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An innovative dual roundabout - design drives behaviour change

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Abstract

The Britannia roundabout in Adelaide is where five major arterial roads meet in an unconventional way due to the physical constraints. The Roundabout forms a critical part of the inner city ring route of Adelaide and over 52 000 vehicle per day traverse through this intersection. Due to the unconventional shape of the roundabout and the resultant complex give way situations, there have been 308 crashes with 47 of these resulting in casualties recorded between 2008 and 2012. This crash rate has placed the roundabout as the worst crash site for un-signalised intersections in South Australia.

To address the major crash problems and keep traffic moving at the intersection, an innovative dual roundabout concept was developed within the physical constraints. The idea was to install a small second roundabout at the location where two roads joined the roundabout in a sharp angle. The existing layout of this area required the traffic entering from the two roads to give way to two streams of traffic at once. The installation of the second three-leg roundabout not only simplified the give way situations but also created a single leg entering into the larger roundabout. Thus the larger roundabout reverted to a standard four-leg conventional roundabout.

Extensive traffic modelling at both the microscopic level (behaviour check) and mesoscopic level (capacity assessment) were conducted at the very beginning of the concept development to prove that it was a workable solution. The dual roundabout design concentrated on the creation of a low speed environment and providing drivers with more space and time to negotiate the roundabout. In addition, large advisory signs were designed and installed on each approach to improve the drivers' lane selection prior to entering the roundabouts.

The dual roundabout became operational in mid October, 2013. The performance of the roundabout was promising in terms of both safety and efficiency. The dual roundabout created a low speed environment and traffic became smooth and calmer during rush hours. On the other hand, shorter queue and travel delay were achieved at the roundabout. Traffic data confirmed that the traffic demand at the roundabout had recovered back to its pre-upgrade level one week after operation.

The lessons learnt from this project will help to stimulate creative thinking on future roundabout design and upgrade in Australia and abroad and also to think about how traffic models are applied to non standard operating environments.

1. Introduction

The Britannia roundabout in Adelaide is where five major arterial roads meet in an unconventional way (see Figure 1). It forms a critical part of the inner city ring route of Adelaide and over 52 000 vehicle per day traverse through this intersection. Due to its unconventional shape and associated complex give-way mechanism, there have been 308 crashes with 47 of these resulting in casualties recorded between 2008 and 2012. This crash rate has placed the roundabout as the worst crash site for un-signalised intersections in South Australia.

Figure 1. Britannia Roundabout in Adelaide, South Australia

The Britannia roundabout is situated next to the highly protected city green-belt parklands that surround the central business district. There is also a heritage building and two other large multistorey commercial buildings on its three corners. Any physical expansion of the intersection to either create a larger five-leg conventional roundabout or install traffic signals would encroach into the park lands and result in significant social and environmental impacts. A long term underpass solution to separate city ring route (i.e. Dequetteville Terrace and Fullarton Road south) from the rest three legs would incur significantly high costs. These may explain why there has been no real cost-effective solution found in the last three decades.

This paper reports on the development of an innovative dual roundabout solution to the site. The dual roundabout addresses the major crash problems while keeping the traffic moving at this strategic location.

2. Crash problems at the Britannia roundabout

A crash analysis of the Britannia roundabout suggests that more than two-third of the crashes which happened in the last five years is concentrated in the following two areas (see Figure 2):

- *Crash Area 1* – the triangle area where Dequetteville Terrace and Wakefield Road meet, and
- *Crash Area 2* – the Kensington Road entry / exit areas.

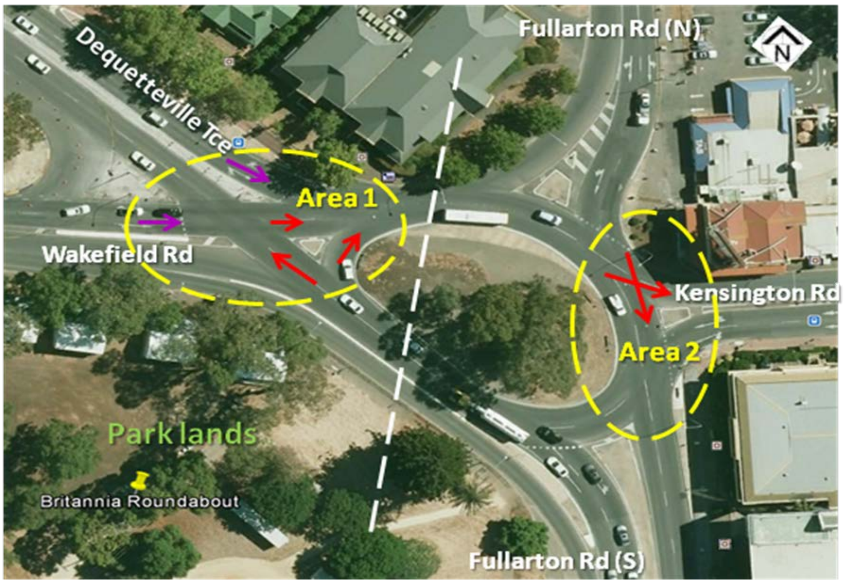


Figure 2. Two major crash areas of the Britannia roundabout

Crash Area 1

The dominant crash type in the area is the Right Angle crash (i.e. vehicles entering the roundabout failed to give-way to the right). It is followed by the Rear End crash as heavy traffic queues and start-stop traffic conditions are prevalent during peak periods.

