffic engineering. The classification and relationship between mobility on the one hand and accessibility on the other hand are well known.

At the one end of the spectrum mobility routes exist with limited access such as freeways, which have no traffic control devices and where access to the supporting road network is provided only via grade separated interchanges. No direct access is generally provided to adjacent land use, except service facilities for the driving public.

Major highways typically have at grade intersections at 600 m to 800 m minimum intervals. In urban areas these roads generally consist of dual carriageway roads with traffic signal controlled intersections at 600 m spacing. Access is not generally provided directly to adjacent developments and mobility is more important than access. The 600 m spacing between intersections therefore allows acceptable traffic progression under traffic signal control. Mobility remains more important than access along urban arterial roads because the greater majority of vehicles on these roads travel long distances between major land uses on a metropolitan scale. Urban arterial roads are characterised by high traffic volumes, relatively high speeds and limited access. The land adjacent to these arterial roads is often favoured for development as a result of the high exposure because of high traffic volumes.

The high mobility function of these arterial roads also ensures regional accessibility to the land adjacent to these roads. The environmental impact, in particular noise and emission pollution as a result of the high traffic volumes often results in a reduction of the amenity of the residential areas adjacent to these roads. This usually encourages non-residential development and the resultant linear strips of development along urban arterials are well known phenomena both locally and internationally and are often used by planners to motivate a change of land use to exploit economic opportunities generated by these roads. There is therefore often a need to provide additional access to these land uses without unduly impeding through traffic.

Consideration of one-way couplet roads should be given where both mobility and accessibility are considered important. The couplet roads will typically be Class 2 or Class 3 Roads with high geometric design standards. Operating speeds of between 60 and 80 km/h is suggested as a result of increased frequency of accesses along the one-way roads as well as the presence of public transport and pedestrians.

3 OPERATIONAL CHARACTERISTICS

3.1 Widely spaced one-way couplet crossed by major two-way road (>500m)

This section considers a one-way couplet pair crossed by a major two-way road. In order to achieve traffic signal progression along the cross road the required spacing between the intersections with the couplet roads is in the order of 600 m. This would allow optimum progression along the cross road as indicated on **Figure 1**.

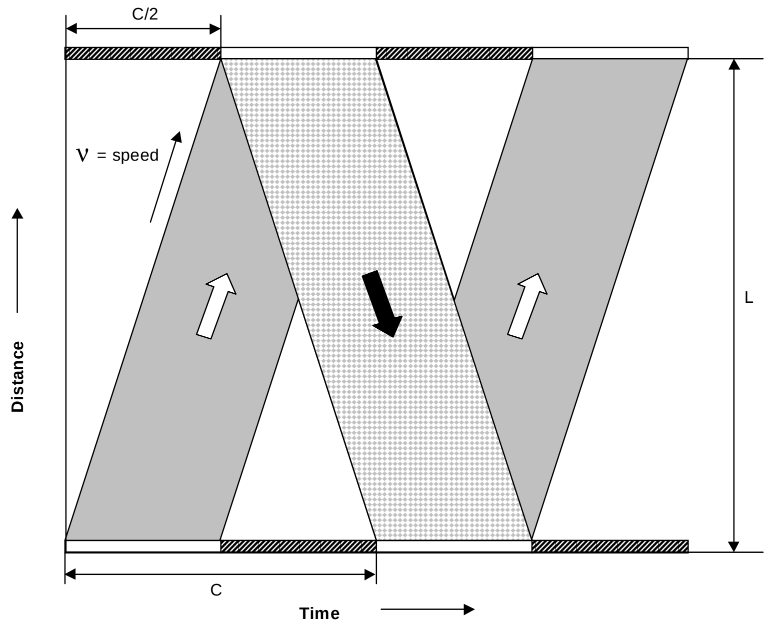

Figure 1 : Relationship between cycle time, progression speed and intersection spacing

The relationship between cycle time, progression speed and intersection spacing is given by $L = \frac{vC}{2}$ which is derived from **Figure 1**.

i. Cross road traffic signal operation

It follows that for optimum traffic progression along the cross road (two-way road), for a cycle time of 72 seconds and progression speed of 60 km / h that the intersection legs of the couplet system should be spaced 600 m apart. If the couplet legs are spaced widely apart (600 m or more) they should have alternating phase changes. This results in optimum traffic progression in both directions along the cross road.

The traffic signal progression along the cross-road is indicated on the upper right hand time-space diagram on **Figure 2**. It indicates traffic progression between points **a** and **b** along the two-way cross road.

