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**VIRTUAL ANALYSIS AND EVALUATION OF ROUNDABOUT SAFETY AND
OPERATIONAL FEATURES**

by

Elisha Jackson Wankogere

A thesis submitted to the Graduate College
in partial fulfillment of the requirements
for the degree of Master of Science in Engineering
Civil and Construction Engineering
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VIRTUAL ANALYSIS AND EVALUATION OF ROUNDABOUT SAFETY AND OPERATIONAL FEATURES

Elisha Jackson Wankogere, M.S.E.

Western Michigan University, 2014

Roundabouts can be a solution to safety concerns present at other types of intersections. Recently in the United States, there has been an increase in conversion of problematic intersections to roundabouts to improve their safety. However, it is difficult to make these roundabouts, especially multi-lane roundabouts, safe to all ranges of users. Roundabout features such as advance warning and signage play an important role in determining driver performance as they navigate the roundabout.

This research is an effort to evaluate new and existing roundabout safety and operational features such as signs and pavement markings and how they influence performance of drivers at multi-lane roundabouts. It evaluates the two-lane roundabout and the rotor turbo roundabout as an alternative geometric design to a multi-lane roundabout. Virtual scenario simulation by use of a driving simulator is employed to probe driver response to a variety of roundabouts features.

The results indicate that lane keeping and speeding are still a problem in multi-lane roundabouts. The rotor turbo roundabout performs better in correctness of lane choice and navigation speed control. Yielding was not a significant problem in both kinds of roundabouts. Furthermore, it was found that roundabout signs and pavement markings used in the United States can be adopted for turbo roundabouts.

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Elisha Jackson Wankogere

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CHAPTER 1 INTRODUCTION

1.1 Study Background and Motivation

Roundabouts can be a solution to safety concerns present at other types of intersections. Recently in the US, conversion of such problematic intersections to roundabouts to improve their safety to road users has been increasing (1), (2). However, it is difficult to make these roundabouts, especially multi-lane roundabouts, safe to all ranges of road users, especially those with reduced cognitive and physical capabilities, such as older drivers. Roundabout features such as advance warning and signage play an important role in determining driver performance as they navigate the roundabout.

It has been observed that single-lane roundabouts perform better safety-wise compared to multi-lane roundabouts (3), though due to demand the requirement to serve higher demands with higher capacity roundabouts multilane roundabouts are preferred. Getting motorists to choose and stay in appropriate lanes has been observed to be the main challenge and problem when it comes to navigating multilane roundabouts.

Two studies have specifically evaluated roundabout signage and lane marking through the use of driving simulators. These studies [(4) which deals with three-lane roundabouts and (5), which deals with two-lane roundabouts] have investigated different combinations of signs and marking strategies that result in proper lane selection by letting drivers drive towards a given direction. They all followed the Manual on Uniform Traffic Control Devices (MUTCD) recommended signing and markings of roundabouts. However, these studies above did not consider the effect of

ambient traffic and its influence on driver behavior when navigating through roundabouts. Ambient traffic affects the amount of gap accepted by drivers, driver attention, as well as lane keeping behavior. These factors play a major role in the safety and operational aspects of multilane roundabouts. Factors such as location of navigation signs and lane use markings may be influenced by the presence of ambient traffic as is in real life and thus influence driver behavior in navigating roundabouts.

Other treatments or design alternatives such as the use of turbo roundabouts have been observed to increase safety by reducing conflicts during navigation as well as increase capacity especially in two-lane roundabouts. Though still open for discussion (6), (7), (6) capacity of turbo roundabouts have been reported to be 25-35% higher than the standard two lane roundabouts (8). Two-lane roundabouts present a typical weaving conflict between drivers on the inner lanes trying to exit and those in the outer lane not exiting.

Despite a relatively larger proportion of the US driving population preferring normal intersections to roundabouts (9), (10), roundabouts are expected to continue replacing intersections due to their various advantages (1). For this reason and the rapid acceptability of turbo roundabouts as alternatives to normal modern multilane roundabouts especially in Europe, more turbo roundabouts may make their way into the United States. Though turbo roundabouts haven't yet found extensive adoption in the US, they have already been used in a few locations such as in Indiana (two turbo roundabouts) and as explained in (11). Therefore there is need to study how the US driving population behaves on such roundabouts.

A two lane modern roundabout and a rotor turbo were adopted for the study. The rotor turbo roundabout was adopted as it is relatively very new compared to other kinds of

turbo roundabouts. By the time of writing of this report only one physically existed at Rosmalen, Netherlands. Since the navigation basics of turbo roundabouts are basically the same, the newness of the rotor turbo roundabout and the fact that to the researchers' knowledge no driving simulation studies have been done on turbo roundabouts before, it was decided to adopt the rotor turbo roundabout. For modern multilane roundabouts the two lane modern roundabout was chosen for the study as it the most common multilane roundabout and its safety concerns are lower than those of the three-lane modern roundabout counterpart (4).

1.2 Objectives of the Study

The objective of this research was to evaluate new and existing roundabout safety and operational features such as signs and pavement markings and to determine how these influence performance of drivers at multi-lane roundabouts. In addition, the study evaluated other possible alternatives to the roundabout's geometric designs and how the geometry influences safety and operational aspects. The study employed virtual roundabout scenario simulation and measured driver response to a variety of roundabout features. These virtual roundabouts were tested by allowing participating drivers to navigate through them virtually through driving simulation. In this study, the evaluation of driver response and navigation for different signs and markings, design alternatives as well as related aspects was performed with the presence of other vehicles (ambient traffic) using the roundabouts.

Specifically, the study concentrates on two types of multilane roundabouts, the two lane roundabout which is the most common modern multilane roundabout and a relatively new kind of roundabout known as turbo roundabouts developed by

Lambertus G.H. Fortuijn in 1996 (12) and which have found favor in the Netherlands and recently in several other European countries (13), (14), (15) . Though there are many kinds of turbo roundabouts as explained later, the rotor turbo roundabout was adopted for this study.

1.3 Hypotheses of the Study

To meet the objectives of the study as stipulated above, two hypotheses were stated.

1. The American driving public can navigate turbo roundabouts just as well as they do at normal modern multi-lane roundabouts. In this hypothesis four questions had to be answered:
 - a. Will drivers choose correct entry and exit lanes as necessary?
 - b. Will drivers generally observe advisory speeds at roundabouts?
 - c. Will drivers yield whenever they are supposed to?
 - d. Will drivers travel within correct lanes with respect to the turn movements they make?
2. The same signs and pavement markings used in the US for modern roundabouts can be adopted for turbo roundabouts. For this hypothesis the effect of signing and pavement marking schemes on navigation was to be observed.

For signing and pavement markings, two schemes of pavement markings and signs were used for the study. One was a scheme with fish-hook markings and pavement markings as shown in Figure 1 and 2 below, the other was a pavement and sign

scheme adopted from those used in the Netherlands for turbo roundabouts as shown by Figure 3 and 4 below (These are referred to as NED from here onwards) albeit with some modifications as explained in later sections.

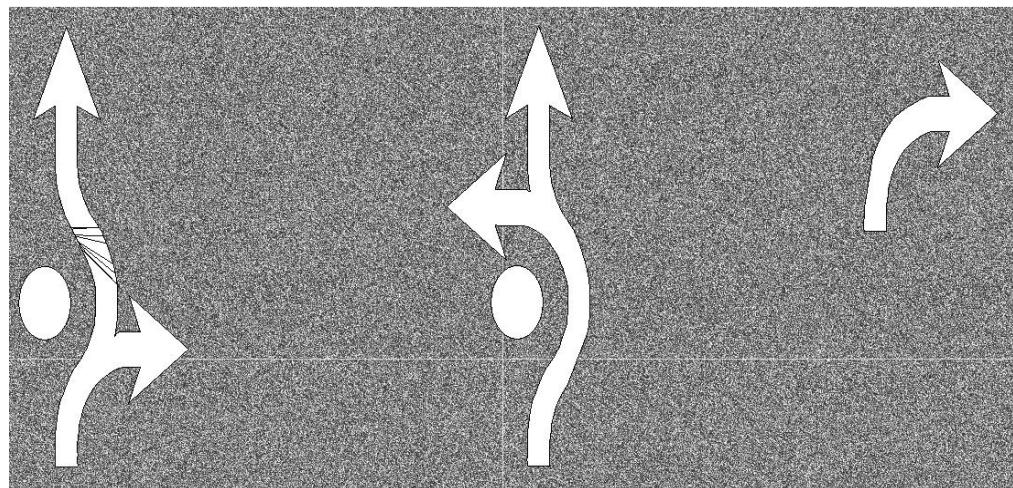


Figure 1 The fish-hook pavement marking scheme

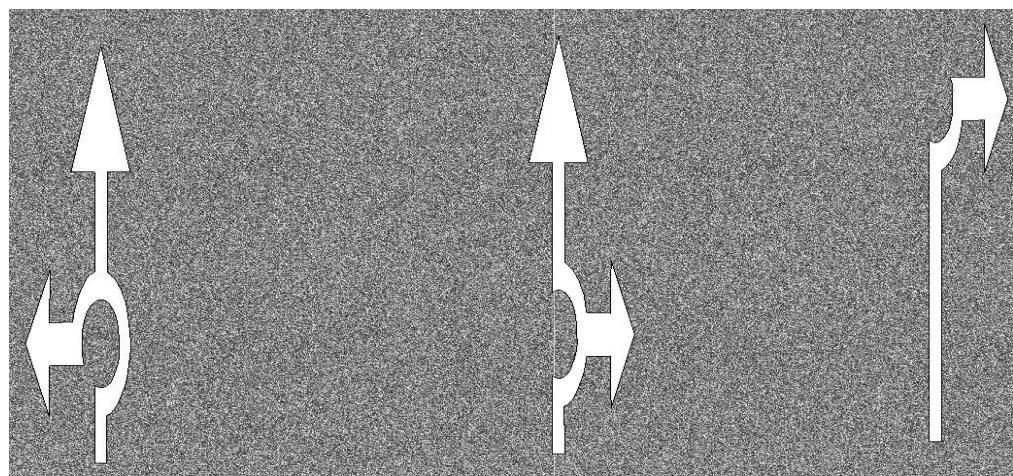


Figure 2 NED pavement marking scheme

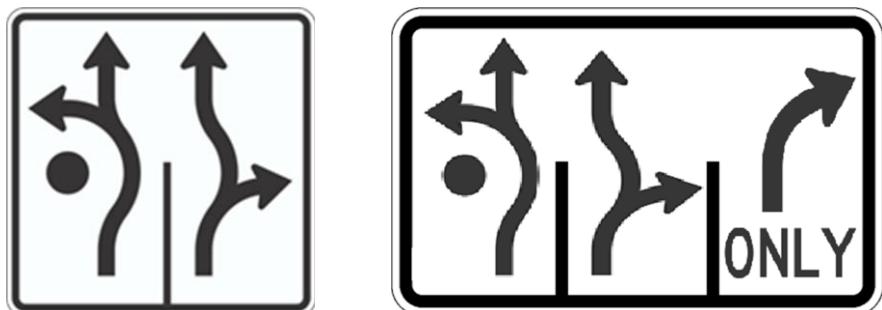


Figure 3 Fish-hook signing scheme

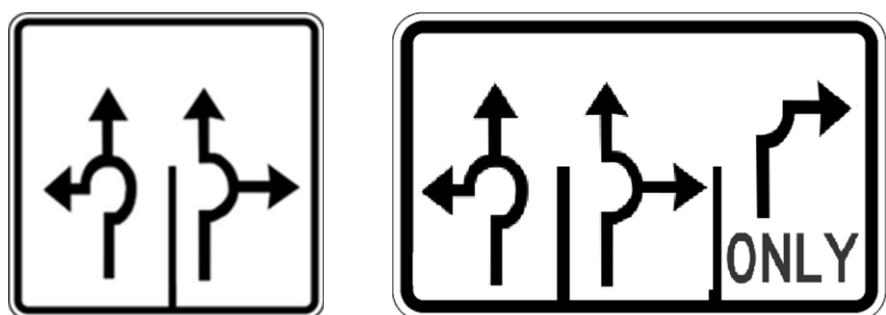


Figure 4 The NED signing scheme

1.4 Benefits of the Study

The results of this research are expected to be beneficial in several ways;

1. It will enable roadway planners, designers and engineers to understand how different schemes of signing and pavement markings affect navigation of the roundabout for different scenarios.
2. It will help compare navigability differences between different kinds of roundabouts especially the relatively new turbo roundabout which is not common in United States .This may lead to identification of improvements or precautions (if any) are needed when such roundabouts are adopted.

CHAPTER 2 LITERATURE REVIEW

2.1 The Modern Roundabout

A roundabout is a circular intersection that is a result of continued improvements of circular intersections that have been in existence since early 1900s. Roundabouts have been under development since then as transportation experts try to solve different safety and operational challenges experienced at different stages since then such as traffic circles, rotaries, signalized rotaries, neighborhood traffic circles (1). Though innovation and improvements are still on-going, the modern roundabout shown in Figure 5 below is arguably widely accepted as a standard of roundabouts (2), (1), (16). The modern roundabout which saw its adoption in the US in early 1990s has the following characteristics (10):

- It provides traffic control without the need of stop signs or traffic signals where circulating vehicles already within the roundabout have a right of way and other incoming vehicles at the entry have to yield.
- It has flared approaches, slows, deflects and channels traffic to appropriate entry angles and lanes.
- It has features which ensure safety for other vulnerable road users such as pedestrians and cyclists (17), (18), (19), (20) .



Figure 5 A two-lane modern roundabout

Since its introduction into the US, the modern roundabout has experienced acceptance within the transportation expert community. As of December 2013, there existed about 3700 roundabouts (21) increasing from a few hundreds between 1990s and early 2000s (3). They have been replacing other kinds of intersections for several reasons. Enough research (3), (1) has documented these reasons which include, but not limited to, the following; increased safety levels, traffic calming, aesthetics, lower space requirement, lower operation and maintenance costs, lower delays and queues and reduced fuel consumption.

Increased safety levels are due to lower number of conflict points (for example from 32 conflict points on a four leg intersection to 8 on a four leg single-lane roundabout) between vehicles, pedestrians and cyclists compared to other kinds of intersections. Lower speeds allow more reaction time to potential conflicts, reduced relative speeds

between users thus reducing crash severity. Vulnerable road users can cross in stages and face fewer conflicting vehicles. An overall reduction of about 35% and 76% in total and injury crashes respectively has been observed (1).

Modern roundabouts can generally be grouped as mini roundabouts, single-lane roundabouts, and multilane roundabouts. Depending on the needed capacity and space availability, among other factors, a choice of the type of roundabout can be made.

Innovation and improvements to the concepts guiding roundabout navigational, safety and operational features is still an on-going process. So far several design alternatives have been developed to solve different challenges experienced with the modern roundabout despite the many advantages it has demonstrated over normal intersections. Such innovative alternatives include the turbo roundabout, hamburger roundabout, four bridges roundabout, dumb-bell, dog-bone roundabout, flower roundabout and target roundabouts (22), (13) .

2.2 Challenges of the Modern Roundabout

As pointed out above, roundabouts can be solutions to safety concerns present at other types of intersections and that recently the conversion of such problematic intersections to roundabouts to improve their safety to road users has been increasing (1), (2). However, it is difficult to make these roundabouts, especially multi-lane roundabouts, safe to all ranges of road users, especially those with reduced cognitive and physical capabilities such as older drivers. This is pointed out by Dominique et al as they suggest strategies to help vulnerable users to safely negotiate intersections in their study (23).

Roundabout features such as advance warning and signage play an important role in determining driver performance when navigating the roundabout. It has been observed that single-lane roundabouts perform better safety-wise compared to multi-lane roundabouts (3), though because of the requirement to serve ever increasing demands with higher capacity roundabouts multilane roundabouts are preferred.

Getting motorists to choose and stay in appropriate lanes has been observed to be the main challenge when it comes to navigating multilane roundabouts (4), (5), (24). In order to help motorists to choose and maintain their lanes of travel, signs and pavement markings play an important role. The Manual on Uniform Traffic Control Devices (MUTCD) provides guidance on the signs, pavement markings and other traffic control devices (25). However the challenge of choosing and maintaining lanes is more prominent in multilane roundabouts and concerns are even higher with the increase in number of lanes as drivers face difficulties interpreting signs and pavement markings as they approach a roundabout. In their research on navigation signing for roundabouts, Inman et al finds among other things, a less than 70% correct lane selection performance and suggests further research on the recommended markings (24). In his study on signing and pavement markings strategies for multilane roundabout Kinzel (26) also suggests further studies on marking and signing of roundabouts including field research and human factor research such as surveys, simulation studies and direct observation.

2.3 The Turbo Roundabout

The modern two-lane or three-lane roundabout is also known to face challenges despite higher capacities when compared to single-lane roundabouts.

Because of the extra lanes introduced to offer higher capacities, other challenges are introduced. These include lane changing possibility as vehicles weave and potential for higher navigation speeds. This increases the risks of crashes within the roundabout. One of the best known solution to this problem within the roundabout is the use of turbo roundabouts as introduced by Lambertus G.H. Fortuijn in 1996 (12). The success of the turbo roundabout has made it preferable in the Netherlands and recently in several other European countries to an extent that in the Netherlands no more multilane modern roundabouts are constructed and existing ones are being replaced with turbo roundabouts since the first turbo roundabout constructed in 2000 (27) (13), (14), (15).

The use of turbo roundabouts has been observed to increase safety by reducing conflicts during navigation as well as arguably increase capacity. Though still debated within the research community (6), (7), (28) the capacity of turbo roundabouts have been reported to be 25-35% higher than the standard two lane roundabouts (8). Compared to turbo roundabouts, two-lane roundabouts present a typical weaving conflict between drivers on the inner lanes trying to exit and those in the outer lane not exiting. This does not happen in turbo roundabouts due to separated (by a divider) lanes .Safety-wise, turbo roundabouts have been reported to have up to about 80% reduction in crash rates depending on the type of normal intersection is replaced or compared to. (12)

Basic distinguishing characteristic of a turbo roundabout are:

- i. entries and exits are defined by spirals lanes which continuously shifts away from the center of the roundabout,

- ii. No lane changing is possible(at least not comfortably) near the entry, at the circulating roadway or at the exit thus the correct entry lane to lead a driver to the desired exit must be selected ,
- iii. Lower driving speeds through the roundabout due to the sharp alignment (approaches are at right angle to the roundabout) and raised lane dividers.

Turbo roundabouts have the following advantages among others over modern roundabouts (12):

- Reduction of speed at the entry, circulatory and exit lanes-a factor attributed to the geometry of the roundabout.
- Reduction of conflict points; for example from 16 of a concentric two-lane roundabout with double lane exits to 10 for the basic turbo as a result of elimination of weaving and cut-in conflicts.
- Low risk of side-by-side crashes due to raised mountable lane dividers that separates traffic in different lanes.

