A Literature Review of the Road Safety Performance of Seagull Intersections in Australian and International Evaluations

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Abstract

The aim of this study is to conduct a review of evaluations of seagull intersections, in terms of road safety, undertaken in Australia and worldwide. Strengths of each evaluation and areas for further considerations will be identified. The results of this review will provide Main Roads Western Australia and other responsible agencies with comprehensive information about Australian and international reviews/evaluations of seagull intersections. Such information is essential to assist future decision making regarding the use of the seagull intersections.

Keywords

Road safety; seagull island; seagull intersection; continuous green T-intersection; turbo-T; high-T

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EXECUTIVE SUMMARY

Multiple studies in Australia utilising "*before and after*" designs, found the importance of seagull intersections being correctly designed and implemented (Radalj et al. 2006; Meuleners & Hendrie 2008a; 2008b; Zhang et al. 2014a; 2014b; Harper et al. 2011). Given the benefits of seagull intersections in improving/maintaining smoother traffic flow, Radalj et al. (2006) found that seagull intersections would not increase the frequency of crashes if they were designed and implemented correctly with carefully planned angle and median width. They also suggested that well-designed seagull intersection configuration could have the potential to reduce the number of crashes involving medical treatment. The studies by Meuleners & Hendrie (2008a; 2008b) and Zhang et al. (2014a; 2014b) appeared to support the findings by Radalj et al. (2006), that the later implementations of seagull intersections had reduced the frequency of crashes when compared to earlier implementations. However, the sample sizes were small and the evaluations did not consider the design of the intersection. The findings from the case study by Harper et al. (2011) also agreed with the importance seagull intersections being correctly designed.

The study by Tang & Levett (2009; 2010) had identified a group of drivers that had a higher risk of crashes at their sample of seagull intersections on rural undivided roads in New South Wales with a speed limit of 90 km/h or above and with significant traffic volume, namely male drivers above 67 years of age. Tang & Levett suggested that seagull intersections provided relatively safe positions for drivers to stop before turning, but they did not affect the speeds of through traffic at rural T-intersections.

The New Zealand study by Durdin (2014), however, was not a "*before and after*" study design like most of the studies performed in Australia. Given the limitations of the study, the only clear outcome was that the urban seagull intersections chosen for their study appeared to have good to moderate safety performance, while the rural seagull intersections chosen had a very poor safety performance. However, whether the performance at each of the selected locations was due to the implementation of the seagull intersection instead of the nature of traffic at the location, and whether the performance levels at those locations were the same before treatment, remain unknown.

The seagull intersection is more commonly known as a continuous green T-intersection (CGT) design in the United States. There had been a number of reports on seagull intersections either in terms of traffic flow performance or road safety performance (Boone &

Hummer 1995; Jarem 2004; Reid 2004; Office of Traffic, Safety & Operations 2007; Rice & Znamenacek 2010; Sando et al. 2011; Litsas & Rakha 2012; Bowen et al. 2014).

Rice & Znamenacek (2010) who also utilised a "*before and after*" design similar to the Australian studies, found that the implementation of the CGT version of the seagull intersection was effective in substantially reducing angle, injury and total crashes at their study locations. The other studies in the United States mostly investigated the characteristics of crashes at locations with CGT/seagull intersections, without attempting to isolate the effect on road safety due entirely to the presence/absence of the seagull layout. These studies offered their own recommendations in the potential improvements to the design of seagull intersections, thus also highlighting the importance of the correct design and implementation of seagull intersections.

Based on these findings (Tables i and ii), the authors of this literature review recommends that future analysis into the safety performance of seagull intersections should follow a "*before and after*" design similar to Radalj et al. (2006), but with additional details/characteristics of each study location and each crash included in the analysis like those considered by Tang & Levett (2009; 2010) and Sando et al. (2011) if available. Data on traffic volume similar to those used by Durdin (2014) should also be utilised if available. As Radalj et al. (2006) had demonstrated the importance of design specifications of seagull intersections such as angle and median width, this literature review also recommends that the design specifications should be considered as factors in any future analysis or modelling.

Table i Road Safety Performance of Seagull Intersections from Australian Literature

Study		Sample/Location	"Before and After" Experimental Design?	Results
Western Australia	Radalj et al. 2006	76 sites in Perth metro area.	Yes.	Badly designed seagull intersections would result in more crashes and higher severity. Well-designed seagull intersections could potentially result reduce casualty crashes. Angles and median width were important factors.
	Meuleners & Hendrie 2008a	18 sites in WA.	Yes.	WA seagull intersections installed in 2000-2002 increased all reported crashes by 14% but did not affect casualty crashes.
	Meuleners & Hendrie 2008b	12 sites in WA.	Yes.	WA seagull intersections installed in 2003-2004 reduced all reported crashes by 16% but did not affect casualty crashes.
	Zhang et al. 2014a	3 sites in WA.	Yes.	WA seagull intersections installed in 2007-2008 reduced all reported crashes by 24% but did not affect casualty crashes.
	Zhang et al. 2014b	2 sites in WA.	Yes.	WA seagull intersections installed in 2009-2010 did not affect all reported crashes nor casualty crashes, possibly due to small smaple size.
New South Wales	Tang & Levett 2009; 2010	23 sites in rural NSW.	No, only crashes after installation of seagull intersections were considered.	Older male drivers at or above 67 years of age had a higher risk of crashes at the study locations.
	Harper et al. 2011	Case study on 1 site in NSW.	Yes.	Revision of the seagull intersection with a better design at the study location could reduce all reported crashes and casualty crashes.

Table ii Road Safety Performance of Seagull Intersections from International Literature

Study		Sample/Location	"Before and After" Experimental Design?	Results
New Zealand	Durdin 2014	16 urban sites and 17 rural sites in NZ.	No, only crashes after installation of seagull intersections were considered.	Seagull intersections appeared to have good to moderate safety performance in urban areas but poor safety performance in rural areas at the study locations. All "high-risk" intersections were located in high-speed rural environments with speed limit of 80 km/h or above.
United States (U.S.)	Boone & Hummer 1995	Study did not consider any road safety aspect.		
	Jarem 2004	5 sites in Orlando, Florida.	Unknown.	Crashes that were considered to be directly related to design of seagull intersection ranged from 8% to 24% out of all crashes at each of the sites studied.
	Reid 2004	No substantial evaluation was conducted.		Only anecdotal results were provided.
	Office of Traffic, Safety & Operations 2007	No substantial evaluation was conducted.		Only anecdotal results were provided.
	Rice & Znamenacek 2010	Case study on 2 sites in Colorado.	Yes.	Seagull intersections cumulatively reduced angle crashes at the treated intersections by 97%, injury crashes by 70% and total crashes by 60%. Seagull intersections were effective in substantially reducing angle, injury and total crashes at the sites studied.
	Sando et al. 2011	9 sites in Florida.	No, only crashes after installation of seagull intersections were considered.	3 common types of crashes at seagull intersections were identified. There was a significant difference between proportions of sideswipe crashes in the CGTL direction compared with opposite direction, but no significant difference between proportions of rear-end and right-angle crashes for the two directions. Right-angle crashes and lane changing crashes associated significantly with injury severity, with level of injury higher for these crashes compared with rear-end crashes. Crashes that took place from 6 am to 6 pm were associated with lower injury severity. Drivers above 65 years of age had higher injury levels.
	Litsas & Rakha 2012	Computer simulation that did not directly consider any road safety aspect.		
	Bowen et al. 2014	No substantial evaluation was conducted.		