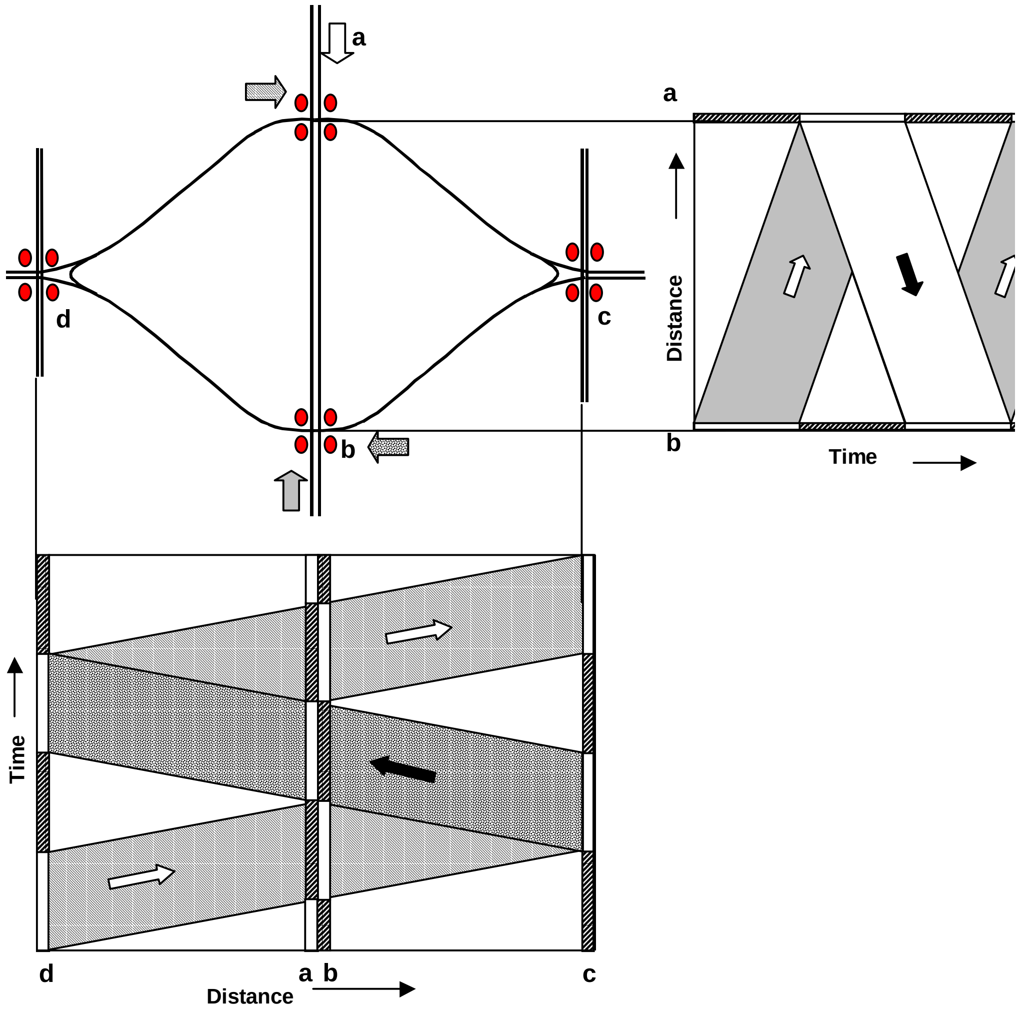

Figure 2 : Operational aspects of widely spaced couplet crossed by two way road

Although the spacing between the intersections allow for traffic progression it should be noted that progression is severely impeded by right turn vehicles which are stored in the central section of the cross road (between point **a** and **b**).

The vehicles are right turning vehicles from the couplet pair (from **c** to **b** turning right at **b** and queuing at **a** and from **d** to **a** turning right at **a** queuing at **b**) which turned into the central section during the preceding phase. The traffic progression will therefore be reduced as a result of the requirement to clear the vehicles stored in the central section of the cross road at **a** and **b** respectively

ii. Couplet roads traffic signal operation

The minimum spacing between the first two-way intersection along the couplet road and the two-way cross road (minimum spacing between points **d** and **a** and **a** and **c** on **Figure 2**) is given by $L = \frac{vC}{4}$. For a cycle time of 72 seconds and progression speed of 60 km / h the spacing to the first intersection on the two-way section is 300 m. The time-space diagram on the lower left hand side of **Figure 2** illustrates the traffic signal progression along the couplet roads in both directions (**d** to **a** to **c** and **c** to **b** to **d**)

3.2 Closely spaced one-way couplet crossed by major two-way road (>200m)

The traffic signal operation of closely spaced couplet roads crossed by a major road is examined in this section. Traffic progression along the cross road is an important consideration.

i. Cross road traffic signal operation

If the couplet legs are very closely spaced, the phases of the intersections along the cross road (point **a** and **b** on **Figure 3**) should change simultaneously. The traffic progression along the cross road is reduced as a result of the reduced traffic signal spacing. The upper right hand time-space diagram on **Figure 3** indicates the traffic progression along the two-way cross road (between point **a** and **b**) for signals changing phases simultaneously.

The simultaneous phase operation of the two traffic signals along the cross road results in an initial green period at the down stream intersection along the cross road before the arrival of the platoon from the upstream intersection (initial green period on northern approach of intersection **b** before arrival of vehicles from intersection **a** travelling southbound to **b** and vice versa). The initial green period can be used to clear the right turn vehicles stored on the northern approach to intersection **b** and the southern approach to intersection **a** which turned into the central section of the two-way road during the preceding green phase.