There exists several types of turbo roundabouts. The choice depends on several factors including major flow volume, minor flow volume, desired capacity and the like. The variation between the types of turbo roundabouts depends on how the basic design element ('turbo block') is arranged. The different types of turbo roundabouts include; Basic turbo roundabout, Egg roundabout, Spiral roundabout, Knee roundabout, Rotor roundabout, Stretched-knee roundabout and Star roundabout. Figure 6 and 7 below shows the basic turbo and the rotor turbo. Readers interested with the details can find them in (12) and (29).



Figure 6 The basic Turbo roundabout



Figure 7 The rotor turbo roundabout

2.4 Driving Simulation Studies

In transportation engineering, simulators have been used to study different roadway geometric designs and their alternatives, study signal controls, study signs and pavement markings, collision studies, distracted driving, or simply for visualization and training purposes (30).

Two studies have specifically evaluated roundabout signage and lane marking through the use of driving simulators. These studies [(4) which deals with three-lane roundabouts and (5) which deals with two-lane roundabouts] have investigated different combinations of signs and marking strategies that result in proper lane selection. They all followed the Manual on Uniform Traffic Control Devices (MUTCD) recommended signing and markings of roundabouts.

Despite the fact that ambient traffic affects the amount of gap accepted by drivers, driver attention, as well as lane keeping behavior, the two studies above did not consider the effect of ambient traffic and its influence on driver behavior when navigating through roundabouts. These factors play a major role in the safety and operational aspects of multilane roundabouts. Factors such as location of navigation signs and lane use markings may be influenced by the presence of ambient traffic as is in real life and thus influence driver behavior in navigating roundabouts.

2.5 Simulator Sickness in Simulation Studies

One of the main challenges of research employing simulation devices is simulator sickness (SS). It has been reported in a wide range of studies and simulator types and is not limited to a specific kind of simulation devices (31). It is not a new challenge to simulation related studies as it was reported as early as 1957 (30).

Simulator sickness is a visually induced motion sickness (MS) in which involved participants report ill feelings during or after the use of simulators. SS is related to participants feeling nausea, dizziness, sweating, blurred vision and other related symptoms which may lead to extremes such as vomiting. These and other symptoms are known to last for as short as immediately after leaving the simulator to as long as a few days after. Factors associated to SS are widely grouped into simulator related, task related and individual participant characteristics (30).

Though simulator sickness shares some symptoms with motion sickness (MS), they are not the same. SS is less severe and affects a much lesser proportion of the population compared to MS as a result of simulator adaptation especially to participants who have been exposed to a particular simulator before (32) , (33). Research also suggests that MS requires stimulation of an individual's vestibular system, a situation that may not be present in some types of simulators such as fixed-base simulators which have no motion cues. It is not motion only that is responsible for sickness, other factors such asvection (perceived motion), visual stimuli and other complex interactions of factors are also responsible for SS (30).

Despite extensive research on simulator sickness theories behind the concept of SS, there are still no theories without criticism and no single theory has explicitly explained the simulator sickness concept. Some of the widely known theories include cue conflict theory where SS is believed to occur when there is mismatch between what the sensory system expects based on experience and what is actually presented by the simulator and thus sickness occurs as a result of unresolved internal conflict. Such a conflict is common in fixed base simulators where motion perceived is not accompanied by corresponding vestibular cues of motion. The poison theory for SS suggests that the symptoms observed such blurred vision, vomiting and the like are

similar to how the body reacts to poisoning as the body tries to get rid of the poison. The postural stability theory claims that the sickness is due to participants trying to adjust using skills they already know from real road experience to maintain stability in the new environment without yet mastering the strategies to do so in such a new environment. Other known theories include the eye movement theory and the rest-frame theory, (31), (30).

Simulator sickness may have a negative impact on simulation results and thus cogency of a simulation based study if not taken into account and efforts taken to control it. SS may result in abnormal behavior, boredom, loss of concentration, distraction and other undesired outcomes that may affect the way the test subjects interact with the simulator and hence affecting the validity of their results (30) .

It is important to understand the effects of simulation exposure and likelihood of SS so as to protect participants as well as obtain valid results with minimal effects resulting from SS. To do this, earlier measurement and detection of the likelihood of SS before experiment, during experiment as well as after experiment is important. Several methods and efforts have been developed and implemented through many researches in the past (33), (30). Such methods and effort include:

- Simulator sickness questionnaire (SSQ)
- Postural stability measurement
- Continuous physiological measures

2.5.1 Simulator Sickness Questionnaire (SSQ)

Simulator Sickness Questionnaire (SSQ) a tool developed by Kennedy (32) from a previously developed Motion Sickness Questionnaire (MSQ) and used extensively (33) , (30). The SSQ (see Appendix D and E) consists of 16 symptoms

namely general discomfort, fatigue, headache, eye strain, difficulty focusing, salivation increasing, sweating, nausea, difficulty concentrating, fullness of the head, blurred vision, dizziness with eyes open, dizziness with eyes closed, vertigo, stomach awareness and burping. A participant rates the symptoms with scores of 0,1,2,3 (i.e none, slight, moderate and severe) corresponding to the extent to which the symptoms applies to them for that particular moment. The scores are assigned weights under three categories known as Oculomotor, Disorientation, and Nausea (32) which are later summed using given factors to get a general score that by comparison can give an overall description of likelihood of SS. The higher the SSQ score, the higher the likelihood of SS.

It is common to administer the SSQ at least twice, Once at the beginning before a driving simulation session as a baseline and then at the end of the session. Continuous testing such as during driving breaks is also common, (33), (34), (30). It is also noted as shown in (34) and (30) that administering the SSQ before the experiment or any suggestion of possibility of SS may increase the likelihood of participants reporting higher scores on the SSQ.

2.5.2 Postural Stability Measurement

Researchers have also found a relationship between the differences in postural stability measured before and after simulator exposure to be correlated to development of simulator sickness (35) , (30) , (36), (37). (38). This postural stability can be used as an indicator of SS. In the past several methods have been used as postural equilibrium tests. Such tests as described in different studies include standing heel to toe with arms folded on the chest and eyes closed, standing on one preferred leg or non-preferred leg with eyes closed and arms on the chest, walking in straight

line and other variations of such tests, (38). Some researchers have also warned of the complexity of stability measurements, unreliability of such tests and their lack of standardization. Some of them go further and propose a limited use of postural stability test since similar results can be obtained using more sensitive measures such as the SSQ which is more reliable (38) , (39).

2.5.3 Continuous Physiological Measures

Continuous physiological measures during simulation to monitor variables such as skin potential, skin resistance, skin temperature, heat frequency and the like which are correlated with SS can also be used to measure SS (30), (38).

It is advised to reduce roadway geometries and maneuvers that maximize discrepancy between visual and vestibular inputs (30), (33). Such may include reducing the number (frequency) of stops, turns and curves. Other precautions include screening of participants for motion sickness history, stability and health related issues, maintaining low temperatures in the simulator room, allowing incremental adaptation to the simulator especially to participants naïve to the simulator through simulator practice and well-designed scenarios, breaks within study scenarios and reminding participants to inform the experimenter any discomfort they experience during a study (31) , (30) , (37).

Regardless of precautions that may be taken, SS may still happen to some participants. Different studies report different percentages of participants experiencing SS. (31) reports a total of 19 out of 73 participants (about 26%) experiencing SS, (40) reports 7 participants out of 30 (about 23%) experienced simulator sickness. In a roundabout study evaluating signing of three lanes roundabouts (4) after screening for

participants that had experienced in prior studies 7 participants still dropped out while 96 completed (6.8%).

CHAPTER 3 EXPERIMENT DESIGN

3.1 Overview

The experiment design involved creation of scenarios that could enable testing of the hypotheses previously stated. These scenarios were created in such a way that they allowed using the driving simulator to test how drivers performed with respect to signing/pavement marking schemes on the two lane roundabout and the rotor turbo roundabout.

During the experiment participants were instructed to drive to a city called Kzoo while interacting with other traffic (ambient traffic) by following directions posted on guide signs. There were two other cities alongside Kzoo on the guide sign namely Bcreek and Otsego. Participants were required to navigate through a series of three roundabouts. As they moved from one roundabout to another they made a through movement, took the left turn or the right turn as appropriate. Data on parameters of interest were recorded automatically as the participant drove. The experimenter also recorded some data manually. When participants reached Kzoo they were asked to park the vehicle on the shoulders.

3.2 Creating Scenarios

The design and creation of the scenarios was divided into two parts:

- Design of the roundabouts and connecting roadways graphics.
- Addition of correlated data and other objects.

3.2.1 Design of Roundabouts and Connecting Roadways Graphics

Design of roundabouts was achieved through the use of 400m length by 400m width graphics tiles, other straight connecting roadways were made to a size of 200m by 200m. Two roundabouts were created, the two lane roundabout and the turbo roundabout.

The design of all the simulation graphics was achieved by use of Presagis Creator Pro software. This is a 3D graphics design software for creation of models optimized for real-time simulation. The choice was due to the fact that the same software (though likely older versions) were used to make other default tiles in the simulator that was used for the study.

The graphics created in Creator Pro are made of polygons following a well arranged hierarchy. These polygons along with other properties such as lighting, shadows and the like, are textured with different textures accordingly to create graphics that represent the real object being modeled as much as possible. Cautions should be taken not to have too much polygon counts unnecessarily as this may hinder the real-time performance capacity of the simulator.

The procedure followed in Creator Pro to create the rotor turbo roundabout graphics model is summarized by Figure 8 to Figure 13 below. Creation of the two lanes roundabout followed the same procedure albeit with a lot of tracing from an existing two lane roundabout satellite image. Using provided AutoCAD design templates known as turbo blocks as the one shown in Figure 8 below, Creator pro flight (.flt) supported files made of polygons were created and used as design templates in Creator. On these templates basic elements of roundabouts were added as progressively shown in Figure 8 to Figure 13 to create the final roundabout of which

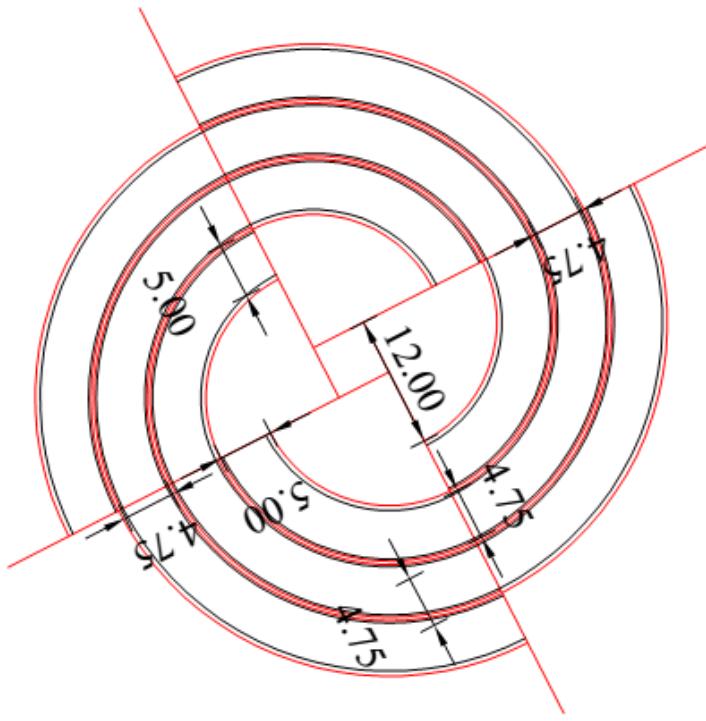


Figure 8 Turbo block for the rotor turbo roundabout (dimensions in m)

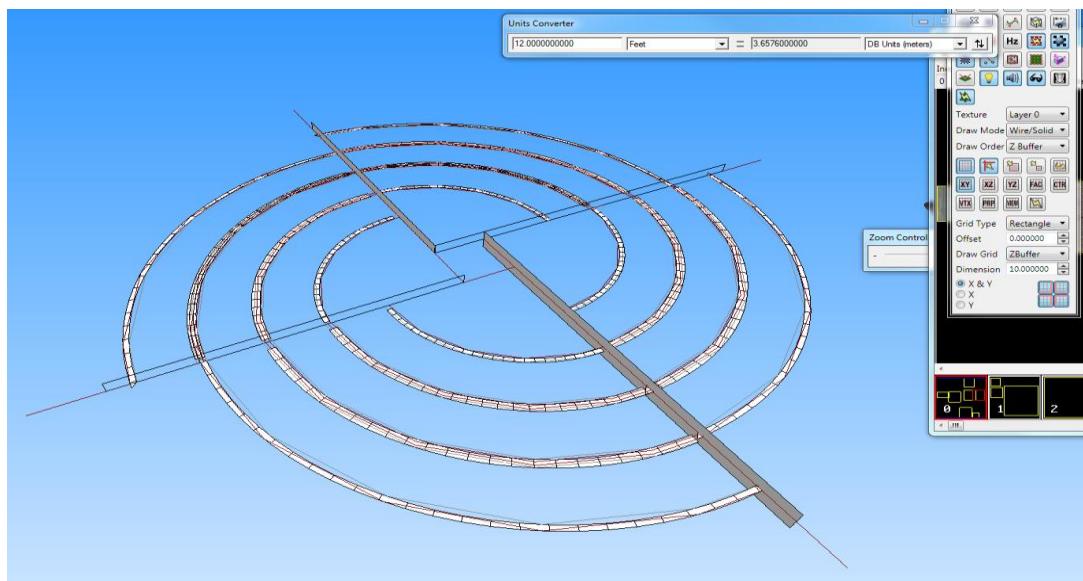


Figure 9 Flight file geometry template for the rotor roundabout in Creator Pro

Other roundabout features such as pavement markings, splitter islands created as separate flight files (see Figure 10 and 11) within creator were added. The design of the physical lane dividers, which is a distinguishing feature of the turbo roundabout followed standards suggested in (12). The preliminary path to be followed by vehicles during the simulation was also added and a path file containing the path information such as number of lanes, lane width, lane offsets, shoulder width, centerline location and the like (See Appendix A for a path file example) was created. After all the details such as those mentioned above, the central island, tapers, textures, curbs, pavement and pavement markings of the graphics design were added, a final product was achieved as shown in Figure 13.

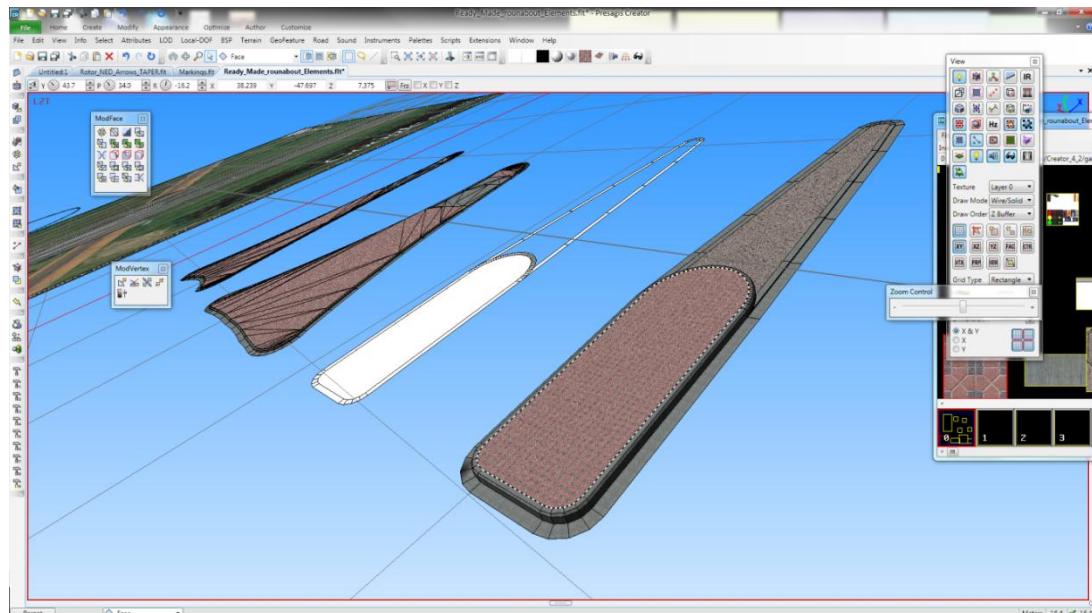


Figure 10 Design of individual roundabout elements in Creator Pro.

