The DIAMOND Study: Diverging Diamond Interchanges in Western Australia: Performance on a Driving Simulator

CURTIN-MONASH ACCIDENT RESEARCH CENTRE
Faculty of Health Sciences
Curtin University
Hayman Road
Bentley WA 6102

Meuleners L, Roberts P, Chow K, Logan D, Fraser M
December 2016
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Meuleners L, Roberts P, Chow K, Logan D, Fraser M

Curtin-Monash Accident Research Centre (C-MARC)
Faculty of Health Sciences
Curtin University
Hayman Road
BENTLEY WA 6102
Tel: (08) 9266-2304
Fax: (08) 9266-2958
www.c-marc.curtin.edu.au

Neurotrauma Research Program

This study aimed to evaluate driver performance on a Diverging Diamond Interchange (DDI) compared to a traditional intersection, using a driving simulator. A total of 201 drivers aged 18 to 80 years completed a simulator assessment and questionnaires. No wrong-way violations or navigation errors were observed while navigating the DDI. A low number of other driver errors were observed, with red light violations being more common while navigating the DDI than the traditional intersections. Drivers also travelled over the speed limit more in the DDI than the traditional intersection. There was some indication that older drivers aged 60+ may have experienced more difficulty negotiating the DDI. Overall, WA drivers had minimal difficulty negotiating the DDI and they should be considered for use on WA roads.

Intersection safety, diverging diamond interchange, road user behaviour

This report is disseminated in the interest of information exchange. The views expressed here are those of the authors and not necessarily those of Curtin University or Monash University.
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EXECUTIVE SUMMARY

Aim

The aim of the study was to evaluate driver performance while navigating a diverging diamond interchange (DDI) compared to a traditional intersection, using a laboratory-based driving simulator. Specific objectives were to:

1. Assess driving performance and cognitive/physical workload when navigating a DDI compared to a traditional intersection, using a driving simulator.
2. Determine specific groups of drivers at increased risk of a driving error when navigating a DDI, compared to a traditional intersection.
3. Provide recommendations on areas of risk for drivers particularly targeted to high risk groups for the use of a DDI in Western Australia.

Methods

An experimental study using a driving simulator was undertaken. Two hundred and one drivers aged between 18 and 80 years with a current WA C class licence (passenger vehicle) completed the study. Two researcher-administered questionnaires, a driving simulator assessment and the NASA Taskload Index were completed by each participant.

The driving scenario consisted of the DDI interchange with two ‘control’ traditional intersections used for comparison. The control intersections were matched for the same road and traffic conditions as the DDI. Each participant drove through two conditions (East-west and West-east) in a simulated drive of several kilometres during the daytime.

Simulator outcome measures included compliance with speed limits, lane excursions, time spent out of lane and number of crashes/near-misses. A researcher also observed the driver as they negotiated the scenario recording driver errors and where they occurred. These included wrong-way violations, navigation errors, red light violations, observation errors, physical control of the vehicle errors, road law errors and vehicle positioning errors. Qualitative data regarding the difficulty participants had navigating the DDI was also collected.
Descriptive and univariate analyses were undertaken to describe the profile of the sample, NASA task load index scores and observation of errors made in the simulator. A repeated measure of analysis of variance (ANOVA) was undertaken to examine the effect of type of intersection (DDI versus traditional intersection) on each of the driving simulator performance measures: time spent out of lane, number of lane excursions, compliance to speed limit and total number of crashes/ near-misses.

**Results**

A total of 201 participants completed the study, ranging in age from 18 to 80 years with a mean age of 47 years (SD=16). The majority of participants were male (61.2%).

**NASA Taskload Index**

Overall, there was a mean NASA Taskload Index score of 30.3 for all participants, indicating they considered the simulator task to require ‘low’ cognitive workload. However, a dose–response relationship was evident, with increasing age (41-59 and ≥60 years) significantly associated with a higher cognitive workload, after adjusting for potential confounding factors, particularly evident with mental workload and effort.

**Driving simulator measures**

There was a non-significant difference between the effects of type of intersection on time spent out of lane: \(F(1, 656) = 0.57, p = 0.45\). The mean time spent out of lane on while negotiating the DDI was 0.03 (SD=0.17) seconds compared to 0.01 (SD=0.14) seconds on the traditional intersection. While most participants did not spend any time out of lane (98%), the majority of those who did were aged over 60 years (58%) and were travelling through the DDI (93%). There was also a non-significant difference between the types of intersection in terms of the number of lane excursions: \(F(1, 656) = 0.35, p = 0.55\).

A significant effect was evident between the type of intersection and compliance to the speed limit: \(F(1, 656) = 160.11, p <0.001\) with drivers tending to travel over the speed limit in the DDI. The majority of participants who did report episodes of speeding were aged less than 60 years of age (85%).

There were no crashes/ near-misses recorded by any participants in the simulator.
Qualitative measures

Qualitative data regarding the difficulty participants had navigating the DDI found that only 16% of participants reported any difficulty negotiating the DDI in the simulator. These self-reported difficulties included: negotiating the curves of the DDI, short distance between the traffic lights at the entry and exit of the DDI, participants missing signage on approach to the DDI and discomfort felt when required to drive on the ‘wrong’ side of the road in the DDI.

Behavioural observation measures

No wrong-way violations or navigation errors were observed while negotiating the DDI. Overall, a low number of other driver errors were observed at intersections with a total of 46 errors from 394 simulator trips. Seventy two percent of these errors occurred entering or leaving the DDI and 28% occurred at the traditional intersections. The most frequent type of error at intersections were red light violations (44%), including running the red light or stopping with the bumper over the stopline. These violations were more common at the DDI than the traditional intersections. Other errors included failure to keep two hands on the steering wheel and road law errors.

Conclusion

This study is the first study of its kind to provide objective comprehensive evidence on the difficulties WA drivers may experience while negotiating a DDI, compared to a traditional intersection. Consistent with previous international studies, minimal difficulties for drivers negotiating the DDI were identified.

Importantly, no wrong way violations or navigation errors were observed while negotiating the DDI in the simulator, suggesting these errors are unlikely to increase with the installation of a DDI in WA. While the overall number of errors observed at intersections was low, the most frequent type of error were red light violations (44%) and these were more common at the DDI than the traditional intersections. In addition, drivers travelled over the speed limit more in the DDI than the traditional intersection.

While all drivers performed well, there was some indication that older drivers may have experienced more difficulty negotiating the DDI. The majority of participants who spent any time out of lane were aged 60+ and older drivers reported significantly higher
cognitive workload scores, particularly related to mental workload and effort while negotiating the intersections than younger drivers.

Therefore, recommendations surrounding the installation of new DDIs in WA and Australia include:

1. Community education on how to use the new DDI interchanges, in order to avoid red light violations and the crashes that may result from these.
2. Obvious and well-placed speed signage on the approach to the DDI in order to improve compliance to the 40 km/h speed limit.
3. Community education for all drivers on the reduced 40 km/h speed limit at new DDIs.
4. Targeted education for older drivers on how to navigate the DDI safely.

Overall, this simulator study confirmed that WA drivers had minimal difficulties negotiating the DDI. The reduction in conflict points and lower speed limit afforded by the DDI in combination with the very few recorded driver errors, imply that installation of DDIs would have safety benefits and should be considered for use in the WA road environment.
ACKNOWLEDGEMENTS

The authors would like to acknowledge the contribution of Dr Simon Wilson from the Transport Research Laboratory (TRL) in the United Kingdom for his development of the complex driving scenario and his support throughout the data collection process. We would also like to thank John Hess for his assistance with the driving simulator.
1. **INTRODUCTION**

Nearly 400,000 serious injuries and approximately 14,500 fatalities have occurred on Australian roads over the last decade (Australian Institute of Health and Welfare (AIHW), 2012; Bureau of Infrastructure Transport and Regional Economics (BITRE), 2014). In Western Australia (WA), 181 people were killed and 2,434 seriously injured in road crashes in 2012 (Bramwell, Hill, & Thompson, 2014). Thirty-five percent of these fatal crashes and nearly half of serious injury crashes occurred at intersections in the Perth metropolitan area (Bramwell et al., 2014). Right angle crashes are the most common type of intersection crash and account for 39% of serious injury crashes in WA (Devlin, Candappa, Corben, & Logan, 2011). They typically result in severe injuries, including head and spinal injuries, often as the result of high speeds and impact to the side of the vehicle (Devlin et al., 2011). In recent years, road safety organisations in WA have been advocating intersection designs to improve safety, while meeting the demands for increasing capacity and cost constraints associated with new road infrastructure. One such intersection treatment gaining attention in WA is the Diverging Diamond Interchange (DDI).

In a DDI, traffic coming through the intersection is diverted onto the opposite side of the road, allowing those who would originally need to turn across arterial traffic, to make a left-like simple turn before merging onto the on-ramps. Through traffic is then diverted back onto the correct side of the road. The road safety benefits of DDIs include the elimination of right angle crashes, improved sight distance, better traffic calming, reduced crossing distances for pedestrians and fewer conflict points. An independent study conducted in the US evaluated the effectiveness of DDIs and found that the total number of crashes reduced by 46%, left turn crashes (equivalent to right-turn crashes in Australia) were eliminated, rear-end crashes were reduced and traffic flow improved (Chilukuri, Siromaskul, Trueblood, & Regan, 2011).

While strong evidence of the safety benefits of DDIs exists overseas, in Australia DDIs are yet to be introduced and so are unfamiliar to Australian drivers. There is concern that human errors due to unfamiliarity/confusion may actually increase crashes at new DDI sites, particularly for high risk groups such as younger (McKnight & McKnight, 2003) and older drivers (Braitman, Kirley, Ferguson, & Chaudhary, 2007). These
drivers may have difficulties negotiating the increased complexities of intersections, particularly at night and under adverse environmental conditions.

Novel technologies, such as driving simulators, allow empirical investigation of how changes in the road layout may affect driver performance. Driving simulators represent an approach that is repeatable and easily adaptable, including the ability to quickly alter driving scenarios and expose drivers to hazardous situations in a systematic way, which is difficult to study in a natural driving environment (Engström, Johansson, & Östlund, 2005). They can also distinguish safe from unsafe drivers (Engström et al., 2005) and can be configured specifically to test particular components of the physical driving environment and evaluate driver performance.