The simultaneous operation of the signals along the cross road has another very important benefit. The platoon passing through the intersections during simultaneous phase operation is limited by the end of the green period of the downstream intersection. **Figure 3** indicates that the traffic progression between point **a** and point **b** is limited by phase change of intersection **b**. This implies that a portion of the green phase of the upstream intersection (intersection **a**) exists which cannot be used to improve traffic progression between **a** and **b**. This time can however be used as a lagging right turn phase on the southern approach of intersection **a**. This is indicated on **Figure 3** as P_1. The lagging right turn phase can be used as no opposing right turn vehicles are present. The lagging right turn phase and through phase are used to allow unopposed right turns from the cross road onto the couplet roads and simultaneous clearance of through traffic while no additional traffic is allowed to enter the central section of the cross road. This ensures adequate storage for vehicles turning right from the couplet pair into the central section during the next phase. The above applies in both directions along the cross road and results in right turn and through phases on the southern approach of intersection **a** and on the northern approach of intersection **b** respectively.

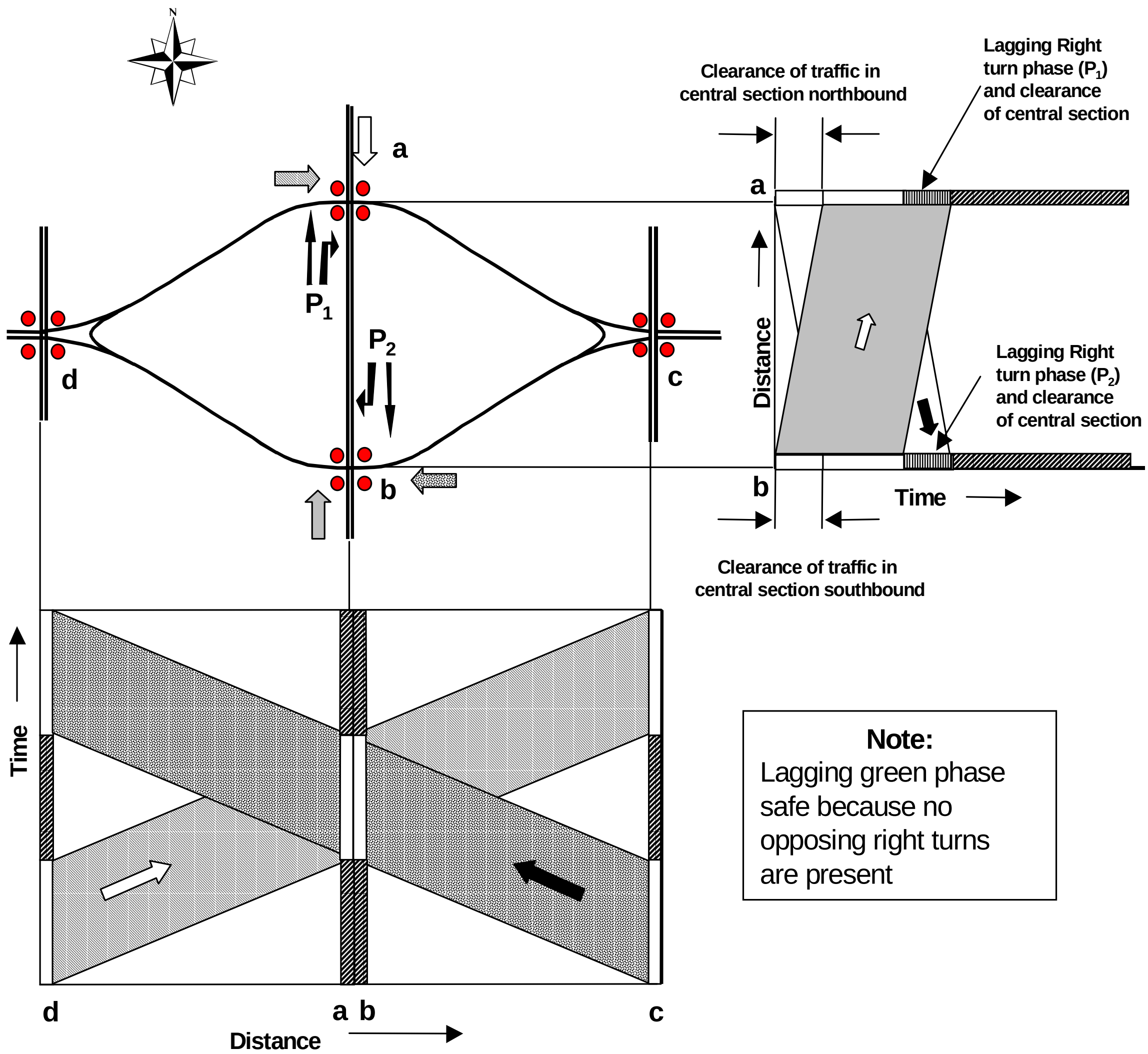

Figure 3 : Operational aspects of closely spaced couplet crossing a two way road (simultaneous phase change operation along cross road)

The capacity of the cross road is significantly increased as a result of the proposed signal operations. The proposed operation allows unopposed right turns from the cross road and allows clearance of the central section both for platoons along the cross road as well as for right turn traffic from the couplet roads.