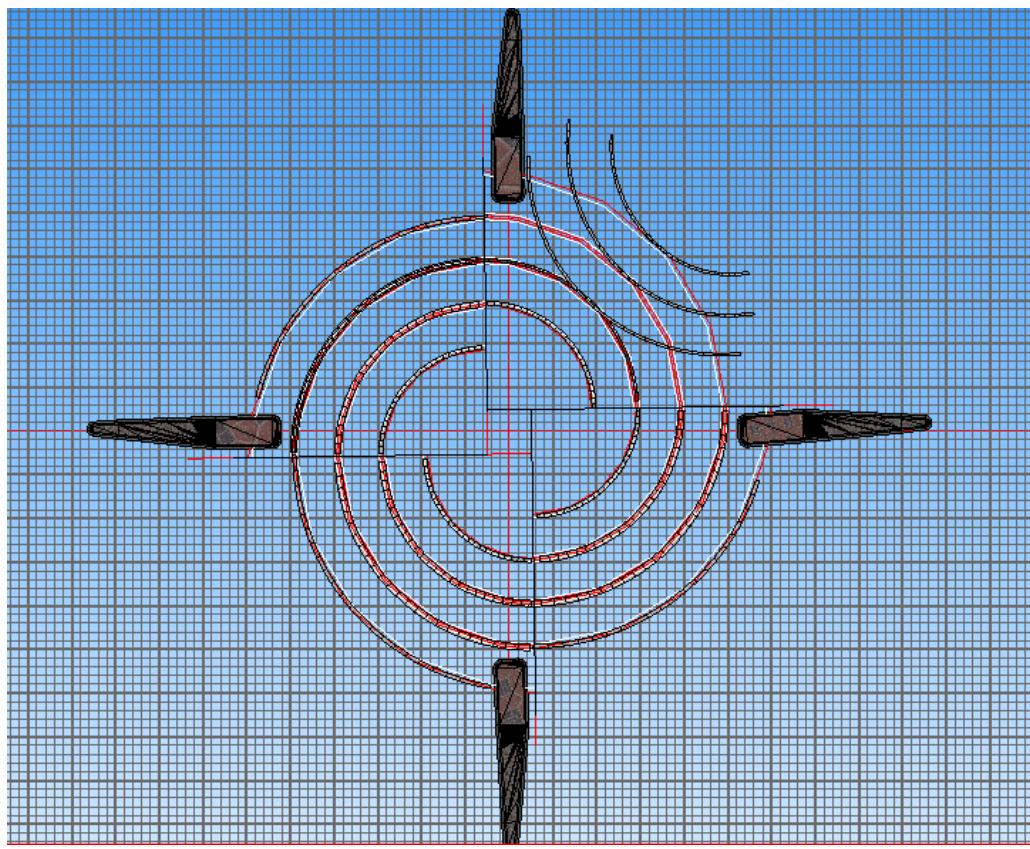


Figure 11 Adding splitter islands on the template

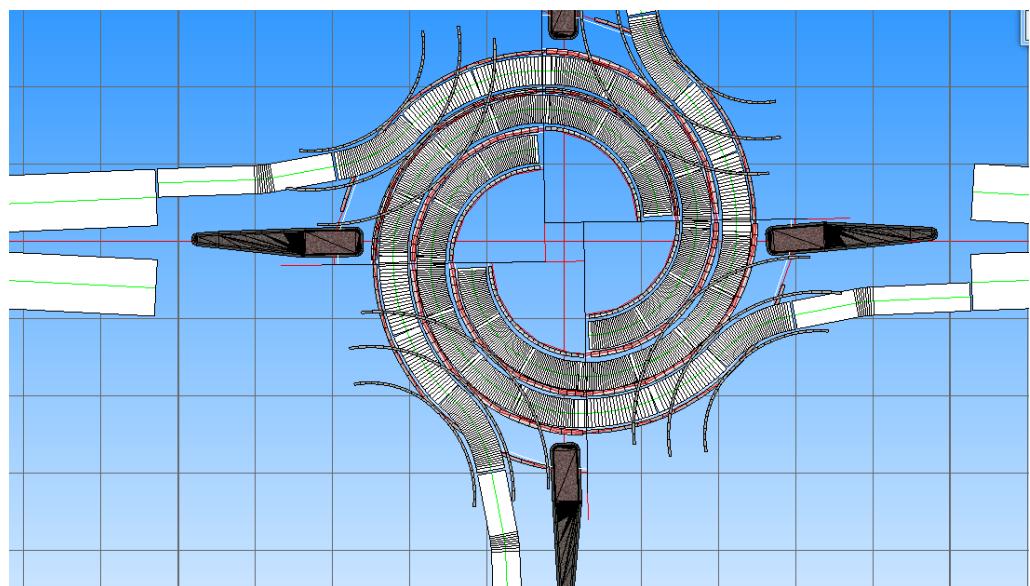


Figure 12 Adding roadways and path to the geometry

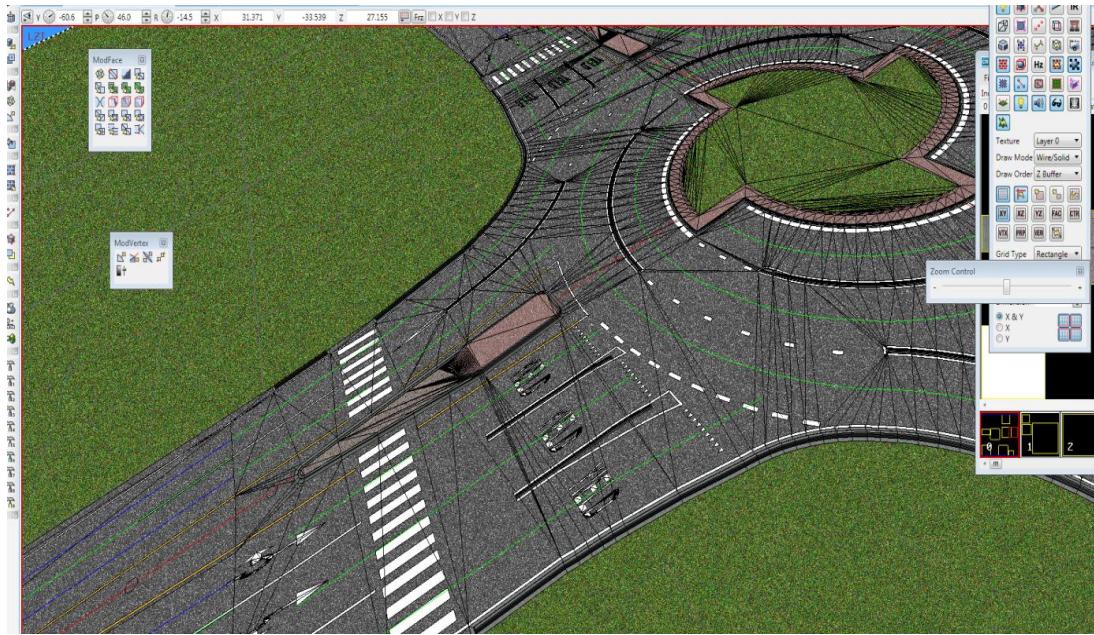


Figure 13 Final graphics product of Creator Pro

Pavement markings used in the graphics followed the MUTCD standard for the fishhook lane arrow use, YIELD, yield triangles, crosswalk and other pavement lines. The solid white lines at the entries started at 350ft upstream of the yield line. Proximal and distal lane use pavement markings were at 70ft and 350ft from the yield line.

3.2.2 Addition of Correlated Data and other Objects

To be usable for real-time simulation, once the model is completed in Creator Pro it is moved to a software called Internet Scene Assembler (ISA). ISA is a scenario creation software installed on the simulator workstation for further processing of Creator Pro produced tiles. This involves a series of conversions following a guide provided by Realtime Technologies Inc. (41). The final file type is a .wrl file that is now usable for further editing in ISA and real-time simulation.

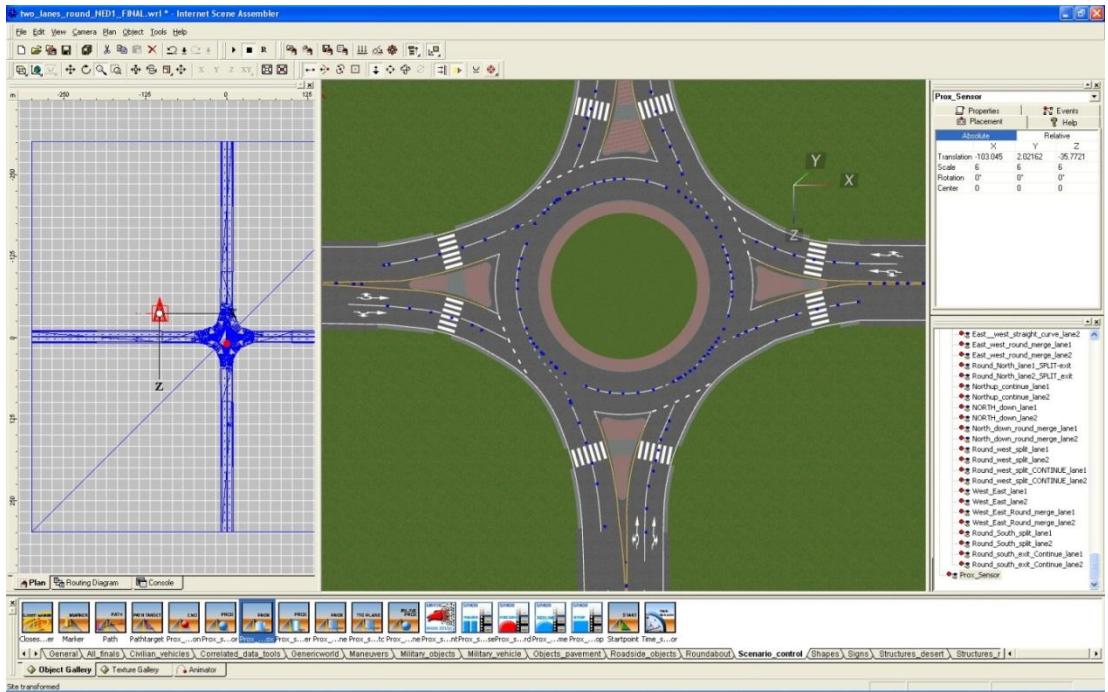


Figure 14 A final ISA usable file ready for final modeling in ISA

Once the conversion to usable .wrl files is completed in ISA, editing and addition of correlated data developed in Creator Pro follows. Correlated data refers to the data that vehicles use during simulation to be able to move from one point to another properly. This includes road splines that define the roadway parameters, connectors connecting one road spline to another and control points that the vehicles follow. Figure 15 shows parameters of road splines and connectors during the editing and adding process in ISA. Figure 14 above shows a typical arrangement of control points (blue points) on a two lane roundabout.

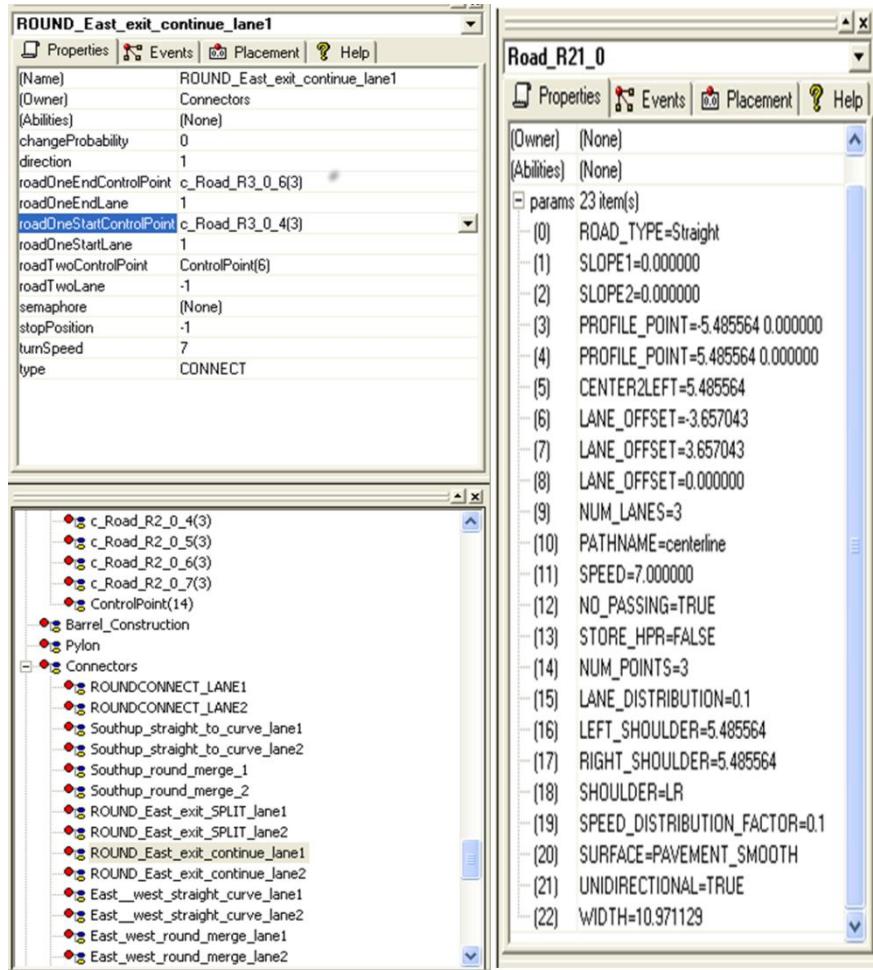


Figure 15 Defining parameters of road splines and connectors

One of the features provided by ISA is the ability to use different kinds of sensors such as time sensors (activated by time), proximity sensors (activated when vehicle is in the sensor's proximity) to control scenario through the use of JavaScript programming language. To be able to track how drivers behave through the data collected at locations of interest such as the beginning of solid white line at approaches, yield line, exits and the like, proximity sensors were placed at these locations. These sensors were given unique identification numbers to represent that particular location. Figure 16 below shows an example of where these sensors were located.

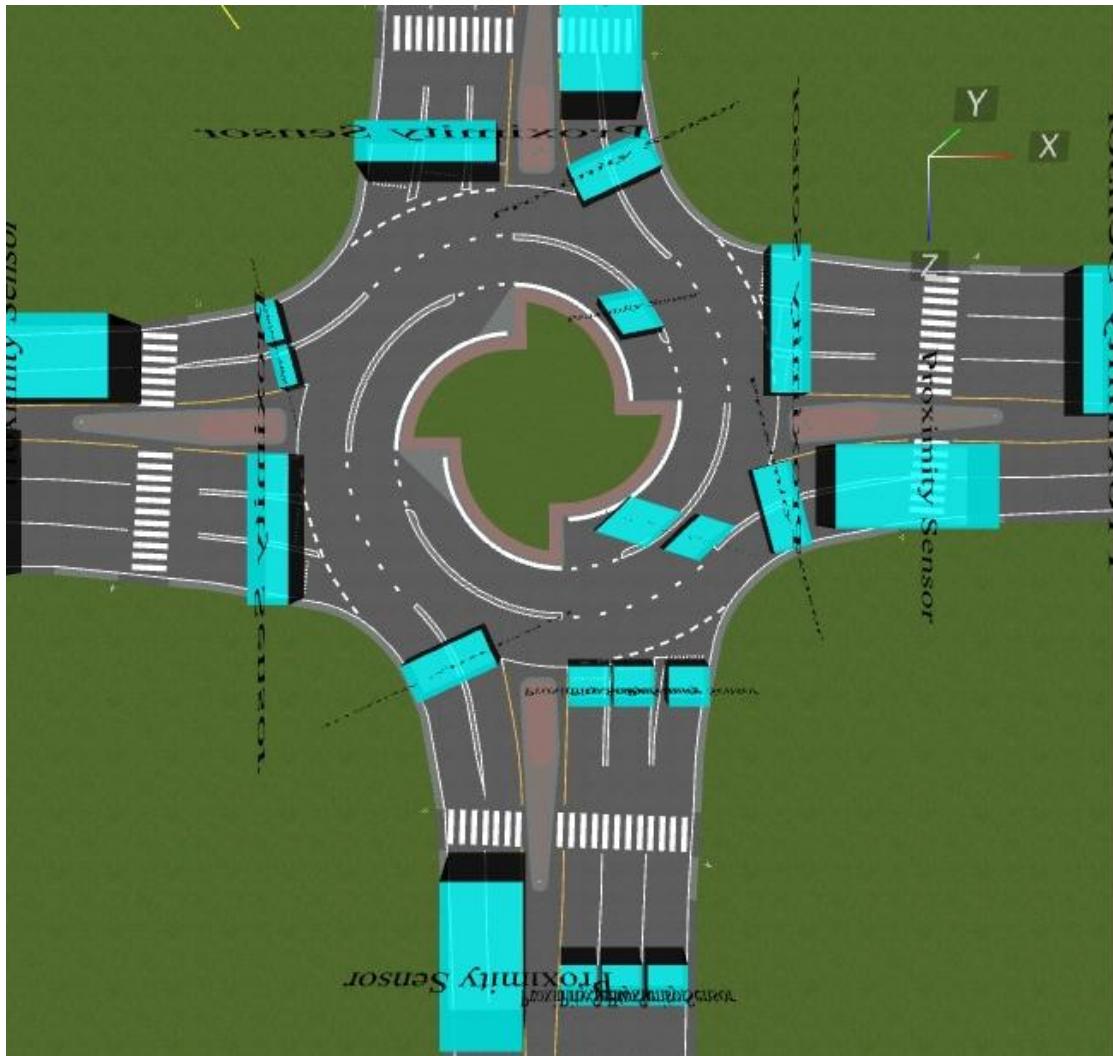


Figure 16 Location of proximity sensors

3.3 Lane use Marking and Signing Schemes

Since one of the objectives of the study was to find if lane use signs and pavement markings used in modern roundabouts in the US can be adopted for the turbo roundabouts, two schemes were adopted. One is with the fish-hook arrow pavement marking and signing scheme (from here onwards just called fish-hook

scheme) and the other was the turbo roundabout pavement marking and signing scheme used in the Netherlands (from here onwards referred to as the NED scheme) where turbo roundabouts were invented.

The fish-hook arrow lane use pavement marking and signing scheme is widely accepted as the standard for lane use guidance in modern roundabouts. However other schemes such as the normal arrow scheme are also used (4) (24) (5).

Since the signs used in the Netherlands follow a different color scheme compared to those in the US, the NED signs were changed to reflect the properties of those in the US to avoid confusion to drivers. For example, the signs were placed on US based sign templates and color changed from white sign on a blue background to a black sign on a white background. Figure 1 to Figure 4 presented previously shows the pavement markings and signs for both schemes.

3.4 Other Roadway Signs and Markings

All other signs such as pedestrian crossing warning signs (W11-2), YIELD Signs (R1-2), Advisory Speed Plaques (W13-1P), Circular Intersection signs (W2-6), Roundabout Directional Arrow Signs (R6-4b), Roundabout guide signs (Exit destination-D1-5) and Exit destinations (D1-1d), followed MUTCD standards of roundabout signing. These signs are shown in Figure 17 below. The proximal and distal lane use signs were placed 70ft and 350ft from the yield line respectively. The W2-6 and W13-1P signs were placed at 1000ft from the yield line to allow for enough decision sight distance. The R6-4b signs were placed at 650ft from the yield line. The D1-1d sign was placed on every island to indicate exit. Four R6-4b signs were placed on the central island facing each approach to inform drivers of the direction of

circulation at the roundabout. The W11-2 sign was placed close to the crosswalk at each approach and exit. The R1-2 was located on every approach and in line with the yield line.



Roundabout guide sign (D1-5)



Exit destination (D1-1d)



Roundabout Directional Arrow Signs (R6-4b)



YIELD Sign (R1-2)



Pedestrian crossing warning sign (W11-2)



Advisory Speed Plaque (W13-1P)



Circular Intersection (W2-6)

Figure 17 Other signs used in the study

3.5 Participant Recruitment

Due to the fact that this research involved human subjects, it is a requirement by the Office of the Vice President of Research at Western Michigan University that the researcher responsible obtain approval for the research protocol from the Human Subjects Institutional Review Board (HSIRB). Appendix B shows the HSIRB approval letter.

After HSIRB approval experiment participants/subjects were recruited through e-mails and flyers (Appendix F shows the flier used). The subjects recruited were of both genders and of all possible driving age ranges. They had to be legal to drive in the US and capable of operating a motor vehicle. Each participant was scheduled on a specific study time slot.

CHAPTER 4 EXECUTION OF THE STUDY AND DATA COLLECTION

4.1 Procedure for the Study

The study was conducted at the Western Michigan University's Transportation Research Center for Livable Communities (TRCLC) Driving Simulation Lab located at the Parkview campus. The driving simulator was a fixed base simulator as depicted in Figure 18 below. It is made of a car seat fixed on a base that supports the simulator's computers, a steering wheel and a dashboard. The dashboard displays information such as speed in miles per hour (MPH), revolutions per minute (RPM), current gear and fuel level to the driver. The base also supports the gear stick, brakes and the gas pedal. Three screens make the display system of the simulator. These are placed in front of the seat and dashboard. The rear, left, and right view mirrors are displayed within the three display screens. Speakers to reproduce audio that reflects the car and driving environment are also part of the simulator. The real-time simulation software used with the simulator was SimCreator 3.0. A driver's perspective of the driving scenario close to the roundabout was as seen in Figure 19.