1.1 Aims and objectives

The aim of the study was to evaluate driver performance while navigating a DDI compared to a traditional intersection using a laboratory-based driving simulator. Specific objectives were to:

1. Assess driving performance and cognitive/physical workload when navigating a DDI compared to a traditional intersection, using a driving simulator.
2. Determine specific groups of drivers at increased risk of a driving error when navigating a DDI, compared to a traditional intersection.
3. Provide recommendations on areas of risk for drivers particularly targeted to high risk groups for the use of a DDI in Western Australia.
2. SIGNIFICANCE

A well-functioning road-transport system is vital to the well-being and prosperity of WA. However, crash statistics suggest that intersections are associated with a higher level of crash risk than other types of road infrastructure (Bramwell et al., 2014). Intersection crashes also typically involve severe injuries, including head and spinal injuries, often as the result of high speeds and impact to the side of the vehicle (Devlin et al., 2011). In WA, the economic cost of crashes in 2012 alone was estimated at $2.1 billion, of which 22% were due to fatal crashes and 56% from hospitalisation crashes (Bramwell et al., 2014). The human body has a certain biomechanical tolerance over which serious injury is almost certain. At intersections, it is estimated that this tolerance is reached in crashes where impact speeds to the side of a passenger vehicle exceed 50 km/h (Tingvall & Haworth, 1999). Therefore, significant effort is being made to reduce crashes at intersections through innovative designs that seek to minimise crash risk and in particular, eliminate conflict points with other vehicles and lower speeds.

The DDI design has shown to be extremely promising results in terms of crash reduction overseas, but is yet to be trialled in Australia. While strong evidence suggests that introducing DDIs in WA would decrease crashes, improve safety and reduce the financial impact on the WA community, it is essential that any potential for an increase in crashes due to driver unfamiliarity and confusion be minimised.

This study is the first study of its kind to provide objective comprehensive evidence on the difficulties WA drivers may experience while negotiating a DDI, compared to a traditional intersection. The use of the driving simulator provides an extremely valuable tool to safely assess a large sample of drivers under identical conditions. The sample is also large enough to investigate whether particular groups of drivers are at increased risk of driving difficulty while navigating a DDI; for example, young drivers, older drivers and the specific issues that may be problematic for the various groups.

Finally, the results of the study will combine both elements of the research objectives of the Neurotrauma Research Program and the Road Safety Commission and provide important information for road safety organisations.
3. LITERATURE REVIEW

3.1 Introduction

The last several decades in Australia has seen a significant increase in the total number of drivers on the road, with a corresponding increase in the total number of kilometres travelled. From the 1970’s to 2011, the average number of kilometres travelled per capita in Australia increased from roughly 8,000 to 10,000 kilometres per year (Bureau of Infrastructure Transport and Regional Economics, 2012).

Despite increased investments in public transport in recent decades, the use of cars and other private vehicles still accounts for 85% of urban transport (Bureau of Infrastructure Transport and Regional Economics, 2015).

There is a clear need to address safety and congestion problems, and ensure that efficient traffic management strategies are in place to minimise congestion and maximise the efficiency of existing infrastructure, within budgetary constraints. Since intersections are associated with a higher overall crash risk as well as increased risk of severe and fatal crashes, implementing new safe and efficient intersection designs is an area of high priority.

A thorough literature review was conducted to investigate an alternative interchange design, the Diverging Diamond Interchange (DDI) that has been used in the United States (US) over the last decade to address these same issues.

3.2 Diverging diamond design

The DDI is an alternative approach to the traditional interchange that is relatively new to mainstream application. Whilst originally being utilised 30 years ago in three locations in France, the DDI was introduced for discussion in the US in 2003, and has gained rapid popularity in the region since the first DDI was built in 2009 (Bared & Saiko, 2010). In less than a decade dozens of DDIs have been built across the US, with more in the planning and construction phases (Chlewicki, 2014).

Comparative illustrations of the traditional and diverging diamond interchanges are provided below, in figure 1. The DDI is an intersection where traffic is diverted to the opposite side of the road (depicted by the blue and yellow lines in Figure 1, Image B) which allow right turns to be completed without conflict with other traffic, after which
traffic is diverted back to the original side of the road (Chlewicki, 2003) with two-phase traffic signals controlling traffic flow at the cross-overs.

**Figure 1: Conflict point comparisons**

(A) WA Standard Grade Separated Interchange (B) Diverging Diamond Interchange

### 3.3 Benefits of diverging diamond design

The popularity of the DDI centres around three main benefits: the alleviation of congestion; a reduction in crash frequency and injury severity; and reduced cost and construction time when compared to other intersection designs.

#### 3.3.1 Improved interchange performance

Where the traditional intersection interchange usually involves the use of at least four signal phases, the diverging diamond interchange halves the number of signal phases required by merging traffic lanes that are travelling in the same direction, increasing the overall throughput and in many cases the capacity of the interchange (Hughes, Jagannathan, Sengupta, & Hummer, 2010).

When signal changes occur, as the current green phase moves to red, there is a brief overlap of red signals with no traffic movement, which can be considered lost time for traffic movement. Reducing the number of signal phases reduces the amount of time that is lost between phase changes, allowing for more overall green phase time, which increases the amount of vehicular traffic that can be moved through the intersection (Leong, Mahdi, & Chin, 2015).

Additionally, the free flowing traffic onto the on-ramps at all points, requires less room for storage of cars on the intersections between signal phases as traffic travelling in this
direction can move through and exit the intersection onto the freeway or highway underneath without needing to stop unnecessarily.

### 3.3.2 Improved safety

The road safety benefits of DDIs include the elimination of right angle crashes, improved sight distance, better traffic calming, reduced crossing distances for pedestrians and fewer conflict points. For example, Figure 1A shows a standard WA interchange with 18 possible conflict points, of which four are classified as being likely to cause serious injury in the event of a crash. Figure 1B shows the layout of the DDI with 12 conflict points, none of which are classified as serious, thereby significantly reducing the potential for death and serious injury from vehicular impact.

Due to the nature of the crossover in the DDI, and the increased number of curves for through traffic, travel speeds are reduced in the DDI. This provides an additional safety benefit, reducing the likely impact in the event of a crash, thus reducing the severity of crashes, particularly right-angle crashes (Inman et al., 2007).

There have been several evaluations of the safety benefits of DDIs that have demonstrated the link between the reduced number of conflict points and reduced crash frequency/severity (Claros, Edara, Sun, & Brown, 2015; Hummer et al., 2016). Claros et al. assessed the effectiveness of six DDIs in reducing the frequency of crashes in Missouri, US, 3-4 years prior to, and 10 months to 4 years post installation (Claros et al., 2015). An overall reduction of 40.8% to 47.9% was found in the total number of crashes, (Claros et al., 2015). Of particular significance, there was a reduction of 59.3% to 63.2% in the number of crashes involving fatalities and/or serious injuries (Claros et al., 2015). The reduction in crashes involving property damage only ranged between 33.9% and 44.8% (Claros et al., 2015).

Hummer et al. built upon Claros’ study and evaluated the effectiveness of the seven oldest DDIs in the US, which included one of the sites from the Claros et al study, plus additional sites from other states (Claros et al., 2015; Hummer et al., 2016). This extended both the geographical application of the evaluation undertaken, but also the time period of the study, with a total of 28 years of cumulative crash data prior to the DDI installation and 19 years of cumulative crash data post DDI installation (Hummer et al., 2016). An overall reduction of 41% in all crashes was reported, as well as a reduction of 63% in fatal and serious injury crashes, and a reduction of 35% in the
property damage only crashes. They also formulated a crash modification factor (CMF) to use in estimating the reduction in the number of crashes when converting a traditional intersection to a DDI. The CMF attributed a reduction in the total number of crashes of 0.67, and fatal and serious injury crashes were assigned a CMF of 0.59, corresponding to an estimated crash reduction of 33% and 41% respectively (Hummer et al., 2016).

3.3.3 Cost and time savings

A final important feature, particularly in the implementation of a DDI design, is the cost and time associated with the construction of a DDI. Where a traditional interchange exists, the conversion to a DDI can usually be done using existing infrastructure, and does not require the same significant additions to infrastructure that alternative intersection designs may require. Published examples of cost variation give estimates of cost savings of between 83-433% of the total construction cost, depending on the specific site and existing infrastructure (Hansen, 2006; McCubbins et al., 2007). Should the existing infrastructure not require extensive modification, the time taken to implement the conversion of the intersection to a DDI is also reduced. This provides another incentive to the implementation of a DDI over other forms of intersection design.

3.4 Application of the DDI: Springfield and Kansas City interchanges

The most commonly evaluated DDIs in the US include the Route I3 and I44 interchange in Springfield, which was the first DDI to open in the US in 2009, as well as the interchange at I-435 and Front Street in Kansas City (Chilukuri et al., 2011; Claros et al., 2015; Hummer et al., 2016; Maji, Mishra, & Jha, 2013; Schroeder, Salamati, & Hummer, 2014; Yeom et al., 2014).

The total change in traffic volume was different between each site, with one experiencing increased volumes after the introduction of the DDI (Springfield), and the other experiencing a slight reduction in traffic volume (Kansas City) (Hummer et al., 2016). Despite increased volumes of traffic in Springfield, it was generally reported by the public that traffic delays and flow were improved after the DDI installation (Chilukuri et al., 2011).

Safety evaluations of these two interchanges have reported consistent reductions in crashes of between 33 and 65 percent based on crash type, with a reduction in the
number of severe or fatal crashes of between 58 and 63 percent (Claros et al., 2015; Hummer et al., 2016).

3.5 Diverging diamond design limitations

Whilst the majority of the implications of DDI implementation are positive, there were several concerns and design limitations which were raised in the review of the literature. These include concerns for the safety of new and unfamiliar drivers manoeuvring through the DDI, as well as the effects of additional traffic volumes generated by the improved efficiency of the intersection.

3.5.1 Manoeuvring for new DDI users

One of the most obvious concerns in the utilisation of a DDI design is the ability to safely facilitate drivers crossing over to the opposite side of the road at the initial intersection. There have been several studies to evaluate the response of drivers in unfamiliar driving situations, both specific to DDIs, but also to new situations in general (Inman et al., 2007; Zhao, Yun, Zhang, & Yang, 2015).

The Federal Highway Administration in the US conducted a simulation with a cohort of 70 people to investigate the performance of drivers who were unfamiliar with the DDI design (Inman et al., 2007). They reported no incidences where the participants crossed over into oncoming traffic at the crossover points, but five wrong way crossings at other points of the intersection out of a potential 1,041 opportunities. Three of these were for the same person. There were several other errors made by participants during the simulations, but these were also made when participants were run through a traditional interchange simulation, with the authors concluding that the DDI did not have additional errors in this regard, over the traditional interchange (Inman et al., 2007). Interviews with those who committed the wrong way crossings resulted in suggested design and signage modifications (Inman et al., 2007).