The minimum spacing of the couplet legs are considered to be 160 m which is based on practical considerations to allow adequate space to provide two back to back right turn lanes of 60 m with a 40 m taper in between (60 m + 40 m + 60 m = 160 m).

ii. Couplet roads traffic signal operation

As the traffic signals at the intersections between the couplet roads and the cross road changes phases simultaneously the intersections of the couplet roads with the cross road (spacing between **d** and **a** and **a** and **c**) should be located where the platoons from opposite directions intersect. The spacing between the intersection of the cross road and the first signalised intersection along the two-way section of the couplet roads is given by $L = \frac{vC}{2}$.

The traffic progression along the couplet roads is indicated on the lower left hand time-space diagram on **Figure 3**.

iii. Practical application

The concept of one-way pairs was applied in the planning of the K68 route in the Kempton Park area. The route provides access from the R21 Johannesburg International Airport freeway to the Pomona Agricultural Holdings located to the north of Kempton Park. The area is rapidly being developed for warehousing and light industrial purposes. The conventional dual carriageway was not able to accommodate the traffic generated by the proposed developments on the one hand whilst providing adequate access to encourage and support development of the area on the other hand. A one-way pair spaced approximately 240m apart was planned for the area. Developers in the area favoured the proposed solution.

3.3 Closely spaced one-way couplets crossed by minor two-way access road (>200m)

Two closely spaced couplets can also operate with alternating phase changes at the intersections along the cross road. This can be implemented where high order access from a major arterial road to adjacent land is required. Traffic progression along the cross road is not considered important.

i. Cross road traffic signal operation

The traffic signals along the cross road operate with alternating phase changes. This significantly impacts on traffic progression along the cross road as a result of the reduced spacing between the traffic signals along the cross road. The traffic progression along the cross road for a closely spaced couplet operating with alternating phase changes is indicated on the right hand upper time-space diagram on **Figure 4**. Traffic progression is however not considered of prime importance but rather the provision of access to adjacent land. The alternating phase changes of the signals along the cross road results in a continuous green band for right turn ingress traffic. This implies that vehicles from **d** turning right at **a** have a green signal indication at **a** as well as at **b**. This also applies to right turn ingress vehicles from **c** turning at **b**.

ii. Couplet road traffic signal operation

The traffic progression along the couplet roads for a closely spaced couplet pair with alternating phase operation is indicated on the lower left time-space diagram on **Figure 4**.