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1. INTRODUCTION

1.1 Seagull Islands/Seagull Intersections

A seagull island is defined as "*a triangular island used to separate right turning traffic from through traffic in the same carriageway*" (Austroads 2005). A T-intersection/T-junction which utilises a seagull island (Figure 1.1) is known as a seagull intersection (Harper et al. 2011). For the remainder of this report, the mention of any seagull intersection shall refer to both the seagull island and the intersection.

In other countries such as the United States, this type of intersection is also known as a continuous green T-intersection, T-intersection utilising continuous green through lanes (CGTLs), turbo-T intersection, or high-T intersection (Jarem 2004; Reid 2004; Federal Highway Administration 2010).

Figure 1.1 An Example of Seagull Intersection in Western Australia (Radalj et al. 2006)

The seagull layout is a common "at-grade" treatment for three legged T-intersections and is usually used on high traffic volume roads and dual carriageways (Tang &

Levett 2009). There are many seagull intersection layouts across the road network. They exist with many variations in design layout, road geometry and site conditions (Harper et al. 2011).

Seagull islands/intersections are a form of traffic control device (Radalj et al. 2006; Austroads 2005) that is used to:

- channelize traffic into appropriate paths through intersections
- prevent or discourage inappropriate traffic movement
- stage pedestrians and cyclists crossing of roads
- separate potentially conflicting movements
- warn of traffic islands and the presence of an intersection
- accommodate traffic signs and signals in a conspicuous place

Seagull islands/intersections are named due to the two right-turn lanes (or the two left-turn lanes in countries driving on the right) looking similar to the wings of a seagull when viewed from the sky (Figure 1.2). Such intersections usually allow both directions of traffic on a through road to flow with minimal interruptions. Those travelling on the through road and wishing to turn right into the side road at the intersection simply bear right into a separate lane (usually a channelized right-turn filter lane acting as a deceleration lane), which forms one "wing" of the seagull. Here, they meet the opposite carriageway then the side road. Traffic wishing to turn right out of the side road and into the through road, simply cross the intersecting carriageway and drive up the other "wing" of the seagull, and merge onto the other carriageway. This second "wing" can be implemented with or without the assistance of a protected filter lane (as an acceleration lane) that merges with the flow of the through road which is more common in some countries.

Seagull intersections may have a second smaller seagull formed by two left-turning lanes into and out of the side road (or two right-turning lanes in countries driving on the right). The left-turn from the through road into the side road forms one "wing" of the smaller seagull, and a left-turn filter lane is usually implemented. The left turn from the side road into the through road forms the other "wing", but another left-turn filter lane might only be implemented if a significant traffic flow is expected from the side road.

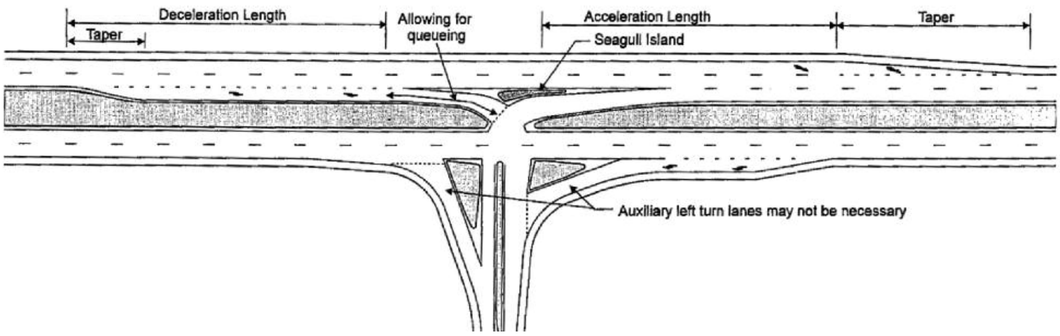

Figure 1.2 A Typical Design of Seagull Intersection (Tang & Levett 2009; 2010)

The advantage of this design type over a more traditional T-intersection design is that delay(s) through the intersection can be reduced – with the flow of traffic on the main road being maintained (straight both ways as well as into the side road), even at the most basic implantation. The flow of traffic out of the side road can also be smoothened with the addition of filter lanes. For example, a left-turn filter lane from the side road into the main road and another filter lane that merges with the main road traffic after right-turn from the side road.

In theory, by reducing delay through the intersection, vehicles use less fuel on average passing through the intersection, thus emissions are reduced across the intersection. The emission savings per vehicle may not seem very significant, but when scaled to account for all vehicles passing through the intersection, the total savings can be significant. There are also potential economic and social benefits from reducing delay time and smoother traffic flow through the intersection (Litsas 2002).

In terms of road safety, one advantage of the seagull layout is the separation of conflicting vehicle paths. Motorists turning right from the stem of the T-junction only need to worry about traffic from one direction at any time (Tang & Levett 2009). Therefore, the aims of installing seagull intersections has often been to reduce certain type of crashes, especially right angle crashes (Radalj et al. 2006) which in some cases were contributed to by substandard sight distance (Rice & Znamenacek 2010). The seagull layout provided opportunities for stepwise vehicle when attempting to make right turns movements by utilising median spaces between the carriageways and in doing so reducing the likelihood of right or indirect right angle crashes (Radalj et al. 2006).

The seagull intersection is a common road treatment in Western Australia (WA) as well as in other states such as New South Wales (NSW). Radalj et al. (2006) identified 89 seagull intersections constructed between the beginning of 1999 and the end of 2005 in the Perth metropolitan road network. In NSW, Tang & Levett (2009) utilised a sample of 23 seagull intersections with significant traffic volumes and located within high speed rural sections found on 15 state highways.

Seagull intersections are also popular in New Zealand (NZ), another country driving on the left side of the road. A NZ study was conducted utilising 33 priority controlled intersections with seagull intersection markings (both urban and rural speed environments) (Durdin 2014).

In the United States (U.S.), a country driving on the right, the state of Florida appears to utilise the seagull layout the most, with several Florida Department of Transportation districts reporting long-term experience with the layout without significant accident problems (Reid 2004; Office of Traffic, Safety & Operations 2007). Other states known to have implemented the layout include: North Carolina, South Carolina, Maryland, Virginia and Michigan (Office of Traffic, Safety & Operations 2007; Hughes et al. 2010). Figure 1.3 shows an example of a seagull intersection in Virginia.

