to 2017 design was done to include some traffic volume data for the base design scenario. The two PTSU scenarios include the built in the existing geometry scenario and the ideal PTSU dimensions. Using the inputs of the HSM spreadsheets, the dimensions of the roadway were adjusted to fit PTSU within the existing geometry and follow the HSM limitations. The limitations were four foot outside shoulders and two feet inside shoulders at a minimum. To factor in these minimum values, the lane width across all lanes was eleven feet. The ideal PTSU dimensions used twelve-foot lanes throughout, the existing left shoulder dimensions, and four foot outside shoulders (following the HSM minimum dimension for the outside shoulder). Since HSM cannot model part-time dimensions, these scenarios were modeled as use all day use. The overall research approach is in Figure 2. There are different approaches to mimic PTSU, but this study is focusing on the geometric effects as they are a major factor in the safety performance.

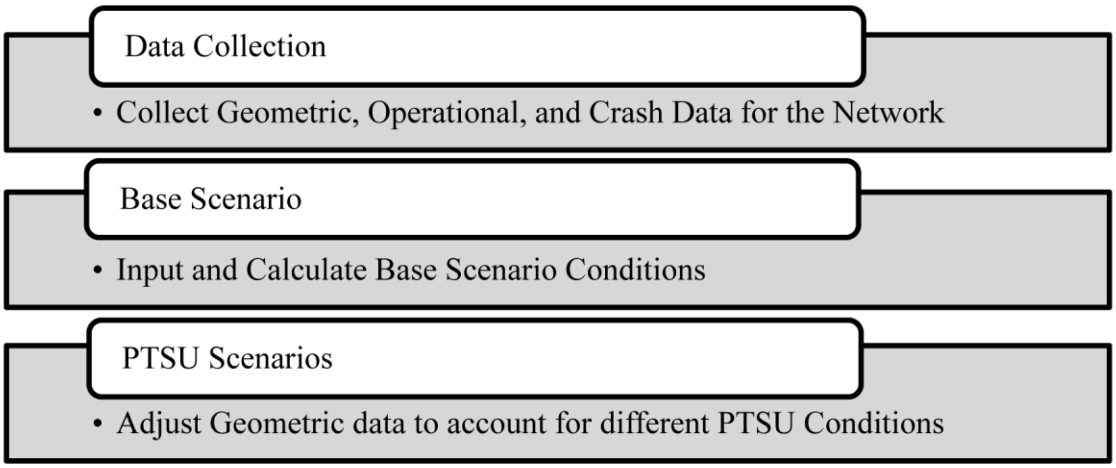

Figure 2. Research Approach Process.

RESULTS AND DISCUSSION

The results of this analysis are in Table 2. They were put in order of least amount of crashes to the highest amount of crashes. For this study, the order was the base, the ideal PTSU, and then the built within the existing geometry PTSU scenario. The PTSU scenarios were approximately four crash per year higher than the base scenario.

The results are divided by crash type and level of severity on the KABCO scale. The KABCO scale breaks down into fatal, (K), incapacitating injury, A, non-incapacitating injury (B), possible injury (C), and no injury (O) (Kolody et al. 2014). Both PTSU scenarios performed in similar manners but the ideal PTSU scenario safety performance was better than the existing geometry scenario. The ideal PTSU scenario performing better was expected, but the overall difference was minimal with the total amount of crashes per year only differing by a total of0.8 crashes per year. The existing geometry PTSU scenario only had fewer total crashes for the possible injury level with 0.5 crashes fewer per year.

The main benefit found for PTSU was the reduction in multiple vehicle crashes. PTSU reduced the total number of multiple vehicle crashes by approximately 6 to 7.5 crashes per year. Across all injury levels, the total, possible injury, and no injury crashes all reduced for both PTSU scenarios. The reduction in the total multiple injury crashes per year was balanced between possible injury and no injury. Both PTSU scenarios increased for the incapacitation and non-incapacitating injury levels with a slight increase, 0.1 crashes per year, for the fatal rear-end crash type for the existing geometry PTSU scenario. The increase in the incapacitating crashes was the same for both PTSU scenarios. The increase in the non-incapacitating crashes was higher for the existing geometry PTSU scenario. The most significant decrease in multiple vehicle crash types is the rear end crash type which is to be expected as the vehicles are more spread out and less likely to be directly behind the vehicle in front of them.