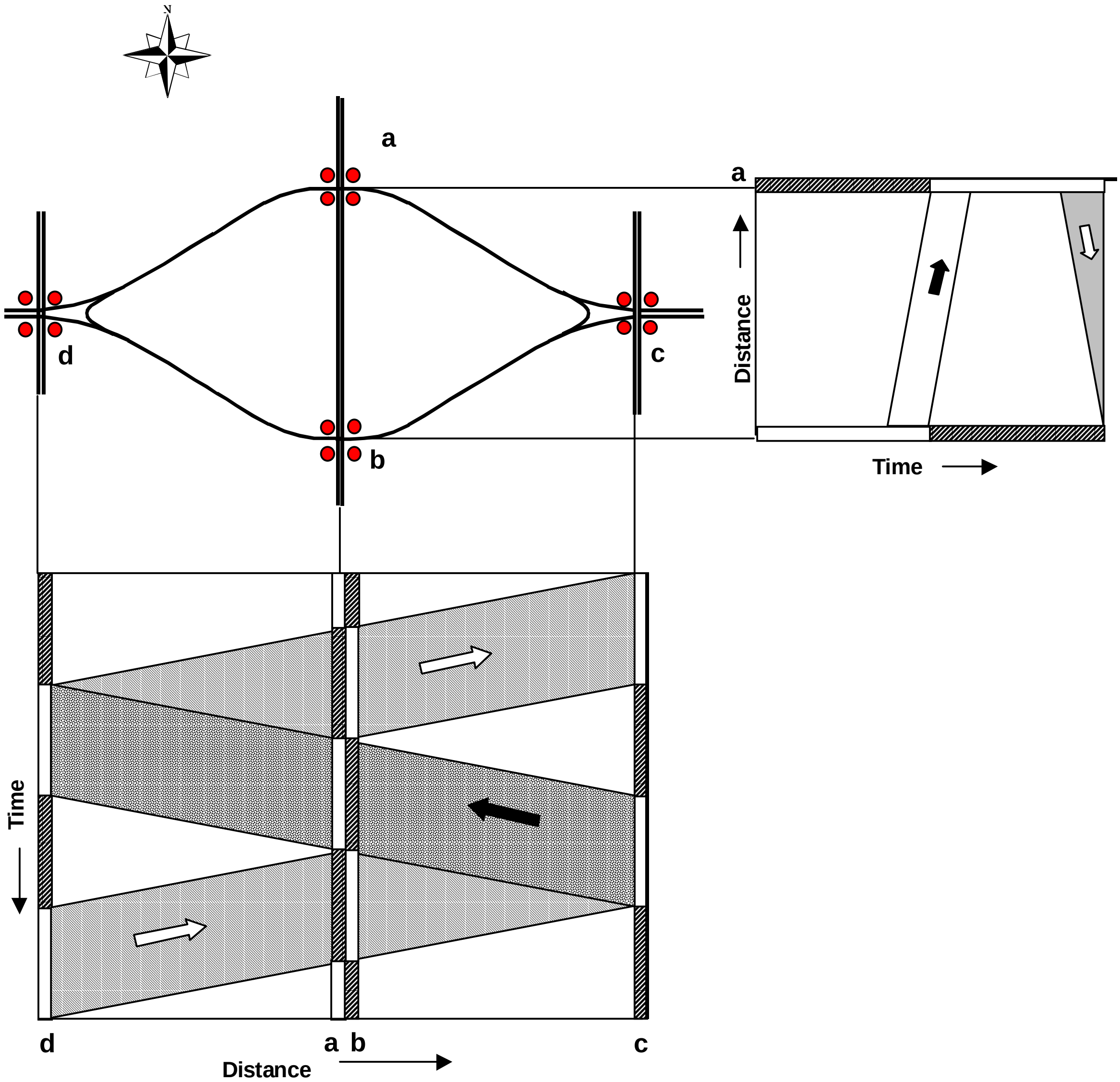

Figure 4 : Operational aspects of closely spaced couplet crossing a two way road (alternate phase change operation along cross road)

It can be seen that in order to ensure traffic progression along the couplet road, the spacing between the intersection with the access road and the first intersection along the two-way section of the couplet road is given by $L = \frac{vC}{4}$. This results in a minimum spacing of 300 m for 60 km/h progression speed and 72 second cycle time.

The following important benefit can be achieved by local widening of arterial roads to operate as closely spaced one-way couplets where high order access is required from the arterial road:

- Improved operation of right turn movements as vehicles do not have to turn in the face of oncoming traffic. Right turn vehicles from the couplet roads also have a continuous green band to accomplish the right turn ingress manoeuvre.
- Improved capacity as the traffic signals generally require only two phases
- Improved traffic progression along the arterial route as a result of the separate functioning of the two traffic signals controlling the traffic streams along the arterial.
- More frequent access along arterial road without impedance of through traffic along the arterial road.

iv. Practical application

The concept of local widening in order to provide access from a major arterial was recently included in planning of the road network undertaken in the east of Pretoria in the Menlyn Node. The proposed road network included the widening of an existing undivided four lane arterial to allow access to adjacent land. The land consisted of residential development, which was earmarked for redevelopment as offices. The proposed widening consists of separation of the eastbound and westbound carriageways by approximately 80 m. The capacity analysis indicated that the access point can serve substantial land-use rights on the adjacent land.

3.4 Intersection of two couplet pairs

This section considers the operational aspects of the intersection of two one-way couplet pairs. The spacing between the intersection along the central block as well as the spacing along the couplet pairs to the first intersection along the two-way section in each direction will be determined to ensure traffic progression in all four directions along both couplet roads.

i. Signal requirements at central block

The traffic signal requirements of the central block are illustrated by means of the time-space diagram in **Figure 5**. The signal co-ordination is based on the requirement that a vehicle that travels along any of the one-way roads that form the block must be able to follow a perfect green band. It is therefore accepted that vehicles that turn at any intersection will stop at the first downstream intersection. A 50/50 split of the cycle time is assumed at all intersections.

