DESIGN AND IMPLEMENTATION OF A SIGNALISED ROUNDABOUT: SH20 HILLSBOROUGH RING ROAD

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Abstract

To cater for the construction of a grade-separated interchange as part of State Highway 20 Mt Roskill Motorway extension project, an innovative solution was developed and implemented by combining two conventional intersection types. New Zealand's first fully signalised roundabout "Hillsborough Ring Road" was constructed at the intersection of State Highway 20 and Hillsborough Road. Various diversion schemes were initially developed but a temporary roundabout configuration was selected to meet the constructability requirements. Due to high and unbalanced traffic flows in the morning and afternoon peaks, roundabout signalisation was considered necessary. The need to address safety concerns and to cater for an at-grade haul crossing, pedestrian facilities and site accesses led to the signalisation of all the approaches to the roundabout.

Innovative traffic signal system design allows traffic to flow through the roundabout with minimal stoppage. The vehicle stream entering the roundabout follows an anticlockwise sequence, whereby the signal start up and cut off losses are minimised. Despite some undesirable driver behaviours, the Ring Road has operated safely and effectively as an intersection replacement. The ease to switch the traffic over to new motorway alignments also demonstrates the versatility of the Ring Road for temporary traffic management.

The Ring Road, a signalised roundabout, is an excellent traffic engineering solution for balancing the operational performance of all approaches and improving traffic safety for all the road users.

1. Introduction

1.1 BACKGROUND

The State Highway 20 (SH20) Mount Roskill Extension will be a 4 km long motorway extending from the current SH20 Hillsborough intersection to west of Sandringham Road. This is part of the Western Ring Route which will provide a high speed motorway link between North Shore City and Manukau City, bypassing the Auckland Harbour Bridge and central business district.

As a critical part of the project, a grade separated interchanges interchange would need to be built over Hillsborough Road. The difficulty with the bridge construction was the fact that the roads were being used by the high volume of traffic and would have to be accommodated during the construction staging without disruption.

Fulton Hogan proposed an innovative concept whereby the motorway overbridge construction would take place in the central island of a large diameter roundabout or 'Hillsborough Temporary Ring Road'.

1.2 PHILOSOPHY

The Ring Road cut down on the amount of temporary pavement that would have otherwise been required to build a one sided diversion road. The design utilised a combination of existing pavement levels and ultimate design road construction with relatively small areas of temporary transitions between the two. The design maintains traffic flows at levels that were not worse than the original situation, and no compromise to the safe operation of the intersection.

1.3 APPROACH ROADS AND LOCAL NETWORK DESTINATIONS

The intersection is at the terminus of the State Highway 20 Motorway section and is a busy intersection servicing the main route to and from Auckland International Airport. The average daily traffic volume (ADT) for the intersection is approximately 40-50,000 vehicles per day. See Figure 1 for the locality plan for the Ring Road.