For a conventional roundabout, the vehicles entering the roundabout only need to give-way to one stream of traffic - the vehicles are already on the roundabout. At the Britannia roundabout, the vehicles entering from Wakefield Rd must give way to two traffic streams at a time - the traffic leaving the roundabout via Dequetteville Terrace and the circulating traffic behind the traffic island (see Figure 2). The traffic on the Dequetteville Terrace approach experiences the similar complex give-way situation (i.e. giving way to two traffic streams at once). Meanwhile, the sharp angle between the two road approaches makes it difficult for the traffic from the Dequetteville Terrace approach to observe opposing traffic movements. In addition, the close proximity of the two approaches and the straight road alignment between them result in traffic from both the Wakefield Road and Dequetteville Terrace to compete for the same gaps to enter the roundabout.

Site observation reveals that the heavy peak hour traffic demands and the long queues on these two approaches make drivers very aggressive (especially in afternoon peak). They tend to pick smaller gaps to enter the roundabout, at times these smaller gaps result in risky behaviour and at times end with crashes. Quite often the traffic from the Dequetteville Terrace approach stops beyond the holding line and waits inside the roundabout for gaps from the circulating traffic behind the traffic island. Traffic entering from Wakefield Road end up in a two stage manoeuvre storing near the small triangular island to wait for the turning traffic to clear with the traffic from the Dequetteville Terrace approach. The aggressive behaviour and the complex give-way situations make the area crash-prone.

Crash Area 2
In contrast to Crash Area 1, the Side Swipe crash is the major crash type in this area. The traffic on the roundabout often choose inappropriate lanes to either leave the roundabout via Kensington Road or continue circulating to Fullarton Road south.

Given the unconventional layout of the Britannia roundabout, it would be difficult for the UNFAMILIAR drivers to decide which lane to use before entering the five leg roundabout. On the other hand, the heavy peak hour traffic demands from the Wakefield Road and Dequetteville Terrace approaches to both Kensington Road and Fullarton Road south often encourage the FAMILIAR drivers purposely pick the wrong lanes to enter the roundabout and change lane abruptly inside the roundabout to gain advantage. Therefore, both the unconventional five leg layout of the roundabout and the peak hour traffic demand patterns could be ascribed to the unexpected lane changes inside the roundabout which cause crashes.

Even though the dominant crash types in the two crash areas are different, they are all geometrically design induced. Without a dramatic change of the existing roundabout layout, the key safe features of roundabouts (simple give-way arrangement and easy lane selection) would be difficult to achieve.

3. Innovative dual roundabout concept

The two distinct crash areas lead us to a detailed function review of the Britannia roundabout. If we cut the existing roundabout into two parts using a straight dash line (as shown in Figure 2), we would have two different function areas:

- *Function area 1* (on the left hand side of the line)
  The area 1 is an irregular junction of two roads plus a small triangular traffic island that separates the circulating traffic on the roundabout from the traffic entering the roundabout from the two roads. As discussed before, this area makes the normal give-way rules difficult to follow. Since roundabouts are very effective in sorting out the conflicting movements, it would be natural to think of replacing this complex junction with a small three leg roundabout (RB1).

- *Function area 2* (on the right hand side of the dash line)
  This area consists of three legs of a conventional four leg roundabout. The physical separation between each pair of the adjacent legs is reasonable. If we treat the other part of the roundabout as the forth entry leg, then we would have a conventional roundabout (RB2) which is much easier to negotiate.

If we allow RB1 and RB2 to share one leg with each other, we would have the following concept – the Britannia dual roundabout concept (see Figure 3). The proposed second roundabout (RB1) not only simplifies the give way between Dequetteville Terrace and Wakefield Road but also creates a single leg entering into the larger roundabout (RB2). We can now convert the larger roundabout to a conventional four leg roundabout.