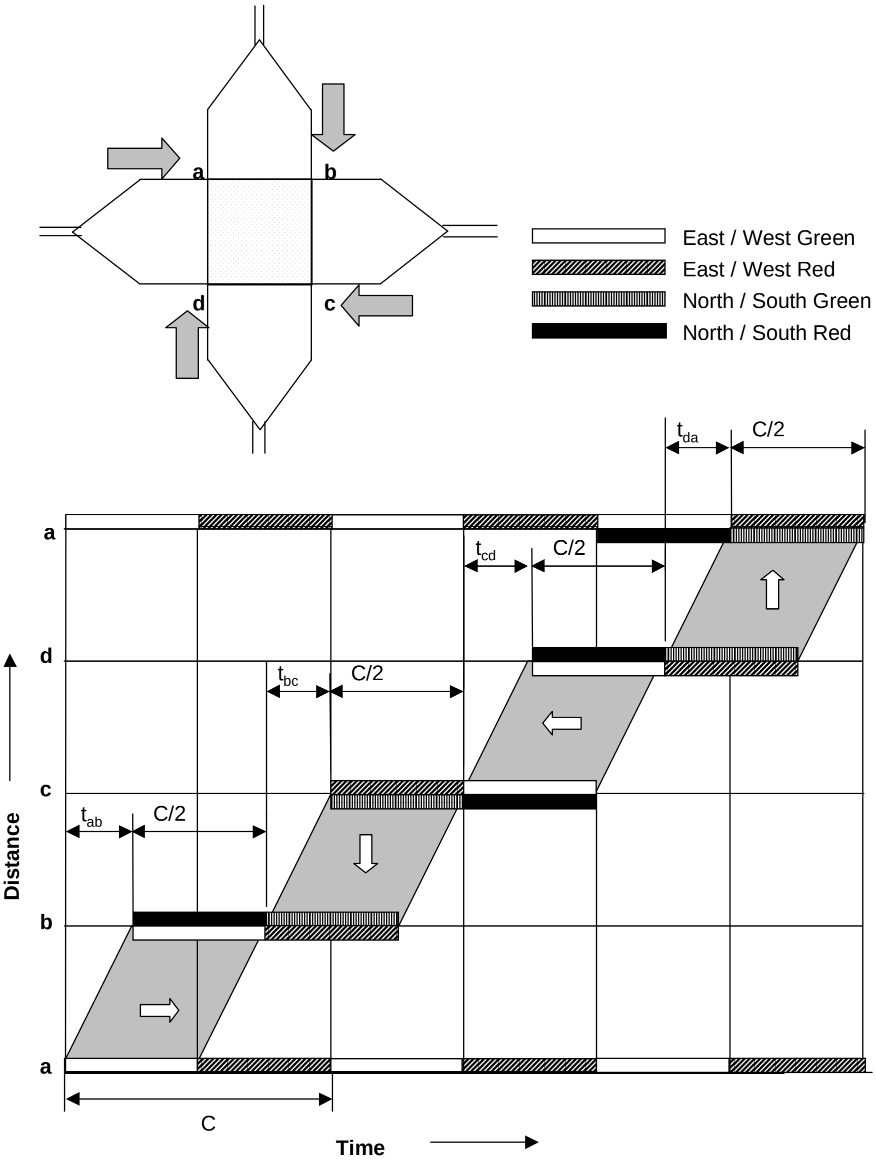

Figure 5 : Signal requirements - central block of two intersecting couplets

The green phase length should allow adequate time for pedestrians to cross the road. If a maximum number of five lanes is assumed and a walking speed of 1.2 m / s, the minimum green time to allow pedestrian to cross the roadway is 14.6 seconds. If a signal phase split of 50/50 is assumed, a minimum cycle time to allow an initial walk period for pedestrians, pedestrian clearance and intergreen time is 54 seconds. A minimum practical cycle time of 60 seconds is therefore recommended to ensure adequate provision for pedestrians at the intersections.

The spacing of the intersecting couplet roads as a function of progression speed and cycle time can be determined as follows:

$$t_{ab} + t_{bc} + t_{cd} + t_{da} + 4(\frac{C}{2}) = nC$$

$$t_{ab} + t_{bc} + t_{cd} + t_{da} = C(n-2)$$

The smallest dimension of the block is found for $n = 3$ - Therefore

$$t_{ab} + t_{bc} + t_{cd} + t_{da} = C$$

This implies the cycle time is equal to the travel time around the block.

If a rectangular block is assumed

$$t_{ab} = t_{bc} = t_{cd} = t_{da}$$

$$t = \frac{C}{4}$$

and

$$t = \frac{L}{v}$$

therefore

$$4t = C$$

$$4(\frac{L}{v}) = C$$

$$L = \frac{Cv}{4}$$

For a cycle time of 72 seconds and progression speed of 60 km / h, the spacing therefore becomes 300 m. For a cycle time of 80 seconds and 60 km / h progression speed, the block length is 333 m.

It can be concluded that the block size of the area defined by two intersecting one-way couplets is determined by the travel time to complete the distance along the circumference of the block.

ii. Spacing between the central block and other traffic signals on two-way section of the corridor

The spacing between the intersections along the central block of the intersection of two one-way couplet pairs and other traffic signals on two-way sections of the corridor (e.g. spacing between **x** and **a** – **Figure 6**) can be determined as follows:

It follows from **Figure 5** that the offset between signals at intersections **a** and **d** respectively is C / 4. The time lapse (T) between the start of the green phase at intersection **a** for eastbound traffic and the start of the green phase at point **d** for westbound traffic is given by $T = t_1 + \frac{C}{2} + t_2 + \frac{C}{2} + t_3$ (see **Figure 5**). Due to the cyclic nature of traffic signals, the 2(C/2) which equals time may be subtracted leaving a time lapse of $T = t_1 + t_2 + t_3$. Assuming a rectangular central block

$$t_1 = t_2 = t_3 = \frac{l}{v}$$

where l = the distance between the one-way pairs

therefore $T = \frac{3.l}{v}$

l_1 can be determined as follows:

$$l_1 = \frac{C - T}{2}.v$$

$$l_1 = 0.5v(C - \frac{3l}{v})$$

$$l_1 = 0.5vC - 1.5l$$

For a central block with couplets spaced 300 m apart, cycle time of 72 seconds and progression speed of 60 km / h, the minimum spacing to the first traffic signal on the two-way section is 150 m. This is however impractical as the dimensions of the central block is 300 m. A minimum spacing of 750 m (600 m + 150 m) is considered more appropriate. The distance between the traffic signals along the two way section is therefore given by $l_1 = 0.5v.n.C - 1.5l$