Figure 1.3 A Seagull Intersection in Arlington, Virginia (Federal Highway Administration 2010)

Sando et al. (2011) commented that escalating traffic demands on urban roadways had caused traffic engineers to use various measures to reduce congestion, especially at signalised intersections. Transportation agencies in different U.S. states were using unconventional measures where conventional measures had been exhausted. The installation of the seagull layout in parts of Florida was considered to be an unconventional low cost design strategy, with the intention to reduce increasing demand for longer green times for through movement at intersections with considerably higher through volumes. Installation of the seagull layout was less costly than intersection widening alternatives, hence in most cases they provided a cost effective solution for handling high through traffic at T-intersections. Sando et al. (2011) further commented that although the seagull layout had been used for more than three decades in Florida and their operational benefits were evident, they were still considered a relatively new design alternative by many agencies in the United States. Figure 1.4 shows more examples of seagull intersection designs used in some parts of the United States.

Figure 1.4 Channelized (Merge-control) and Non-channelized (Lane-control) Seagull Intersections used in some parts of the United States (Office of Traffic, Safety & Operations 2007)

In terms of the road safety, an U.S. safety report published by the Federal Highway Administration (Rice & Znamenacek 2010) stated that angle crashes were among the most severe crashes that occurred in intersections including T-intersections, and in some cases the problem could have been contributed to by substandard sight distance. To counter the problem, several aforementioned states including Colorado, Florida, Maryland, North Carolina, and South Carolina had converted from fully-signalised to continuous green T-intersections. This was done with the intention of reducing angle crashes due to left-turning traffic on the stem turning in front of the through movement on the top of the “T”.

The implementations of seagull intersections in Florida typically utilise continuous green through lanes (CGTLs) to allow main line through traffic with no conflicting vehicular movements to the right to pass through a signalised intersection without stopping (the top side of the “T”). CGTLs are installed in the outside lane on the flat side of the "T" and are usually controlled via single section green arrow indications (Jarem 2004). In some states, the through movement to the main line approach to the intersection is also denoted by pavement markings or other lane delineation devices so left-turning-turning traffic stays in its respective lane. For instance, the Colorado Department of Transportation implemented advance warning signs to inform drivers of the special lane configuration (Rice & Znamenacek 2010). The seagull layout is more commonly known as a continuous green T-intersection (CGT-intersection) in Florida, or a turbo-T intersection in south Florida (Reid 2004). It is also known as a High-T intersection in Nevada and Utah (http://www.udot.utah.gov; http://www.nevadadot.com), or simply as Florida T-intersection in other states (Bowen et al. 2014).

The seagull design implemented in Florida (and also other states), the continuous green T-intersection (CGT intersection), can be enhanced by using free-flow turn and acceleration lanes for right turn movements so that only three approach movements require signal control (Reid 2004; Office of Traffic, Safety & Operations 2007). There also exist design variations on how the CGT-intersection allows one free-flow through-movement (Reid 2004). Different methods are used to control traffic where two turning movements and the through movement meet: most intersections use traffic lights, while others use Give Way and Stop signs, and sometimes roundabouts (Tang & Levett 2009).

Seagull intersections have varying safety records and have been the object of much discussion about their operational safety (Harper et al. 2011). The aim of this research is to review the national and international literature on seagull intersections and their performance/effectiveness in terms of road safety.

1.2 Aim

The aim of this study is to conduct a review of evaluations of seagull intersections, in terms of road safety, undertaken in Australia and worldwide. Strengths of each evaluation and areas for further considerations will be identified.

1.3 Significance

The results of this review will provide Main Roads Western Australia (MRWA) and other responsible road safety agencies with comprehensive information about Australian and international reviews/evaluations of seagull intersections. Such information is essential to assist future decision making regarding the use of the seagull intersections.

2. METHODS

A comprehensive review of national and international literature was undertaken using databases including Medline/PubMed, ScienceDirect and Google Scholar without restriction of publication year. Keywords used in the search included "*seagull*" in combination with "*island*", "*intersection*", "*junction*", "*continuous green*", "*turbo T*", or "*high T*". Publication reference lists were also scanned for relevant articles. In addition, each Australian State road authority's website was searched for information as well as the websites of various Transport Authorities in other countries including those in North America, Europe and New Zealand.

3. LITERATURE REVIEW OF SEAGULL INTERSECTIONS

3.1 National Review

3.1.1 Western Australia

In Western Australia, Radalj et al. (2006) conducted a study on the effectiveness of seagull intersections in terms of crash reduction. The study was conducted on 76 seagull intersections between 1999 and 2005, in the Perth metropolitan area.

Radalj et al. (2006) utilised a "*before and after*" experimental study. For each seagull intersection, they investigated the total number of crashes before the construction and the total number of crashes after the construction; the nature of crashes as well as the severity of crashes. The effects of the design of seagull intersection with respect to the angles and median widths were also examined with respect to each of the above areas.

Radalj et al. (2006) utilised observation periods of equal time lengths of up to 3 years before and after the construction of the intersection between 1st January 1995 and 31st December 2005.

The study by Radalj et al. (2006) utilised formal statistical techniques and procedures such as log-linear and Poisson regression analyses, and was able to draw statistical inference on the population from the sample. Their "*before and after*" analysis also calculated p-values for each hypothesis on the population. Therefore, the results from this study could also reflect seagull intersections from locations outside of WA that had similar demographics, infrastructure and traffic etc.

One acknowledged limitation of the study was the unavailability of data on traffic volume at each of the intersections, so the authors could only assume that the average three-year change in traffic volume between the periods "before" and "after" had not significantly changed to affect the number of crashes in the "after" period. Otherwise, the study by Radalj et al. was comprehensive, and the results from the study can be considered reliable if the assumption was true.

Radalj et al. (2006) found that the median width did not significantly affect the number or severity of crashes. On the other hand, the nonstandard angle seagull intersections appeared to be associated with a change in the type and severity of crashes occurring at the treated intersections. Their finding suggested that the angle could be the most important factor in the design and installation of the seagull intersections.

Comparison of safety indices before and after installation of the seagull intersections at the sample of locations by Radalj et al. (2006) suggested that the installation of these types of treatments did not significantly improve traffic safety at the intersections, neither in terms of reduced number of crashes nor severity of the crashes, apart from an estimated 9.7% reduction in the number of casualty crashes for seagull intersections constructed according to construction guidelines recommended by MRWA. However, their analysis of crashes by type of the design with respect to angle size and the median width suggested that incorrectly designed seagull intersections not conforming to a recommended angle size of between 55° and 70° or a recommended median width of between 6 and 9 metres could result in worse traffic safety such that the number of crashes could increase together with the severity of the crashes. Improperly installed seagull intersections could result in deteriorated rather than increased traffic safety at the intersection. However, apart from negative effects of the substandard designs of the seagull intersections, the study did not demonstrate substantial benefits (in terms of road safety only) arising from well-designed seagull intersections either.

Radalj et al. (2006) concluded that badly designed seagull intersections were very likely to result in an increased number of crashes and increased severity of the crashes. They suggested that well-designed seagull intersection configuration could potentially result in a reduced number of crashes involving medical treatment in the best possible scenario, but a confirmation was only possible with further research.

Based on their findings, Radalj et al. (2006) implied that seagull intersection installations could be continued as a treatment in smoothing traffic flow as they caused no harm to the traffic safety, but recommended that the installations should be avoided as a type of treatment targeting traffic safety as they did not appear to significantly reduce certain types and severity of crashes. If the installation of seagull intersections was to be chosen as a treatment at a particular intersection then such installation should fully comply with the recommended installation guidelines.