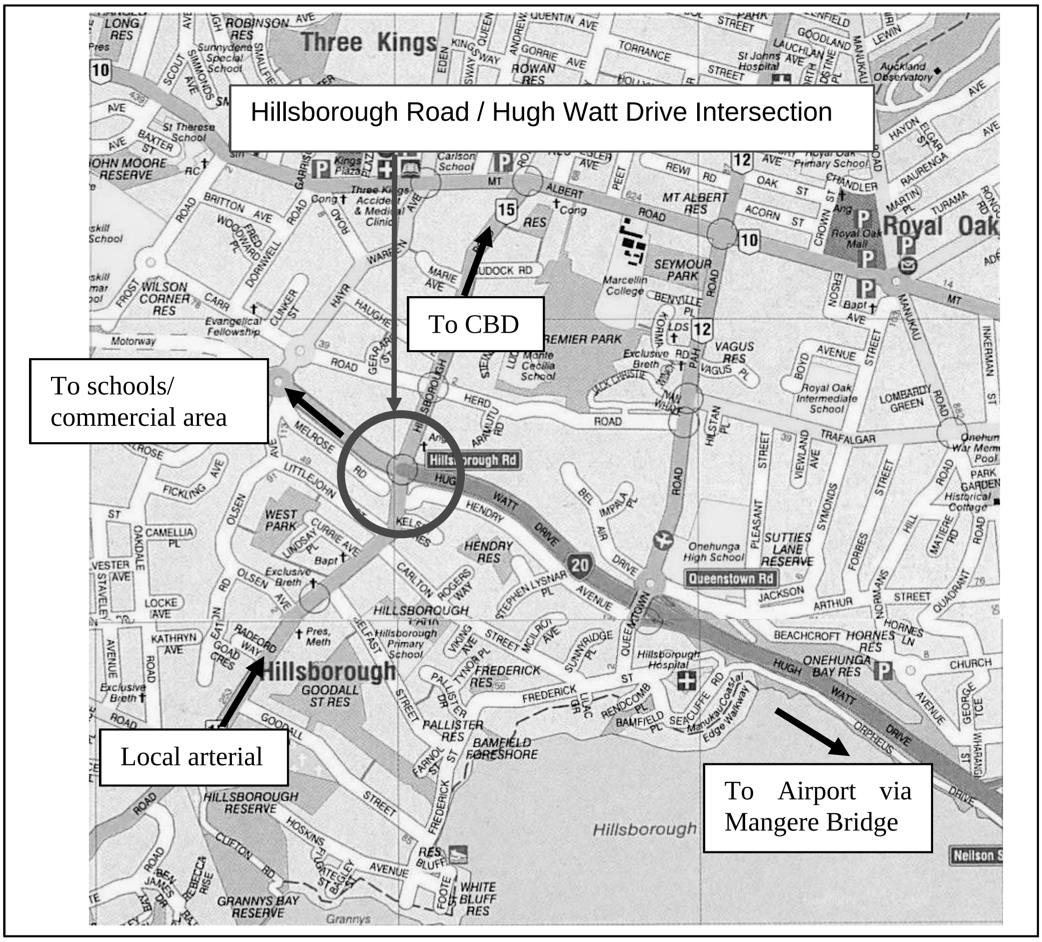

Figure 1: Locality Plan

The intersection has unbalanced flows during peak hours due to the high demand to and from the motorway.

2. PREVIOUSLY CONSIDERED STAGING METHODOLOGIES

A major project driver was to minimise the impact of the construction on the everyday road user. With this in mind, various options were explored at the earlier stage of the project and it was considered the most feasible option is to construct a detour road to the west running parallel to the existing Hillsborough Road. This would allow construction of the bridge but would require various re-locations of the on and off ramps and would be a disruption to the local users in the fact that the traffic lights would be re-located and their normal route would be adjusted over several stages.

This option, facilitating the construction of Hillsborough underpass, would have almost certainly resulted in an increase to traffic delay and queuing at the intersection. The scheme would have involved a one sided diversion road linked to the future ramps by signalised intersections (refer to Figure 2 for details). The diversion road would have taken traffic around the worksite and would require the existing signals to be temporarily relocated as well as additional temporary signals installed. The scheme required a number of stages to take traffic from the existing approach alignments and onto interchange ramps as each ramp construction is completed. The efficiency of the intersection would almost certainly be worsened with two signalised intersections in close proximity to one another operating as a staggered-cross intersection. Several signal movements would not be able to run concurrently, thus lengthening the cycle time for the intersection signals. In addition, the delay impact of this option would be spread over a longer time period and lead to redistribution of traffic in the local road network as predicted by network wide modelling.

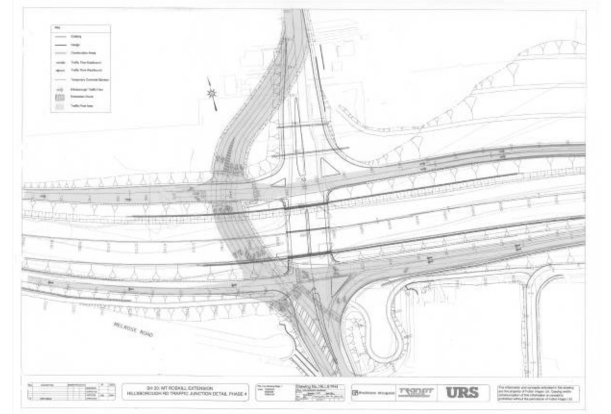	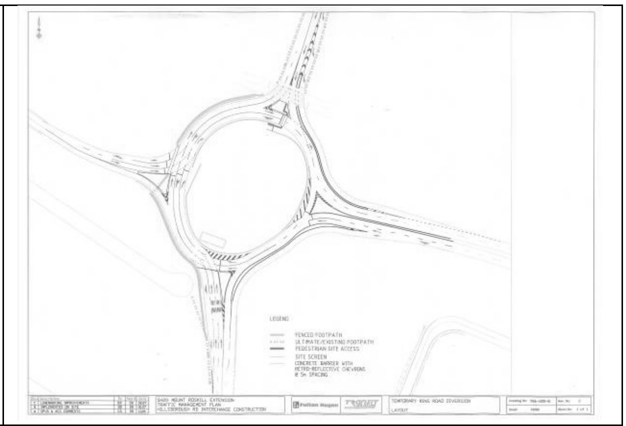
Figure 2(a): Initial Proposed Diversion Road	Figure 2(b): Ring Road Intersection

Figure 2: Hillsborough Road Diversion Proposals

3. RING ROAD DESIGN

The Ring Road has the advantage of easily allowing for entry and exit approaches to be changed as construction proceeds. As various ramps are constructed and opened, the alignment can be modified to accommodate these with relative ease. The fewer construction stages afforded by the Ring Road scenario have created a less confusing intersection to road users, as only one fundamental change has been required.