Table 2: HSM Result Comparison

	Crash Type	**Estimated Number of Crashes During the Study Period**																	
		Current Base						**Ideal PTSU**						**Existing Geometry PTSU**					
		Total	**K**	**A**	**B**	**C**	**PDO**	**Total**	**K**	**A**	**B**	**C**	**PDO**	**Total**	**K**	**A**	**B**	**C**	**PDO**
Multiple vehicle	Head-on	0.3	0.0	0.0	0.1	0.2	0.1	0.3	0.0	0.0	0.1	0.1	0.1	0.3	0.0	0.0	0.1	0.1	0.1
	Right-angle	1.7	0.0	0.0	0.2	0.6	0.9	1.6	0.0	0.0	0.2	0.5	0.8	1.6	0.0	0.0	**0.3**	0.5	0.8
	Rear-end	55.1	0.4	1.0	5.3	15.4	33.0	49.6	0.4	**1.1**	**5.9**	12.0	30.1	51.0	**0.5**	**1.1**	**6.4**	12.3	30.6
	Sideswipe	18.0	0.1	0.2	1.3	3.7	12.7	16.2	0.1	**0.3**	**1.4**	2.9	11.5	16.6	0.1	**0.3**	**1.6**	3.0	11.7
	Other multiple vehicle	2.0	0.0	0.0	0.2	0.6	1.1	1.8	0.0	0.0	0.2	0.5	1.0	1.8	0.0	0.0	**0.3**	0.5	1.0
	Total multiple vehicle	77.1	0.5	1.3	7.1	20.5	47.8	69.5	0.5	**1.5**	**7.9**	16.0	43.5	71.3	**0.7**	**1.5**	**8.5**	16.4	44.2
Single vehicle	Animal	0.6	0.0	0.0	0.0	0.0	0.6	**0.8**	0.0	0.0	0.0	**0.1**	**0.7**	**0.8**	0.0	0.0	0.0	0.0	**0.7**
	Fixed Object:	30.5	0.2	0.5	2.7	7.8	19.3	**38.7**	**0.3**	**0.9**	**4.9**	**10.0**	**22.5**	**37.9**	**0.4**	**0.9**	**4.8**	**9.3**	**22.5**
	Other Object:	4.6	0.0	0.0	0.2	0.6	3.8	**5.6**	0.0	**0.1**	**0.4**	**0.7**	**4.4**	**5.5**	0.0	**0.1**	**0.3**	**0.7**	**4.4**
	Parked vehicle:	0.6	0.0	0.0	0.1	0.2	0.4	**0.8**	0.0	0.0	0.1	0.2	**0.5**	**0.8**	0.0	0.0	0.1	0.2	**0.5**
	Other single vehicle	6.1	0.1	0.1	0.8	2.3	2.8	**8.0**	0.1	**0.3**	**1.4**	**2.9**	**3.3**	**7.8**	0.1	**0.2**	**1.4**	**2.7**	**3.3**
	Total single vehicle	42.5	0.3	0.7	3.8	10.9	26.9	**53.8**	**0.5**	**1.3**	**6.8**	**13.9**	**31.4**	**52.8**	**0.6**	**1.2**	**6.7**	**13.0**	**31.4**
	Total crashes:	119.6	0.7	2.0	10.8	31.4	74.7	**123.3**	**1.0**	**2.7**	**14.8**	29.9	**74.9**	**124.1**	**1.3**	**2.7**	**15.2**	29.4	75.5

Highlight: Reduced Number of Crashes, Bold: Increased Number of Crashes *Rounded results may not add up to total

Any change in the single-vehicle crash types was an increase for both PTSU scenarios. The increase in total single-vehicle crashes was over 10 to 11 crashes per year. The existing geometry PTSU scenario increased less when compared to the ideal PTSU scenario. The increase was on nearly all injury levels for the fixed object, other object, and other single vehicle (representing miscellaneous types of single-vehicle crash types) crash types. An increase in hitting objects, both fixed and other, is unsurprising with small shoulder widths in both PTSU scenarios.

The crash type changes in crashes per year for rear-end crashes, side-swipe, other single vehicle, fixed object, and other object were all significant with at least one whole crash change per year. Factoring in these PTSU scenarios are only open part-time, the commuting period accounting for about 25% of the daily commuting volume, the change in crashes per year would only be about a quarter of the changes (PennDOT 2016). The other changes in performance would be minimal to the point where some would need over a decade of time for a change of a single total crash to occur.