After arrival each participant was assigned a unique driver ID and was introduced to the experiment. They then reviewed and signed the consent form (see Appendix C), took a pre-administered questionnaire and took the postural stability test. They were then allowed a test drive to orient themselves to the simulator and its controls. Then the actual study scenarios were loaded in the sequence explained in the experiment procedure summarized below. The total approximate time for the experiment was 57 minutes.

1. Reading and signing the consent form (3 minutes)
2. Introduction to the driving simulator and experiment (3 minutes)
3. Pre stability test (3 minutes)
4. Pre-experiment questionnaire (3 minutes)
5. Test drive (5 minutes)
6. Rest (3 minutes while simulator is loading)
7. 1st run (5 minutes)
8. Rest (3 minutes while simulator is loading)
9. 2nd run (5 minutes)
10. Rest (3 minutes while simulator is loading)
11. 3rd run (5 minutes)
12. Rest (3 minutes while simulator is loading)
13. 4th run (5 minutes)
14. Post stability test (3 minutes)
15. Post-experiment questionnaire (5 minutes)



Figure 18 The driving simulator used for the study



Figure 19 Driver's perspective close to the roundabout

4.2 Data Collection

The driving simulator collected data at 60Hz (i.e data was collected 60 times every second).and at each time stamp the collected data included the following; lane of travel, lane offset, roadway offset, vehicle speed, acceleration, pedal forces, headway distances, steering wheel position and X,Y,Z positions of the vehicle, This data was later extracted from the computer for further analysis. Data such as gender, age, driving experience, easiness of navigating roundabouts and perception of safety at roundabouts compared to intersections were recorded before the experiment during the pre-test questionnaire. See Appendix D for details of the pre- and post-experiment questionnaires

4.3 Mitigating Simulator Sickness During Experiment

Because this study involved turns close to 90 degrees, tight curves within the roundabout, accelerations and stops, which are linked to higher risks of simulator sickness (30), several precautions were taken during the study. As used in one study (37) a section of the pre-experiment questionnaire (See Appendix D) was used to understand a participant's likelihood of experiencing simulator sickness. Participants were asked to rate how often they experienced three symptoms linked to simulator sickness (nausea, headache and dizziness) under four different scenarios (while driving an automobile, on amusement rides like roller coasters, during air travel and while playing computer games). A four point scale (never, sometimes, often and nearly always) was used for rating. If a participant reported to have experienced any of those symptoms with a rating of nearly always more than three times in the four scenarios then they were not be allowed to continue. None of the participants reported ratings that disallowed them to continue.

The pre-experiment questionnaire mentioned above also contained a pre-experiment SSQ in which participants were asked to rate the 16 symptoms of the SSQ depending on how they were feeling at that time. Later after completion of the experiment they were also asked to fill another SSQ section (for post exposure) contained in the post experiment questionnaire (See Appendix E). These two ratings of the SSQ were used to determine the likelihood that a participant suffered simulator sickness during the driving session.

A standing on a preferred leg test was also administered as a postural stability test just before the participant had a test drive. The same test was also administered as soon as the participant finished the last scenario. Participants were asked to stand on one leg

of their preference (with the non-preferred leg raised up about one third of the one they prefer standing on) with arms folded across their chest and eyes closed for a maximum of 30 seconds for two trials and average time for maintaining stability (If the pivot foot is moved, raised foot is raised away from the standing leg, or grossly losing of the erect body position, the trial was ended and the time recorded as the score for that trial. Depending on the differences between the standing time before and after experiment as well as the difference between SSQ scores before and after the experiment, participants were advised to take rests accordingly.

Participants that dropped out due to simulator sickness and those that seemed to have experienced simulator sickness though didn't drop out of the study were asked to rest longer before they left the room. Short breaks within experiment sessions are also known to reduce the possibility of simulator sickness. Therefore participants were allowed short breaks after completion of every driving scenario.

CHAPTER 5 DATA ANALYSIS

5.1 Introduction

Data analysis was performed on various levels, at participant driver level such as for SSQ score calculation and at aggregated level for most of the analysis. Mostly Stata 12 statistical software (42) and was used for association tests using the Fisher's exact test (smaller sample sizes led to using this test). Microsoft Excel was used for data reduction and some analysis as well. The Fisher's test tested the null hypothesis that the proportion distribution between the considered categorical variables were the same, i.e the distribution of proportions of one variable did not depend on the value of the other variable. The analyses were designed to test the hypotheses presented in the introduction part of this report.

Several factors were analyzed to test the hypotheses. These include correctness of lane choice at entry and at exit, lane keeping behavior of the drivers, speed profiles of drivers and yielding behavior. Initial analysis was done on the data to obtain descriptive statistics of the collected data especially participant driver data. This is presented in the section that follows.

5.2 Descriptive Statistics

The statistics discussed below were extracted from the pre-experiment and post-experiment questionnaires that were administered to the participants to collect basic information as required by the design of the study (refer to Appendix D and E) A total of 56 participants were recruited for the study during a two weeks period. As

shown in Table 1 out of 56 participants 10 (17.86%) dropped out as a result of suffering from simulator sickness. The remaining 46 participants consisted of 62.22% males and 37.78% females. Three age groups were used to identify young drivers (Y), middle-aged drivers (M) and older-drivers (O). These age groups were less or equal 25 years for younger drivers, greater or equal to 26 years and less than 60 years for middle aged drivers and greater or equal to 60 years for older drivers. The age distribution between the groups by gender is as shown in Table 1 below.

Table 1 Distribution of participants by gender and age

	Males			Females			Total
	<=25	26 - 60	60+	<=25	26 - 60	60+	
No. of Participants	11	17	4	11	7	6	56
% of Total	19.64	30.36	7.14	19.64	12.50	10.71	100.00
Drop out (SS)	0	4	0	2	4	0	10
% of Total	0.00	7.14	0.00	3.57	7.14	0.00	17.86
Finished experiment	11	13	4	9	3	6	46
% of Total	19.64	23.21	7.14	16.07	5.36	10.71	82.14
Used for Analysis	11	13	4	9	3	5	45
% of Total	19.64	23.21	7.14	16.07	5.36	8.93	80.36
% of Used		62.22			37.78		100.00

Table 2 shows a summary of SSQ scores as well as driving experience of participating drivers. SSQ scores were calculated as suggested by Kennedy in (32). As explained previously, the motivation to collect SSQ scores was firstly to start establishing SSQ reference database for future studies. Secondly, to help predict SS condition of participant before and after the experiment so that decisions such as extended rest periods could be given. Lastly, to have an overall estimation of simulator sickness effect to the study. Also, as shown in Table 2 the most experienced driver had an

experience of 70 years of driving while the least experienced driver was 4 months of driving.

The distribution of these SSQ scores and driving experience are shown in Figure 20 and Figure 21. As expected, SSQ scores after the experiment are higher than those before. For participant's driving experience the groups 0-5 years and 6-10 years had the most number of participants compared to other groups. Also as shown in Table 2 the median for driving experience was 10 years. For this reason when drivers were grouped as experienced or not for analysis this was the cut-off point. That is, drivers with more than 10 years of driving experience were considered highly experienced while those at 10 or below were considered less experienced

Table 2 SSQ scores and driving experience statistics

	<i>SS Score Before</i>	<i>SS Score After</i>	<i>Driving experience</i>
Mean	4.04	11.91	20.66
Standard Error	1.02	2.05	2.61
Median	1.00	7.48	10
Mode	0.00	0.00	5
Standard Deviation	6.84	13.74	19.51
Sample Variance	46.74	188.73	380.69
Range	31.44	58.14	69.67
Minimum	0.00	0.00	0.33
Maximum	31.44	58.14	70
Count	45	45	56

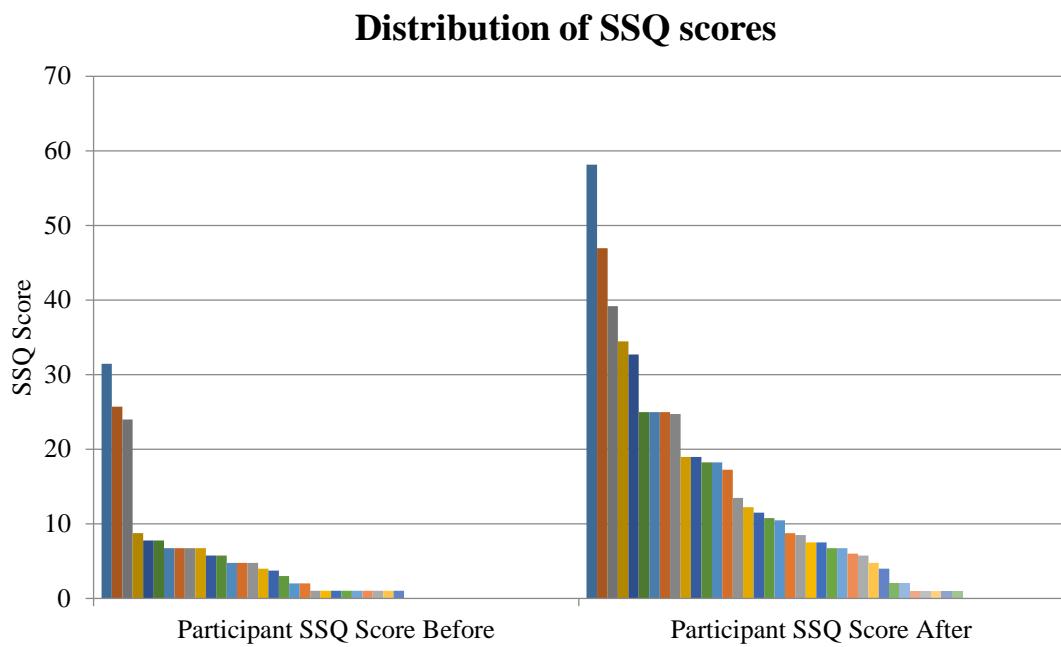


Figure 20 Distribution of Simulator sickness scores

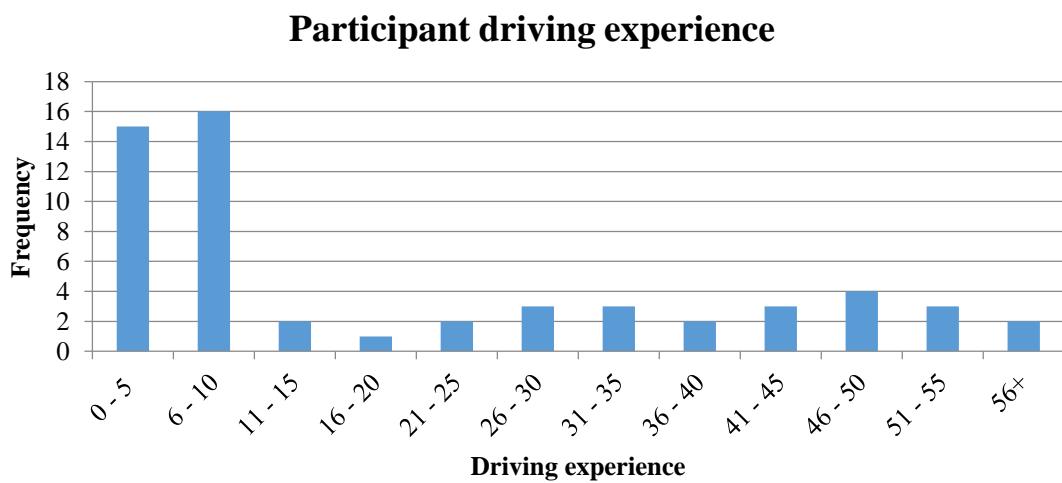


Figure 21 Distribution of Participant driving experience

To determine how experienced with roundabout navigation a participant was, a question on how often they drive through roundabouts was included in the pre-experiment questionnaire. The participant had four choices, which were ‘every day’, ‘often’, ‘once in a while’ and ‘never’. When grouping participants in terms of experience with the roundabout, those that answered this question with ‘every day’ and ‘often’ were considered experienced while those that selected the remaining two options were considered inexperienced. As shown in Figure 22 none of the drivers answered ‘never’. Eighteen percent drove through roundabouts every day, 29% often and 53% once in a while.

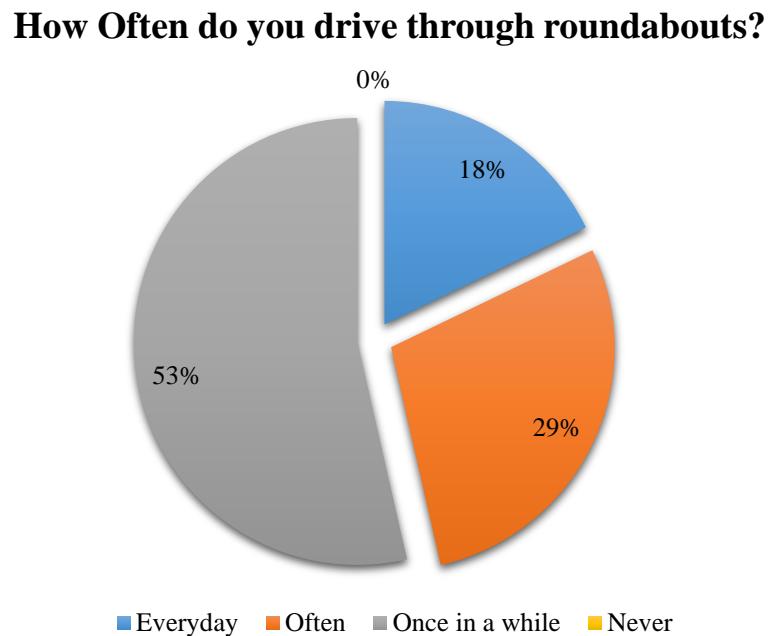


Figure 22 How often participants drove through roundabouts

To understand the participants’ overall perception of roundabouts navigability and safety, two questions were included in the pre-experiment questionnaire. These were

intended to probe the acceptability of roundabouts within the sample of participants involved in the study. Figure 23 and Figure 24 below provide the responses given.

As shown in Figure 23 only 18% consider roundabouts to be easier to navigate than intersections, while only 5% perceive intersections to be easier to navigate than roundabouts. Eleven percent thought they were all the same. Of interest is that a higher proportion 48% (compared to 41% favoring roundabouts) thought intersections to be at least a little easier to navigate than roundabouts.

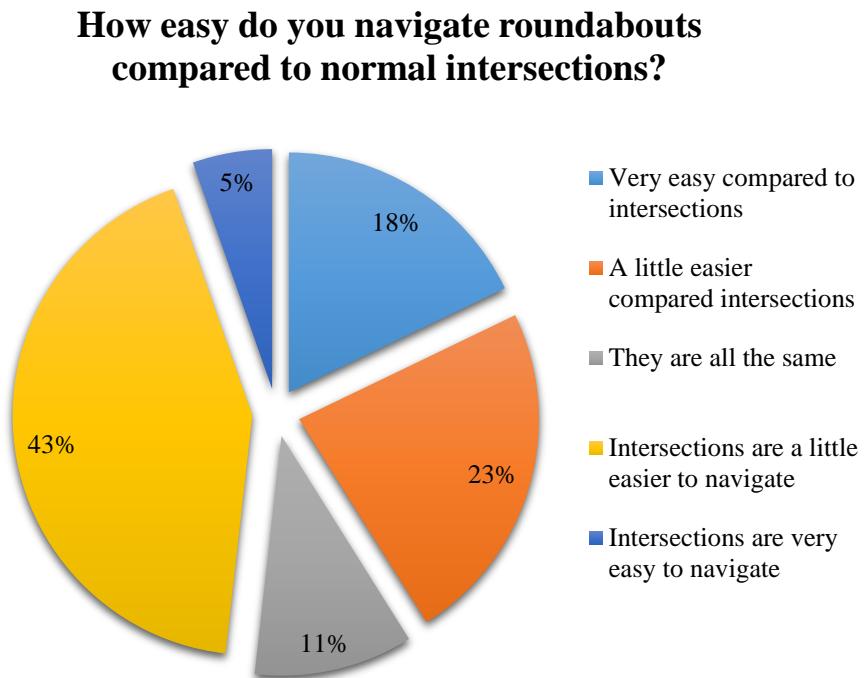


Figure 23 Participants' Perception on navigability of roundabouts

In terms of safety as shown by Figure 24, 20% perceive roundabouts to be safer than intersections while 27% perceive intersections to be safer. Thirty percent reported the two being the same in terms of safety. Of interest is that 43% perceive roundabouts to be at least a little safer than intersections.

How safe do you feel when navigating a roundabout compared to intersections?

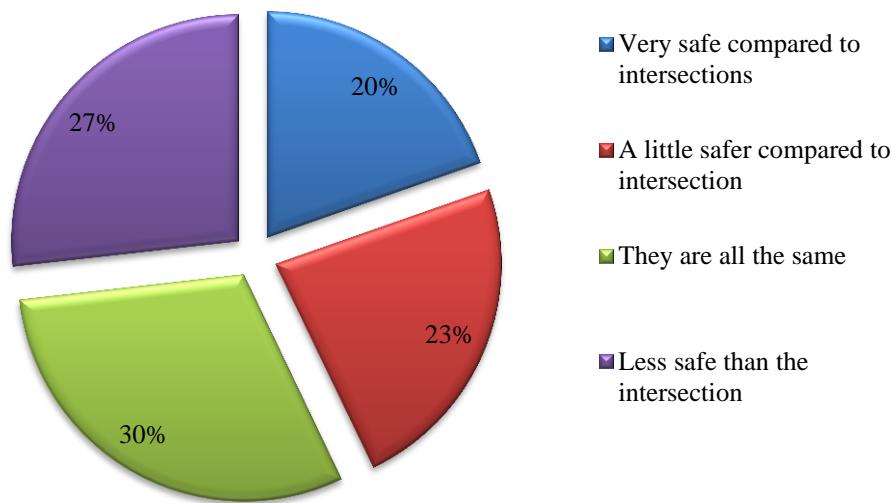


Figure 24 Participants' safety Perception on roundabouts

To understand what participants consider to be correct in terms of lane changes within the roundabout, a question asking them of whether they can change lanes while already driving within the roundabout was included in the pre-experiment questionnaire. Surprisingly, as shown in Figure 25, about 66% of the participants thought they could change lanes when already driving within the roundabout. Changing lanes within the circulatory roadway within the roundabout is discouraged in MUTCD (25), since it is a potential cause of crashes within the roundabout.

Can you change lanes when you are already driving within the roundabout?