The Ring Road is essentially a one-way system and there are no turning movements that call for a ban on all other movements.

The staggered-T intersections required for a one sided diversion would have been even more sensitive to signal failure than normal cross intersections due to the complex phases that would have been required under that regime.

3.1.1 Design Considerations Leading to Signalisation

The initial concept of a give-way controlled roundabout was considered unacceptable in the early stage of the design process. With unbalanced flows one leg would dominate over the others and there would not be adequate gaps in the circulating flow. Some form of signalisation was considered necessary because the traffic volumes were too high and unbalanced to allow for adequate gap creation and selection.

As more site specific constraints were identified during the process, the need for a fully signalised roundabout became apparent. These constraints are summarised in Figure 3 for each of the approaches and are discussed below.

3.1.2 SH20 Motorway East Approach (from Airport)

For a conventional roundabout, the heavy traffic volume exiting the motorway from the East approach was predicted to dominate the right turning traffic entering the motorway from Hillsborough Road South. This was a problem particularly for the morning peak where both the traffic flows in and out of the motorway were high. Due to the random arrival pattern of the motorway traffic, it was considered necessary to use signals to create sufficient gaps for Hillsborough Road South traffic to enter the roundabout.

"Roundabout metering", that is the installation of signals a distance of approximately 50m upstream of the roundabout to create gaps in a dominant flow, was considered in the conceptual stage to reduce the dominance of the East approach. This has been used successfully on the SH20 Queenstown Road off ramp. However, preliminary traffic modelling suggested the metering would not provide sufficient gaps for the Hillsborough Road South traffic and it was concluded that the roundabout needed to be signalised at the limit line to provide sufficient gaps.

3.1.3 Hillsborough Road North Approach

Provision was required for an at-grade haul crossing, so that approximately 100,000m3 of material can be moved across Hillsborough Road safely and efficiently, while not adversely affecting the traffic flow at the intersection.

Due to the proximity of the haul crossing to the roundabout, the signals for the haul crossing and the roundabout approach were combined to avoid clustering of signals and queuing across the haul road. The signal for the approach needed to be set back approximately 20m from the roundabout to accommodate the haul crossing.

3.1.4 SH20 Hugh Watt Drive West Approach

The north–south pedestrian movement had to be maintained for the roundabout and a pedestrian crossing facility was required on this approach. It is common to use zebra crossings for smaller sized roundabouts. However, due to the multilane approach at Hugh Watt Drive, a signalised pedestrian crossing incorporated into the roundabout was considered the safest option.

3.1.5 Hillsborough Road South Approach

The pre-safety audited design proposal suggested this approach should be left as give way because:

- The upstream signal at the north approach would create sufficient gaps for a give way operation
- There was no need for pedestrian crossing and haul crossing facilities
- There was sufficient room for stacking at the roundabout signal downstream of this approach (the widest section of the roundabout).
- There would be substantial improvement to the intersection performance, particularly the lesser delays and shorter queue on Hillsborough South approach.

However, the safety auditors for the proposal considered this was a significant safety concern due to:

- Sight distance from the approach to the roundabout is limited, in particular the middle and the left hand lanes.
- The high traffic volume of Hillsborough Road South approach (middle and right lanes turning into motorway) would induce shorter headway and gap acceptance and lead to heedless entry by some drivers.