Zhao et. al put two groups through a simulation to evaluate whether increased experience and training versus none, made a significant difference in the groups’ response to new lane usage. They found that whilst the inexperienced drivers did show some hesitation and confusion when navigating the situation for the first time, this was overcome relatively quickly, and promoted the use of driver education, but also the impact of following cues from other vehicles (Zhao et al., 2015). In summary, the new
experience for these drivers was not considered to be overly dangerous (Zhao et al., 2015).

### 3.5.2 Additional traffic in the road network

Other potential issues can be caused through increased left-turn volumes (right-hand turns in the Australian context), which may cause traffic to back up through the interchange, causing what is termed ‘a fail’ of the interchange (R. Hale, 2014). Additional traffic volume through an interchange, as a result of its increased efficiency, will have flow-on effects on the surrounding road network. There is potential to cause increased delays elsewhere along the network with this increase in traffic volume. There have been several investigations into the potential influence of a DDI on the related road network (Chilukuri et al., 2011; Leong et al., 2015). These studies have been in various locations, and extend past the DDI to various levels. All have reported that despite increased traffic volumes, there have not been overall increased delays caused in surrounding intersections and interchanges (Chilukuri et al., 2011; Leong et al., 2015).

### 3.5.3 Evaluation of planned DDIs, and post construction evaluation

There are currently a variety of analysis and modelling tools to evaluate the potential influence of a DDI installation at existing interchanges. Many are well documented, and have been thoroughly tested (Maji et al., 2013; Schroeder et al., 2014; Xu, Liu, Tian, & Zhang, 2011). The availability of such models allows for thorough evaluation of the impacts of a DDI, compared to before its installation. Additionally, there are also tools available to ensure that the function of the DDI after installation is optimised, such as the timing of signal phase changes and lane utilisation (Hainen et al., 2015; D. Hale, Hummer, Mackey, & Stevanovic, 2015; Yang, Chang, & Rahwanji, 2014; Yeom et al., 2014).

### 3.6 Alternative interchange designs

Several other alternative interchange designs have also been suggested, and implemented, in attempts to address traffic congestion and flow efficiency problems in other countries, including the single point interchange and the use of roundabouts.

As summarised by David Stanek in 2007 these different designs have, in some cases, strengths as well as limitations over the DDI design depending on the existing
infrastructure in the situation that is to be modified (Stanek, 2007). In most cases, the DDI is the cheapest option, providing a clear cost benefit, as well as providing additional storage for cars waiting to enter and exit the intersection, and being more compact than most of the other suggested intersection designs (Stanek, 2007). Of significant importance as well, is the reduced crash and injury potential provided by the DDI, which in most scenarios is greater in the DDI than other suggested alternatives (Stanek, 2007).

Another novel design is the one-sided interchange which provides space saving benefits over the DDI, but as of 2015, this design was not in wide use and investigations into its overall safety and efficiency were incomplete (Melson, Krause, & Bared, 2015).

In almost all cases, the safety benefit of the DDI is superior to the suggested alternatives. Therefore, investigation of the implementation of a DDI when investigating potential changes to an intersection has potential benefit in most circumstances.

3.7 Conclusion

The DDI has the potential to increase traffic efficiency and reduce congestion at a relatively lower cost than other potential approaches to interchange modification. The DDI also provides additional safety benefits through reduced conflict points; which result in less crashes and less severe collisions according to currently available data. Where existing traditional interchanges are lacking in traffic flow efficiency and capacity and safety benefits, the DDI provides a viable option that should be investigated using the variety of existing evaluation and planning models.
Table 1: Studies investigating safety and/or efficiency of diverging diamond interchanges.

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Size</th>
<th>Findings</th>
</tr>
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<tbody>
<tr>
<td><strong>Cross Sectional studies</strong></td>
<td></td>
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<tr>
<td>Diverging diamond interchange performance evaluation</td>
<td>- 7 runs through intersection &amp; surrounding network, pre &amp; post DDI.</td>
<td>- Increase in traffic delay, queuing in AM (74 to 68.2 hours). Increase in PM (95.7 to 107.5 hours). - Average of 104 crashes per year (p/y) reduced to 56 p/y. - Survey found 83% believed there were less delays. - Minor injury crashes reduced 29 p/y to 8 p/y. - Property Damage Only crashes (PDO) reduced 73 p/y to 46 p/y. - Rear-end crashes reduced 41 p/y to 29 p/y. - Left turn Right Angle crashes reduced 18 p/y to 5 p/y. - Rear-turn type crashes reduced 17 p/y to 0 p/y.</td>
</tr>
<tr>
<td>(Chilukuri et al., 2011)</td>
<td>- Online survey of 53 motorists.</td>
<td></td>
</tr>
<tr>
<td>- Traffic volumes through intersection during 2008.</td>
<td>- 5 years pre, 1 year post DDI crash data.</td>
<td></td>
</tr>
<tr>
<td>FHWA Tech Brief: Driver’s evaluation of the diverging diamond interchange</td>
<td>- 70 drivers, unfamiliar with DDI design, run through simulation.</td>
<td>- No ‘bear right’/cross over into oncoming traffic errors out of 1,041 chances. - 5 wrong way incidents, (3 with the same person) at other parts of the interchanges. Attributed to signage misinterpretation. - No significant increase in navigational errors by participants (change of 0.48, p&gt;0.78). - Reduced speed on arterial roads approaching interchange. 37.3km/h - 39.6km/h in DDI, 55.4km/h in the traditional interchange.</td>
</tr>
<tr>
<td>(Inman et al., 2007)</td>
<td></td>
<td></td>
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<tr>
<td>Safety evaluation of diverging diamond interchanges in Missouri</td>
<td>- 6 sites in Missouri US, from 3 to 4 years pre-DDI, &amp; 10months to 4 years after DDI.</td>
<td>Reductions across all three sites: - 57.7% for fatal and injury crashes, - 26.4% for property damage only, - Crashes overall by 34.7%. Top Two Crash Types: - Before DDI: Collision of left-turn movements from inside crossroad and oncoming through movement, rear end collisions on exit ramps. - After DDI: rear end collisions b/w right turning movements on exit ramp &amp; rear end collisions of the outside crossroad, approaching the leg to ramp terminal.</td>
</tr>
<tr>
<td>(Claros et al., 2015)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Case Control Studies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety evaluation of seven of the earliest diverging diamond interchanges installed in the United States.</td>
<td>- 28 cumulative years of crash data before - 19 cumulative years after DDI. - Over 3,000 crash reports in total.</td>
<td>- Reduction at most of the sites - Recommended Crash Modification Factor (CMF) of 0.67 (i.e. Installation of DDI should reduce all crashes by 33%). Specific to injury crashes CMF recommended was 0.59. - 41% reduction in all crashes, - 35% reduction in PDO - 63% reduction in fatal and injury crashes. - All sites had moderate to large reduction in angle collisions and rear end collisions. - Sideswipe crashes tended to increase in most cases. - Total improvement in crash frequency is across sites, but consistently reported decreases across all.</td>
</tr>
<tr>
<td>(Hummer et al., 2016)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design and operational performance of double crossover intersection and diverging diamond interchange.</td>
<td>- VISSIM computerised simulation of DDI and traditional interchange. - Vehicle inputs of 1700-8500 vehicles/hour.</td>
<td>- At low and medium volumes the DDI and traditional interchange perform almost identically. - High/peak volumes, DDI markedly better than traditional interchange. Capacity increased from 330-390 to 600-700 vehicles. Stop times, numbers and delay times all decreased.</td>
</tr>
<tr>
<td>(Bared, Edara, &amp; Jagannathan, 2005)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. METHODS

The project was conducted in two phases.

4.1 Phase 1: Scenario development

The DDI driving simulator scenario was developed by software engineer Dr Simon Wilson from the Transport Research Laboratory in the United Kingdom, in consultation with Professor Meuleners who is a road safety expert, Dr Roberts who is a human factors/psychology expert and Dr Logan who is a mechanical engineer.

4.1.1 Driving scenario

The driving scenario was based on drawings developed by an engineering company based in the Eastern States of Australia that are being used to develop a DDI in Queensland. The scenario consisted of the DDI interchange (Figure 2) with two ‘control’ traditional intersections which were used as comparisons (Figure 3). The comparison intersections were located at the start and the end of the driving scenario. The control intersections were matched for the same roads and traffic conditions as the DDI. Each participant drove through two conditions (East-west and West-east) in a simulated drive of several kilometres during the daytime. Relevant signage and speed limits were present throughout the drive.

Figure 2: DDI driving scenario in the simulator
4.2 **Phase 2: Driving simulator assessment**

This study used a state-of-the-art driving simulator to assess driver performance as a driver navigated through the DDI, compared to driver performance while navigating through a normal traditional intersection. A questionnaire was also used to assess the associated cognitive and physical workload while navigating the DDI. The state-of-the-art driving simulator is based at Curtin University.

4.2.1 **Study design, sample and recruitment strategy**

An experimental study design was undertaken. Two hundred and one drivers aged between 18 and 80 years with a current WA C class licence (passenger vehicle) completed the study. This sample size had sufficient statistical power to detect small differences at alpha of 0.05 with at least 80% power. Care was taken to include a range of ages. Using C-MARC’s previously successful recruitment methods, a convenience sample of Perth-based participants were recruited from universities, through industry organisations, using social media, Twitter, Facebook, newspaper and radio advertisements (see Appendix A for study flyer). An information sheet was provided to
all participants and informed consent was obtained prior to any data collection (see Appendix B).

*Inclusion criteria:* No previous driving exposure to DDI; licensed to drive a motor vehicle for at least one year; drive at least three times a week; live in the Perth metropolitan area, able to attend a driving assessment at Curtin University and not moved to WA from interstate or overseas in the past twelve months.

*Exclusion criteria:* A diagnosis of dementia, epilepsy, a head injury, a history of nausea/vomiting, Parkinson’s disease or wheelchair-bound.

### 4.2.1.1 Data collection

Two researcher-administered questionnaires and a driving simulator assessment were undertaken by each participant. The assessments took approximately one hour to complete.

A small pilot study of five participants was undertaken prior to study commencement. The purpose was to confirm content validity as well as the length and appropriateness of the questionnaire and driving simulator tasks. It was reviewed by a panel of road safety, human factors and engineering experts and modifications were made accordingly to the questionnaire. The driving scenario was reviewed by engineers at Main Roads Western Australia (MRWA) and ARUP to ensure accuracy of all road infrastructure with WA standards (for example all poles were yellow).