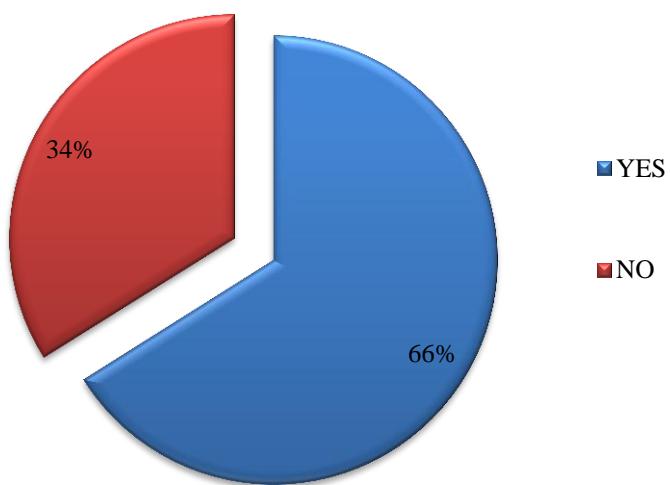


Figure 25 Participants' response to lane changing within the roundabout

Two questions on lane use signs and pavement markings were included in the post-experiment questionnaire. These were designed to help understand whether the participant noticed a difference in the signing and marking schemes used in the study and thus determine what participants paid more attention to. The questions also helped determine if there is a noticeable difference between the schemes. Furthermore, the questions obtained the driver's rating for a particular scheme on how easy it was for them to understand what to do when navigating a roundabout.

The questions asked were whether the driver noticed the difference between the two lane use pavement schemes (i.e the fish-hook markings and those adopted from Netherlands' turbo roundabout markings) when driving. Similar questions were asked for lane use signs.

From Figure 26 and 28 below, it can be observed that 58% of the drivers noticed the difference between the two lane use pavement marking schemes, while only 47% noticed the difference between the lane use signing schemes. From the drivers' ratings for the two schemes shown in Figure 27 and Figure 29 it was observed that for both lane use pavement markings and signs, drivers highly rated the fish-hook compared to the NED. (i.e 55.6% and 62.2 % of drivers reported fish-hook to be very easy to understand for pavements and signs respectively). No scheme was reported to be very hard to understand.

When you were driving, did you notice the difference between these pavement markings?

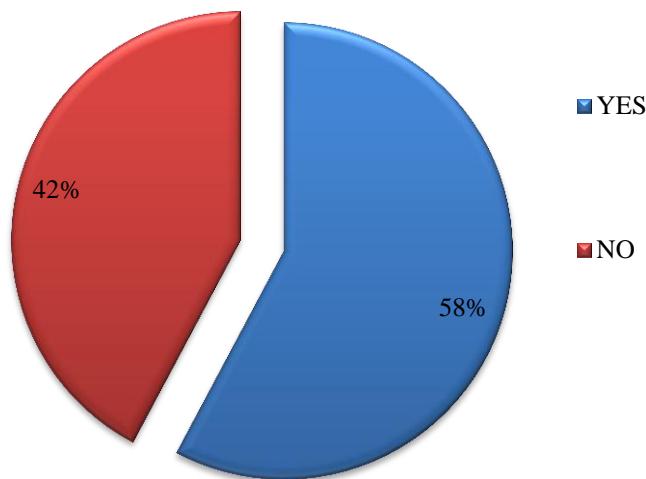


Figure 26 Driver response on noticing differences between lane use pavement markings

Please rate the pavement marking's easiness to understand by checking the appropriate box

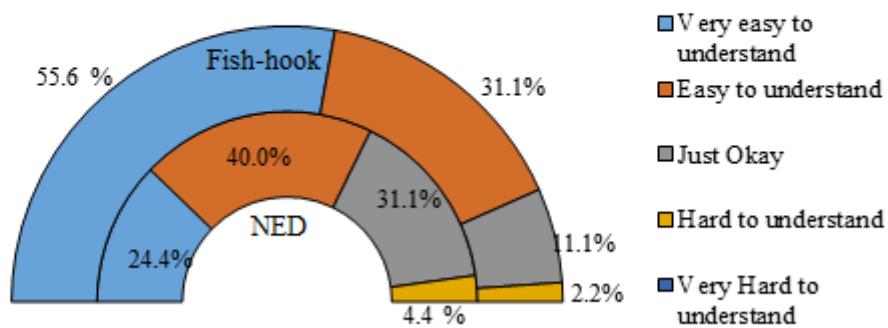


Figure 27 Drivers' lane use pavement markings rating

When you were driving, did you notice the difference between these signs?

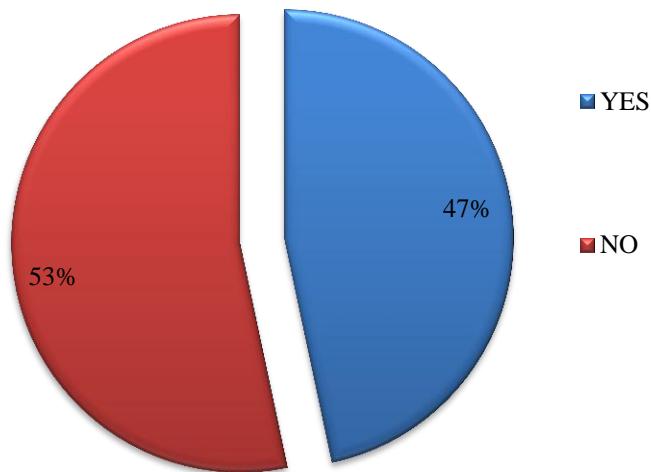


Figure 28 Driver response on noticing differences between lane use signs

**Please rate the sign's easiness to understand by
checking the appropriate box**

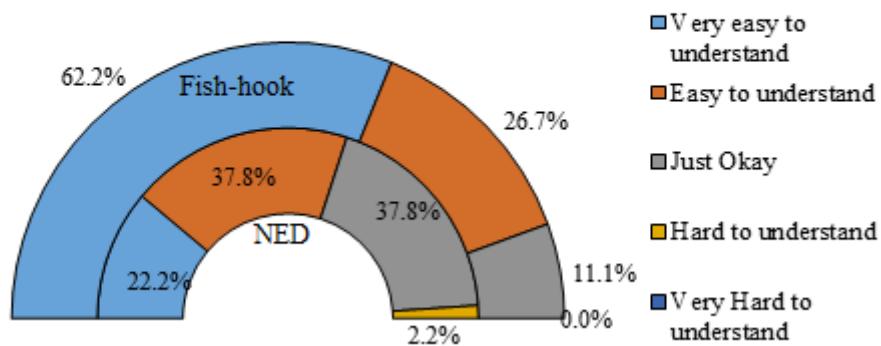


Figure 29 Drivers' lane use sign rating

5.3 Analysis of Lane Choices at Entry and Exits

Through the use of installed proximity sensors at the approaches and exits (as explained earlier), driver's lane choices could be extracted from the data. Lane choices were also recorded and maintained manually by the experimenter. This was later used as a reference to check the correctness of the sensors as well as a means of filling in missing data whenever possible.

Lane choices were recorded at the entry as soon as the subject vehicle reached the solid white line at the approach and at the yield line. The choice of exit lane was also recorded. Recording was done both automatically by the simulator's computers and manually.

Depending on the direction of the specified destination and the turn movement a driver was required to make, lane choices at the entry were classified as correct (given a dummy variable of 1) or incorrect (given a dummy variable of 0). At the exits, the lane used to exit was also classified in the same manner. For a driver that changed

his/her lane within the roundabout and ending up with a wrong lane at the exit the exit lane was classified as incorrect. It is also important to note that at some instances when drivers had choices two lanes could all be named as correct. Such instances were when going through for the two-lane and rotor turbo roundabouts and when turning right for the rotor turbo roundabout.

After reducing and compiling data from both computer recorded data and manual records a final dataset of each participants' lane choices was made ready for further analysis. Further analysis included determining what proportion of the participants chose lanes correctly in each of the scenario. The analyses also probed the existence of any association between correct lane choices and roundabout type, marking and signing scheme, gender, driving experience, roundabout driving experience and age.

Determination of what proportion of participants drove the wrong way, took the wrong exits, or made wrong entries especially at the rotor turbo roundabout (where some participants were tempted to use inner circulatory lanes starting within the roundabout designed for traffic from a different approach) was also performed. This information was also recorded by proximity sensors placed on these locations that drivers were not supposed to use for particular movements. Once such a sensor's number was recorded it was known that the driver took the wrong path, entry or exit.

5.4 Lane Keeping Analysis

Lane keeping was measured through the use of offsets of the subject vehicles center of gravity from the centerline of the roadway known as 'lane offset'. This is a continuously recorded data by the simulator. In this study the data collection frequency was 60Hz.

Lane keeping was observed/analyzed from the beginning of the yield line of each roundabout through the circulating roadway up to the exit lane where a driver leaves the roundabout.

It is important to note that due to design details of roundabout configurations used, the correlated data elements that defines the roadway as explained previously have some technical limitations. For example when placing control points at given distances for efficient/ logical flows of traffic, roadways are not solidly connected to each other. Gaps exist between the end of one roadway and another especially at the intersection of approaches and circulating roadway. For this reason when a driver is traversing this connecting short distance, incorrect values may be recorded. Such values need to be checked or cleaned before further analysis is performed. For this reason specific sensor locations where chosen for lane keeping analysis.

As adopted in one of the studies mentioned earlier (4), a vehicle was considered to be within a lane if not more than half of the vehicle was outside the white edge lines of a lane. As soon as a vehicle records an offset more than half the vehicle width outside the lane margins it was considered that the driver did not keep lane. The through and left turn movement were considered for lane keeping analysis as right turns at roundabouts are quite easy to make mostly and the right turn is usually a short one.

With reference to the lane size of the two-lane roundabout used, which was 4.2672 m, (14ft) calculations of the offset of the center of gravity from the centerline was done. If the difference between half the lane size and square root of the square of offset (this is done to obtain positive numbers as offsets are reported both as positive and negative) is less than zero then that driver was considered not to keep lane.

A challenge existed when picking the lane width for the rotor turbo roundabout for lane keeping analysis, because as the lanes of turbo roundabouts progress from start point within the roundabout towards to exit, they tend to fan out and narrow in width. So picking a single value was a challenge. A decision to use 4.75m which as shown in Figure 8 (the turbo block used for design of the used rotor roundabout) in the previous section is the width of the lane after a right angle transition. Further narrowing of the lanes is not considered as by that time, the lane has left the roundabout already.

Due to unforeseen circumstances, it was found that the exit proximity sensor for the left turn at the rotor turbo roundabout was not recorded for the fish-hook scheme. This particular information could also not be retrieved from manual record as it was not recorded manually. Lane keeping was only analyzed through the NED scheme both for two-lanes and rotor turbo roundabouts. It should be noted that the effect of lane use sign/marketing schemes on lane keeping was minimal especially since turbo roundabouts do not have lane use markings within the roundabout.

Just as with lane choice, the existence of any association between correct lane choices and roundabout type, marking and signing scheme, gender, driving experience, roundabout driving experience and age were also investigated.

5.5 Navigation Speed Analysis

Since navigation speeds play an important role in roundabout safety, operational efficiency and capacity, an analysis and comparison of speed was also done. The speeds were measured from the beginning of the solid white line to the exits. For reasons explained earlier, only the NED scheme was used. Analysis was

also limited to through and left turn movements because of the shortness and relative easiness of right turns at roundabouts.

Driver speeds were automatically recorded by the simulator just as it was for the offset. The relevant speeds at sections of interest, which are between the beginning solid white line and exit, were extracted from the collected data using corresponding sensor numbers at these locations.

To determine whether a driver was speeding or not, two criteria were considered. Their maximum speeds had to be above 20 MPH and their 50th percentile speed had to be above 20MPH. When both of these conditions were met when driver was driving between the beginning of the solid white line and the exit then the driver was considered to be speeding and so assigned a dummy variable of 1 for the speeding variable.

The decision criteria were set for different reasons; 5 MPH above the set advisory speed which was 15MPH as explained in previous sections because usually this is the threshold for speeding enforcement in many jurisdictions (43), (44). The mean speed could not be used alone as there were drivers who spent a lot of time stopped at the approaches either waiting for other vehicles or for other reasons and for this period of time very low velocities were recorded, thus the mean would be too low. Looking at maximum speeds alone also could classify a driver who had a slight increase in speed above threshold for a very short duration as a speeding driver. For this reasons the 50th percentile was used so that if drivers had their 50th percentile above 20MPH and maximum speed above 20MPH, then they were regarded as speeding. Analysis of how speed or speeding was related to other variables such as yielding, gender, driving experience, roundabout experience age and lane keeping was performed.

5.6 Yielding Behavior Analysis

Yielding characteristics of drivers were recorded manually by the experimenter and later supported by examination of each drivers speed profiles for the four movements (through and left for the rotor turbo and two lane roundabout). Again, only two the NED scheme was used since sensor data wasn't recorded in the fish-hook scheme on a rotor turbo roundabout as explained earlier.

Yielding behavior was particularly hard to collect automatically as not under all situations drivers are required to yield. Yielding is necessary if there are vehicles already circulating the roundabout. Programming the simulator to be able to record the need to yield for a particular vehicle did not seem feasible especially due to exhausted simulator processing capacity. The experimenter manually recorded if a driver yielded at the entry or not. Recording of whether there was a vehicle within the roundabout to yield to or not was also done manually. Later, after sketching speed profiles (plots of speeds versus time data points) for all participants for all the scenarios as shown in Figure 30 below (For all profiles see Appendix H), it was decided that since the advisory speed was 15MPH if a driver reduced speed between the beginning of solid white lines and the yield line to 10MPH or less, then the driver was assumed to have yielded whether there was traffic to yield to or not (Yielding requires you to slow down and stop when necessary to give right of way). This information was used to supplement the manually recoded yielding behavior. Figure 30 shows the speed profiles of two drivers and the 10 MPH threshold indicated by a dashed red line. In this case for example, driver number 24 yielded while 39 did not. Final data form such an analysis was used to classify drivers as 'yielded' or 'did not yield' and 'required to yield' or was 'not required to yield' using dummy variables.

This was used for further analysis to study yielding behavior relationship to other observations.

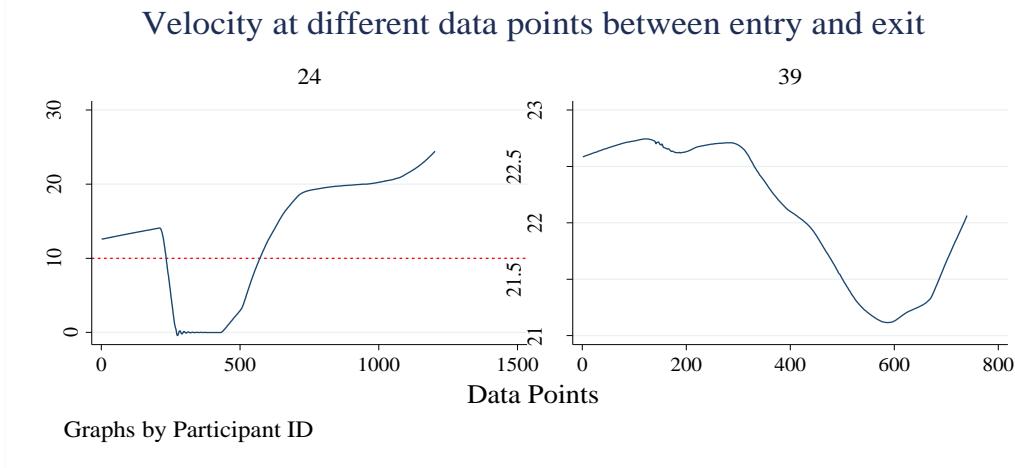


Figure 30 Velocity profiles of participant 24 and 39

CHAPTER 6 RESULTS AND DISCUSSION

The sections below present and discuss results of this study. The details of how the data used to obtain these results were discussed in the data analysis section. The results and discussion is grouped into four categories in support of the hypotheses to be tested.

6.1 Lane Choice

The initial analysis of entry and exit lane choices by individual drivers indicated that, for the through movement, where drivers had two choices of lanes as per the lane use restrictions, (i.e the inner lane, and the middle lane for the rotor turbo, and either lanes for the two-lane roundabout) those using the two-lane roundabout tended to distribute the choice between the two lanes almost proportionally as shown in Table 3. For both markings/signing schemes the distribution between the lanes was almost proportional, that is close to 50% of drivers using either lane. However, for the rotor roundabout, drivers going through tended to prefer using the center lane for both marking/signing schemes (68.9% of the drivers for the fish-hook scheme and 73.3% for the NED scheme)

This may lead to operational problems, specifically, affecting the capacity of the rotor turbo roundabout. One of the solutions to the challenges of the two-lane roundabout the turbo roundabout is supposed to provide is better use of inner circulatory lanes which is a problem that affects capacity in the concentric two-lane roundabout (12). For this case the results were different, indicating that the either lane choice is still a problem in the rotor turbo roundabout. Molino et al in their study (5) pointed out that as little as only 44% of drivers studied understood the correct meaning of having

either lane as a choice. Though direct comprehension surveys were not done in this study as they did, it is likely that with higher number of entry lanes as with the rotor turbo roundabout the problem is much more eminent.

Table 3 Either lane choice distribution for all scenarios

Through Movement (with 2 lane options)							
ROTOR_FISH		ROTOR_NED		TWO_LANES_FISH		TWO_LANES_NED	
Left lane	Center lane	Left lane	Center lane	Left lane	Right lane	Left lane	Right lane
Number	14	31	12	33	22	23	22
% of Total	31.1	68.9	26.7	73.3	48.9	51.1	48.9

For the right turn movement at the rotor turbo roundabout, most drivers preferred the rightmost lane (above 95 % for both cases of signing and markings) as seen in Table 4. Again as mentioned above, since there were two lane options for going right at the rotor turbo roundabout, this can be an underutilization of the center lane especially when right turn volumes are higher. This may affect capacity of the roundabout.

Table 4 Either lane choice distribution for right turn at the Rotor

Right turn Movement (with 2 lane options)			
ROTOR_FISH		ROTOR_NED	
	Center lane	Right lane	Center lane
Number	2	43	1
% of Total	4.4	95.6	2.2

Table 5 shows that more drivers (11.11%) going left on the rotor turbo roundabout when the NED scheme was used took the wrong exit leg. This may be attributed to drivers not understanding or not being familiar with the NED scheme of pavement markings or signs especially when taking the left turn whose navigation is more

involving than the through or right turns as indicated by having at least a driver take the wrong exit in each of the scenario.

Table 5 Percentage of Wrong exit legs per scenario

	Scenario type			
	ROTOR_FISH	ROTOR_NED	TWO_LANES_FISH	TWO_LANES_NED
Through	0.00	0.00	2.22	0.00
Left turn	2.22	11.11	4.44	4.44
Right turn	0.00	0.00	2.22	0.00

Because of the configuration of turbo roundabouts especially the rotor turbo roundabout, drivers who are unfamiliar to the design and making left turns, are sometimes tempted to enter into the inner left lane as their lane of travel fans out as shown by the red path in Figure 31 below.