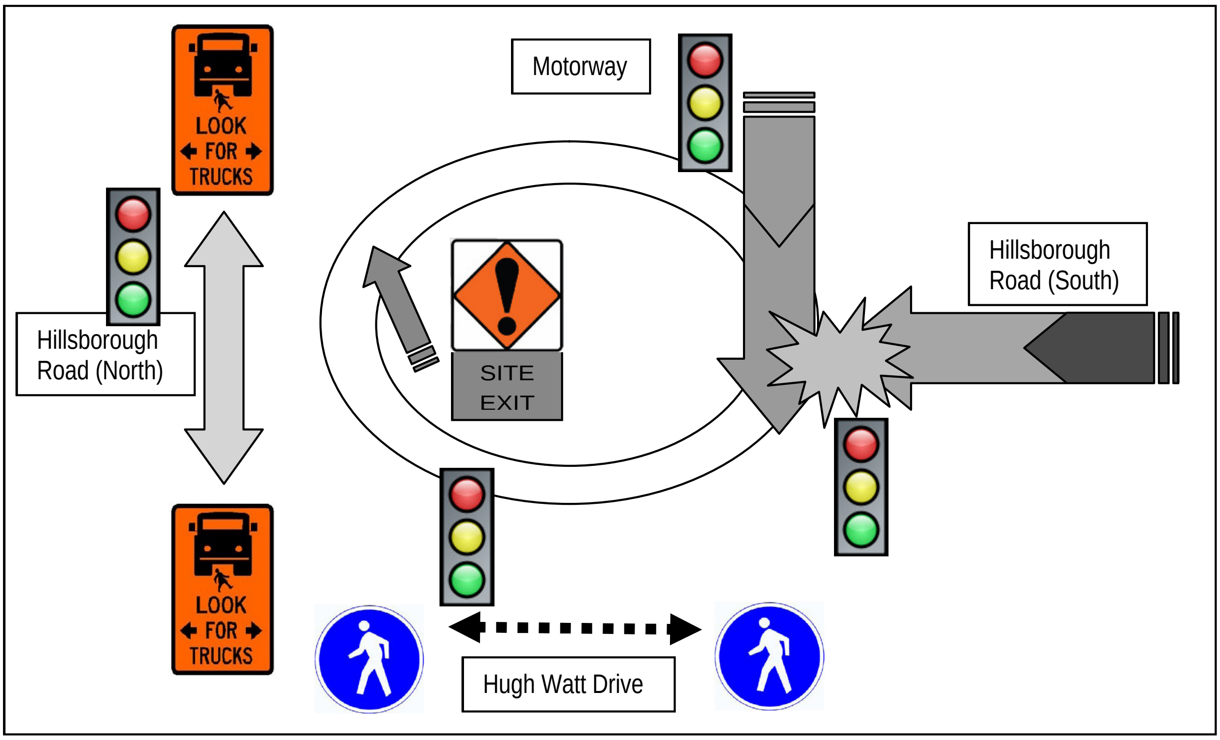

Figure 3: Design Considerations Leading to Full Signalisation

In addition to the safety audit comment, there was also concern that an isolated improvement to one approach may add to the congestion problems elsewhere in the network. As the objective of the ring road is to provide a temporary "replacement" facility during construction, localised capacity improvement was in fact not desired.

The S-Paramics micro-simulation traffic model confirmed that a fully signalised roundabout would still manage and balance queuing and congestion appropriately. Therefore the final agreed configuration was to fully signalise all the four legs of the roundabout to meet all the site constraints and to balance the safety and the operational requirements.

3.2 Part-Time vs. Full-Time Signalisation

Based on the modelling results, the signals are only required for the peak hours, especially the AM peak. However, to allow for part time signalisation costly variable message signs and traffic regulation changes would be required. These were considered unnecessary for a temporary construction solution.

It was decided that the intersection must remain actively signalised 24hrs per day so the public are not confused by changes to the intersection control type.

3.3 Lane Configuration

3.3.1 Slip Lanes

Left turn slip lanes onto and off the motorway (east approach) allowed for smoother operation during AM and PM peak periods by removing these heavy movements from the circulating signalised traffic stream.

3.3.2 Roundabout Lanes

The lane configuration of the rotary is asymmetric and changes from one to three lanes around its length. The main reason for this is to meet the capacity requirements for the intersection operation. But in addition to that a design objective was to eliminate the need for weaving manoeuvres on the rotary itself. The idea is that drivers select their lane on each entry approach and follow it through to their exit destination; thus creating a safer intersection. This is evident in the movement of motorway traffic turning right into Hillsborough Road North, which has a two lane exit to the north. This is not a capacity driven design choice, as only one of the lanes need be occupied at any time. The configuration of other lanes dictated that a lane change would be required for the particular right turn manoeuvre. On a roundabout this produces problems with road markings and delineation as the lanes would need to convey two conflicting messages.

3.3.3 Approaches

Map-style advance direction signs (ADS) on each approach replicate the configuration from the ground. These signs are important to the intersection operation as they assure drivers of their route through the junction.

The road marking design threw up a unique problem. Each signalised sub-intersection must be treated as an approach to a one-way road in terms of markings. Right turn arrows on the entry approach were not allowed because the signals led to a one way system. A driver could have conceivably turned right, following the painted arrow, and driven the wrong way around the roundabout. Road marking in the form of destinations written "in words" was the only way around this legal problem. However, the only obvious destination suitable for this use is the motorway. "M'WAY ONLY" is painted for the relevant approach lanes; whereas other right turn lanes must be left blank to maintain the legality of the signalised roundabout.

The use of slightly curved "through" arrows help convey the correct movement to traffic. Repeat arrows around the rotary itself also guide traffic through as their journey progresses.