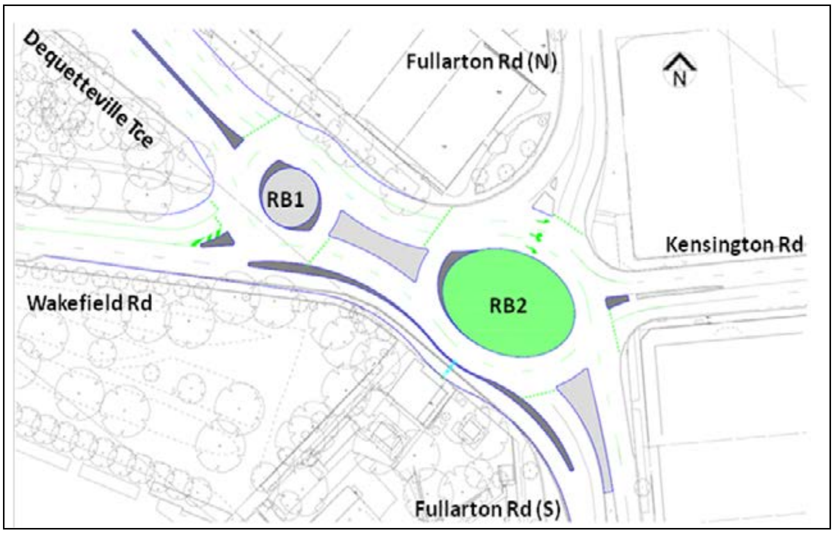


Figure 3. Britannia dual roundabout concept

The dual roundabout concept simplifies the give-way situations at each entry of the existing Britannia intersection. To cater for the existing peak demand patterns and tackle the Side Swipe crash problems of Crash Area 2, a third lane between the two roundabouts (see Figure 3, northern section) is also introduced. The middle lane would be shared by the two traffic streams - the traffic leaving the roundabout via Kensington Road and the circulating traffic to Fullarton Road south. Meanwhile, the introduction of the third lane improves the capacity of the larger roundabout.

4. Traffic Modelling

The dual roundabout concept looks simple; would the double roundabout cope with the high peak demands or increase the congestion at these times? Roundabout performance is heavily influenced by traffic demand pattern and associated give-way behaviour. Detailed traffic modelling that is capable of capturing individual driver's gap acceptance behaviour at the roundabout is crucial in the dual roundabout concept development. We want to know whether a 'normal' driver can follow standard give-way rules to negotiate the dual roundabout with ease and ensure that the throughput of the existing roundabout can be maintained. Hence, extensive traffic modelling at both microscopic level (behaviour analysis) and mesoscopic level (capacity assessment) were conducted in the very early stage of concept development (Zhang and Excell 2013).

Following the standard modelling practice, the base case models which reflect the exiting roundabout performance were developed with intensive calibration. The dual roundabout concept was then implemented in the scenario models to test its viability and to quantify the performance difference.

4.1 Base case models – confirming issues

AIMSUN modelling

The microscopic traffic simulation has been widely used in areas of traffic management (Hansen et al. 2000, Stazic et al. 2005, Zhang and Excell 2011), incident detection and management (Dia and Cottman 2005, Zhang and Taylor 2006a, 2006b), travellers information systems (Zhang et al. 2008, Zhang et al. 2009), and other advanced ITS applications. In this project, the micro-simulation package AIMSUN (Barcelo and Casas

2002) was chosen to conduct detailed behaviour modelling. AIMSUN can distinguish between different types of vehicles and drivers, and model conflicting manoeuvres in very fine detail in addition to its highly detailed traffic network representation.

The base case AIMSUN modelling started with a set of standard parameters representing the general behaviour of Adelaide drivers. The initial base case AIMSUN model failed to replicate the existing peak hour traffic performance of the Britannia roundabout in terms of throughput, delay and traffic queue. This was clearly evident during afternoon peak periods where the model produced a lower entry capacity at both the Dequetteville Terrace and Wakefield Road approaches with the development of an excessive long queue.

During model calibration the give-way rules between Wakefield Road and the Dequetteville Terrace had to be removed to improve gap utilisation and the behaviour of the traffic was changed to a very aggressive state. Only in this way we were able to produce the existing roundabout capacity. On the other hand, the dramatic change of model parameters made the area where the above two roads meet chaotic during simulation runs. This again highlighted the geometry induced complex gap selection process may be ascribed to the crash problems of the Britannia roundabout.

LINSIG modelling
To be confident about the base case AIMSUN modelling results, a mesoscopic modelling of the Britannia roundabout using LINSIG (JCT 2009) was carried out. The LINSIG modelling tried to capture the relationship between the entry capacity and the opposing circulating flow rate of each approach of the roundabout. It takes empirical approach to infer the entry/circulating flow relationship from capacity observation in the form of a first order model

$$Q_e = F - f_c Q_c \qquad (1)$$

where Q_e is the entry capacity, Q_c is the circulating flow across the entry, and F and f_c are positive constants that depend on geometry of the individual entry and entire roundabout respectively.

Similar to the AIMSUN base case modelling, the initial base case LINSIG model also failed to produce the accurate existing roundabout capacity when the recommended entry-circulating flow curve (f_{c-1} in Figure 4) was used. This curve represents the 'normal' give-way situation at an entry of a conventional roundabout, which is similar to the curve C in the Fig.7 of the TRRL Report (Kimber 1980).