Ethical approval was obtained from Curtin University’s Human Research Ethics Committee (RDHS-105-15).

### 4.2.1.2 Questionnaires

*Demographics*

A short researcher-administered questionnaire collected participants’ socio-demographic data including age, sex, marital status, education, co-morbid medical conditions, current prescribed medications, driving experience, driving patterns and habits, as well as the number of crashes and demerit points/infringement notices incurred over the past year (see Appendix C). At the end of the driving simulator assessment each participant also answered a questionnaire that consisted of six open and closed-ended questions about the difficulty they found driving through the DDI and
what improvements could be made in terms of signage, road markings or any other suggestions (see Appendix D).

**NASA Task Load Index**

The NASA Task Load Index is a subjective, multidimensional assessment tool that rates perceived workload in order to assess a task, system, or a team's effectiveness or other aspects of performance (Colligan, Potts, Finn, & Sinkin, 2015). The NASA Task Load Index was used to assess the cognitive and physical workload level of each participant at the completion of the two driving simulator routes. Each participant was assessed on six different subscales: mental demands, physical demands, temporal demands, own performance, effort and frustration. A computer-based questionnaire was used and participants were asked to rate the perceived amount of effort on the six subscales after driving in the simulator. Each subscale is rated for each task within a 100-point range with 5-point steps. The raw scores from the six scales were then combined to create an overall workload scale (0–100). The NASA Task Load Index is a reliable tool which has been used widely to assess cognitive demands and physical workload in different contexts (Colligan et al., 2015) (see Appendix E).

4.2.1.3 **Driving simulator and assessment**

The C-MARC-ARRB simulator represents a fully functioning Kia sedan with working controls and instruments (car and visual system) and is enclosed to remove any outside distractions. It is mounted on a six degree of freedom motion system to recreate driving inertia forces for ultimate realism. When seated in the driving simulator the driver and occupants are immersed in a virtual environment that includes a 360-degree projector wrap-around visual system, allowing for the use of vehicle mirrors. It also features real feeling brake and accelerator systems and includes an audio system that provides realistic traffic sounds as well as instructions and an instructor panel interface for the researchers. Images are displayed in full high resolution of 1920 x 1080 pixels per channel and updated at a frame rate of 120 Hz (Figure 4).
The use of driving simulator technology allows situations to be presented to participants safely under controlled conditions, which is impossible to achieve on-road. It has been shown that behavioural changes seen in the simulator translate to the real world, and thus these can be considered representative of an analogous change in real world driving performance (Freund, Gravenstein, & Ferris, 2002; Lee & Lee, 2005; Lenne et al., 2011).

4.2.1.4 Driving procedure

Initially, participants were given the opportunity to drive a practice circuit for approximately five minutes to familiarise themselves with the vehicle control dynamics, road environment and simulator tasks. They were instructed to operate the simulator as they would drive their own car. This also provided participants with an opportunity to ask any questions before the start of their drive, and allowed them to make any necessary adjustments to the vehicle so that they were comfortable prior to commencing.

Participants were instructed to drive as they normally would and to keep to the posted speed signs in each condition (70 km/h in the traditional intersections; 40 km/h through the DDI). The scenario included a traditional intersection, followed by a straight section
of road, the DDI, followed by another straight section of the road and lastly, a traditional intersection followed by a straight section of the road. There were no other vehicles in the scenario as it was felt that if other traffic was included, participants may have just followed the lead vehicle, which may not identify any issues they may have had with the DDI. The scenario also contained several cyclists who were travelling in the same direction as the driver. After participants completed the drive in one direction (E-W or W-E) they were asked to complete the drive again but from the opposite direction. These were counterbalanced to reduce order effects. It took approximately 10 minutes to complete each of the driving conditions, depending on speed.

4.2.1.5 Driving simulator data

Measures of surrogate driving performance evaluated in the study included: attention, situation awareness, hazard perception, and decision-making. These constructs were measured through several dependent driving performance measures that were collected in the simulator which included: speed and compliance to speed limits, lateral control (number of lane excursions and time spent out of lane), near-misses and actual crashes. These measures have been shown to correlate with real-world incidence of traffic violations and on-road driving test performance (Freund et al., 2002; Lee & Lee, 2005; Lenne et al., 2011).

A number of driving measures were used to measure lateral control. It was considered that stability measures such as lane deviation standard deviation would not be an appropriate measure on a road that contained both straight and curved (the DDI) sections. As Young and Stanton (2002) argued, lateral stability can be misrepresentative of proper driving techniques on curved road sections where the advice to adopt a position towards the outside edge of the bend before cutting the apex can lead to inflated instability information. It can be more reasonably assumed that proper driving techniques involve remaining inside one’s own lane with any departures being considered as potentially unsafe behaviours. Therefore, measures of lane excursions were used to evaluate lateral control with the assumption that good driving performance is characterised by fewer lane excursions (Young & Stanton, 2002). Therefore, total number of lane excursions and time spent out of lane were the dependent variables for lateral control.
For speed control, compliance to speed was used instead of mean speed. Since the speed limit was different at the normal intersection compared to the DDI it was reasonable to assess whether drivers complied with the speed limit while driving through each intersection condition.

The total number of crashes/near misses were recorded at each location. Although there was no traffic in the driving scenario, it was still possible that the driver could hit a cyclist. Finally, driver attention was addressed through the NASA-TLX workload scales at the end of the simulator run.

4.2.1.6 Behavioural observations

The study also addressed the major concern with the DDI design, which is that drivers will bear left at crossovers and drive against the intended traffic flow, thus increasing the possibility of a low speed head-on collision. Therefore, behavioural observations tested specifically for the DDI included: wrong-way violations - participant bears left or turns into an oncoming traffic lane at the DDI; navigation errors – participant follows a path to the destination other than the one he or she was asked to follow; red-light violations – running through a red light at the DDI. The researcher also recorded errors in observation, physical control of the vehicle, obeying road laws and vehicle positioning. Table 2 provides a definition and examples of driving errors that were recorded by a researcher who sat in the front passenger seat with each participant as they drove through the DDI. The researcher recorded these errors as they occurred and noted the location in the scenario where each error was made.

Table 2: Definitions and examples of driving errors

<table>
<thead>
<tr>
<th>Error category</th>
<th>Example(s) of errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrong way violation</td>
<td>Turning into oncoming traffic. Bear left.</td>
</tr>
<tr>
<td>Navigation error</td>
<td>Fail to proceed straight through traffic lights.</td>
</tr>
<tr>
<td>Red light violation</td>
<td>Run red light (fail to stop). Stop with bumper after stop line.</td>
</tr>
<tr>
<td>Observation</td>
<td>Mirror checking, i.e. not looking at rear-view or side mirrors.</td>
</tr>
<tr>
<td>Physical control of vehicle</td>
<td></td>
</tr>
<tr>
<td>Steering</td>
<td>Fail to keep two hands on steering wheel.</td>
</tr>
<tr>
<td>Indicating</td>
<td>Not using indicators when merging, turning or crossing lanes.</td>
</tr>
<tr>
<td>Road laws</td>
<td></td>
</tr>
<tr>
<td>Obeying signs</td>
<td>Fail to obey signs.</td>
</tr>
<tr>
<td>Obeying road markings</td>
<td>Fail to obey road markings.</td>
</tr>
</tbody>
</table>
4.2.2 Statistical analysis

Descriptive and univariate analyses were undertaken to describe the profile of the sample, NASA task load index scores and observation of errors made in the simulator. A repeated measure of analysis of variance (ANOVA) was undertaken to examine the effect of type of intersection (DDI versus traditional intersection) on each of the driving simulator performance measures: time spent out of lane, number of lane excursions, compliance to speed limit and total number of crashes/near-misses.
5. RESULTS

5.1 Characteristics of the sample population

5.1.1 Demographic characteristics

A summary of the drivers’ demographic information is presented in Table 3. The final convenience sample consisted of 201 drivers.

The mean age of drivers was 46.8 years (SD=16.2), with a median age of 46.0 years. The drivers ranged in age from 18 to 80 years. The 41-59 years age group had the highest number of participants with 69 (34.3%), followed by the 25-40 years age group with 63 (31.3%). Approximately 26% of the sample were aged 60+. The majority of the participants were male (n=123, 61.2%), married or in a de facto relationship (n=130, 64.6%) and had a university degree (n=137, 68.2%). Almost two-thirds of participants were born in Australia (n=129, 64.2%), with the United Kingdom being the second most frequent country of birth (n=23, 11.4%).

Table 3: Demographic characteristics of the sample population

<table>
<thead>
<tr>
<th>Variable</th>
<th>Participants/Drivers (n = 201)</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td>78</td>
<td>38.8</td>
</tr>
<tr>
<td>Male</td>
<td></td>
<td>123</td>
<td>61.2</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17-24</td>
<td></td>
<td>16</td>
<td>8.0</td>
</tr>
<tr>
<td>25-40</td>
<td></td>
<td>63</td>
<td>31.3</td>
</tr>
<tr>
<td>41-59</td>
<td></td>
<td>69</td>
<td>34.3</td>
</tr>
<tr>
<td>≥60</td>
<td></td>
<td>53</td>
<td>26.4</td>
</tr>
<tr>
<td>Marital status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single</td>
<td></td>
<td>56</td>
<td>27.9</td>
</tr>
<tr>
<td>Married/de facto</td>
<td></td>
<td>130</td>
<td>64.6</td>
</tr>
<tr>
<td>Separated/divorced/widowed</td>
<td></td>
<td>15</td>
<td>7.5</td>
</tr>
<tr>
<td>Highest educational qualification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary school</td>
<td></td>
<td>30</td>
<td>14.9</td>
</tr>
<tr>
<td>TAFE, apprenticeship</td>
<td></td>
<td>34</td>
<td>16.9</td>
</tr>
<tr>
<td>University</td>
<td></td>
<td>137</td>
<td>68.2</td>
</tr>
<tr>
<td>Employment status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unemployed</td>
<td></td>
<td>47</td>
<td>23.4</td>
</tr>
<tr>
<td>Employed</td>
<td></td>
<td>154</td>
<td>76.6</td>
</tr>
</tbody>
</table>
Country of birth