3.4 GEOMETRY

The Ring Road has an increased level of traffic flow control over conventional roundabouts because of the signalisation. As a consequence, a greater deflection angle and greater approach angle can be achieved without impacting upon safety or performance. In fact, it is observed that an approach with a tight radius curve onto the circulating lanes operates very well. Whereas an approach with a wider radius curve creates higher speeds and lower signal compliance.

The rotary alignment at the Hillsborough Ring Road is shaped like a "dented egg" and is comprised of a complex series of broken back curves which tighten and relax around its length. This geometry is far from ideal but has numerous site constraints driving it. The compromised temporary geometry is compensated for by the signalisation.

3.5 CONSTRUCTION SITE ACCESS TO THE CENTRAL ISLAND

The central work area has vehicular site access from the inside circulating lane. Regardless of which approach direction site vehicles arrive from, they are able to enter the rotary directly into the inside lane, eliminating weaving manoeuvres as they circulate.

3.6 PEDESTRIANS AND CYCLISTS

Vulnerable road users are safer in a signalised roundabout system than a normal roundabout because of the increased control the signals provide. With pedestrians and cyclists excluded from the motorway approach to the Ring Road their facilitation is made somewhat simpler, however their design considerations remain the same and could be adapted to provide a full complement of facilities should the need arise.

Pedestrians were provided with signalised crossing phases running in tandem with the circulating flow. Across the north exit the pedestrians also had a signalised crossing in tandem with the haul crossing phase. The only unsignalised pedestrian movement was across the single exit lane of Hugh Watt Drive. Despite the busy intersection, the signals provide sufficient gaps in the flow exiting at this point that this crossing is made safely and with minimal delay.

Cyclists' safety is enhanced by the signalisation because the signals help them defend their lane while they are negotiating onto the rotary. The vulnerability of their slow start up and consequently longer gap requirement at entry is no longer a major issue for the cyclists.

4. TRAFFIC SIGNAL DESIGN

4.1 DESIGN OBJECTIVES

The intersection was modelled using S-Paramics micro-simulation and determined that a series of signalised one way T-intersections (signalised roundabout) were required to cater for peak flows. Without signals the S-Paramics model predicted unacceptable queuing to result during the peak periods.

All the overseas experiences to date are based on retrofitting an existing give-way controlled roundabout into a signalised roundabout. The "Hillsborough Temporary Ring Road" is unique in this regard as the previous signalised cross intersection was turned into a signalised roundabout.

Due to the site constraints, there are very limited stacking spaces available for three quadrants of the roundabout. Therefore the signal sequence design needed to minimise:

- Stopping and queuing within the roundabout
- The newly entering traffic stopping in the roundabout. (Majority of vehicles should only stop once at the approach limit line to the roundabout).
- The high volume of traffic stopping at the roundabout exit and "locking" up the roundabout for other movements. (This was also a safety concern as drivers may not expect stopping within the roundabout).

4.2 SIGNAL LOGIC AND SEQUENCES

The results from the S-Paramics model were used as the basis for the signal logic design. Although the modelling had been completed with preset logic and time sequence, further inputs were required to refine this time sequence into a workable solution that met the local practices on traffic signals and Transit's requirements.

It was agreed "sequential phasing" was the most appropriate signal logic to meet the design objectives and was the most suitable for the geometry of the Ring Road. Sequential phasing means each approach takes turn around the circle to enter the roundabout, and only one approach would have the green at any one time. This phasing may not be efficient if the demand for right turning movements is low for a particular approach, as only half of the roundabout would be utilised during the green time for that approach.

The other alternatives are to overlap some of the green time for different approaches and to skip the approach with low-demand. However, these all resulted in right turners queuing within the roundabout, which did not meet the design objectives.

It is also interesting to note the "green wave" of the sequential phasing is anticlockwise (against the circulating flow of the traffic). Figure 4 demonstrates the anticlockwise "green wave" can allow the upstream traffic entering into the roundabout early and enable this bunch of traffic to chase the prior bunch of vehicles entered from downstream approach. This arrangement helps to reduce the start up loss time of a signal and minimise the wasted gaps between greens for each approach.