This action may need vehicles to slow down extremely to be able to make the turn, thus slowing the rest of the vehicles and may lead to crashes. From Table 6 it can be observed that of all the drivers, only 5 of them made the wrong move with most (four) being from the NED scheme. This is another indication of drivers not really comprehending the lane use signs. This may even be more complicated for drivers who are new to turbo roundabout since by design, there are no guiding lane use pavement markings for lanes within the roundabout (as in modern concentric lanes multilane roundabouts).

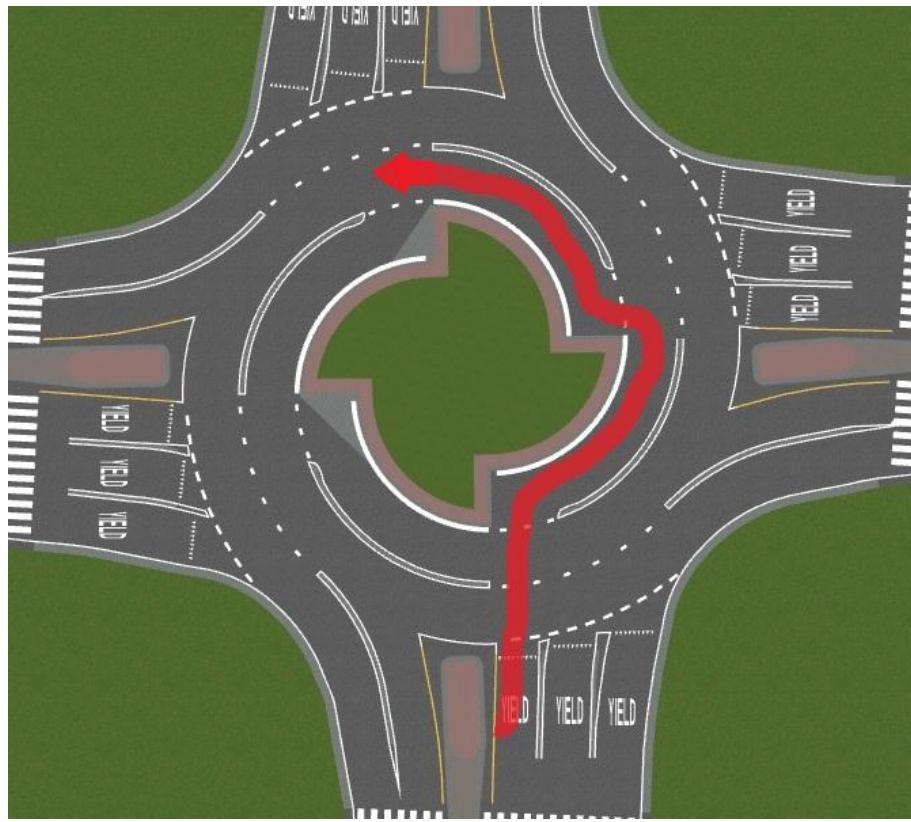


Figure 31 Wrong entry when turning left

Table 6 Number of Wrong entry when turning left

	Scenario type	
	ROTOR_FISH_250	ROTOR_NED_300
Number	1	4
% of Total	2.22	9.09

Another analysis performed was to evaluate the correctness of lane choices at entry and exit made by drivers. As seen in Figure 32 and Figure 33 comparing marking/signing schemes within the same roundabout, and looking at similar turn movements, there is no significant difference between signing schemes in the rotor turbo roundabout. However, when going through, the NED scheme performs a little

better than the fish-hook scheme. In the two-lane roundabout the NED scheme performs much better than the fish-hook. With the fish-hook on two lanes as low as 81.4% of drivers get the exit lanes correct when going left compared to 97.6% for the NED scheme for the same movement.

As it can be observed, drivers chose incorrect exit lanes more than they did for entry lanes on both schemes as well as roundabouts types. When comparison was done at roundabout level, the turbo roundabout did better as it had a minimum of 92.5% drivers getting correct lanes compared to 81.4% or 86% for two-lane roundabout.

From this analysis the NED scheme and the rotor turbo roundabout outperformed the fish-hook scheme and the two-lane modern roundabout.

Correctness of lane choice at entry and exit for Rotor

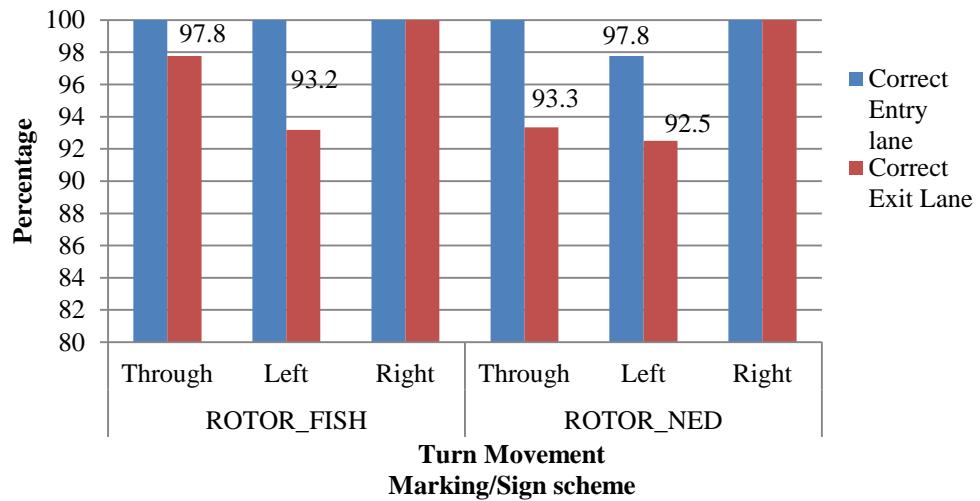


Figure 32 Correctness of lane choices at entry and exit for the rotor roundabout

Correctness of lane choice at entry and exit for Two-lane

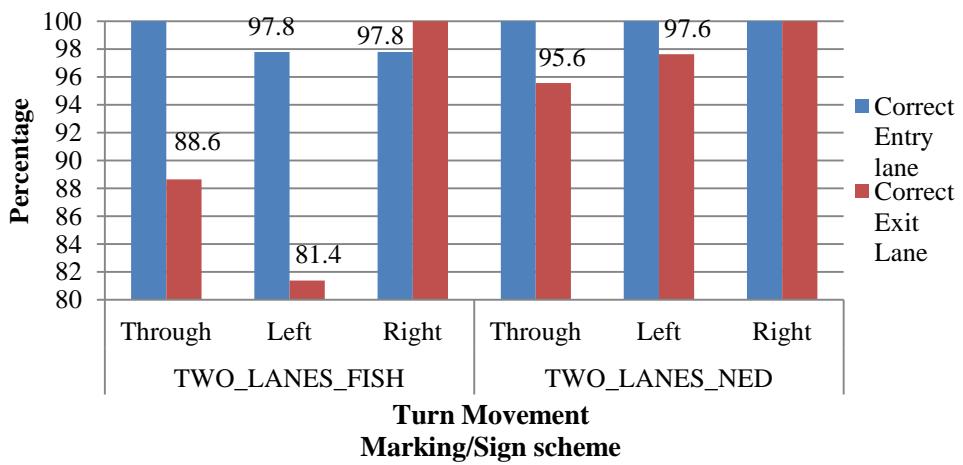


Figure 33 Correctness of lane choices at entry and exit for the two-lane roundabout

When a test of association using the Fisher's exact test was performed to check possible association of lane choices and other variables only gender was significant at the 95% level of confidence when the exit to go left was happening on a rotor roundabout with the NED scheme. Since 1 represented male, we can observe in Table 7 that no males (0%) took the wrong exit lanes when going left while 7.5% the total chose wrong exit lanes, and these were females.

Table 7 Association of gender and left exits for the NED scheme

		Rotor	
		Gender	
		0	1
Exit lane NED Left	0	7.5	0
	1	30	62.5

Fishers exact test P value = 0.046

6.2 Lane Keeping

The results show that when going through, proportions of drivers who keep lanes is almost the same (see Figure 30). However the two lane roundabout performed better than the rotor turbo roundabout when going left (97.1% compared to 85.2% lane keeping drivers' percentages). This is the opposite of what was expected since turbo roundabouts are specifically designed to solve this problem by dividers that keep users in their lanes.

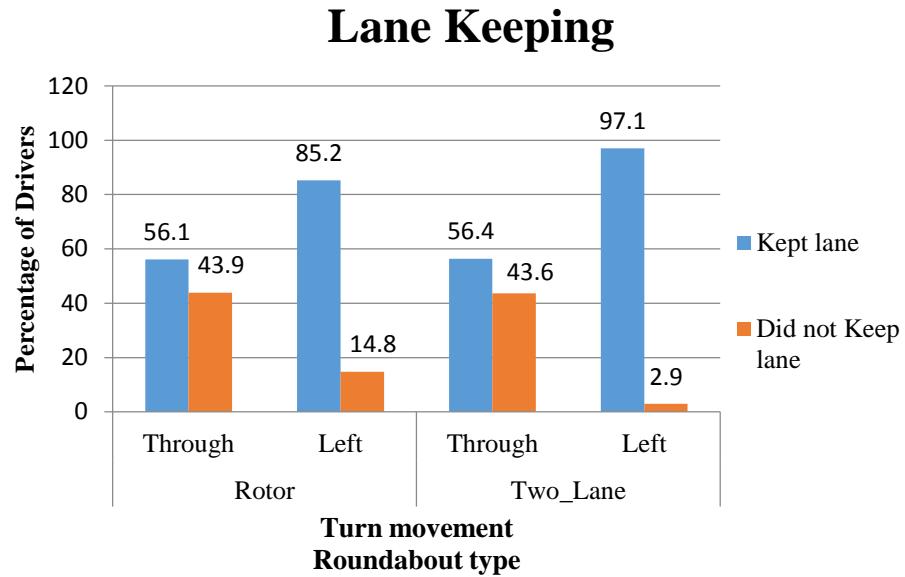


Figure 34 Lane keeping at different roundabouts and movements.

For an association analysis (see Table 8) it is observed that for lane keeping when going through gender was significant at the 95% level of confidence in a two-lane roundabout. Age was significant at the 90% level of confidence in a rotor roundabout while driving experience was significant at the 90% level of confidence when the roundabout is a two-lane. Table 9 shows that when going left on a rotor turbo roundabout, roundabout experience was a significant factor in determining lane keeping at 95% level of confidence. From the observed proportions people who are more experienced with roundabouts were more likely to keep lane in a rotor turbo roundabout than less experienced ones.

Table 8 Association of lane keeping when going through with different factors.

	Two-lane roundabout		Two-Lane roundabout			Rotor	
	Gender		Driving Experience			Age	
	0	1	0	1	Y	M	O
Lane Keeping-Through	0	25.64	17.95	20.51	23.08	26.83	7.32
	1	10.26	46.15	43.59	12.82	19.51	29.27
Fishers exact test		P-value 0.017		P-value = 0.091		P-value = 0.07	

Table 9 Association of lane keeping when going left with roundabout experience

Rotor roundabout		
Roundabout Experience		
	0	1
Lane Keeping-Left	0	14.81
	1	33.33
Fishers exact test P-value	= 0.041	

6.3 Navigation Speed

Rotor roundabouts performed better compared to two-lane modern roundabouts with respect to lower navigational speeds. As Figure 35 depicts, as high as 32.5% of drivers were speeding when making a through movement compared to 11.9% for the rotor. When going left, the rotor turbo even performed better as no diver was found speeding compared to 28.6% of the two-lane roundabout. This proves the advocating given to the geometry of the rotor roundabout being designed in such a way that it slows vehicles to lower travel speeds hence reduce number of crashes, crash severities and improve capacity (12) .

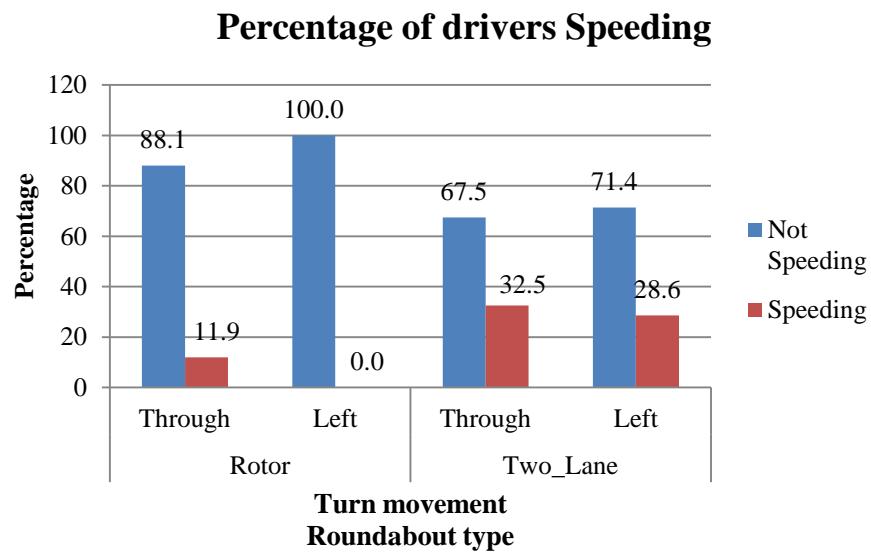


Figure 35 Percentage of drivers speeding

Table 10 shows that the variable roundabout type as seen from the above results and age (when driving on a two lane) were significantly associated to speeding .However, age was not significant when speeding was during left turns. As it can be seen from the higher proportions, it is more likely for drivers on the two lane roundabout to be speeding compared to the rotor.

Table 10 Association of speeding with roundabout type and age

	Roundabout Type			Age		
			Two-lane			
	Rotor	Two-lane		Y	M	O
Speeding-Through	0	45.12	32.93	30	20	17.5
	1	6.1	15.85	15	17.5	0
Speeding-Left	0	46.97	37.88			
	1	0	15.15			
Fishers exact test		P-value= 0.033 (through) P-value= 0.001 (left)		P-value= 0.097		

From the box plot of the velocity at all the data points between entry and exit below (Figure 36), the mean speeds and interquartile ranges show that on average rotor roundabouts had lower navigational speeds as expected compared to modern two-lanes roundabout. Left turns of each roundabout type had lower velocities than through movements. This is more eminent with the rotor turbo roundabouts due to its geometry.

It is important to note that both rotor turbo roundabout turn movements had mean velocities below the posted advisory speed (15MPH) as indicated with a red dotted line. This was not attained by the two movements of the two lane roundabout.

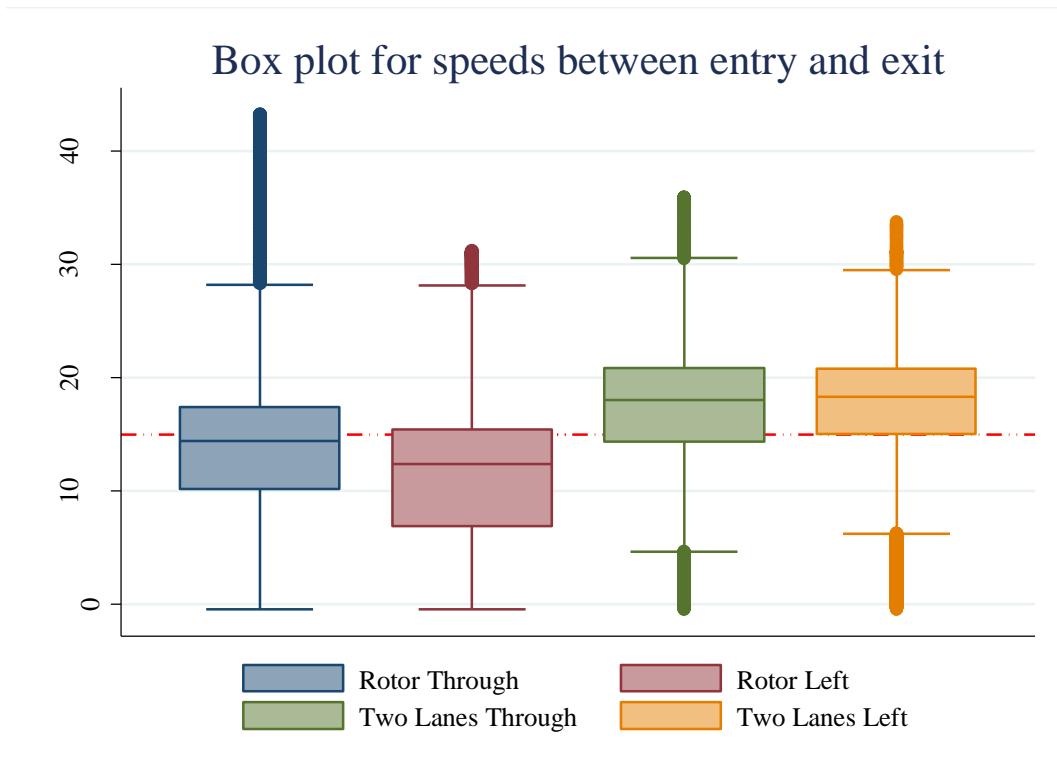


Figure 36 Box Plot for speeds between entry and exit.

For further analysis to ascertain the relationship between speeding and lane keeping, another box plot was prepared. From the Figure 37, it can be seen that with the exception of the left turn on a rotor turbo, the mean speed for those that didn't keep

lane for each corresponding roundabout and turn movement type was slightly higher than those that kept lane. Navigation speed is thus an important factor in lane keeping.