<table>
<thead>
<tr>
<th>Country</th>
<th>Participants</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>129</td>
<td>64.2</td>
</tr>
<tr>
<td>New Zealand</td>
<td>7</td>
<td>3.5</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>23</td>
<td>11.4</td>
</tr>
<tr>
<td>China &amp; Hong Kong</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>Singapore</td>
<td>6</td>
<td>3.0</td>
</tr>
<tr>
<td>Malaysia</td>
<td>4</td>
<td>2.0</td>
</tr>
<tr>
<td>India</td>
<td>4</td>
<td>2.0</td>
</tr>
<tr>
<td>South Africa</td>
<td>4</td>
<td>2.0</td>
</tr>
<tr>
<td>Germany</td>
<td>4</td>
<td>2.0</td>
</tr>
<tr>
<td>Other</td>
<td>17</td>
<td>8.4</td>
</tr>
</tbody>
</table>

Language spoken at home

<table>
<thead>
<tr>
<th>Language</th>
<th>Participants</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>English only</td>
<td>189</td>
<td>94</td>
</tr>
<tr>
<td>English plus other</td>
<td>5</td>
<td>2.5</td>
</tr>
<tr>
<td>Other</td>
<td>7</td>
<td>3.5</td>
</tr>
</tbody>
</table>

5.1.2 Health-related characteristics

The participants’ health-related characteristics are summarised in Table 4. Of the 201 participants, 80 (39.8%) reported that they had been diagnosed with a co-morbid condition. Of these 80 participants, 55 reported having one co-morbid condition, 14 reported two, and 11 reported three or more co-morbid conditions (Table 4). The most frequently self-reported co-morbid conditions were depression (n=11, 5.5%), anxiety (n=9, 4.5%), diabetes (n=9, 4.5%) and sleep apnoea (n=8, 4.0%). Moreover, 84 (41.8%) participants reported that they were currently taking medication with 21.9% (n=44) taking one medication, 15.5% (n=31) two to four medications and 5% (n=10) more than five medications.

Table 4: Health-related characteristics of the sample population

<table>
<thead>
<tr>
<th>Variable</th>
<th>Participants/Drivers (n = 201)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Co-morbid condition</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>121</td>
</tr>
<tr>
<td>Yes</td>
<td>80</td>
</tr>
<tr>
<td>Number of co-morbid conditions reported by driver</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>121</td>
</tr>
<tr>
<td>1</td>
<td>55</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>3+</td>
<td>11</td>
</tr>
</tbody>
</table>
Number of drivers with a self-reported diagnosis of:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart disease</td>
<td>7</td>
<td>3.5</td>
</tr>
<tr>
<td>Angina</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>Stroke</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diabetes</td>
<td>9</td>
<td>4.5</td>
</tr>
<tr>
<td>Arthritis</td>
<td>6</td>
<td>3.0</td>
</tr>
<tr>
<td>Kidney disease</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Hearing impairment</td>
<td>7</td>
<td>3.5</td>
</tr>
<tr>
<td>Visual impairment</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>Sleep apnoea</td>
<td>8</td>
<td>4.0</td>
</tr>
<tr>
<td>Depression</td>
<td>11</td>
<td>5.5</td>
</tr>
<tr>
<td>Anxiety</td>
<td>9</td>
<td>4.5</td>
</tr>
<tr>
<td>Physical impairment</td>
<td>5</td>
<td>2.5</td>
</tr>
<tr>
<td>Other medical condition</td>
<td>53</td>
<td>26.4</td>
</tr>
</tbody>
</table>

Currently taking medication(s)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>117</td>
<td>58.2</td>
</tr>
<tr>
<td>Yes</td>
<td>84</td>
<td>41.8</td>
</tr>
</tbody>
</table>

Number of medications taken

<table>
<thead>
<tr>
<th>Number</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>117</td>
<td>58.2</td>
</tr>
<tr>
<td>1</td>
<td>44</td>
<td>21.6</td>
</tr>
<tr>
<td>2-4</td>
<td>31</td>
<td>15.2</td>
</tr>
<tr>
<td>≥5</td>
<td>9</td>
<td>5.0</td>
</tr>
</tbody>
</table>

### 5.1.3 Driving-related characteristics

All drivers (100%) stated that they ‘always’ wore a seat-belt whilst driving with half of participants (49.8%) rating their driving as ‘good’ and 39.8% as ‘excellent’. The mean number of years of driving experience since obtaining a driver’s license was 28.8 (SD=17.4) years with a minimum of one and a maximum of 61 years. Forty-eight percent of participants wore glasses and 82.1% obtained their driver’s license in Australia. Approximately 10.9% were involved in a crash in the past year and 19.9% had received at least one traffic infringement in the past year. In terms of driving exposure, 49.8% had driven less than 249 km in the past week and 36.8% had driven between 250 and 499 km in the past week. Approximately 61.7% drove on average seven days a week. Eighteen percent of participants (n=37) had undergone additional driver training/qualifications (Table 5).
<table>
<thead>
<tr>
<th>Variables</th>
<th>Participants/Drivers (n = 201)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Glasses/contact lenses worn whilst driving</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>103</td>
</tr>
<tr>
<td>Yes</td>
<td>98</td>
</tr>
<tr>
<td>Driver’s licence obtained in Australia</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>36</td>
</tr>
<tr>
<td>Yes</td>
<td>165</td>
</tr>
<tr>
<td>Driven motor vehicle in another country for 12+ months</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>134</td>
</tr>
<tr>
<td>Yes</td>
<td>67</td>
</tr>
<tr>
<td>License(s) held in addition to C/CA license</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>122</td>
</tr>
<tr>
<td>Yes</td>
<td>79</td>
</tr>
<tr>
<td>Additional driving qualifications/training</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>164</td>
</tr>
<tr>
<td>Yes</td>
<td>37</td>
</tr>
<tr>
<td>Self-rated quality of driving</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>0</td>
</tr>
<tr>
<td>Fair</td>
<td>1</td>
</tr>
<tr>
<td>Average</td>
<td>20</td>
</tr>
<tr>
<td>Good</td>
<td>100</td>
</tr>
<tr>
<td>Excellent</td>
<td>80</td>
</tr>
<tr>
<td>Self-reported crash involvement in previous 12 months (as the driver)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>179</td>
</tr>
<tr>
<td>Yes</td>
<td>22</td>
</tr>
<tr>
<td>Traffic infringement(s) received in previous 12 months</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>161</td>
</tr>
<tr>
<td>Yes</td>
<td>40</td>
</tr>
<tr>
<td>Number of traffic infringements received in previous 12 months</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>161</td>
</tr>
<tr>
<td>1</td>
<td>31</td>
</tr>
<tr>
<td>2+</td>
<td>9</td>
</tr>
<tr>
<td>Years of driving experience since receiving license</td>
<td></td>
</tr>
<tr>
<td>≤9 years</td>
<td>27</td>
</tr>
<tr>
<td>10-19 years</td>
<td>44</td>
</tr>
<tr>
<td>20-29 years</td>
<td>41</td>
</tr>
<tr>
<td>≥30 years</td>
<td>89</td>
</tr>
</tbody>
</table>
Average number of days driven per week

<table>
<thead>
<tr>
<th>Days</th>
<th>Mean (SD)</th>
<th>13 (6.5)</th>
<th>6 (3.0)</th>
<th>22 (10.9)</th>
<th>36 (17.9)</th>
<th>124 (61.7)</th>
</tr>
</thead>
</table>

Average kilometres driven per week

<table>
<thead>
<tr>
<th>Kilometres</th>
<th>100 (49.8)</th>
<th>74 (36.8)</th>
<th>20 (10)</th>
<th>7 (3.5)</th>
</tr>
</thead>
</table>

≤249 km
250-499 km
500-749 km
≥750 km

5.2 NASA Task Load Index results – subjective workload

The results of the NASA Task Load Index, completed at the conclusion of the simulator assessment are presented in Table 6. Overall, for all participants the six domain scores were considered to be low cognitive workload with an overall mean score of 30.3 (SD=16.6). When examining by age-group, those aged 60+ experienced the most difficulty on all six domain scores with the exception of frustration. In particular, the mean mental (44.6, SD=26.3) and mean effort scores (42.8, SD=28.1) were high compared to the other age-groups.

Table 6: Mean NASA-TLX measure of perceived workload demands by age group

<table>
<thead>
<tr>
<th>Domain</th>
<th>Overall Mean (SD)</th>
<th>17-24 years Mean (SD)</th>
<th>25-40 years Mean (SD)</th>
<th>41-59 years Mean (SD)</th>
<th>≥60 years Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental</td>
<td>38.69 (24.36)</td>
<td>31.93 (23.19)</td>
<td>34 (24.23)</td>
<td>40.04 (22.44)</td>
<td>44.56 (26.28)</td>
</tr>
<tr>
<td>Physical</td>
<td>19.87 (18.61)</td>
<td>11.12 (10.40)</td>
<td>16.69 (17.19)</td>
<td>22.39 (18.74)</td>
<td>23.01 (20.87)</td>
</tr>
<tr>
<td>Performance</td>
<td>20.20 (19.34)</td>
<td>13.62 (12.86)</td>
<td>15.95 (18.74)</td>
<td>23.34 (20.06)</td>
<td>23.15 (19.73)</td>
</tr>
<tr>
<td>Effort</td>
<td>38.82 (24.76)</td>
<td>39.81 (24.37)</td>
<td>32.23 (22.62)</td>
<td>41.52 (23.25)</td>
<td>42.83 (28.12)</td>
</tr>
<tr>
<td>Frustration</td>
<td>15.59 (19.40)</td>
<td>9.75 (9.8)</td>
<td>10.92 (13.44)</td>
<td>19.98 (20.19)</td>
<td>17.20 (24.61)</td>
</tr>
<tr>
<td>Total Score</td>
<td><strong>30.27 (16.64)</strong></td>
<td><strong>24.74 (12.09)</strong></td>
<td><strong>25.13 (15.97)</strong></td>
<td><strong>32.58 (16.43)</strong></td>
<td><strong>35.02 (17.13)</strong></td>
</tr>
</tbody>
</table>
When examining factors that were associated with a higher cognitive workload a dose–response relationship was evident, with increasing age (41-59 and ≥60 years) significantly associated with a higher cognitive workload, after adjusting for potential confounding factors. Male drivers also experienced marginally significant lower cognitive workload then female drivers after adjusting for potential confounding factors (Table 7).