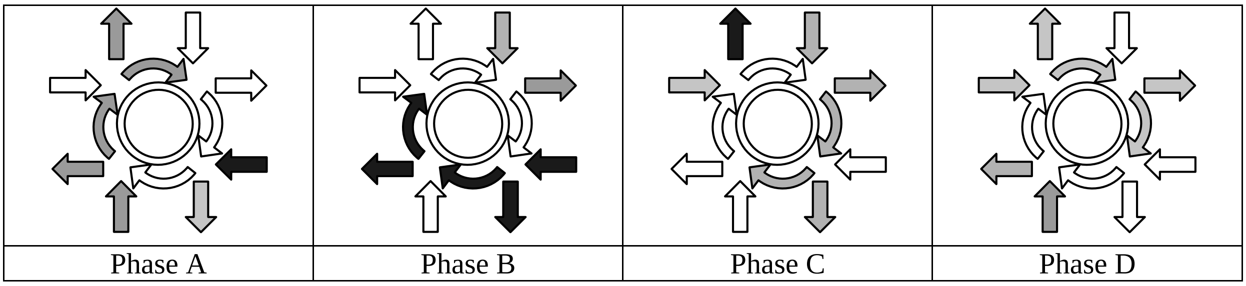

Figure 4: Signal Phasing - Anti-Clockwise Green Wave

4.3 CYCLE TIME

Overseas practice (Chard, 2006) suggests that a short cycle time (less than one minute) is desirable for signalised roundabouts to minimise the internal queuing of the roundabout. It is noted this is significantly shorter than the cycle time of a major signalised intersection (up to 3 minutes). A short cycle time also maintains a moving queue for the entry traffic, which is commonly observed for approaching a roundabout.

The maximum cycle time for the Ring Road is set approximately at 2 minutes. Table 1 summarises the maximum cycle time for am and pm peak.

Period	Hillsborough Rd North	Huge Watt Drive West	Hillsborough Rd South	Huge Watt Drive East	Total Cycle time *
AM	16 sec	16 sec	36 sec	31 sec	**99 sec**
PM	36 sec	16 sec	26 sec	41 sec	**119 sec**

** Total cycle time assumed no demand for pedestrian, haul crossings and site exits.*

Table 1: Ring Road Signal Phase Timings

These are considerably longer than the typical cycle time for similar signalised roundabouts found overseas. However, it was considered acceptable in this case because the ring road was previously a signalised cross intersection and drivers expected queuing and long cycle time on all the approaches.

It is also noted one of the benefits of a signalised roundabout is to enable sharing the available capacity more equably. In a sequential phasing, the total green time available can simply be re-distributed to balance the performance of all the approaches.

During peak hours, the signal is effectively running on a fixed time as the demand at each approach is near or exceeds the allowable maximum green time. While it runs very efficiently during peak hours, it may not be responsive to the actual demand during off peak periods. This is because the cycle has to go through all phases regardless of where the demands are.

To reduce the wasted time in the cycle, vehicle detection loops were installed at the approaches to detect the gaps of the entering traffic. The "green" moves upstream when the gaps exceed the preset limit (typically 3 seconds). However, as the change in phase requires two cut off sequences at two separate signal sets (one in the roundabout circulating stream and one at the entry approach), the minimum waste time is still 13 seconds between phases (i.e. 3 seconds gap + 5 seconds early cut off at the roundabout signal + 5 sec cut off at the approach signal).

This highlights the most efficiency use of the sequential phasing is to ensure the change in phase occurs when maximum green time is reached for each approach, and the cycle time should be kept as short as possible to increase the bunching of successive traffic streams entering the roundabout.

4.4 HAUL CROSSING AND PEDESTRIAN CROSSING AT RING ROAD EXIT

The exit signal must be synchronised with the other signals at the roundabout to ensure the roundabout is not "locked" up when traffic stops at the exit. In sequential phasing, the best time to have green pedestrian crossing at the adjacent exit is when it is green for entering traffic in the same approach. However, it is not practical for the haul crossing as it has to cross both the entrance and the exit in one green phase and it cannot be broken into two crossings.

The haul truck phase runs simultaneously with the entry phase for the Western approach. In this way, the only traffic stream that was stopped at the haul road southern limit line was traffic turning left from Hugh Watt Drive into Hillsborough Road which is a very minor flow, even during peak hours. Most of the left turning traffic are site staff and construction workers.

5. OPERATION OBSERVATIONS

5.1 GIVE WAY AT THE ROUNDABOUT

A significant number of drivers are still observing the give way rules at the entrance to the roundabout even if they have the right of way with the green signal. This can disturb the entering flow to the roundabout slightly as the drivers hesitate and slow down. However, this generally does not result in any dangerous situations due to the slow entry speed environment.

It is noted this behaviour may not necessarily need to be discouraged as this provides an additional safety net to the approach traffic. It also shows that the combination of a roundabout and signalisation further enhances the traffic safety over conventional intersection types.

5.2 RED LIGHT RUNNING

Two types of red light runners have been observed.

- Stopping at the red signal but taking off when they see a gap.
- Running late amber and red lights with no intention to stop.