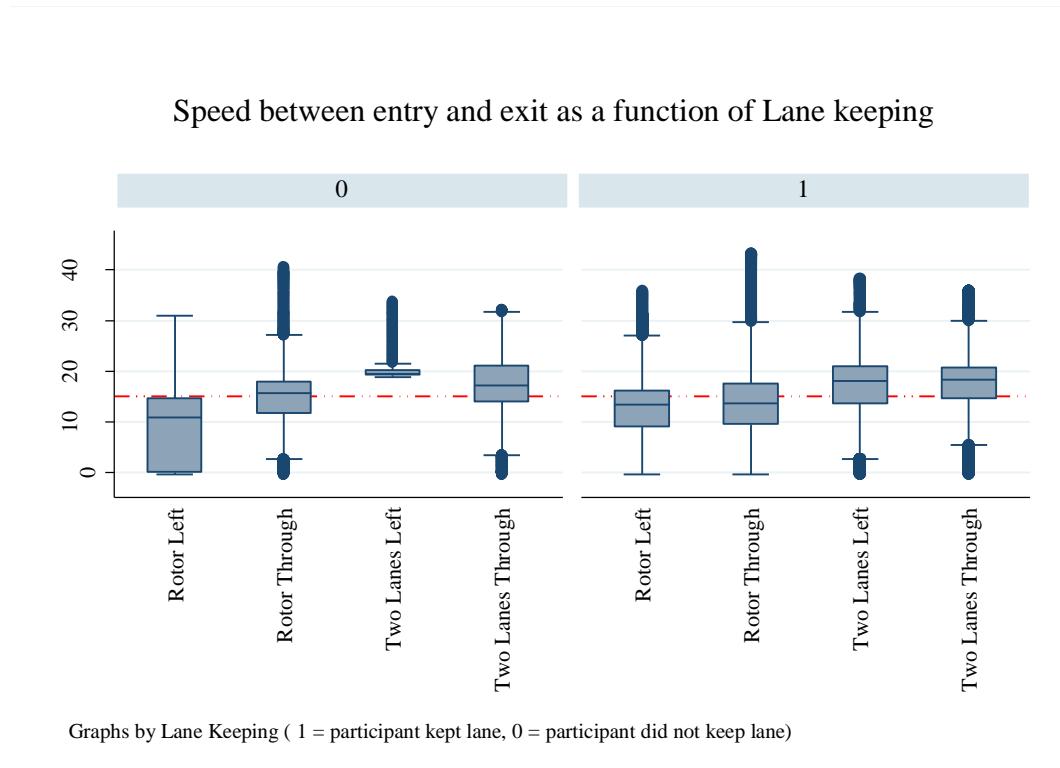


Figure 37 Speed between entry and exit as a function of lane keeping

6.4 Yielding Behavior

From Figure 38 a general observation is that more people yielded than they were required to in all types of roundabouts. Drivers at the rotor turbo roundabout generally yielded more as shown by the higher yielding rates on both turn movements (60% and 69.8% yielding rate compared to 37.8% and 40.9% yielding rate of the two-lane roundabout). They were required to yield more as the required to yield percentages shows. From this analysis, it is difficult to conclude that rotor turbo roundabouts influence drivers' yielding behavior more than the two lane roundabout. This is because the percentage of drivers were required to yield differed in each case.

A ratio of yielded/(required to yield) was calculated to determine the relative yielding behavior weighted against requirement to yield (i.e when there was a vehicle to yield to within the roundabout). The higher the ratio the better is the yielding and from Table 11 drivers going through on the two-lane did better than other movements with a ratio of 2.13 and so are the two lane roundabout left turning drivers compared to the rotor turbo left turning drivers. A further analysis showing percentage of those required to yield but did not yield indicate low percentages (0% to 4.44%) of drivers who were required to yield but did not yield (see Table 11). This implies that most drivers yielded when they were required to and the yielding behavior was not so different between the two kinds of roundabouts when yielding was required.

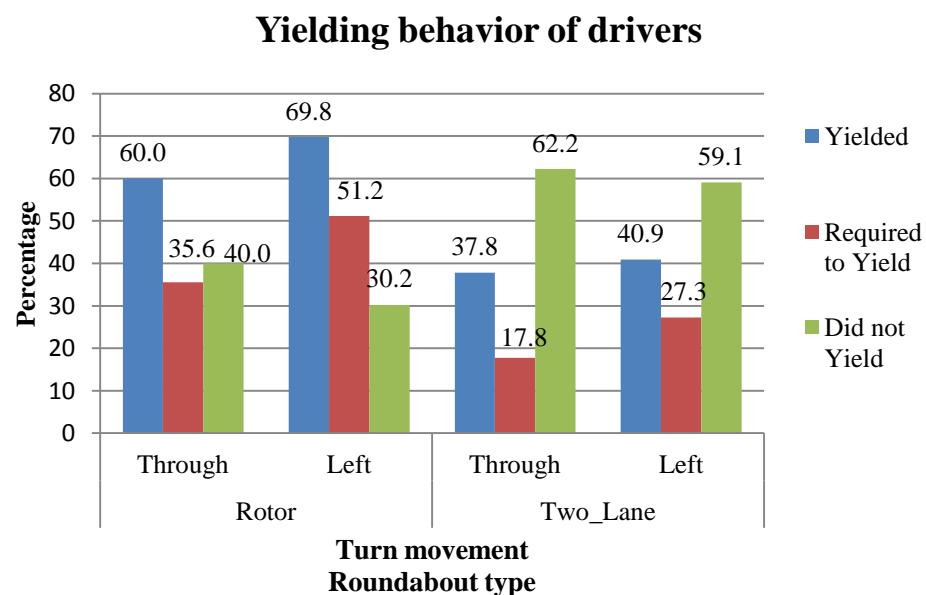


Figure 38 Yielding behavior of drivers

Roundabout type had a significant association with yielding when turning left at 95% level of confidence. According to the proportions shown in Table 12, the rotor roundabout performed better in terms of yielding when turning left.

Table 11 Yielding behavior of drivers between roundabouts.

	Rotor		Two-Lane	
	Through	Left	Through	Left
Did not Yield (%)	60.00	69.77	37.78	40.91
Required to Yield (%)	35.56	51.16	17.78	27.27
Yielded/Required	1.69	1.36	2.13	1.50
<u>Required but didn't yield (%)</u>	0	4.44	2.22	4.44

Table 12 Association of Yielding Left and Roundabout type

	Roundabout Type	
	Rotor	Two-lane
Yielding Left	0	14.94
	1	34.48

Fishers test P value = 0.01

CHAPTER 7 CONCLUSION, RECOMMENDATION AND CHALLENGES

6.1 Conclusion

From the above results, it has been observed that drivers' understanding of the 'either lane' concept at roundabouts is still of concern. Drivers tend to prefer one option only as it was for the very high percentage of drivers using the right most lane to go right and the middle lane to go through at the rotor turbo roundabout while not using the other available options. This can be an issue that affects the capacity of a turbo roundabout when one lane is overused while the other optional lane is not.

From descriptive statistics it was shown that more drivers preferred the intersections for navigability while safety-wise they preferred roundabouts. It is important to educate the public on how roundabouts are navigated to reduce negative public opinion on roundabouts (9) especially if the rotor or other turbo roundabouts are to enjoy a much more acceptance to the US driving public.

With 66 percent of the drivers reporting that they can change lanes while already driving within the roundabout, the weaving problems experienced on modern roundabouts is prominent. Though, the results showed to slightly favor two lane roundabouts albeit with no statistical significance. The turbo roundabout can help solve this problem especially when raised lane divers are used instead of painted ones. For this case, since the simulator was a fixed base simulator, the full effect of the raised lane dividers used in turbo roundabouts could not be experienced by drivers.

The fish-hook scheme was preferred compared the NED scheme due to being highly rated for easiness to understand as compared to the NED Scheme. The performance of

the two schemes in all the scenarios was not significantly different. So, the fish-hook scheme can be adopted for lane use signing and pavement marking for turbo roundabouts in United States.

In terms of lowering navigation speeds, the rotor turbo roundabout gave better results than the two lane modern roundabout. Its mean speeds for different scenarios were all below the advisory speed of 15MPH.

The turbo roundabout does better with a minimum of 92.5 percent drivers making correct lanes choices compared to 81.4 percent for two lanes. This may be attributed to having lanes that are physically separated by dividers which also help channel vehicle into the right lane at the entry as well as the exits. The NED scheme outperformed the fish-hook for guiding drivers to choose correct lanes when used at a two lane roundabout.

People who are more experienced with roundabouts were more likely to keep lane in a rotor turbo roundabout than less experienced ones. This suggests that if turbo roundabouts are to be adopted in the United States, drivers will perform better when driving through them as they gain experience with them.

From the yielding analysis, drivers generally did well when they were required to yield to other vehicles with right of way at both kinds of roundabouts. However, it is hard to conclude which kind of roundabout performed better as different measures showed different results. The yielding/(required to yield) ratio showed the two lane to be better whereas bigger proportions of drivers turning left from the Fisher's test which was significant indicated drivers to yield more on the rotor turbo roundabout.

6.2 Recommendation

One of the important features of a turbo roundabout is the physical lane divider. These help to deter drivers from changing lanes within the roundabout. Fixed base simulators cannot replicate the intended discomfort the dividers provide to drivers when they cross or drive on them in real world driving. Further research should be done on how these actually affect driver behavior such as lane keeping within turbo roundabouts.

It would be advantageous to study how drivers behave on turbo roundabouts and modern roundabouts under different levels of traffic. For this study, the control of traffic density could not be achieved, thus random traffic conditions were experienced by drivers. For this study ambient traffic did not yield at the roundabouts. The effect of using better vehicle logic such as yielding behavior especially for the ambient traffic at the roundabout by employing software with better vehicle logic at complex intersections is worthy studying.

7.2 Challenges of the Study

Some of the challenges experienced during the study are that most design details of turbo roundabouts are not yet available in English. This presented a challenge when trying to gather important design details of these roundabouts. Creation of the driving scenarios especially the roundabout vehicle flow logic was cumbersome, an easier and flexible way that can enable defining roadway priorities and rules would have been of value to the research. The virtual databases of the roundabouts were also huge due to large number of polygons used for fidelity purposes. This sometimes led into lags

during the simulation and limited the number of models that could be loaded in one scenario.

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Appendix A Example of a .Path File

ROAD_ID: R38.0
ROAD_TYPE: Curve
ARC_RADIUS: 31.912483
SPIRAL_LEN1: 0.000000
SPIRAL_LEN2: 0.000000
SUPERELEVATION: 0.000000
CONTROL_POINT: -3.631880 -33.231908 0.030000
VCURVE_LEN: 400.000000
VCURVE_MIN: 20.000000
SLOPE1: 0.000000
SLOPE2: 0.000000
PROFILE_POINT: 1.828800 0.000000
PROFILE_POINT: -1.828800 0.000000
WIDTH: 3.657600
CENTER2LEFT: 1.828800
LANE_OFFSET: 0.000000
NUM_LANES: 1
PATHNAME: Default Road
SPEED: 7.000000
NO_PASSING: TRUE
STORE_HPR: TRUE
NUM_POINTS: 31
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Appendix B HSIRB Approval Letter

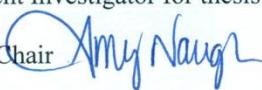
WESTERN MICHIGAN UNIVERSITY



Human Subjects Institutional Review Board

Date: May 28, 2014

To: Valerian Kwigizile, Principal Investigator
Elisha Jackson, Student Investigator for thesis

From: Amy Naugle, Ph.D., Chair 

Re: HSIRB Project Number 14-05-12

This letter will serve as confirmation that your research project titled “Virtual Analysis and Evaluation of Roundabout Safety and Operational Features” has been **approved** under the **expedited** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note: This research may **only** be conducted exactly in the form it was approved. You must seek specific board approval for any changes in this project (e.g., *you must request a post approval change to enroll subjects beyond the number stated in your application under “Number of subjects you want to complete the study.”*) Failure to obtain approval for changes will result in a protocol deviation. In addition, if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

Reapproval of the project is required if it extends beyond the termination date stated below.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: May 27, 2015

251 W. Walwood Hall, Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276

Appendix C Consent Form

Western Michigan University Department of Civil and Construction Engineering

Principal Investigator: Valerian Kwigizile, Ph.D., P.E.
Student Investigator: Elisha Jackson Wankogere
Title of Study: Virtual Analysis and Evaluation of Roundabout Safety and Operational Features.

You have been invited to participate in a research project titled “*Virtual Analysis and Evaluation of Roundabout Safety and Operational Features*.” This project will serve as **Elisha Jackson Wankogere’s** thesis for the requirements of the MSc. in Civil Engineering. This consent document will explain the purpose of this research project and will go over all of the time commitments, the procedures used in the study, and the risks and benefits of participating in this research project. Please read this consent form carefully and completely and please ask any questions if you need more clarification.

What are we trying to find out in this study?

The purpose of this study is to evaluate the effectiveness of different roundabout navigation signing and markings on different roundabouts and how they affect operation.

Who can participate in this study?

Anyone who can legally drive in the USA and capable of operating a motor vehicle can participate in this study.

Where will this study take place?

The study will be performed at the WMU’s Transportation Research Center for Livable Communities (TRCLC) Driving simulator lab, located at Parkview campus room number F-212.

What is the time commitment for participating in this study?

The study will require at most **75 minutes** inclusive of breaks where if you will be required to sign this consent form, given instructions of the experiment, and drive in a virtual world. A simple questionnaire may be administered before the experiment as well as after the experiment.

What will you be asked to do if you choose to participate in this study?

After being introduced to the experiment, signing the consent form, taking a pre administered questionnaire, taking the postural stability test (where observation on how long you can stand on one leg of your choice for a maximum of 30 seconds will be made) and having a test drive, you will be asked to drive through a series of virtual roundabouts connected by other roadways to an instructed destination. A post study postural test and a simple questionnaire will be administered to the participants after the driving is finished.

What information is being measured during the study?

During the study, the data recorded will include selection of appropriate lane of entry, maintenance of appropriate lane when navigating the roundabout, use of the correct exit leg and exit lanes to the instructed destination, lane position, vehicle speed, acceleration, pedal

forces, headway distances, steering wheel position, distance at which you recognize and comply to the different signing and marking schemes, gender and age.

What are the risks of participating in this study and how will these risks be minimized?

The only rare risk related to the study is simulator sickness, which mostly ends few minutes after leaving the simulator. This situation is common to flight simulators. Driving simulators (the one you will drive) have even lower risks. To avoid any possibility of simulator sickness, breaks will be provided during the session.

What are the benefits of participating in this study?

Other than the chance to experience the use of the driving simulator and familiarization of its basics, there are no direct benefits to individual participants. Direct benefits through the knowledge obtained from this thesis are more intended to the roadway design, safety and operating community.

Are there any costs associated with participating in this study?

There are no costs of participating in this study.

Is there any compensation for participating in this study?

As a token, we will be giving a lottery ticket after your completion of the study. No other compensation is to be expected

Who will have access to the information collected during this study?

Data for participants who consent to participate will be anonymized by assigning you a unique ID. Since no personal information is needed nor will be collected, there is no confidentiality issue.

The results of the study are expected to be disseminated on an aggregate basis through a student thesis, a report to FHWA as well as possible journal publications.

What if you want to stop participating in this study?

You may choose to not take part of discontinue the study during any time of the study may you experience any discomfort or for any other reason. You suffer no penalty by deciding to not participate or end your participation at any time of the experiment. The investigator can also decide to stop your participation without your consent may he/she deem it necessary.

Should you have any questions prior to or during the study, you can contact the primary investigator Dr. Valerian Kwigizile at (269) 276-3218, You may also contact the Chair, Human Subjects Institutional Review Board at 269-387-8293 or the Vice President for Research at 269-387-8298 if questions arise during the course of the study.

This consent document has been approved for use for one year by the Human Subjects Institutional Review Board (HSIRB) as indicated by the stamped date and signature of the board chair in the upper right corner. Do not participate in this study if the stamped date is older than one year.

I have read this informed consent document. The risks and benefits have been explained to me. I agree to take part in this study.

Please Print Your Name

Participant's signature

Date

Appendix D Pre-experiment Questionnaire

Pre- EXPERIEMENT QUESTIONNAIRE

Please answer the following questions by filling, checking or circling as appropriate.

1. What is your age group:

< 25 yrs

26 – 60 yrs

60+
yrs

2. What is your gender?

Male

Female

3. For how long have you been driving (in years)

4. How often do you drive through roundabouts?

Everyday

Often

Once in a while

Never

5. How easy do you navigate roundabouts compared to normal intersections?

Very easy compared to intersections

A little easier compared to intersections

They are all the same

Intersections are a little easier to navigate

Intersections are very easy to navigate

6. How safe do you feel when navigating a roundabout compared to intersections?

Very safe compared to intersections

A little safer compared to intersection

They are all the same

Less safe than the intersection

7. Can you change lanes when you are already driving within the roundabout?

Yes

NO

8. Have you (in the past) experienced the following symptoms in the following situations:

While driving an automobile

1. Nausea:	Never	Sometimes	Often	Nearly Always
2. Head ache:	Never	Sometimes	Often	Nearly Always
3. Dizziness:	Never	Sometimes	Often	Nearly Always

On amusement rides such as roller coaster

1. Nausea:	Never	Sometimes	Often	Nearly Always
2. Head ache:	Never	Sometimes	Often	Nearly Always
3. Dizziness:	Never	Sometimes	Often	Nearly Always

On air travel

1. Nausea:	Never	Sometimes	Often	Nearly Always
2. Head ache:	Never	Sometimes	Often	Nearly Always
3. Dizziness:	Never	Sometimes	Often	Nearly Always

When playing computer games

1. Nausea:	Never	Sometimes	Often	Nearly Always
2. Head ache:	Never	Sometimes	Often	Nearly Always
3. Dizziness:	Never	Sometimes	Often	Nearly Always

9. **Instructions:** Circle how much each symptom below is affecting you **RIGHT NOW.**

1. General discomfort.....	None	Slight	Moderate	Severe
2. Fatigue.....	None	Slight	Moderate	Severe
3. Headache.....	None	Slight	Moderate	Severe
4. Eye strain.....	None	Slight	Moderate	Severe
5. Difficulty focusing.....	None	Slight	Moderate	Severe
6. Salivation increasing.....	None	Slight	Moderate	Severe
7. Sweating.....	None	Slight	Moderate	Severe
8. Nausea.....	None	Slight	Moderate	Severe
9. Difficulty concentrating.....	None	Slight	Moderate	Severe
10. Fullness of the Head	None	Slight	Moderate	Severe
11. Blurred vision.....	None	Slight	Moderate	Severe
12. Dizziness with eyes open.....	None	Slight	Moderate	Severe
13. Dizziness with eyes closed.....	None	Slight	Moderate	Severe
14. *Vertigo.....	None	Slight	Moderate	Severe
15. **Stomach awareness.....	None	Slight	Moderate	Severe
16. Burping.....	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea

Appendix E Post-experiment Questionnaire

POST EXPERIMENT QUESTIONNAIRE

1. **Instructions:** Circle how much each symptom below is affecting you **RIGHT NOW.**

1. General discomfort.....	None	Slight	Moderate	Severe
2. Fatigue.....	None	Slight	Moderate	Severe
3. Headache.....	None	Slight	Moderate	Severe
4. Eye strain.....	None	Slight	Moderate	Severe
5. Difficulty focusing.....	None	Slight	Moderate	Severe
6. Salivation increasing.....	None	Slight	Moderate	Severe
7. Sweating.....	None	Slight	Moderate	Severe
8. Nausea.....	None	Slight	Moderate	Severe
9. Difficulty concentrating.....	None	Slight	Moderate	Severe
10. Fullness of the Head	None	Slight	Moderate	Severe
11. Blurred vision.....	None	Slight	Moderate	Severe
12. Dizziness with eyes open.....	None	Slight	Moderate	Severe
13. Dizziness with eyes closed.....	None	Slight	Moderate	Severe
14. *Vertigo.....	None	Slight	Moderate	Severe
15. **Stomach awareness.....	None	Slight	Moderate	Severe
16. Burping.....	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

2. When you were driving, did you notice the difference between these pavement markings?

SET A



SET B



Yes

NO

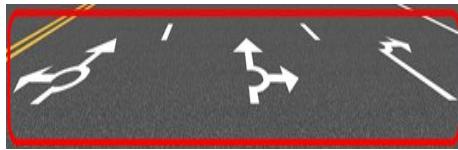
3. Please rate the pavement marking's easiness to understand by checking the appropriate box