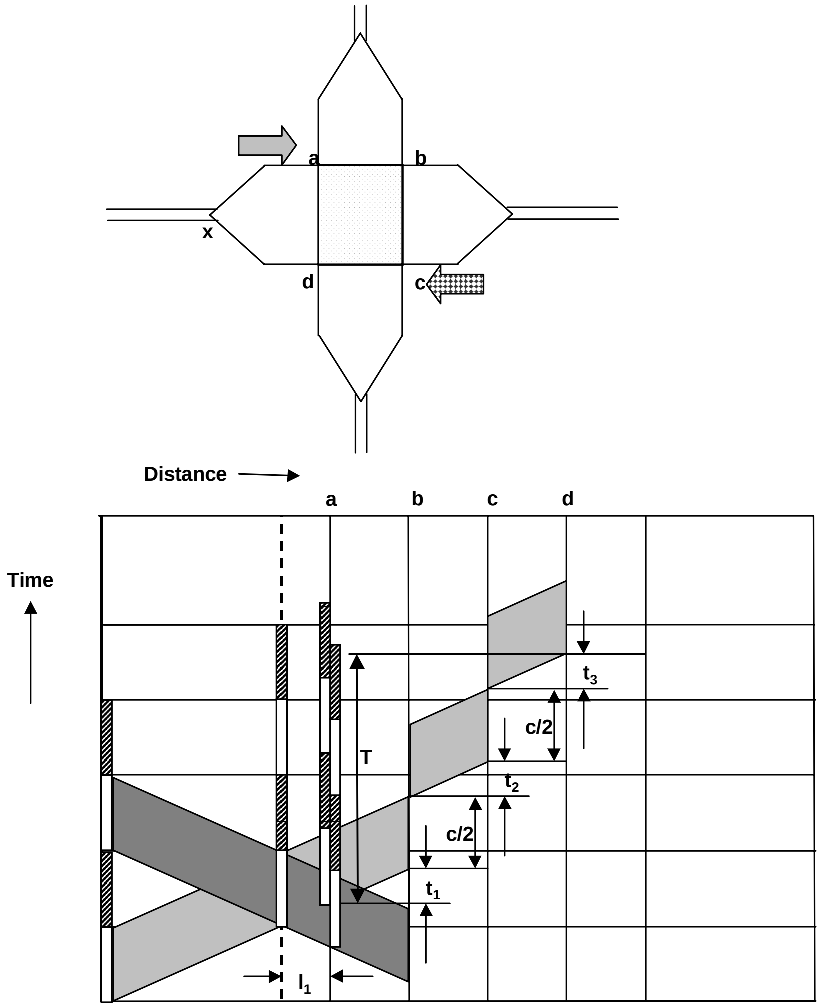

Figure 6 : Spacing between central block of couplet pair and signal on two-way section

iii. Trip Generation

If 300 m couplet spacing is assumed the size of the central block is 90 000 m^2. If a floor space ratio of 0.4 is assumed, it results in 36 000 m^2 of potential development. The potential trip generation of the central block using trip generation rates recommended by the SA Trip Generation Rates document is 2 280 weekday trips and 3 870 Saturday trips during the peak hour. Four signalised access points serve the central block from the one-way pairs at a spacing of 150 m. If an even distribution of traffic is assumed between the access points, and a directional distribution of 50/50 (in versus out for retail developments) is used, it results in 285 vehicles entering and exiting the central block at each access point during the peak hour. This is clearly well below the capacity of the system.

If offices and other service related businesses can be encouraged to settle, the floor space ratio can be increased as a result of the reduced parking need and trip generation per area of floor space. It implies that a development similar to a neighbourhood shopping centre can be located on the central block formed by the crossing of two one-way couplets and would form the nucleus of two corridors of development. This creates the opportunity for creative urban design within the parameters of efficient traffic flow.

4 ADVANTAGES AND DISADVANTAGES

4.1 Advantages

The benefits associated with the use of one-way couplets are the following:

- The delay at intersections is reduced as a result of the unopposed right turn movement from the one-way road.
- Full use may be made of the width of the road. For example a road which is 10 m wide result in one lane per direction in the conventional two way street scenario. If the street is however used as one leg of a couplet pair, three lanes can be provided in one direction along the 10m wide road.
- Numerous international studies have shown that traffic safety is improved if one-way roads are implemented.
- Pedestrian safety is also improved as a result of pedestrians only required to look in one direction before crossing the road.
- Capacity improvements of between 10% and 50% have been achieved by implementing one-way road systems.
- The one-way couplet road systems are favoured by developers as a result of the improved frequency of access points along the one-way section.

4.2 Disadvantages

The following are some disadvantages associated with one-way roads that also apply to one-way couplet systems:

- Traffic signals along the one-way sections should cater for pedestrian need in all directions.
- The travel distances to destinations are increased by the use of one-way road systems.
- Confusion in particular to strangers as a result of one-way road networks.