The earlier type of red light runners is quite common during the interpeak. The sequential phasing is not as responsive during interpeak and drivers tend to get frustrated if they cannot see any traffic within the roundabout. This is not considered as a safety issue as long as they give way to traffic from their right and pedestrians.

It is noted some overseas countries such as Singapore (Wong et al, 2004) allow free left turn when the signal is red. If this rule is adopted by New Zealand, entering a signalised roundabout in red would be legal as the entering traffic in theory is performing a "left turn" into the roundabout.

As mentioned in section 5.1 above, the signalised roundabout is safer for this situation as drivers tend to give way to roundabout traffic (whether it is a red light runner or not) and look right for a gap before entering the roundabout even if they are running a red light.

The approach with the greatest compliance is in fact that with the lowest intersection approach visibility. Where it is favourable to have high approach visibility at a normal roundabout for adequate speed adjustment and gap selection, the signals are designed to regulate those decisions. Lower visibility focuses drivers' attention on the signal aspects rather than circulating traffic. Limit line visibility can be less than for normal intersection types.

5.3 LANE SHIFT WITHIN THE RING ROAD

The signalised roundabout uses "Alberta" style lane marking and hence no lane change is required within the roundabout as long as the drivers enter the roundabout in a correct lane.

However, there is a strong tendency of drivers turning right to drift to the right hand lane and cut across at the last moment to exit the roundabout. This tendency increases the weaving movements within the roundabout and the last minute merges at the exit. While this is not the best practice, it does not create a dangerous situation.

Solid lane marking and additional direction arrows were implemented to reinforce the message of "keep in lane" for the right turners. These initiatives reduced the amount of weaving in the roundabout but approximately one third of right turners still drift right and cut across the lane to exit the roundabout.

One possible further improvement is to install overhead signage or using electronic raised pavement markers to guide the drivers around the correct lane into the roundabout. With a signalised roundabout, the illuminated electronic raised pavement markers could be synchronised with the traffic signal sequence of the roundabout.

5.4 SAFETY

To date there have been no reported accidents at the roundabout over the 8 months of operation. It is noted the roundabout is operating as a temporary road and hence a 30km/h temporary speed limit is imposed. It is believed that the slow speed environment, the combination of a roundabout geometry and traffic signals, and the cautious approach by the drivers has resulted in a safe intersection for all road users.

5.5 SIGNAL POLE LOCATIONS

Signals on the inside curve on the approaches are very vulnerable to vehicle strikes. Optimum lantern positioning and aiming becomes difficult because vehicles have a tendency to track in on the curve and strike the target board, or in some cases the entire pole and lantern assembly. Placement and protection of signal poles should not be overlooked in the overall intersection design (AUSTROADS 1993).

5.6 PERFORMANCE MEASURES

One of the performance measures for traffic management in the project is to maintain traffic flows on the motorway at the original "baseline" levels. After the implementation of the Ring Road there is approximately a 3-4% increase in peak hour flows in both directions (refer to Figure 5: Comparison of Peak Hour Flows). Furthermore, queue length and delays at the intersection approaches have either remained the same or have been reduced. Further study would be required to fully quantify the extent of the improvement made by the intersection change.

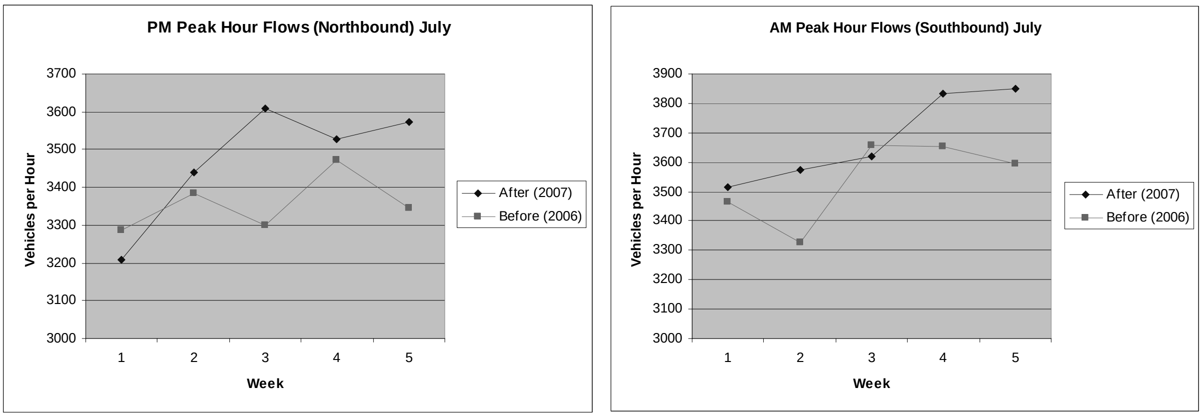

Figure 5: Comparison of Peak Hour Flows

6. RING ROAD OPERATION WITHOUT SIGNALS

The intersection has had a signal failure due to power outage and subsequently reverted to operating as a normal roundabout. The outage even extended over a PM peak period with very minimal queuing on any approach. This demonstrates the adaptability of the system. Power outage, or signal failure at conventional at-grade cross intersections, which are congested and over-saturated, result in mass queuing and delay. Manual intervention is usually required to allow certain movements to flow safely. With the geometry of a normal roundabout, traffic instantly adopted the give way rule and congestion was avoided.