Other researchers from Western Australia also investigated potential crash reductions due to the installations of seagull intersections, but as part of a bigger evaluation of the effectiveness of the State Blackspot Programs in Western Australia implemented in different periods between 2000 and 2010 (Meuleners & Hendrie 2008a; 2008b; Zhang et al. 2014a; 2014b). Utilising a "*before and after*" experimental design and GEE Poisson modelling with a sample of 18 seagull intersections, Meuleners & Hendrie (2008a) found that seagull intersections implemented in the 2000-2002 program increased the frequency of all reported crashes by an estimated 14% (p-value = 0.001) but did not significantly affect casualty crashes (p-value = 0.365) during the study period.

However, Meuleners & Hendrie (2008b) then found that a different sample of 12 seagull intersections implemented in the 2003-2004 program actually reduced all reported crashes by an estimated 16% (p-value = 0.001) but again without affecting the casualty crashes (p-value = 0.162). Using the same methodology, Zhang et al. (2014a) found that a sample of 3 seagull intersections implemented in the 2007-2008 program also reduced all reported crashes by an estimated 24% (p-value < 0.001) without affecting casualty crashes (p-value = 0.119). Zhang et al. (2014b) also found that a sample of 2 seagull intersections implemented in the 2009-2010 program did not affect all reported crashes (p-value = 0.463) nor casualty crashes (p-value = 0.940). The results from the 2007-2008 and 2009-2010 implementations of seagull intersections, however, should be accepted with caution due to the relatively small sample size.

3.1.2 Other Australian States

There have been very few published studies undertaken on seagull intersections in other Australian states other than Tang & Levett (2009; 2010) and Harper et al. (2011), both from New South Wales.

New South Wales (NSW)

Unlike Radalj et al. (2006) who targeted metropolitan seagull intersections, Tang & Levett (2009; 2010) conducted their study on a sample of 23 seagull intersections on rural undivided roads in NSW with speed limit of 90 km/h or above with a significant traffic volume (indicated by the presence of a tourist sign, directional sign or other destination signage). They extracted crash data between 1996 and 2008 for all their selected sites, and only included crashes that were within the operational period of the seagull intersection in their data analysis. In other words, Tang & Levett did not utilise a "*before and after*" design as their study lacked the "before" component. Their analysis also excluded crash types such as "*off road on straight*", "*off road on curve*" and "*hit animal*", which they considered to be unrelated to the presence of the seagull intersection. The remaining crashes were analysed in terms of crash severity, crash types, behavioural factors, road environment factors and road user factors.

Given the limitations, the study by Tang & Levett (2009; 2010) considered behavioural factors such as involvement of fatigue, alcohol and speeding; road environment factors such as natural lighting and road surface condition; crash types; vehicle type; time of day; age group; and gender. The study identified that older male drivers aged 67 years or older had a higher risk of crashes at the study locations. The authors suggested that the seagull intersection treatment separated out conflict points and thereby reduced the conflict complexity. The seagull treatment provided relatively safe positions for drivers to stop before turning as demonstrated by the relatively few rear end crashes. However, the seagull treatment, like other rural intersection treatment, did not affect the speeds of through traffic.

The analysis performed by Tang & Levett (2009; 2010) was very detailed in terms of crash patterns and crash profiles. However, it only provided a summary at the sample level without making any formal statistical inference on the population. Therefore, the results from this study were specific to and indicative/representative of the study locations only, and could not have been used to infer any hypothesis on other locations. This study also did not take into account any potential change in traffic volume within the study period.

The study by Harper et al. (2011) was a case study on three variations of a seagull intersection layout – a single seagull intersection which was upgraded on two separate occasions since 2004 and 2007, at the junction of the Princes Highway and Island Point Road approximately 20km south of Nowra on the south coast of NSW. It examined the impact that the initial layout (1996) and its two subsequent revisions (2004 and 2007) had on the operational safety of the junction (Figure 3.1).

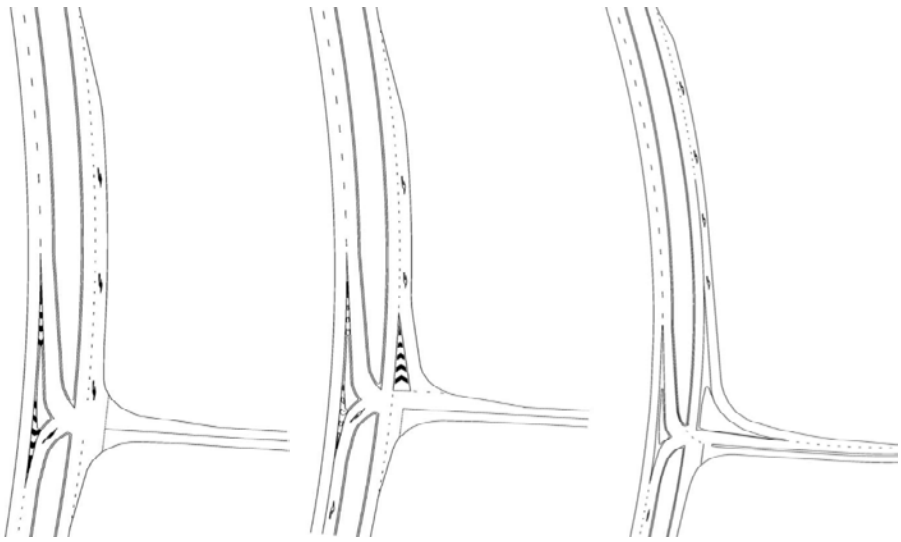

Figure 3.1 Seagull Intersection at the Junction of Princes Highway and Island Point Road (left to right: 1996 installation, 2004 revision, 2007 revision) (Harper et al. 2011)

Harper et al. (2011) conducted the study using the number of crashes at the location from 1st January 2000 to 31st December 2003 to reflect the effectiveness of the initial 1996 construction, the crashes from 1st January 2004 to 31st December 2007 to reflect the effectiveness of the 2004 revision, and the crashes from 1st January 2008 to 31st December 2010 to reflect the 2007 revision. However, unlike Radalj et al. (2006) and Tang & Levett (2009; 2010), Harper et al. appeared to have ignored the construction periods of the treatments, with the choice of crash periods overlapping with the construction periods.

Since this was a case study on one location, the results were representative of the one location only. This study also did not take into account any potential change in traffic volume within the study period.

The study by Harper et al. (2011) considered the impact on non-casualty crashes and casualty crashes associated with the three seagull layouts. The original seagull layout at the study location was designed in accordance with a standard rural seagull design layout. Following the installation of the original treatment crashes of a "*right near*" type started to develop at the site. The 2004 revision was then designed and constructed in an attempt to address the "*right near*" crashes. The 2004 revision involved the inclusion of a short left turn splay which included a small raised concrete island, as well as the installation of a hold line and give way sign at the left turn deceleration lane's junction with the side road. The 2007 revision included two key features. The first was to move the junction of the left turn lane with the side road further away from the through road and to provide a merge of the left turn deceleration lane with the side road. The second was a major widening at the throat of the junction to further separate the left turn deceleration lane from the flow of the main road which significantly opened up available sight distance for vehicles exiting the side road.