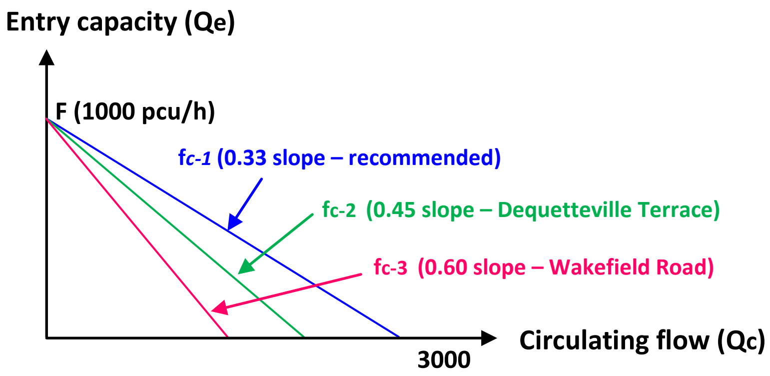


Figure 4. Entry capacity –circulating flow curves

The base case LINSIG model only started to work after we factored in the geometry induced aggressive give-way behaviour for traffic to move through the Britannia roundabout and adjusted the entry-circulating flow curves for both Dequetteville Terrace and Wakefield Road ($f_{c\text{-}2}$, $f_{c\text{-}3}$ in Figure 4). It again confirmed the geometrical design issues of the existing roundabout. In fact, both the AIMSUN and LINSIG base case modelling not only quantified the existing roundabout performance but also played a critical role of confirming the geometry problems of the existing Britannia roundabout.

4.2 Scenario models – testing idea

LINSIG modelling

When the proposed dual roundabout concept was tested using LINSIG, the recommended entry-circulating flow curve ($f_{c\text{-}1}$ in Figure 4) was applied. The reason of making this adjustment to the base case model is simple - if the irregular layout and the resultant complex give-way mechanism of the 'tricky triangle' area forced us to adjust the curves for both the Dequetteville Tce and Wakefield Rd approaches, then the conventional design of the small three-leg roundabout should bring the curves back to its normal form.

As shown in Figure 5 and Table 1 (Zhang and Excell 2013), the overall capacity of the Britannia intersection was increased and a positive practical reserve capacity (PRC) of 2.8% was achieved. For Dequetteville Terrace and Wakefield Road (previously congested legs in afternoon peak), the degree of saturation figures (demand / capacity ratio) dropped to around 0.5. These two legs were no longer congested should the existing traffic demand stay unchanged.