As expected, the roundabout performance (in terms of delays and queue length) was much better for the interpeak period. There were a number of public comments and feedback regarding the redundancy of the signals in a roundabout and perceived delays at the signals.

The use of a conventional roundabout for the off peak and signals for the peak hours would provide the optimum performance in terms of traffic delays and queue length. However, it is important to note the reasons to signalise a roundabout is not purely based on traffic performance. The use of signalisation for traffic safety and the other vulnerable road users are also the very important considerations. In the case of the Ring Road, the signalisation has safely incorporated the work site within a busy intersection and provided major benefits to the project's overall construction.

7. RECENT OPERATION CHANGES

7.1 SWITCH OF MOTORWAY APPROACH CARRIAGEWAYS

The motorway carriageways have been shifted south to cater for subsequent stages of motorway construction. This was achieved with very minimal changes at the tie in to the Ring Road and with no disruption to traffic. This reinforces the adaptability of the Ring Road to the construction staging. Photos 1 - 4 show the stages.

	
Photo 1: Original Intersection	Photo 2: During construction / Pre-commissioning
	
Photo 3: Ring Road with original motorway positions	Photo 4: Ring Road with westbound motorway repositioned

7.2 LEAVING ONE LEG AS GIVE WAY CONTROLLED

Modelling has shown that leaving one leg of the roundabout as give way priority control often provides an optimum solution. The give way can utilise the gaps created by any inefficiency of the signal phasing (at start up and cut off) and it is particularly effective in the off peak situation where gaps become wider between phases in the roundabout.

The re-configuration of the SH20 eastbound lanes has led to the need to remove the slip lane from Hillsborough north approach to the motorway. To maintain the approach capacity, it was decided to change the signal controlled approach to a give way priority. The changes were feasible because:

- The approach only has two lanes into two circulating lanes.
- The haul crossing is not required after the summer earthworks season.
- Other approach changes have increased the stacking distance for internal queuing without blocking the exit to the roundabout.
- The signal sequence can produce sufficient gaps for the give way controlled approach.

Only minor modification to the logic was required to cater for this change. The green phase for the north approach was maintained although the traffic signals have been removed. Effectively, the "de-facto" green time is extended by the queue detector (30 m from the limit line) and this extension provides the gaps required to clear the queue at the approach.

7.3 FUTURE STAGES

Once the construction of Hillsborough Road underpass is complete the Ring Road intersection will be decommissioned. Traffic will need to travel on the new structure to allow completion of the interchange. A new road configuration will be in place and the new challenge will be providing a solution with similar performance to the Ring Road.

8. CONCLUSION

The "Hillsborough Ring Road" is an innovative solution to incorporate a construction site within the SH20 Hugh Watt Drive/Hillsborough Road intersection without adversely affecting traffic operations. The Ring Road has also simplified the construction staging and reduced the number of changes required for temporary road layouts.

The New Zealand's first implementation of a signalised roundabout has proven to be a success. Both the capacity and safety of the intersection have improved while all the site specific constraints and requirements have been met. There have been a few unexpected issues since the implementation but continuous fine tuning of the operations and design have addressed these issues and even enabled further improvements to be made.

The Ring Road, a signalised roundabout, is an excellent traffic engineering solution for balancing the operational performance of all approaches and improving traffic safety for all the road users.

9. ACKNOWLEDGMENTS

The design and implementation of the Ring Road was a joint team effort of the State Highway 20 Mt Roskill site team (Fulton Hogan and Opus International Consultants) and Fulton Hogan's design consultant Connell Wagner. The authors would like to acknowledge all the team members that were involved in developing the Ring Road from a concept to reality, and also would like to thank Transit New Zealand for providing valuable signal design advices and supporting this innovative concept.

10. REFERENCES

AUSTROADS (1993). *Guide to Traffic Engineering Practice Part 7 – Traffic Signals*

CHARD, B. (2006). *Signalled Roundabouts and their Design – A 1-Day Workshop*

WONG, Y.D., HO, J.S., FOO, H.Y.T. (2004). *Left –Turn-On-Red Traffic Scheme in Singapore, Institute of Transportation Engineers, ITE journal, November 2004.*