Harper et al. (2011) found that there was a significant rise in the crash rate following the construction of the first revision of the seagull treatment in 2004, which continued until the second revision in mid-2007. They suggested that the mid-2007 revision resulted in a significant improvement in crash rate. They found that the majority of the casualty crashes and injuries occurred between the first and second revisions, suggesting that the first revision reduced road safety but the second revision improved road safety. However, the suggestion by Harper et al. could only be true if (1) the traffic volume that was ignored had not changed significantly over the study period, and (2) the overlapping of the construction periods with the crash periods chosen did not significantly affect the number of crashes used in the analysis.

With the limitations aside, the finding by Harper et al. did match the suggestion by Radalj et al, in that the design and implementation of the seagull intersection must conform to a certain standard for it to not have an effect in reducing road safety.

3.2 International Reviews of Seagull Intersections

There have been very few published studies undertaken on the effectiveness of seagull intersections other than the United States and New Zealand.

3.2.1 New Zealand

A recent study by Durdin (2014) was conducted on 33 priority controlled intersections with seagull intersection markings in New Zealand, with 16 of these in urban speed environments and 17 in rural speed environments.

Instead of using counts of crashes obtained from the crash data, Durdin (2014) considered traffic volume and calculated "*collective risk*", "*personal risk*", and "*level of safety service* (LoSS)" as defined by the New Zealand Transport Agency (2013). Such measures are essentially frequency of crashes standardised by traffic volume, and its variations.

However, unlike the previous studies done in Australia, which were "*before and after*" experimental study designs, the study by Durdin (2014) considered only crashes at the intersections after their constructions, in a study period between 2009 and 2013. Thus it is questionable whether the crash figures used by Durdin were entirely due to the designs/implementations of the seagull treatments alone, instead of the nature of the traffic along the roads through those intersections. Without a proper "*before and after*" study design, the effect due to the seagull treatment could not have been correctly identified/isolated.

While the availability and utilisation of traffic volume data was a strength over the previous studies, its meaningfulness was lost because the study did not consider the "*before*" period.

Another limitation of the study is that it only provided a summary at the sample level, without making any formal statistical inference on the population. Therefore, the results from this study: (1) would be questionable regarding any effect(s) suspected of the seagull treatments, and (2) could not have been used to infer any hypothesis on other locations.

With the apparent issues aside, Durdin (2014) concluded that seagull intersections appeared to have good to moderate safety performance in urban areas but a very poor safety performance in rural areas. Durdin (2014) found that all of the intersections that got classified as a "*high-risk*" intersection were located in high-speed rural environments with a speed limit of 80 km/h or above.

3.2.2 United States (U.S.)

Please note that the United States is a country driving on the right, and this section should be read with that in mind.

Earlier in the introduction, it was noted that Harper et al. (2011) identified that there exist many seagull intersection layouts across the road network and that they exist with many variations in design layout, road geometry and site conditions. This is especially true in the United States, with many more variations and implementation types across different states.

While it was not the earliest study, Litsas & Rakha (2012) classified the implementations of the seagull intersection popular in the United States (i.e. the continuous green T-intersection (CGT)) into two main design types: traditional version and merging version. In such a classification, the traditional CGT requires some lanes in the continuous direction on the through road to be signalised while others can freely pass the intersection. Vehicles within these signalised lanes stop and allow left-turners form the side road to enter lanes directly when turning onto the main thoroughfare, whereas the other lanes in the same direction not needed to intercept left-turners are allowed to continually bypass the intersection. The merging CGT, on the other hand, allows all lanes in the continuous direction to bypass the signal, with left turners from the side street being required to merge onto the main-thoroughfare, in the same fashion that a vehicle would merge onto a highway. Litsas & Rakha suggested that the merging CGT provides similar benefits as the traditional CGT, yet reduces driver confusion and improves safety.

There have been a number of reports/papers done by academia, government, and the private sector from the United States on the traditional CGT and merging CGT design types in the United States (Boone & Hummer 1995; Jarem 2004; Reid 2004; Office of Traffic, Safety & Operations 2007; Rice & Znamenacek 2010; Sando et al. 2011; Litsas & Rakha 2012; Bowen et al. 2014).

Boone & Hummer (1995) first modelled many intersection designs, thoroughly comparing them in terms of intersection delay, with the traditional CGT design being one of the intersections studied. However, the report only investigated possible gains in travel efficiency and compared in terms of delay time, not in terms of the road safety aspect.

While the study by Jarem (2004) has not been made available publicly, Sando (2011) and Litsas & Rakha (2012) commented that the study by Jarem compared the features and evaluated the safety and cost-and-benefit ratios of five traditional CGT designs in Orlando, Florida. Jarem (2004) found crashes that were considered to be directly related to the traditional CGT design ranged from 8% to 24%, out of all the crashes at each of the five intersections investigated. Litsas & Rakha (2012) commented that the study by Jarem (2004) was a well-developed case-study, but the five intersections evaluated provided a limited evaluation of their effectiveness in reducing crashes.

Reid (2004) performed a review on the traditional CGT design, but mainly on the evolution of design, a description of its operations, design and operational considerations etc., without any substantial evaluation of the safety aspect of seagull intersections. Reid's review, however, did suggest that the driveways along the continuous green through-lane(s) posed two potential problems. First, through-drivers in the continuous green lanes may not expect to slow for anything in those lanes, even a right-turning vehicle. Second, drivers turning left onto the through road from the side road may try to merge into the continuous green through-lane or pass through the lane separation to get to a driveway. Reid (2004) suggested that under the lane-control design, motorists may be confused by the lane signal control and/or may attempt last-minute lane changes to avoid the signal control. Reid then suggested that the lane separation/channelization should be clearly delineated and identified by proper advance signage. Reid (2004) also referenced an interview with a Division Engineer from the Florida Department of Transportation conducted in 2002 and suggested that at typical intersections on four-lane through roads in Florida, about 77% of drivers chose the continuous green lane, while on six-lane through roads about 81% of drivers chose one of the two continuous green lanes.

Reid (2004) further suggested that the separation between the signal-controlled lane and the continuous green through-lane(s) could be narrow and should not present a hazardous fixed object. Most agencies in the United States helped identify the separation with raised reflectors or rumble strips. Reid (2004) commented that the Florida Department of Transportation had found stanchions to be problematic for maintenance. Reid (2004) also suggested that agencies could use more than one continuous green through-lane, but dual left-turn lanes from the side road required signal-controlled through-lanes on top of the T and could potentially put great pressure on the remaining continuous green through lane(s).

In a 2007 report, the Minnesota Department of Transportation (MDOT) suggested that the CGT design had a fairly restricted application niche (Office of Traffic, Safety & Operations 2007) and engineers should only consider the CGT design at T-intersections that have moderate to low left-turn volumes from the side road, high through-volumes, and where there were few pedestrian crossings and no driveways along the through road opposite the side road. The MDOT (2007) suggested that advantages of the CGT design over a conventional multiphase signalised T-intersection design used in Minnesota and other states included significantly reduced intersection delay, narrower right-of-way requirements and free-flow movements for one direction of travel on the through road. However, disadvantages included lack of a protected (signalised) pedestrian crossing of the through road, increased merging or weaving maneuvers, and restricted access to parcels adjacent to the through-lanes.