### Table 7: Factors associated with cognitive workload score after driving the simulator

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>95% confidence interval</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>25.94</td>
<td>17.68 – 34.20</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Gender (Male)</td>
<td>-4.59</td>
<td>-0.06 – -0.32</td>
<td>0.05*</td>
</tr>
<tr>
<td>Age-group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-40</td>
<td>1.59</td>
<td>-0.74 – 10.60</td>
<td>0.07</td>
</tr>
<tr>
<td>41-59</td>
<td>9.70</td>
<td>0.64 - 18.76</td>
<td>0.03*</td>
</tr>
<tr>
<td>≥=60</td>
<td>12.81</td>
<td>3.32 - 22.28</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Kilometres travelled**</td>
<td>-0.02</td>
<td>-0.00 – 0.01</td>
<td>0.96</td>
</tr>
</tbody>
</table>

*Significant at p<0.05  **km travelled in an average week

### 5.3 Driving simulator performance data

#### 5.3.1 Lateral control

A repeated ANOVA was run on the sample of 165 participants who had complete driving simulation records, to examine the effect of type of intersection on time spent out of lane. There was a non-significant difference between the effects of type of intersection on time spent out of lane: \( F(1, 656) = 0.57, p = 0.45 \). The mean time spent out of lane on while negotiating the DDI was 0.03 (SD=0.17) seconds compared to 0.01 (SD=0.14) seconds while travelling through the traditional intersection. While most participants did not spend any time out of lane (98%), the majority of those who did were aged over 60 years (58%) and were travelling through the DDI (93%). A similar pattern also emerged for the number of lane excursions, with a non-significant difference between the type of intersection on the number of lane excursions: \( F(1, 656) = 0.35, p = 0.55 \).
5.3.2 Speed

When examining the driver’s mean vehicle speed through the DDI (speed limit = 40 km/h) compared to a traditional intersection (speed limit = 70 km/h), drivers tended to travel over the speed limit in the DDI (Table 8). A significant effect was evident between the type of intersection and compliance to the speed limit: \( F(1, 656) = 160.11, p < 0.001 \). The majority of participants who did report episodes of speeding were aged less than 60 years of age (85%).

<table>
<thead>
<tr>
<th>Type of Intersection</th>
<th>Mean speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDI (speed limit = 40 km/h)</td>
<td>53.62 (SD=7.60)</td>
</tr>
<tr>
<td>Traditional intersection (speed limit = 70 km/h)</td>
<td>67.54 (SD=6.83)</td>
</tr>
</tbody>
</table>

5.3.3 Crashes/ near misses

There were no crashes/ near-misses recorded by any participants during the drive in the simulator.

5.4 Qualitative results

Three open-ended questions were asked by the researcher at the end of the assessment regarding the difficulty participants had navigating the DDI and whether signage and road markings could be improved.

Only 16% of the cohort reported difficulty navigating through the DDI. Some of the difficulties participants experienced are listed below:

- “First time seeing it is a lot to take in, the second time was easier and understood what to do”
- “The curves were a bit confusing in the beginning. The second time through was fine”
- “Short distance between the two traffic lights. Didn't expect the second set of lights to come up so quick”
- “Hard to understand at first. Not enough warning of what was coming up”
• “A lot of stop/ start in the DDI. Caused a lot of swerving, unfamiliar so didn't know the roads were going to curve”
• “DDI took more concentration, but still easy to navigate. DDI felt like being on the wrong side of the road, which I was”
• “Not as familiar with the DDI so more difficult”
• “Have to concentrate more due to the chicane and curves”
• “Steering on the curve of the DDI was mentally challenging”
• “Lots of turning and twisting on the DDI”
• “Would be possible to go the wrong way easily if you're distracted”
• “Steering around the curve in the DDI was difficult initially”
• “DDI- missed the 40 km/h signage on the first drive through”
• “Speed through the DDI hard to gauge”
• “Concentrating on the curve made me run the red lights at the end of the DDI”
• “Felt like I got a bit disorientated on the curve, and lost my way a bit”
• “Felt a bit uncomfortable being on the wrong side of the road”
• “The number of turns involved”

5.4.1 Signage

Responses to the question regarding “How do you think the signage for the DDI could be improved?” are listed below:

• “Could have been more 40km/h signs in the DDI”
• “Need more signage”
• “Didn’t see the 40km/h signage on the first pass”
• “In a right hand lane, that all of sudden becomes a right turn lane, not signed”
• “Signage should be earlier before the DDI”

5.4.2 Road markings

Responses to the question regarding “How do you think the road markings could be improved?” are listed below:

• “The arrows at the DDI should have started earlier to give you more time to see where you were going”
• “Too many road markings, makes it confusing”
“The line markings at the DDI after the first set of traffic lights point ahead but then there is an unexpected turn at the end of the DDI”

5.5 Behavioural observations/ observed driving errors in simulator

5.5.1 Total errors observed

A total of 71 driving errors were observed among participants. These 71 errors were made by 25 participants in 33 out of 394 simulator trips (8.4% of trips). The number of errors made by each of the 25 drivers ranged from one to nine errors. It should be noted that the nine errors made by one participant were all related to failing to keep two hands on the steering wheel while driving.

The number of driving errors observed whilst participants navigated the East-west and West-east scenarios in the driving simulator are summarised in Table 9. For the 71 driving errors, 44 (62.0%) occurred in the West-East scenario and 27 (38.0%) occurred in the East-West scenario. The most frequently observed error in total and for each direction was the failure of the driver to keep two hands on the steering wheel whilst operating the vehicle (n=32; 45.1%). Red light violations were the second most frequently observed driving error overall (n=20; 28.2%), of which 12 (16.9%) were related to the driver stopping the vehicle with the bumper over the stopline, and eight (11.3%) were associated with the driver failing to stop at a red light. However, the frequency of these red light violations varied for each direction. For instance, the majority of failures to stop at a red light occurred in the East-West direction (n=6, 80%), while the majority of drivers stopping with the vehicle’s bumper after the stopline occurred in the West-East direction (n=10, 83%). Road law violations were observed on 13 occasions and accounted for 18.3% of total driving errors, of which 5 (7.0%) were failures to obey road markings, and 8 (11.3%) were failures to obey street signs. Of note, no wrong way violations were observed in either direction while navigating the DDI driving scenario (Table 9).
Overall, 46 of the 71 driving errors were observed whilst the driver was navigating an intersection in either the East-West or West-East direction. The 46 errors that were observed at intersections were made by 18 drivers in 25 out of 394 simulator trips (6.3% of trips). A summary of the driving errors that occurred at intersections is provided in Table 10. Of these 46 observed driving errors, 33 occurred in the DDI compared to 13 which occurred in a traditional intersection. Furthermore, 12 errors were observed whilst the driver was entering the DDI and 21 occurred whilst exiting the DDI. In regards to the 13 errors that occurred at traditional intersections, 10 took place at traditional intersection 1 and three occurred at traditional intersection 2.

Red light violations were the most frequently observed driving error whilst navigating an intersection (n=20, 43.5%) (Table 10). Eight of these involved running a red light
(17.4%) with six occurring while entering or exiting the DDI and two at the traditional intersections. Twelve red light violations involved stopping with the vehicle’s bumper over the stopline (26.1%) with nine occurring entering or exiting the DDI and three at the standard intersections. The next most frequently observed driving error at intersections was failure of the driver to keep two hands on the steering wheel (n=15, 32.6%). There were also nine road law errors, all occurring entering or exiting the DDI (19.5%). It should be noted there were no navigation errors observed entering or leaving the DDI.

Table 10: Summary of driving errors that occurred at standard and DDI intersections

<table>
<thead>
<tr>
<th>Error Category</th>
<th>Standard Intersection</th>
<th>DDI</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intersection 1</td>
<td>Intersection 2</td>
<td>Entering</td>
</tr>
<tr>
<td>Physical Control of Vehicle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail to keep 2 hands on steering wheel</td>
<td>3 (6.5%)</td>
<td>3 (6.5%)</td>
<td>4 (8.7%)</td>
</tr>
<tr>
<td>Road Laws</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail to obey road markings</td>
<td>- (-)</td>
<td>- (-)</td>
<td>2 (4.3%)</td>
</tr>
<tr>
<td>Fail to obey signs</td>
<td>- (-)</td>
<td>- (-)</td>
<td>1 (2.2%)</td>
</tr>
<tr>
<td>Navigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail to proceed straight through traffic lights</td>
<td>2 (4.3%)</td>
<td>- (-)</td>
<td>- (-)</td>
</tr>
<tr>
<td>Red Light Violations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run red light (no stop)</td>
<td>2 (4.3%)</td>
<td>- (-)</td>
<td>3 (6.5%)</td>
</tr>
<tr>
<td>Stop with bumper after stopline</td>
<td>3 (6.5%)</td>
<td>- (-)</td>
<td>2 (4.3%)</td>
</tr>
<tr>
<td>All Error Categories</td>
<td>10 (21.6%)</td>
<td>3 (6.5%)</td>
<td>12 (26%)</td>
</tr>
</tbody>
</table>
6. DISCUSSION

This is the first study of its kind to provide objective comprehensive evidence on the difficulties WA drivers may experience while negotiating a DDI, compared to a traditional intersection. Consistent with previous international studies, minimal difficulties for drivers negotiating the DDI were identified using the simulator measures, behavioural observations and qualitative measures in this study.

Behavioural observation measures

This study included several behavioural observations of drivers while negotiating the DDI and traditional intersections in the simulator, undertaken by a researcher. Most importantly, no wrong way violation errors were observed while negotiating the DDI. This addresses the major concern with the DDI design, which is that drivers will bear left at crossovers and drive against the intended traffic flow, thus increasing the possibility of a low speed head-on collision. This is consistent with findings from a US-based simulator study examining errors while negotiating a DDI, which also reported no wrong-way violations at the DDI crossovers from 1041 opportunities for this to occur (Inman et al., 2007). Together, these findings indicate that this concern appears unwarranted.

In addition, no navigation errors were observed while entering or leaving the DDI, defined as following a road to a destination other than they were asked to follow. It should be noted however, that in this study, participants were only requested to travel straight through the DDI. Similarly, in the US-based simulator study examining DDI performance, navigation errors were rare (2.3% of opportunities) despite participants being asked to follow more complex directions and use entry and exit ramps (Inman et al., 2007). In addition, there was no significant difference in the number of navigation errors occurring at the DDI and traditional intersections in the US-based study (Inman et al., 2007). This suggests that navigation errors are unlikely to increase with the installation of a DDI.