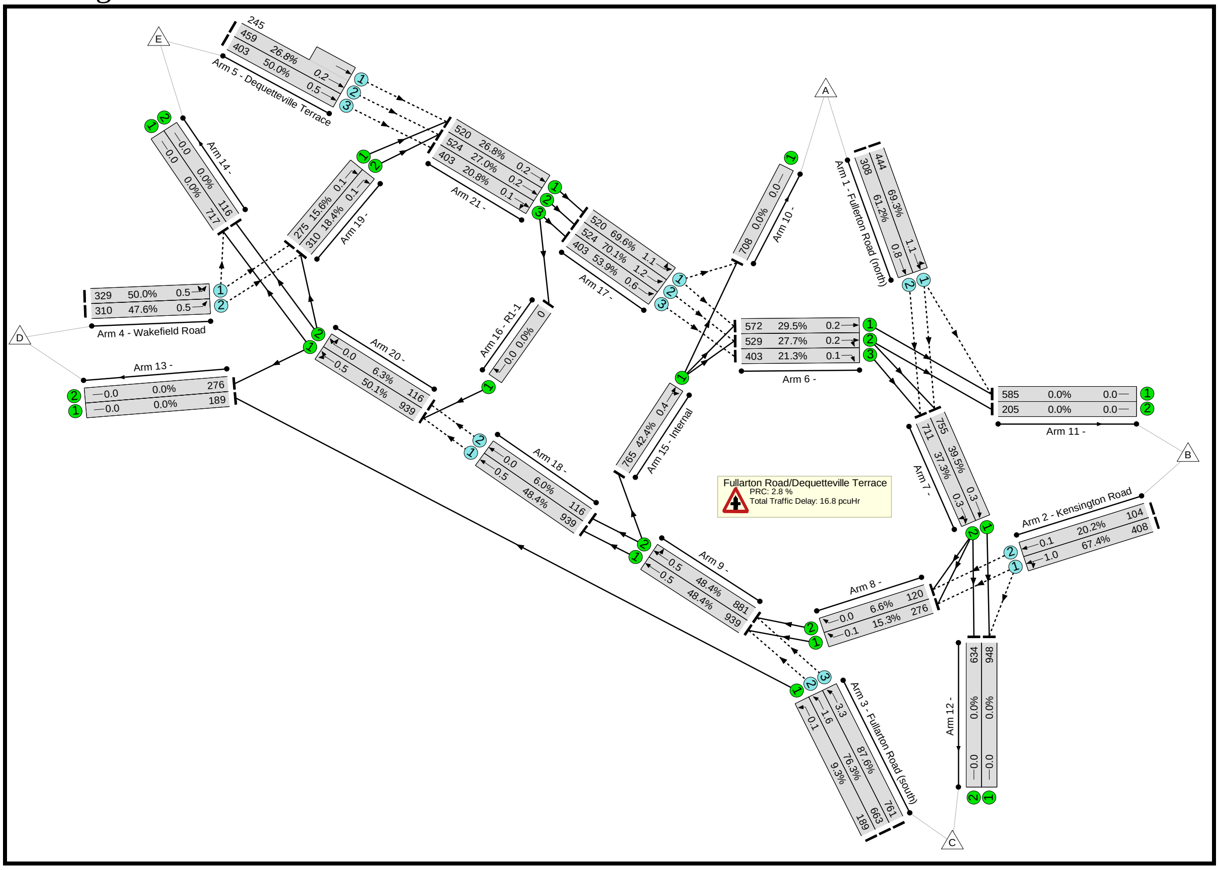


Figure 5. LINSIG model of the proposed dual roundabout (afternoon peak)

Table 1: LINSIG modelling results (afternoon peak)

LINSIG	Total Delay (pcu-h) / Practical Reserve capacity	Degree of Saturation	
		Dequetteville Terrace	Wakefield Road
Base case	36.5 / -8.4%	0.94	0.96
Concept	16.8 / 2.8%	0.4	0.5

AIMSUN modelling

The above LINSIG modelling results were replicated in AIMSUN scenario models (see Figure 6 and Table 2 (Zhang and Excell 2013)). We observed light traffic queues on both the Wakefield Road and Dequetteville Terrace approaches during the peak hours. Meanwhile, the traffic traversing through the dual roundabout was very smooth during the entire simulation runs. Note that the normal give-way rules between Wakefield Road and Dequetteville Terrace were restored in the scenario models, and the drivers' behaviour was set to the normal level. We did a sensitivity test by increasing the aggressiveness of drivers' give-way behaviour to its current level (i.e. matching the calibrated base case model parameters). No significant performance difference was identified following the changes.

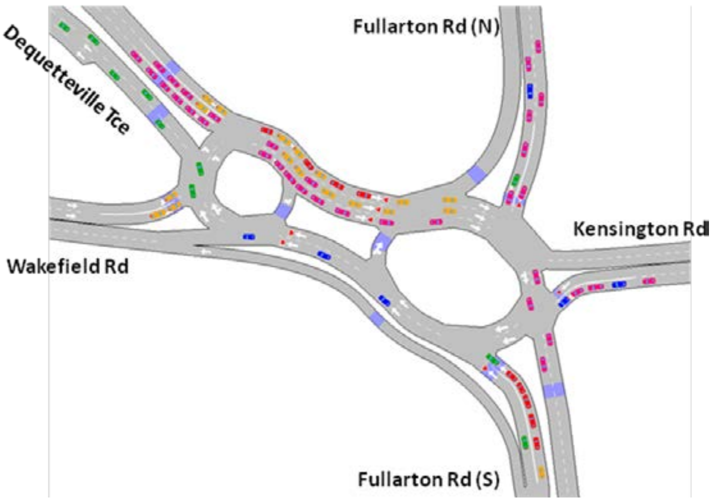


Figure 6. AIMSUN model of the proposed dual roundabout (afternoon peak)

Table 2: AIMSUN modelling results (afternoon peak)

AIMSUN	Average Delay (sec/km)	2-hour throughput (veh)	Vehicles waiting out (veh)
Base case	78	8192	0
Concept	38	8302	0

It was the performance consistency between the AIMSUN and LINSIG scenario models that gave us confidence in the dual roundabout solution. In particular, the model parameters had been set back to the normal level when the positive results were obtained.

5. Dual roundabout design

The dual roundabout design concentrated on creating a low speed environment and providing drivers with more space and time to negotiate the roundabout. As shown in Figure 7, the major change made to the dual roundabout concept is the central island of the larger roundabout. It was changed from an egg shape to a circle to achieve a stable circulating speed. Meanwhile, the slightly reduced central island diameter helped to bring down the circulating speed further to improve both safety and gap utilization of the larger roundabout, as gap selection, distance and speed are closely related to the ability of drivers to see and assess available gaps in such a constrained space. The lane width at both roundabouts is generous (between 4.5 m and 5.5 m in general). Some elements of the design were below the Australian design guideline requirements (Austroads Guide to Road Design, Part 4) but not considered to impact on the safety or suitability of the design at this special location under the prevalent traffic conditions.