Rice & Znamenacek (2010) published a Federal Highway Administration Safety Report of a case study of two traditional CGT designs. The report stated that angle crashes in general were among the most severe crashes that occurred in intersections including T-intersections, and in some cases the problem could have been worsened by substandard sight distance. To counter the problem, several states including Colorado, Florida, Maryland, North Carolina, and South Carolina converted from fully-signalised to continuous green T-intersections, with the intention to reduce angle crashes due to left-turning traffic on the stem, turning in front of the through movement on the top of the "T" at the T-intersection.

The case study by Rice & Znamenacek (2010) examined two rural T-intersections in Colorado (US-50 & SH 141, Grand Junction, CO; US-160 & US-550, Durango, CO). Both sites experienced a high incidence of crashes within a 24 month period before treatment (16 and 19 at the Grand Junction and Durango site, respectively), particularly angle crashes (100% and 79% of all crashes at the two sites) and many with injuries (75% and 42%), due to limited stopping sight distance. For each of these two T-intersections, the signal-controlled through lane on the flat side (top) of the T-intersection was converted to a CGT by the Colorado Department of Transportation to reduce the number of angle crashes, while also improving the efficiency of the intersection (Figures 3.2 and 3.3). The objective of the case study was to evaluate their safety improvements over the previous standard intersection control.

Figure 3.2 Aerial review of the CGT in Grand Junction, Colorado used in the case study by Rice & Znamenacek (2010)

Figure 3.3 CGT in Durango, Colorado used in the case study by Rice & Znamenacek (2010)

Crash reductions were based on a review of "*before and after*" crash data which occurred during the period between 1994 and 2006. At both intersections, 24 months were utilised as the "before" observation period and another 24 months were utilised as the "after" observation period.

Similar to Harper et al. (2011), the study by Rice & Znamenacek (2010) was a case study on two locations only, so the results were representative of the two locations only and could not have been used to infer any hypothesis on other locations in a general context. This study also did not appear to have taken into account any potential change in traffic volume within the study period.

For the first intersection (US-50 and SH 141, Grand Junction, CO), Rice & Znamenacek (2010) found that angle crashes decreased from 16 to 0 (a 100% reduction per year) after the conversion of the intersection to a CGT while injury crashes decreased from 12 to 2 (an 83.3% reduction per year) and total crashes decreased from 16 to 7 (a 56.3% reduction per year).

For the second intersection (US-160 and US-550, Durango, CO), Rice & Znamenacek (2010) found that angle crashes decreased from 15 (including 1 fatality) to 1 (an average crash reduction of 93.3% per year) after the CGT conversion while injury crashes decreased from 8 to 4 (an average crash reduction of

50% per year); and total crashes decreased from 19 to 7 (an average crash reduction of 63.2% per year).

Overall, Rice & Znamenacek (2010) found that implementation of the CGT cumulatively reduced angle crashes at the treated intersections by 96.8%, injury crashes by 70%, and total crashes by 60%, and concluded that the CGTs were effective in substantially reducing angle, injury and total crashes at these intersections.

A study by Sando et al. (2011) performed an evaluation of the effectiveness of the traditional CGT design in Flordia. Sando et al. (2011) commented that although the traditional CGT design had been used for more than three decades in Florida and their operational benefits were evident, they were still considered a relatively new design alternative which many agencies were reluctant to approve. Sando et al. (2011) commented that citizens felt they were unsafe, especially for motorists unfamiliar with their design, and there had been mixed reviews of the suitability and effectiveness of CGTL intersections in Jacksonville, Florida. This had led to their removal from several locations while new ones continued to be installed in other locations.

Sando et al. (2011) conducted their own study on all CGTLs in Jacksonville with the purpose of quantifying the effects of site characteristics on the safety of CGTL intersections. Their study examined safety characteristics of traditional CGT design using paired-t test and ordered probit (OP) statistical models. Sando et al. considered all crashes that occurred at all CGTL intersections in the city of Jacksonville between 2003 and 2008. During the study period, the city of Jacksonville had a total of 17 known CGTL intersections, but eight of them had been converted to traditional intersection configurations or had had major maintenance or construction work done sometime within the study period and hence were excluded. Several data sources were used to examine differences in site characteristics between the nine remaining intersections. These together with field visits were used to collect data on intersection characteristics such as configurations, land use proximity and location of driveways, signs and pavement markings, and number of continuous green through lanes. Categorical values were used to describe the differences in the basic site characteristics, such as the presence/absence of driveways in the vicinity of the intersection, the number of continuous green through lanes, the choice of method (from a selection of 3 alternatives) used to separate continuous green traffic from other movements. Some of these site characteristics were unique to the driving environment in the United States. However, Sando et al. did not consider characteristics such as the median width or angle of the layout like Radalj et al. (2006) did.

Sando et al. (2011) extracted crash data from the Florida Department of Transportation database for the 398 crashes that occurred within 250 feet of the remaining nine CGTL intersections from 2003 to 2008. The data categorised the degree of injury severity as four different levels, as well as traffic and environmental conditions at the time of the crash, driver age, number of vehicles involved in the accident, and time of day. The 398 crashes were further screened by examining crash diagrams to remove those that were not intersection related.

The study by Sando et al. (2011) involved: (1) an examination of crash patterns at CGTLs, (2) a comparison of crash patterns on CGTL to determine whether there was any underrepresentation or overrepresentation of certain crash patterns, and (3) a modelling of injury severity.

The direct question of whether the presence/absence of a CGT increased or reduced road safety was clearly not the objective of the study by Sando et al. (2011). Rather, Sando et al. appeared to have skipped this direct question and only focussed on analysing the characteristics of crashes at the study locations.

In analysing crash patterns, Sando et al. (2011) classified the crashes that occurred at their study locations into 11 distinct patterns (Figure 3.4). Based on their proportions analysis, Sando et al. found three common types of crashes that involved CGTL traffic: (1) sideswipe crashes caused by motorists weaving from adjacent through lanes to avoid having to stop for the red signal indication, (2) angle crashes caused by motorists turning left from a side road and swerving into the CGTL by disregarding the “do not change lane” barriers such as double white lines and rounded domes, and (3) rear-end crashes caused by motorists who unexpectedly stop in the CGTL. The results of the analysis showed that on average the proportion of sideswipe crashes in the CGTL was 6.01% (involving lane changing in the CGTL direction) compared with 1.78% in the opposite direction (the direction which had traditional through lanes). Also, on average, 4.68% of all crashes were right angle collisions on the CGTL caused by left-turning vehicles from the minor direction veering into the CGTLs. Typically, such type of crash was caused by inattentive drivers or motorists who were not familiar with the presence of CGTL and disregarded the lane separation markers. Sando et al. (2011) also noted that on average there were more rear-end crashes on continuous green through lanes (14.25%) compared with normal lanes (9.35%).