Overall, a low number of other driver errors were observed at the intersections with a total of 46 errors from 394 simulator trips. Seventy two percent of these errors occurred entering or leaving the DDI and 28% occurred at the traditional intersections. Of some concern, the most frequent type of error at intersections were red light violations (44%),
including running the red light or stopping with the bumper over the stopline. These violations were more common at the DDI than the traditional intersections. Interestingly, the US-based simulator study found that red-light violations occurred at similar relative frequencies in the DDI and traditional intersections (Inman et al., 2007). This difference may be due to the fact that in the US-based study, each participant drove the route multiple times, giving them a chance to learn the layout of the DDI and location of traffic lights. In the current study, participants drove the route twice meaning the unfamiliarity of the DDI could lead to these errors. In addition, two thirds of red light violation errors in the DDI occurred when exiting the DDI and this may be due to the unexpectedly short distance between entry and exit traffic lights in a DDI design. This finding suggests that WA drivers require education on what to expect and how to use the new DDI interchanges, in order to avoid red light violations and the crashes that may result from these.

Failure to keep two hands on the steering wheel was another observed error (33%) but a similar number of these errors were observed for the DDI and traditional intersections, indicating this error type is unrelated to intersection design. Finally, road law errors accounted for 20% of intersection errors including failure to obey road markings or signs, with all occurring while entering or leaving the DDI. This should also be considered when educating WA drivers on how to safely use the new DDI.

**Simulator performance measures**

The effect of the DDI on several simulator measures were examined including time spent out of lane, number of lane excursions, compliance to speed limit and crashes/near misses.

Drivers spent more time out of lane on the DDI (0.03 seconds) compared to the traditional intersection (0.01 seconds), though this difference was not significant. There was also a non-significant difference in the number of lane excursions between intersection types. This finding is expected and most likely due to the curved nature of the DDI design, while the traditional intersections involve straight roads only. Overall, the effect of the DDI on time spent out of lane appears to be very minor and the majority of participants (98%) did not spend any time out of the lane. It should be noted however, that the majority of those who spent any time out of lane were aged over 60 years (58%) and were travelling through the DDI (93%).
A significant effect was evident between type of intersection and compliance to the speed limit with drivers travelling over the speed limit more in the DDI. This most likely occurred due to the lower speed limit in the DDI (40 km/h) versus the traditional intersection (70km/h). Speed limits are required to be lower in DDI versus traditional intersections because the curvature of the DDI reduces the speed at which the intersection can be safely and comfortably negotiated (Inman et al., 2007). Some participants commented that the DDI required better signage in order for the 40 km/h speed limit to be noticed and observed. This finding highlights the importance of obvious and well-placed speed signage on the approach to the DDI in order to improve compliance to the slower 40 km/h speed limit. The majority of participants who had episodes of speeding were aged less than 60 years of age (85%) so education for all drivers on the reduced speed limit at new DDIs is also recommended.

Despite the poorer compliance with the speed limit in the DDI, the mean speed travelled through the DDI was still 14 km/h lower than the traditional intersection in this study. The US-based simulator study examining DDI performance found that participants drove significantly slower through the DDI when both intersection types were signed at speed limits of 40 km/h (Inman et al., 2007). These findings suggest that even if speed limit compliance is poorer in the DDI than the traditional intersection, actual speed would still likely be lower, conferring a safety benefit in the event of a crash.

Finally, it should be noted that there were no crashes or near misses recorded by any participants in the driving simulator scenario. Although the risk of crashes or near misses was minimised by the lack of traffic, this finding is still encouraging.

**Qualitative measures**

Qualitative data regarding the difficulty participants had navigating the DDI found that only 16% of participants reported any difficulty negotiating the DDI in the simulator. These self-reported difficulties included: negotiating the curves of the DDI, short distance between the traffic lights at the entry and exit of the DDI, participants missing signage on approach to the DDI and discomfort felt when required to drive on the ‘wrong’ side of the road in the DDI. In regards to signage and road markings, participants suggested more signage, earlier signage, earlier road markings and less road markings.
NASA task load index

For the NASA Task Load Index, completed at the conclusion of the simulator assessment, mean overall scores and the six domain scores classified the task as ‘low’ cognitive workload. The scale ranges from ‘very low’ to ‘very high’ and the classification of ‘low’ cognitive workload indicates that overall, participants did not find the task of driving through the DDI to be very complex or demanding (Paxion, Galy, & Berthelon, 2014).

However, after adjusting for confounders, a significant dose-response relationship was evident between increasing age and overall cognitive workload on the driving simulator task. Drivers aged 41-59 years and 60 years and over had significantly higher cognitive workload scores than the younger drivers in the study. This is important because if the new DDI requires increased mental workload for older drivers, they may have reduced ability to switch their attention between critical tasks while negotiating the DDI, e.g. watching for traffic, pedestrians, reading signs, checking speedometer (Rizzo et al., 2004). It should be noted however, that while these findings could be due to the new DDI design being more cognitively demanding for older adults, it may also be due to the simulator itself being less familiar and more demanding than for younger drivers who may be more familiar with electronic equipment and gaming.

Limitations

This study had some limitations. While many measures were taken to ensure the recruitment of participants of a wide range of ages and demographics to the study, there remains some opportunity for bias in the selection of the sample. For example, a high proportion of participants had a university degree (68%), suggesting the sample may have a higher education level than the general population of WA. In addition, some participants experienced simulator sickness (3%) and had to be excluded from the study. In relation to the simulator scenario, there were no other vehicles included in the scenario as it was felt that if other traffic was included participants may just follow the lead vehicle, which may not identify any issues they have with the DDI. This meant there was no opportunity to examine the interaction of the driver with other vehicles in the DDI and is an area for further research. Finally, the safety effects of additional traffic volumes that will be generated by the improved efficiency of the DDI was unable to be examined in this simulator study and is another area for further research.
7. **CONCLUSION**

This study is the first study of its kind to provide objective comprehensive evidence on the difficulties WA drivers may experience while negotiating a DDI, compared to a traditional intersection. Consistent with previous international studies, minimal difficulties for drivers negotiating the DDI were identified using the simulator measures, behavioural observations and qualitative measures in this study.

Most importantly, no wrong way violations or navigation errors were observed while negotiating the DDI in the simulator, suggesting these errors are unlikely to increase with the installation of a DDI in WA. While the overall number of errors observed at intersections was low, the most frequent type of error were red light violations (44%) and these were more common at the DDI than the traditional intersections. In addition, drivers travelled over the speed limit more in the DDI (speed limit = 40 km/h) than the traditional intersection (speed limit = 70 km/h).

While drivers performed well overall, there was some indication that older drivers may have experienced more difficulty negotiating the DDI. The majority of participants who spent any time out of lane were aged 60+ and older drivers reported significantly higher cognitive workload scores while negotiating the intersections than younger drivers.

Therefore, recommendations surrounding the installation of new DDIs in WA and Australia include:

1. Community education on how to use the new DDI interchanges, in order to avoid red light violations and the crashes that may result from these.
2. Obvious and well-placed speed signage on the approach to the DDI in order to improve compliance to the 40 km/h speed limit.
3. Community education for all drivers on the reduced 40 km/h speed limit at new DDIs.
4. Targeted education for older drivers on how to navigate the DDI safely.

Overall, this simulator study confirmed that WA drivers had minimal difficulties negotiating the DDI. The reduction in conflict points and lower speed limit afforded by the DDI in combination with the very few recorded driver errors imply that installation of DDIs would have safety benefits and should be considered for use in the WA road environment.
8. REFERENCES


APPENDIX A

Diverging Diamond Interchange - Simulator Study

The Curtin-Monash Accident Research Centre is seeking volunteers to participate in a study of people’s driving behaviours within a *Diverging Diamond Interchange*.

- The ‘Diverging Diamond Interchange’ is a new type of traffic light intersection design that has shown safety benefits in other countries.
- Our study aims to evaluate the performance of 200 WA drivers on Diverging Diamond Interchanges using a driving simulator (pictured above).
- The results of this research will allow us to develop recommendations for the safest possible construction and signage of new Diverging Diamond intersections in WA and guide education programs for different groups of WA drivers on how to safety negotiate these intersections.

We are seeking 200 people who:
- Are aged 18 to 80 years.
- Have had their driver’s licence for at least 12 months and drive at least three times per week.
- Live in Perth.

If this describes you go to [http://goo.gl/SuTJzb](http://goo.gl/SuTJzb) and register to drive the new Curtin University driving simulator for research.

What’s involved?

Participation in the study will involve you visiting Curtin University once to complete a driving simulator assessment and questionnaires.

Why should you participate?

We hope that the results of this research will benefit the WA community in future by allowing us to develop recommendations for the safest possible construction and signage of new Diverging Diamond Intersections in WA and guiding education programs for different groups of WA drivers on how to safety negotiate these intersections.

This study has been approved by the Curtin University Human Research Ethics Committee (Approval Number RDHS-105-15). If you have any concerns, you may contact the Curtin University Human Research Ethics Committee Secretary on 9266 9233 or hrec@curtin.edu.au

Need more information?

Contact Trish Barrett on ☎ 9266 9964  📧 t.barrett@curtin.edu.au
APPENDIX B

THE DIAMOND STUDY

PARTICIPANT INFORMATION STATEMENT

<table>
<thead>
<tr>
<th>HREC Project Number</th>
<th>RDHS-105-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Title</td>
<td>The DIAMOND Study: Diverging Diamond Interchanges in Western Australia: Performance on a Driving simulator</td>
</tr>
</tbody>
</table>
| Principal Investigator | Professor Lynn Meuleners  
                          | Director, Curtin-Monash Accident Research Centre |

What is the Project About?

- The ‘Diverging Diamond Interchange’ is a new type of traffic light intersection design that has shown safety benefits in other countries.
- There is concern that when new Diverging Diamond Interchanges are introduced in WA, there may actually be an increase in crashes due to drivers being unfamiliar with the intersections.
- Therefore, our study aims to evaluate the performance of 200 WA drivers on Diverging Diamond Interchanges under different conditions, using a driving simulator.
- The results of this research will allow us to develop recommendations for the safest possible construction and signage of new Diverging Diamond Intersections in WA and guide education programs for different groups of WA drivers on how to safely negotiate these intersections.

Who is doing the Research?

- The project is being conducted by Professor Lynn Meuleners, Curtin-Monash Accident Research Centre (C-MARC), Curtin University.
- This research project is funded by a grant from the Neurotrauma Research Program.
- There will be no costs to you for being involved and you will not be paid for participating in this project.

Why am I being asked to take part and what will I have to do?