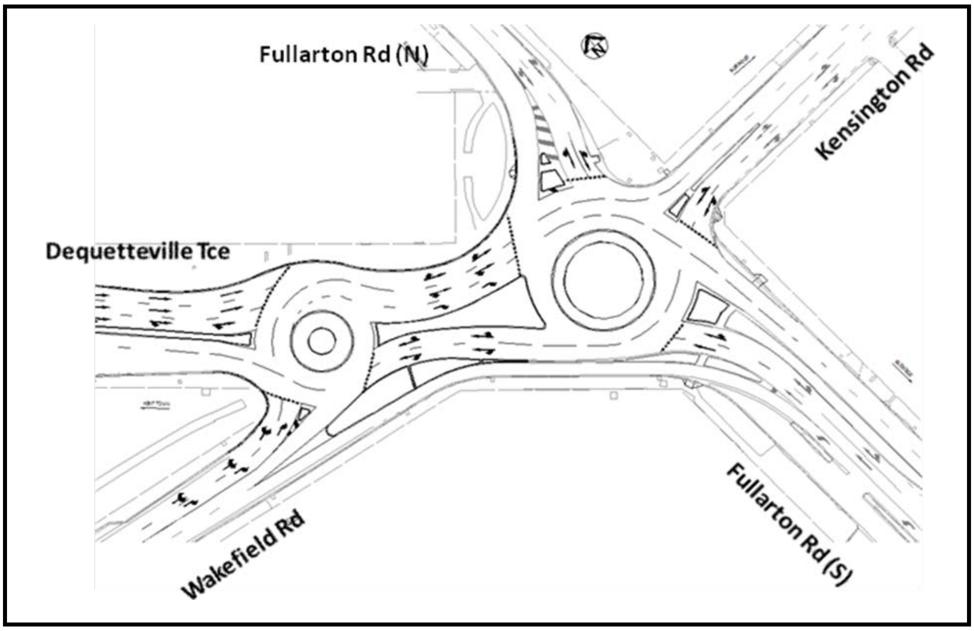
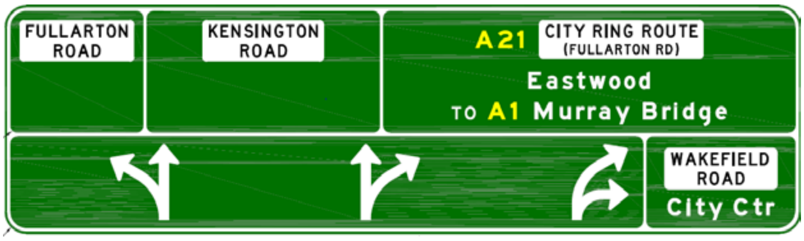
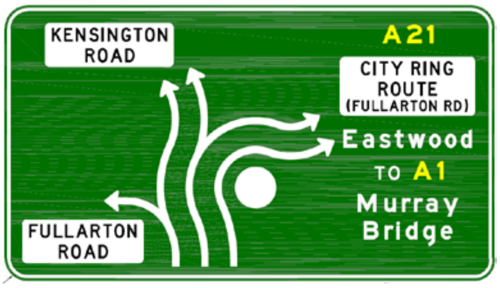


Figure 7. Final design of the Britannia dual roundabout

Given the relatively complex form of the dual roundabout as a whole, selecting the right lanes to enter the roundabout remains essential to the safe operation of the roundabout. Large advance directional signs were designed for each approach of the dual roundabout to guide the drivers' lane selection decision when approaching the roundabout (see Figure 8 (a) & (b) as an example). These signs became an integral part of the dual roundabout. Having drivers selecting the right lanes before entering the roundabouts also assisted with maintaining a stable circulating speed.



(a) - Dequetteville Terrace approach



(b) - Middle section between the two roundabouts

Figure 8. Advance signs at the Britannia dual roundabout

6. Performance of the dual roundabout

The dual roundabout became operational in mid October, 2013. Further analysis was undertaken to confirm if we did achieve the objective of improving the intersection safety while keeping traffic moving.

Safety improvement
A number of site observations were conducted in both morning and afternoon peak periods starting from the second week. It was found that:

- the dual roundabout design created a slow speed environment. It became easier for drivers to pick safe gaps entering the roundabout, and the traffic on the roundabout became smooth and calm during rush hours.

- a number of cyclists were observed using the Britannia intersection during the peak hours - a very rare event before the intersection upgrade. At this stage the cycling number are in the order of 20 cyclists per hour. It is another clear indication of the ease of use of the dual roundabout.

When preparing this paper, the 2013 December quarter crash statistics (15/10/2013 ~ 14/01/2014) had just been released. They were compared with the previous four-year average crash figures of the same quarter (see Table 3). The early results were very promising – a 60% of crash reduction has been achieved.