In the comparison of CGTL crash patterns which employed a paired t-test, Sando et al. (2011) found that there was a significant difference between the proportions of sideswipe crashes in the CGTL direction compared with the opposite direction. On the other hand, the results from their paired-t test did not suggest a significant difference between the proportions of rear-end and right-angle crashes for the CGTL and normal directions.

In terms of injury severity at CGTL intersection crashes, Sando et al. (2011) developed two injury severity models: the first estimated the relationship between injury severity with different crash conflict patterns, while the second estimated the relationship between injury severity and intersection characteristics, environment conditions, and traffic characteristics. The results of the first analysis indicated that right-angle crashes and lane changing crashes associated significantly with injury severity at CGTL intersections, with the two crash types carrying high significance in an ordered probit model built by Sando et al. (p-value = 0.036 and 0.046, respectively). The level of injury was higher for right-angle crashes and lane changing crashes compared with rear-end crashes. From their second model, Sando et al. (2011) found that crashes that took place during the time period of 6 am to 6 pm were associated with lower injury severity. They also found that drivers 65 years or older had higher injury levels.

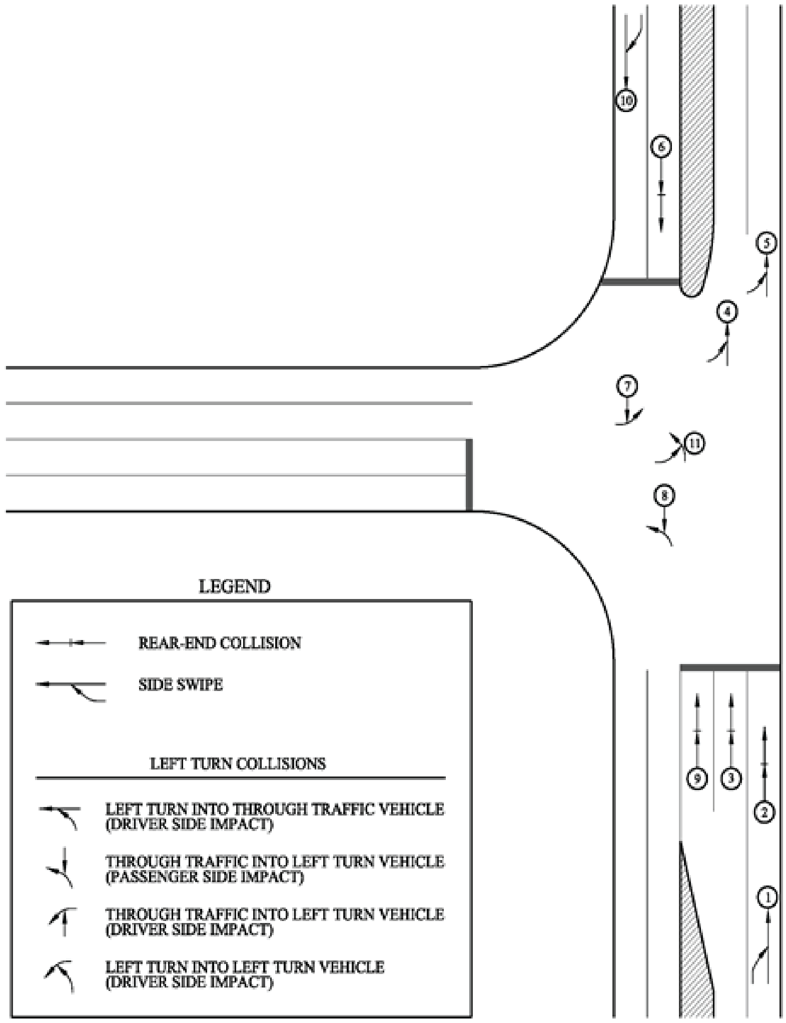

Figure 3.4 CGTL Intersection Crash Patterns Considered by Sando et al. (2011)

Based on their findings, Sando et al. (2011) recommended that design features such as advance warning signs and highly visible raised separators could improve the safety of CGTL intersections. They felt that advance warning signs could provide guidance to motorists as to the purpose of the continuous through lanes and lane use instructions, and would be particularly helpful to non-commuters who were not familiar with continuous green through lanes. On the other hand, providing highly visible raised separators in lieu of double white lines and raised rounded domes, could create a distinct separation between the continuous through traffic and the adjacent lanes. This separation could prevent lane changing caused by motorists crossing the double white lines.

After considering the aforementioned literature from the United States, which were mostly of the traditional CGT design, Litsas & Rakha (2012) conducted their own study, analysing the merging version of the CGT, an alternative intersection design/control that allows certain lanes along the through road to bypass three-way intersections, with side road traffic merging on the through road. Litsas & Rakha suggested that the merging CGT design provides similar benefits the traditional CGT design, yet reduces driver confusion and improves safety.

The study conducted by Litsas & Rakha (2011) was a computer simulation of scenarios, instead of a more traditional observational study or quasi-experimental design. Litsas & Rakha developed a comprehensive model encompassing 2,445 unique intersection condition combinations, comparing the merging CGT design to the standard three-way signalised intersection (Figure 3.5). The study modelled and analysed the performance of the merging CGT design in terms of total delay in time, fuel consumptions, various emissions, and economic analysis, and found significant benefits from the merging CGT design. However, the model did not directly consider social impacts such as road safety, only suggesting that the implementation of the merging CGT design over the traditional CGT design should eliminate most sideswipe conflicts, except the ones created from the merging lane.

The most recently available U.S. report on the seagull/CGT layout was Bowen et al. (2014). It, however, provided only a technical brief/summary of the continuous green T-intersection, and was not a research that provided any new finding.