- You have been asked to take part because you are aged between 18 and 80 years, live in Perth, have a current WA ‘C class’ licence (passenger vehicle), have had your licence for one year or more and drive at least three times per week.
- Participation in the study will involve you visiting Curtin University once to complete a driving simulator assessment and questionnaires.
- The study will take place at the Curtin-Monash Accident Research Centre, 7 Parker Place, Technology Park, Bentley, WA.
- You will be asked to drive the C-MARC simulator. It represents an automatic Holden Commodore sedan with working controls and instruments. When driving the simulator, you will be completely enclosed, surrounded by a 360 degree visual system and experience motion from the simulator. First, you will be given the chance to practice driving the simulator, then you will be asked to drive through a number of intersections in the simulator.
- After each of the driving simulator scenarios, we will ask you to complete a short computer-based questionnaire rating the level of physical and mental effort you experienced while driving.
THE DIAMOND STUDY

- During your visit, you will also be asked to complete a face-to-face questionnaire about you (e.g. age, education, country of birth, medical conditions and medications), your driving experience, habits and difficulties and your crash history.
- It will take approximately one hour to complete the simulator assessment and questionnaires.
- There will be no cost to you for taking part in this research and you will not be paid for taking part.

Are there any benefits to being in the research project?
- There may be no direct benefit to you from participating in this research.
- We hope that the results of this research will benefit the WA community in future by allowing us to develop recommendations for the safest possible construction and signage of new Diverging Diamond intersections in WA and guiding education programs for different groups of WA drivers on how to safely negotiate these intersections.

Are there any risks, side-effects, discomforts or inconveniences from being in the research project?
- Some people experience 'simulator sickness', similar to motion sickness while driving the simulator. Symptoms may include headache, sweating, dry mouth, drowsiness, vertigo and/or nausea. These symptoms are temporary. To minimise your risk of 'simulator sickness', the simulator has been calibrated and scenarios carefully designed. However, if you feel any of these symptoms you will be asked to inform the researcher and the assessment will be stopped immediately. You will be offered water and the researcher will remain with you until you are able to leave. Symptoms usually subside within 15 minutes.
- There are no other foreseeable risks from this research project.
- Potential inconveniences to you from being in this research project include time and travel inconveniences.

Who will have access to my information?
- The information collected in this research will be re-identifiable (coded). This means that the stored information will be re-identifiable which means we will remove identifying information on any data or sample and replace it with a code. Only the research team have access to the code to match your name if it is necessary to do so. Any information we collect will be treated as confidential and used only in this project unless otherwise specified. The following people will have access to the information we collect in this research: the research team and the Curtin University Ethics Committee.
- Electronic data will be password-protected and hard copy data will be in locked storage.
- The information we collect in this study will be kept under secure conditions at Curtin University for 7 years after the research has ended and then it will be destroyed.
- You have the right to access, and request correction of, your information in accordance with relevant privacy laws.
- The results of this research may be presented at conferences or published in professional journals. You will not be identified in any results that are published or presented.
THE DIAMOND STUDY

Will you tell me the results of the research?

- We will write to you at the end of the research and let you know the results of the research. Results will not be individual but based on all the information we collect and review as part of the research.

Do I have to take part in the research project?

- Taking part in a research project is voluntary. It is your choice to take part or not. You do not have to agree if you do not want to. If you decide to take part and then change your mind, that is okay, you can withdraw from the project. You do not have to give us a reason; just tell us that you want to stop. Please let us know you want to stop so we can make sure you are aware of any thing that needs to be done so you can withdraw safely. If you choose not to take part or start and then stop the study, it will not affect your relationship with the University, staff or colleagues. If you chose to leave the study we will use any information collected unless you tell us not to.

What happens next and who can I contact about the research?

- If you would like further information or to ask questions about the project, please contact:
  Professor Lynn Meuleners
  Ph: (08) 9266 4636
  Email: L.Meuleners@curtin.edu.au

- If you decide to take part in this research we will ask you to sign the consent form. By signing it is telling us that you understand what you have read and what has been discussed. Signing the consent indicates that you agree to be in the research project and have your health information used as described. Please take your time and ask any questions you have before you decide what to do. You will be given a copy of this information and the consent form to keep.

All research in Australia involving humans is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this research project have been approved by the Curtin University HREC. This project will be carried out according to the National Statement on Ethical Conduct in Human Research (2007). If you have any concerns and/or complaints about the project, the way it is being conducted or your rights as a research participant, and would like to speak to someone independent of the project, please contact: The Curtin University Ethics Committee by telephoning 9266 2784 or by emailing hrec@curtin.edu.au.
CONSENT FORM

<table>
<thead>
<tr>
<th>HREC Project Number:</th>
<th>RDHS-105-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Title:</td>
<td>The DIAMOND Study: Diverging Diamond Interchanges in Western Australia: Performance on a Driving Simulator</td>
</tr>
</tbody>
</table>
| Principal Investigator: | Professor Lynn Meuleners  
                          Director, Curtin-Monash Accident Research Centre |

- I have read the information statement version listed above and I understand its contents.
- I believe I understand the purpose, extent and possible risks of my involvement in this project.
- I voluntarily consent to take part in this research project.
- I have had an opportunity to ask questions and I am satisfied with the answers I have received.
- I understand that this project has been approved by Curtin University Human Research Ethics Committee and will be carried out in line with the National Statement on Ethical Conduct in Human Research (2007) – updated March 2014.
- I understand I will receive a copy of this Information Statement and Consent Form.

<table>
<thead>
<tr>
<th>Participant Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant Signature</td>
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<tr>
<td>Date</td>
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</table>

**Declaration by researcher:** I have supplied an Information Letter and Consent Form to the participant who has signed above, and believe that they understand the purpose, extent and possible risks of their involvement in this project.

<table>
<thead>
<tr>
<th>Researcher Name</th>
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<tbody>
<tr>
<td>Researcher Signature</td>
</tr>
<tr>
<td>Date</td>
</tr>
</tbody>
</table>
APPENDIX C

Demographic details

Participant ID Number

What is your gender?
- Female
- Male

What is your marital status?
- Single
- De facto
- Married
- Separated
- Divorced
- Widowed

What is your highest educational qualification
- Did not go to school
- Primary School
- Secondary School
- TAFE, Apprenticeship
- University

In what country were you born?
- Australia
- New Zealand
- United Kingdom
- Europe
- Vietnam
- China & Hong Kong
- Middle East
- Other (please specify)
- I don't know

How old are you?

What language do you speak at home?
- English
- Other (please specify)

Are you currently employed?

Yes
No

What is your current occupation?

Do you currently have a diagnosis of any of the following medical conditions?

- Heart Disease
- Angina
- Stroke
- Diabetes
- Arthritis
- Kidney Disease
- Epilepsy
- Hearing impairment
- Visual impairment
- Sleep apnoea
- Depression
- Suffer from anxiety
- Any physical impairment
- Any other medical conditions you have been diagnosed with?

Are you currently taking any medications?

- Yes
- No

If yes, please specify below:

<table>
<thead>
<tr>
<th>Medication</th>
<th>Medication name (including over-the-counter medications e.g cough mixture)</th>
<th>Type of use (e.g. daily)</th>
<th>Length of use (e.g. 1 week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medication 1.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medication 2.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medication 3.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medication 4.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Medication 5.</td>
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<td></td>
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<tr>
<td>Medication 6.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Medication 7.</td>
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<td></td>
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<tr>
<td>Medication 8.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Medication 9.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medication 10.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Driving Habits questionnaire

Do you wear glasses or contact lenses when you drive?

- Yes
- No
Did you get you driving license in Australia?
- Yes
- No

In which state of Australia did you get your license?
- Western Australia
- Northern Territory
- Queensland
- New South Wales
- Victoria
- Tasmania
- South Australia

In which country did you get your driver’s license?

How many years have you been driving since you got your license?

Have you driven a motor vehicle in another country for more than 12 months?
- Yes
- No

How many years did you drive in another country?

What type(s) of driving license(s) do you hold?

Do you hold any additional driving qualifications/training?
- Yes
- No

Do you wear a seat-belt when you drive?
- Always
- Sometimes
- Never

How would you rate the quality of your driving?
- Excellent
- Good
- Average
- Fair
- Poor
In an average week, how many days per week do you usually drive?

In an average week, how many kilometres do you normally drive?

How many accidents have you been involved in over the past year when you were the driver?

How many crashes have you been involved in over the past year when you were the driver?

How many times in the past year have you received a traffic ticket where you were the driver of the motor vehicle?
You may have noticed that there were two kinds of intersections along the route you drove in the simulator. One was a conventional four-leg signalised junction and one was a DDI.
1. Which intersection was easier to understand from a driver point of view?
   Standard intersection [ ]
   Diverging Diamond Intersection [ ]

2. What specific issues did you experience with negotiating each of the intersections?
   [Blank lines for answer]

3. Did you find the find the signage in the simulation adequate?
   Yes [ ]
   No [ ]
   How do you think the signage could be improved? [Blank lines for answer]

4. Did you find the find the road markings in the simulation adequate?
   Yes [ ]
   No [ ]
   How do you think the road markings could be improved? [Blank lines for answer]

5. Did you encounter any problems while driving through the diverging diamond intersection?
   Yes [ ]
   Please describe the problems you encountered [Blank lines for answer]
   No [ ]

6. Do you have any other comments regarding driving through the simulation? [Blank lines for answer]
APPENDIX E

**NASA Task Load Index: computer-administered**

Please indicate the amount of workload involved for each item on the relevant scale:

**Mental Demand**
How mentally demanding was the task?

<table>
<thead>
<tr>
<th>Very Low</th>
<th>Very High</th>
</tr>
</thead>
</table>

**Physical Demand**
How physically demanding was the task?

<table>
<thead>
<tr>
<th>Very Low</th>
<th>Very High</th>
</tr>
</thead>
</table>

**Temporal Demand**
How hurried or rushed was the pace of the task?

<table>
<thead>
<tr>
<th>Very Low</th>
<th>Very High</th>
</tr>
</thead>
</table>

**Performance**
How successful were you in accomplishing what you were asked to do?

<table>
<thead>
<tr>
<th>Perfect</th>
<th>Failure</th>
</tr>
</thead>
</table>

**Effort**
How hard did you have to work to accomplish your level of performance?

<table>
<thead>
<tr>
<th>Very Low</th>
<th>Very High</th>
</tr>
</thead>
</table>

**Frustration**
How insecure, discouraged, irritated, stressed, and annoyed were you?

<table>
<thead>
<tr>
<th>Very Low</th>
<th>Very High</th>
</tr>
</thead>
</table>