Table 3: December quarter crash statistics

Crashes	Average (2009 - 2012)	2013	Variation
All Type	18	8	- 56%
Casualty crashes	2.5	1	-60%

As we know crashes are low probability events, we need at least a whole year's data to better appreciate the crash trend at the upgraded intersection.

Efficiency gain
In addition to the safety improvement, site observation also indicated that the traffic queue on each approach of the roundabout was shorter when compared to the queues prior to the upgrade - an efficiency gain.

Before a definite conclusion can be made on the dual roundabout performance, the post-upgrade traffic demand needs to be confirmed that it has recovered to its pre-upgrade level. Note that, the Britannia intersection was kept open to traffic in both morning and afternoon peaks during the dual roundabout construction due to its city ring route function. However, the speed limit was dropped to 25 km/h to maintain safety on site.

The Adelaide arterial road network is currently managed using the SCATS signal control system (SCATS 2000). The SCATS detector counts at the adjacent signalised intersections (immediate upstream) were used to gauge the traffic demand at the Britannia intersection (see Figure 9).

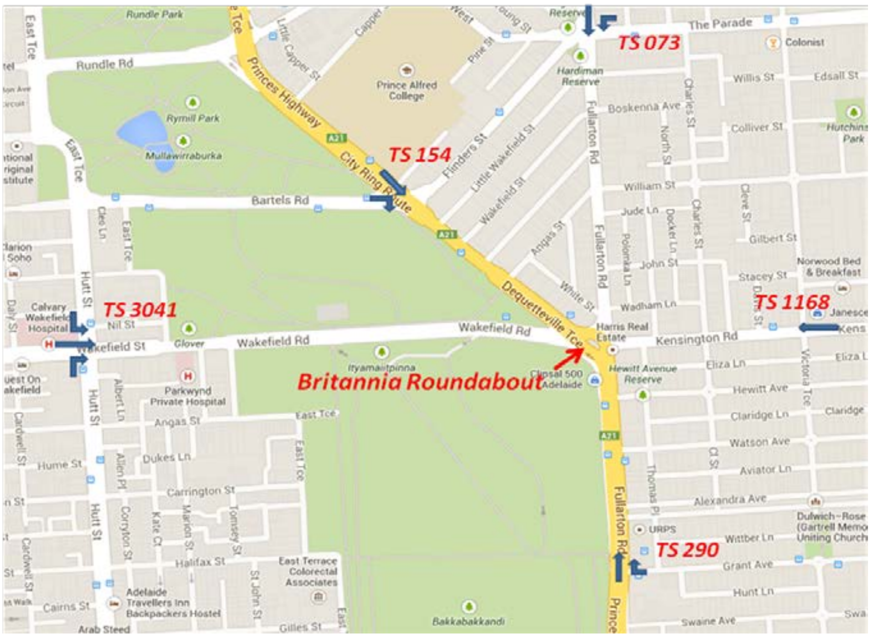


Figure 9. SCATS detector data collection map

Table 4 shows the weekly average peak hour traffic demand estimates from the SCATS detector counts. The ‘Before’ scenario reflects the typical traffic demand at the Britannia intersection before its upgrade. The ‘After’ scenario represents the third week of dual roundabout operation. The figures confirm that both the overall demand and city ring route approach demands (i.e. Dequetteville Terrace and Fullarton Road south) had fully recovered to its pre-upgrade level.

Table 4: Traffic demand estimates at the Britannia intersection (Third Week)

Time period	Scenario	Total Demand (veh/h)	Approach Demand (veh/h)	
			Dequetteville Terrace	Fullarton Road (South)
Morning	Before	6360	1108	2352
	After	6406	1122	2396
Afternoon	Before	4879	1016	1837
	After	4995	1116	1835

Travel time

Given the facts that the traffic demand at the roundabout had recovered and the shorter traffic queue was observed on site, we would expect a reduced travel time through the dual roundabout.

The point-to-point travel time between each pair of the adjacent signalised intersections (where SCATS detector counts were collected) was analysed. The Bluetooth receivers (Cox 2013) installed at these intersections had been used to collect a large number of travel time samples. Figure 10 and 11 (city ring route travel time) typifies the travel time changes following the intersection upgrade. All travel times are weekly average figures (Monday to Friday). Both Figure 10 and 11 suggest a significant travel time reduction during peak hours has been achieved after the intersection upgrade. Note that city ring route traffic needs to pass through both the smaller and the larger roundabouts which require two locations to give way compared to the original roundabout which only required one location to give way.