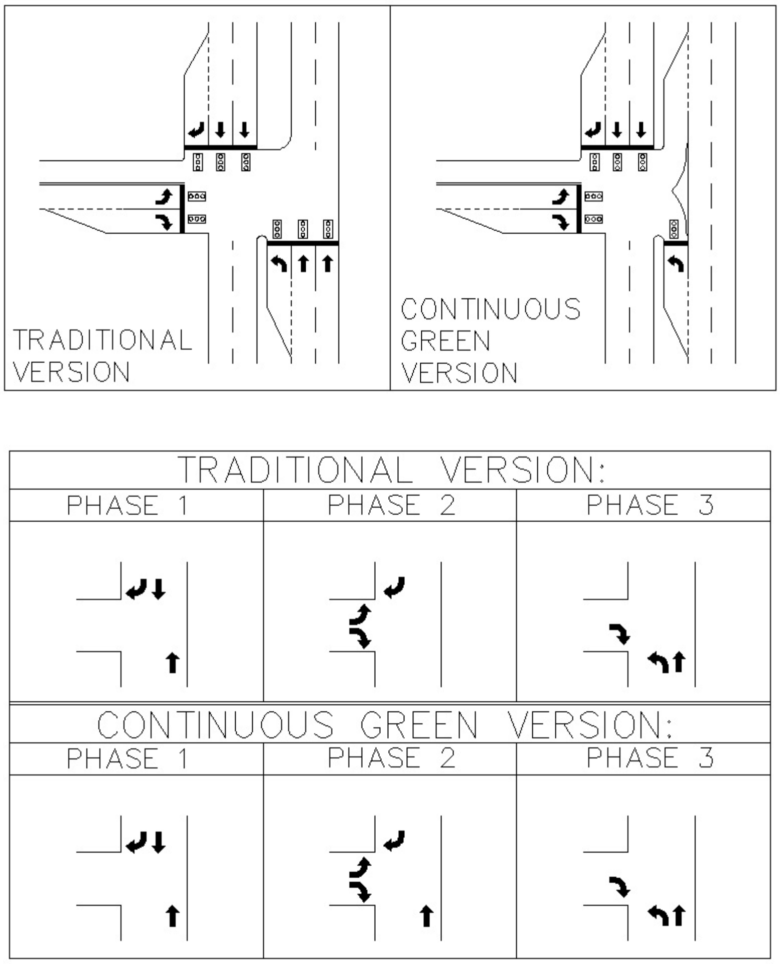

Figure 3.5 A Comparison of the Merging CGT Design with a Standard Three-way Signalised Intersection (Litsas & Rakha 2011)

4. CONCLUSIONS AND RECOMMENDATIONS

A summary of the results on the road safety performance of seagull intersections from Australian literature is presented in Table 4.1, while a summary of the results from international literature is presented in Table 4.2.

Table 4.1 Road Safety Performance of Seagull Intersections from Australian Literature

Study		Sample/Location	"Before and After" Experimental Design?	Results
Western Australia	Radalj et al. 2006	76 sites in Perth metro area.	Yes.	Badly designed seagull intersections would result in more crashes and higher severity. Well-designed seagull intersections could potentially result reduce casualty crashes. Angles and median width were important factors.
	Meuleners & Hendrie 2008a	18 sites in WA.	Yes.	WA seagull intersections installed in 2000-2002 increased all reported crashes by 14% but did not affect casualty crashes.
	Meuleners & Hendrie 2008b	12 sites in WA.	Yes.	WA seagull intersections installed in 2003-2004 reduced all reported crashes by 16% but did not affect casualty crashes.
	Zhang et al. 2014a	3 sites in WA.	Yes.	WA seagull intersections installed in 2007-2008 reduced all reported crashes by 24% but did not affect casualty crashes.
	Zhang et al. 2014b	2 sites in WA.	Yes.	WA seagull intersections installed in 2009-2010 did not affect all reported crashes nor casualty crashes, possibly due to small smaple size.
New South Wales	Tang & Levett 2009; 2010	23 sites in rural NSW.	No, only crashes after installation of seagull intersections were considered.	Older male drivers at or above 67 years of age had a higher risk of crashes at the study locations.
	Harper et al. 2011	Case study on 1 site in NSW.	Yes.	Revision of the seagull intersection with a better design at the study location could reduce all reported crashes and casualty crashes.

Table 4.2 Road Safety Performance of Seagull Intersections from International Literature

Study		Sample/Location	"Before and After" Experimental Design?	Results
New Zealand	Durdin 2014	16 urban sites and 17 rural sites in NZ.	No, only crashes after installation of seagull intersections were considered.	Seagull intersections appeared to have good to moderate safety performance in urban areas but poor safety performance in rural areas at the study locations. All "high-risk" intersections were located in high-speed rural environments with speed limit of 80 km/h or above.
United States (U.S.)	Boone & Hummer 1995	Study did not consider any road safety aspect.		
	Jarem 2004	5 sites in Orlando, Florida.	Unknown.	Crashes that were considered to be directly related to design of seagull intersection ranged from 8% to 24% out of all crashes at each of the sites studied.
	Reid 2004	No substantial evaluation was conducted.		Only anecdotal results were provided.
	Office of Traffic, Safety & Operations 2007	No substantial evaluation was conducted.		Only anecdotal results were provided.
	Rice & Znamenacek 2010	Case study on 2 sites in Colorado.	Yes.	Seagull intersections cumulatively reduced angle crashes at the treated intersections by 97%, injury crashes by 70% and total crashes by 60%. Seagull intersections were effective in substantially reducing angle, injury and total crashes at the sites studied.
	Sando et al. 2011	9 sites in Florida.	No, only crashes after installation of seagull intersections were considered.	3 common types of crashes at seagull intersections were identified. There was a significant difference between proportions of sideswipe crashes in the CGTL direction compared with opposite direction, but no significant difference between proportions of rear-end and right-angle crashes for the two directions. Right-angle crashes and lane changing crashes associated significantly with injury severity, with level of injury higher for these crashes compared with rear-end crashes. Crashes that took place from 6 am to 6 pm were associated with lower injury severity. Drivers above 65 years of age had higher injury levels.
	Litsas & Rakha 2012	Computer simulation that did not directly consider any road safety aspect.		
	Bowen et al. 2014	No substantial evaluation was conducted.		

Overall, two Australian studies found that correctly designed and implemented seagull intersections could reduce the frequency of crashes (Radalj et al. 2006;

Harper et al. 2011), while other studies in Western Australia (Meuleners & Hendrie 2008a; 2008b; and Zhang et al. 2014a; 2014b) found that the later implementations of seagull intersections in WA had reduced the frequency of crashes when compared to earlier implementations. However, the sample sizes were small and the evaluations did not consider the design of the intersection.

In the United States, Rice & Znamenacek (2010) who also utilised a "*before and after*" experimental design similar to most of the Australian studies found that the implementation of the CGT version of the seagull intersection was effective in substantially reducing angle, injury and total crashes at their study locations. Other studies in the United States mostly investigated the characteristics of crashes at locations with CGT/seagull intersections, without attempting to isolate the effect on road safety due entirely to the presence/absence of the seagull intersections (Boone & Hummer 1995; Jarem 2004; Reid 2004; Office of Traffic, Safety & Operations 2007; Sando et al. 2011; Litsas & Rakha 2012; Bowen et al. 2014). These studies offered their own recommendations in the potential improvements to the design of seagull intersections, thus also highlighting the importance of the correct design and implementation of seagull intersections.

The New Zealand study by Durdin (2014), however, was not of a "*before and after*" study design like most of the studies performed in Australia. Given the limitations of the study, the only clear outcome was that the urban seagull intersections chosen for their study appeared to have good to moderate safety performance, while the rural seagull intersections chosen had a very poor safety performance. However, whether the performance at each of the selected locations was due to the implementation of the seagull intersection instead of the nature of traffic at the location, and whether the performance levels at those locations were the same before treatment, remain unknown.

Based on these findings, the authors of this literature review recommends that future analysis into the safety performance of seagull intersections should follow a "*before and after*" design similar to Radalj et al. (2006), but with additional details/characteristics of each study location and each crash included in the analysis like those considered by Tang & Levett (2009; 2010) and Sando et al. (2011) if available. Data on traffic volume similar to those used by Durdin (2014) should also be utilised if available. As Radalj et al. (2006) had demonstrated the importance of design specifications of seagull intersections such as angle and median width, this literature review also recommends that the design specifications should be considered as factors in any future analysis or modelling.

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