SET A



- Very easy to understand
- Easy to understand
- Just Okay
- Hard to understand
- Very Hard to understand

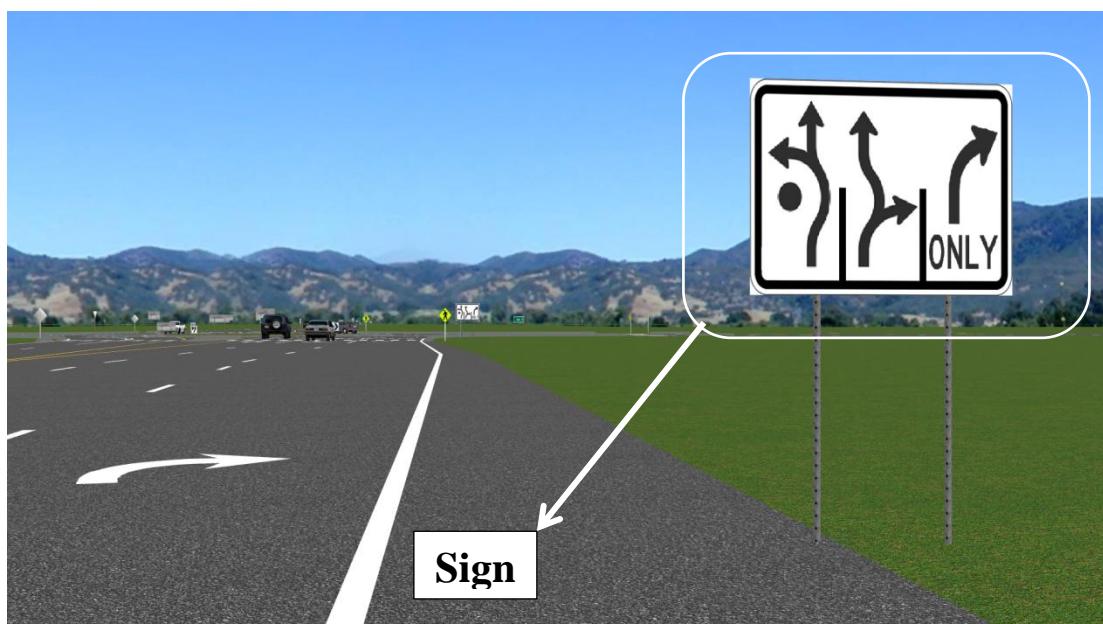
SET B



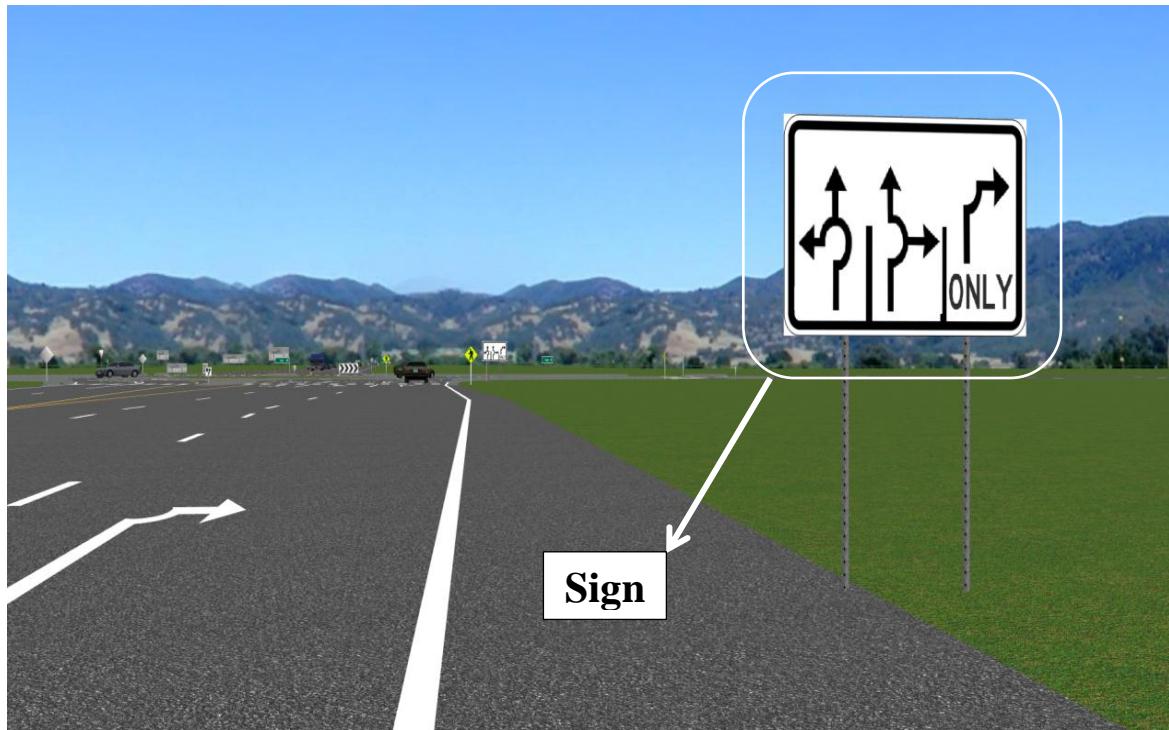
- Very easy to understand
- Easy to understand
- Just Okay
- Hard to understand
- Very Hard to understand

4. When you were driving, did you notice the difference between these signs?

SET C



SET D

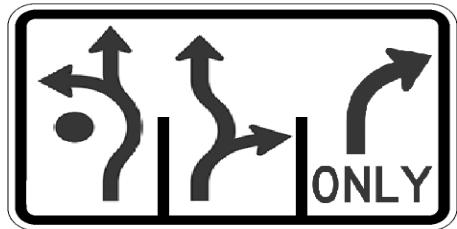


Yes

NO

5. Please rate the sign's easiness to understand by checking the appropriate box

SET C



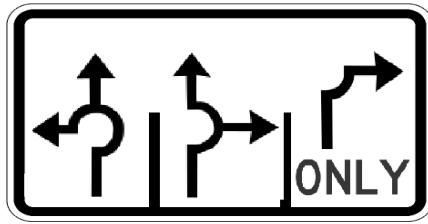
Very easy to understand

Easy to understand

Just Okay

Hard to understand

SET D



Very easy to understand

Easy to understand

Just Okay

Hard to understand

Very Hard to understand

| Very Hard to understand

Postural Stability test results.

	1 st trial (seconds)	2 nd trial(seconds)
Before experiment		
After experiment		

Fun! Fun! Fun!
As you hit the 'road'!



You are invited to the WMU's Transportation Research Center for Livable Communities (TRCLC) to participate in a

driving simulation study

and Pick up a Free Lottery Ticket!

YOU CAN BE THE LUCKY ONE THIS TIME!

Who: Any US legal driver



When: Schedule arranged to fit your own,
Contact us and fix yours today!

Where: At Parkview campus, room F-212.



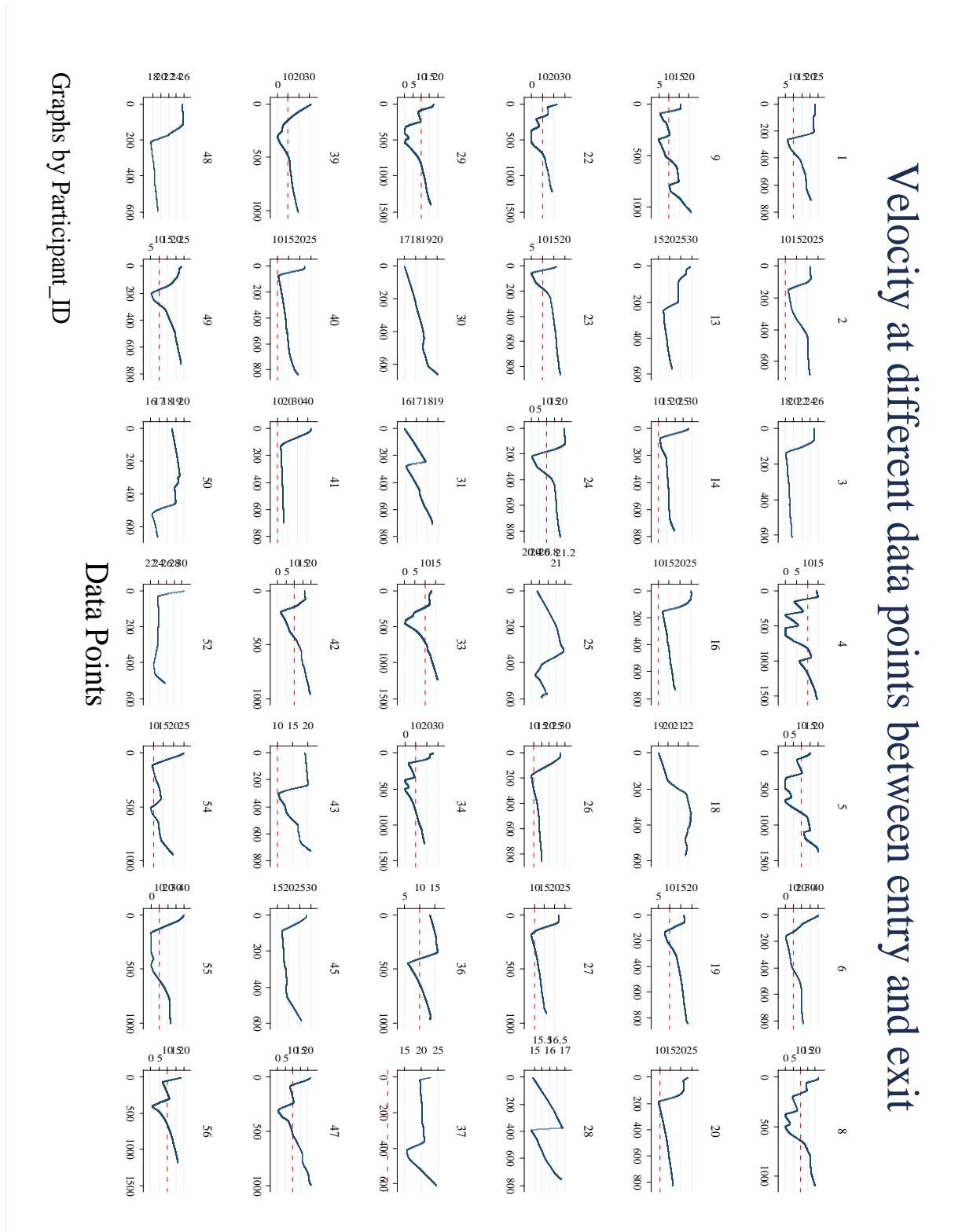
For more info Contact:
(269)267-5780 or (269) 276-3218
valerian.kwigizile@wmich.edu
elishajackson.wankogere@wmich.edu

PosterMyWall.com

Velocity at different data points between entry and exit

Appendix G Speed Profiles of Participants

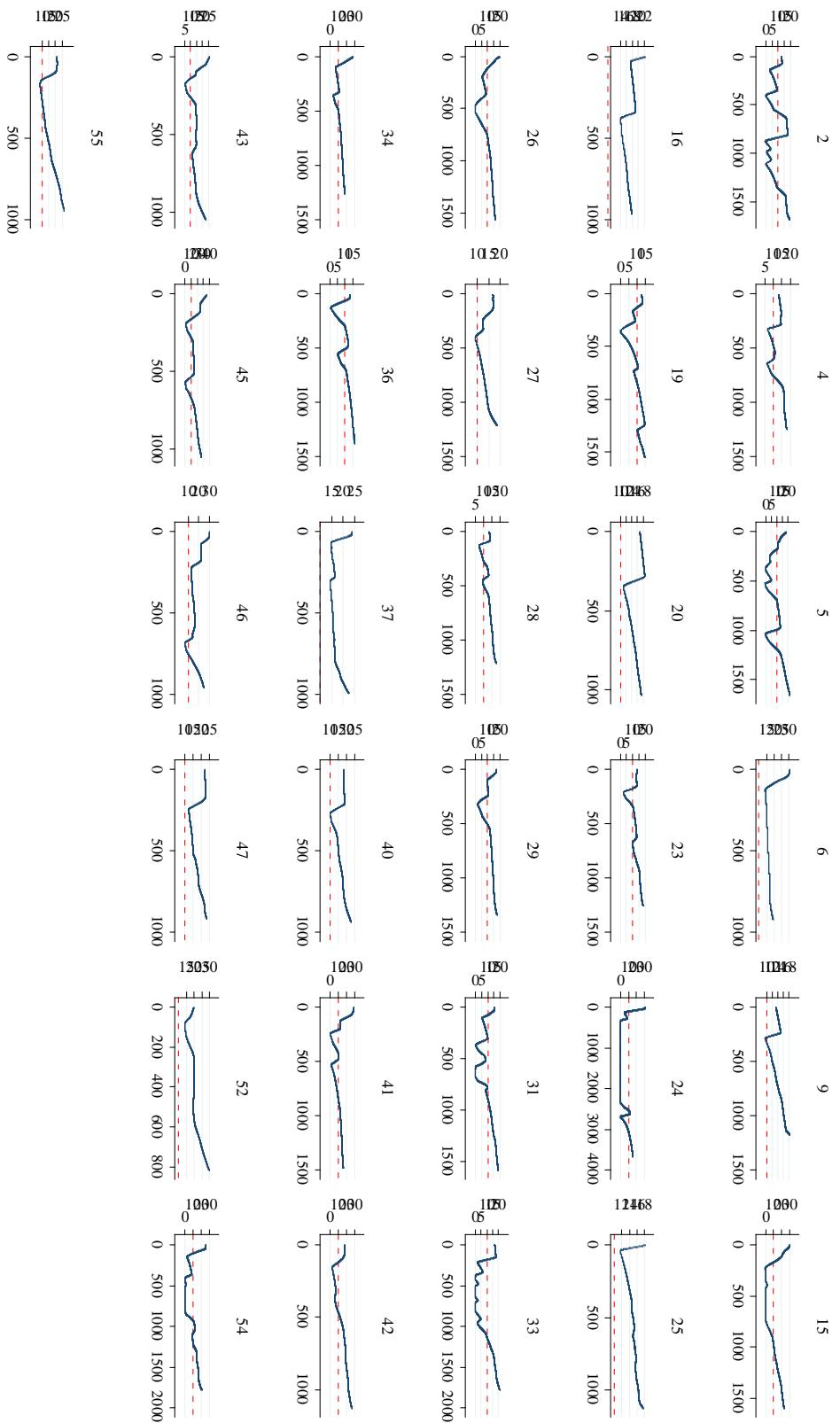
Rotor_NED_through_speeds_All_participants.gph



Graphs by Participant_ID

Data Points

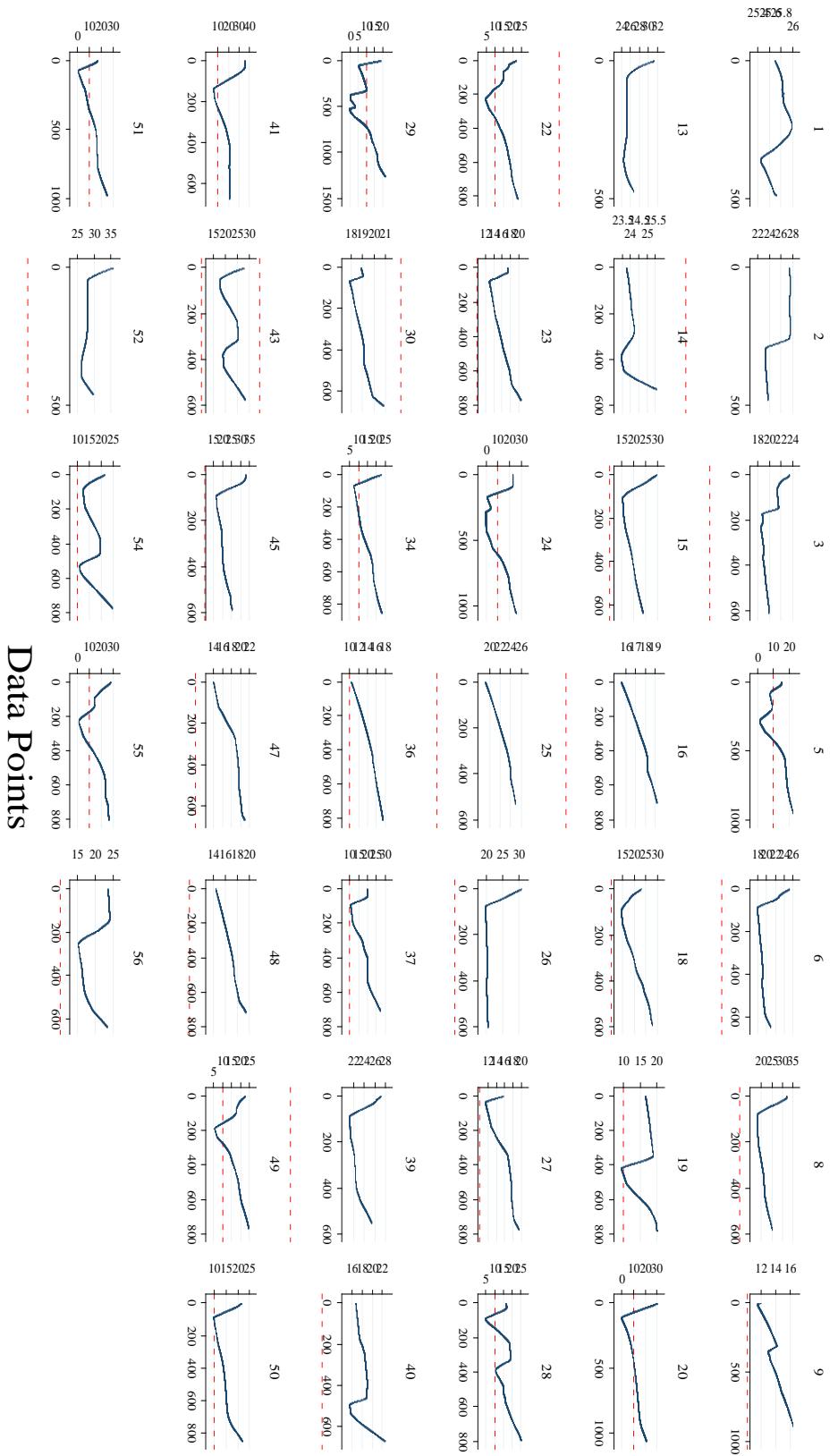
Velocity at different data points between entry and exit



Graphs by Participant_ID

Data Points

Velocity at different data points between entry and exit



Graphs by Participant_ID

Data Points

Velocity at different data points between entry and exit

Two_Lanes_NED_Left_Speeds