5 ACCESS CONSIDERATION

The required spacing between signalised intersections on the one-way section and signalised intersections on the two-way sections have already been considered. This section considers access to the adjacent properties along the one-way sections of the couplets.

i. Intersection spacing along one-way sections

Intermediate traffic signals can be provided along the one-way sections as traffic progression is not negatively affected by additional traffic signals. Side road green should however be provided outside the green bands required to achieve traffic progression along the couplet system.

The following aspects should be taken into account in providing access points.

- Separation of conflict points along road

  In order to separate conflict points along the road it is recommended that access management principles be considered in evaluation of minimum desirable intersection spacing along the couplet roads. Access Management Principles typically require between 95 m and 110 m for non-signalised left-in-left-out access points on two-way roads. The above assures urban conditions, operating speeds of 56 km / h and access to a major trip generator. Furthermore it is recommended that traffic signals along the one-way section of the couplet roads not be spaced at less than stopping sight distance. If an operating speed of 60 km / h, reaction time of 1.5 s and deceleration rate of 2.25 m / s^2 is assumed it results in an absolute minimum spacing of 90 m between intersections.

It is considered desirable to space the intersections to ensure that the functional areas of intersections do not overlap. The functional area is determined as the sum of the following:

- Reaction perception time. Assumed to be 1,5 seconds
- Braking while moving laterally into a turning lane if applicable. A deceleration lane of 1.2 m/s^2 and a maximum speed differential of 16 km/h is assumed
- Deceleration at a rate of 1.75 m/s^2
- Vehicle storage. A minimum of 20 m is assumed for this purpose

The functional area for an intersection assuming 60 km/h operating speed can therefore be determined as follows:

Reaction time	25 m
Deceleration at 1.2 m/s^2	5 m
Deceleration at 1.75 m/s^2	43 m
Storage	20 m
Functional area from stop line of downstream intersection	93 m

Assuming access roads with a minimum of two lanes (one lane per direction), the desired centre to centre spacing between intersections is 100 m (93 + 2 x 3.5)

- Weaving distance between access points

  Weaving between two accesses or an access point and couplet road should be taken into account when considering unsignalised access locations along the couplet road. This however depends on the traffic volume along the couplet road as well as the weaving volume from the access road. Weaving is not considered problematic from signalised access points as unopposed weaving takes place between consecutive green phases. The weaving movements from unsignalised access points are however considered important in particular where two unsignalised access points are located at the opposite sides of the one-way couplet road.

  It is recommended that a minimum spacing between unsignalised access points along the couplet road of 90 m be provided. This ensures separation of decision points and ensures stopping sight distance between access points.

6 DESIGN GUIDELINES FOR ONE-WAY COUPLETS

ELEMENT	COUPLET CONFIGURATION

	Wide couplet crossed by major road	**Narrow couplet crossed by major road** **(simultaneous phases)**	**Narrow couplet crossed by minor access road** **(alternating phases)**	**Intersection of two couplet pairs**
Spacing of couplet roads	$L = \frac{v.C}{2}$	$L = v.C.\rho$ where ρ = progression along cross road as proportion of cycle time (minimum of 160 m recommended)	Minimum dependant on road reserve and other physical constraints. Storage space along central section should be considered	$L = \frac{v.C}{4}$
Spacing to first signalised intersection on two-way section	$L = \frac{v.C}{4}$	$L = \frac{v.C}{2}$	$L = \frac{v.C}{4}$	$l_1 = 0.5v.n.C - 1.5l$
Traffic signal operational requirements	Cross road operates with alternating phases	Cross road operates with simultaneous phases	Cross road operates with alternating phases	Diagonally opposed signals operate with alternating phases

7 CONCLUSIONS AND RECOMMENDATIONS

The paper examines the traffic operations on a system of one-way couplets from a traffic flow theory perspective. It also remarks on the land development and accessibility potential of one-way couplets.

The following conclusions can be reached from the analysis:

- Traffic operations, in particular the right turn movements which are not required to turn in the face of oncoming traffic, are simplified by the use of one-way couplets.
- One-way couplets result in improved traffic signal progression as a result of the one-way road systems.
- The use of one-way couplets result in increased frequency of access points to adjacent properties through the provision of additional signalised intersections along the one-way sections of the couplet roads.
- Local widening of an arterial road to function as a closely spaced couplet results in improved right turn manoeuvres as a continuous green band for right turn ingress vehicles are provided with alternating phase operation of the traffic signals along the cross road.
- One way couplets significantly improve capacity as a result of simplified traffic signal operation as signals typically require only two signal phases.
- The intersection of two one-way couplets provide the ability to serve development with high trip generation whilst maintaining mobility along the arterial roads.

It is recommended that one-way couplets be introduced from the initial stages of township layout and urban design. Urban designers are encouraged and challenged to apply this concept in an effort to resolve the omnipresent conflict between mobility and land accessibility. The design principles recommended in this paper should be applied.

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Garnet is a Registered Professional Engineer with experience in a wide range of traffic engineering aspects. Specific experience includes access management and planning of the road network in the east of Pretoria. The latter include capacity analysis and traffic progression issues.

His paper considered the operational analysis and provides design guidelines for one-way road pairs.