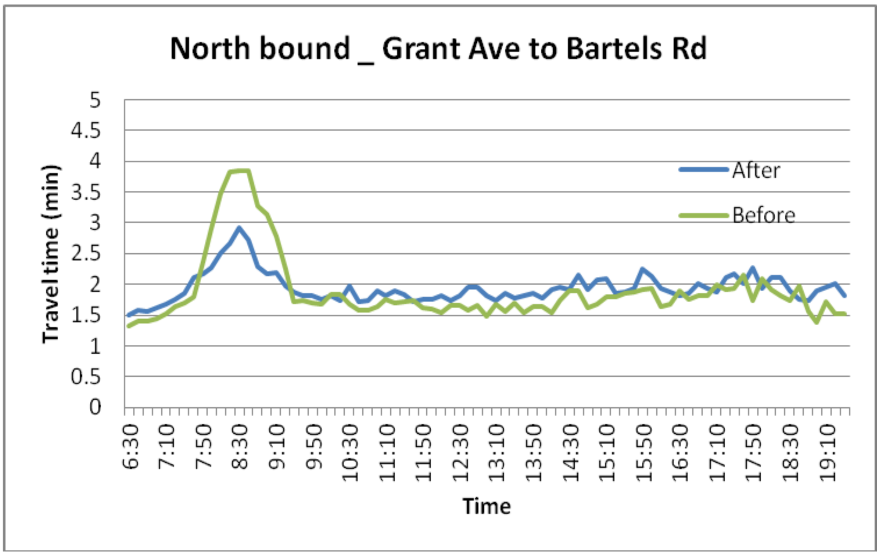


Figure 10. Northbound travel time on city ring route

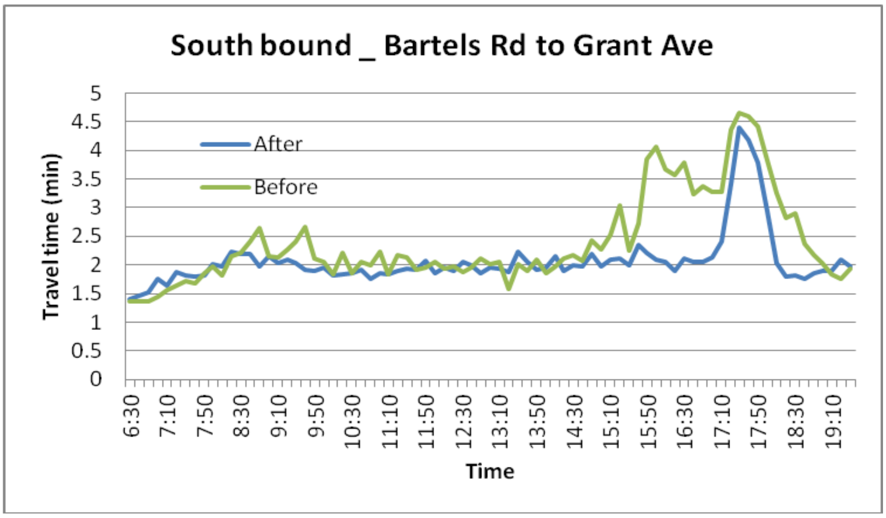


Figure 11. Southbound travel time on city ring route

This has confirmed that the dual roundabout significantly improved the intersection performance. It is worth mentioning that in the fifth week of the dual roundabout operation, there was a further traffic demand increase recorded by the SCATS detectors (i.e. 6% in morning peak and 10 % in afternoon peak). Excitingly, a 20% demand increase actually happened on both the Dequetteville Terrace and Wakefield Road approaches in afternoon peak. These approaches were the worst performance area in afternoon peak before the intersection was upgraded.

7. Conclusion

The Britannia roundabout upgrade project aims to improve safety and keep traffic moving at this strategic intersection of the Adelaide city ring route. Following a thorough crash and traffic analysis and extensive traffic modelling, an innovative dual roundabout solution was developed for the intersection.

The dual roundabout became operational in mid October 2013. Post-implementation traffic and crash analysis suggested the performance of the dual roundabout was promising in terms of both safety and efficiency. It was expected that the dual roundabout design would eventually lead to a significant change of drivers' behaviour and thus be reflected in a reduction in the number and severity of crashes.

The valuable experiences gained from this project include:

- Enabling a simple decisions at each entry point of the roundabout is the key to improving both road safety and traffic efficiency of the roundabout – splitting the complex decision process at the 'tricky triangle' location into two separate singular decision points.

- The low speed environment helps to improve the gap utilisation and facilitate the effective coordination between conflicting movements at the roundabout.

- An innovative / flexible roundabout layout and lane configuration in response to local constraints and traffic conditions should be encouraged, should a conventional design be difficult to achieve performance outcomes.

- Traffic modelling is essential in assessing existing traffic performance, identifying operation issues and testing different ideas in the very early stage of concept development, especially when dealing with complex give-way situations. Engaging in traffic modelling prior to geometric design would allow innovation and flexibility in the thought processes rather than being constrained by design standards.

In general, roundabouts are safe and efficient in managing conflicting traffic movements. There is a great potential for roundabouts to be used on major traffic routes and handle complex traffic issues and larger volumes of traffic.

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