CONCLUSIONS

The key takeaway from this study is a shift from multiple vehicle to single vehicle crash types occur with the implementation of PTSU. Typically this would relate to a general decrease in total severity, but overall the severity of the crash types increased except for the possible injury crash type. The difference between the ideal PTSU scenario and the existing geometry PTSU is minimal. To expand the roadway to the required cross-section to fit the ideal scenario would total to an estimated 56,000 square feet of additional pavement. This increase would be costly with only the pavement costs and does not factor in any possible bridge replacements that would need to occur to implement the wider design. Overall, both scenarios performed similarly. The increase in total crashes is minimal when factoring in the part-time use reducing the increase. The safety performance difference of the PTSU scenarios to the base scenario is not significant which agrees with the FHWA study results (Jenior et al. 2016).

LIMITATIONS OF HSM

The limitations mentioned in the FHWA study were evident throughout this study, especially not being able to factor in part-time use (Jenior et al. 2016). One additional limitation of the HSM methodology is the assumption that the dimensions in either direction are relatively similar at all times. In some segments of I-476, the inside shoulders were several feet different. If an operational or safety strategy were to be evaluated for either side of the roadway with the HSM, there would be no way to differentiate each direction of the roadway. If roadways dimensions differed in key locations, the performance could shift in one direction indicating the strategy being beneficial but for the other direction being detrimental regarding safety. The directional issue is unique, but with more plans being designed for localized scenarios, strategies implemented for specific directions of roadway may become more significant.

FUTURE WORK

The I-476 corridor used within this paper will also be evaluated with a Surrogate Safety Assessment Model (SSAM) analysis to complement this study. SSAM estimates possible conflicts, situations that could become crashes if they continue, based on Vissim model vehicle trajectory data. The Vissim model addresses the part-time issue of HSM with the ability to model specific periods of a day. The information from SSAM will provide a roadway safety disposition. The more possibilities of crashes to occur on a roadway, the less safe the roadway is for a driver. This study provides a predicted safety performance with the SSAM analysis providing a probabilistic safety performance. Together they provide two essential safety factors: shoulder there be a change in the distribution of crashes and is it less probable that collisions are to occur.

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Developing Crash Modification Factors Using Multiuser Driving Simulator

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ABSTRACT

A multiuser driving simulator is used in this study to explore the relationship between road and weather conditions, vehicle speed, and crash potential due to driver's behavior. In this study, ten driving simulator scenarios were conducted. A total of 10 participants were recruited from different age groups to use the driving simulator. This study aims toward finding the relationship between the change in speed limit in certain weather condition and the number of crashes that are likely to occur as a sequence to this change. The data obtained from the driving simulator was used to estimate the crash modification factors (CMFs). The expected CMF gives the notion on whether a treatment or a change in speed limit in a certain weather condition will lead to change in the number of crashes and consequently a change in the safety level. The resultant CMFs from this study are considered a new dimension that will increase road safety and reduce the rate of road traffic crashes.

KEYWORDS: Crash Modification Factors (CMFs); road and weather conditions; Driving Simulator

INTRODUCTION

Road traffic collisions are the leading cause of injuries in the world. Every year, there are more than 20 million accidents leading to more than 1.5 million deaths globally (Buddhavarapu, 2015). In the United States, road traffic accidents are the leading cause of death among youths aged between 15 and 29 years. The annual cost of road collisions in the US is about $300 billion. Working towards road safety and hazard elimination are the key to insuring reduced road crashes. Driver's behavior, weather, and the state of the road are considered the major contributing factors for road traffic crashes.

The majority of crashes occur during rainy conditions and due to hazardous driving behavior. It is crucial to examine the driver's behavior and type of collisions during adverse weather and road conditions. This study is, a novel work because it uses a multi-user driving simulator to derive the crash modification factors (CMFs). The CMFs enable the prediction of the frequency of crashes on particular road sections when a specific treatment is applied. Driving simulators create real driver sensations in a controlled environment (Lee, 2015).

The multi-user driving simulator has the potential of developing CMFs because it simulates various traffic systems and examines driver's behavior. The purpose is to create a safe environment simulator to drive in real traffic systems. Road safety has become a vital domain of concern for road developers and those who are concerned with public safety and well-being (Apparao, 2012). The aim of the study is to come up with ways in which road crashes can be reduced on the highways. The development of CMFs using a multi-user driving simulator will cost-effectively predict the number of future crashes using the observational before-after method to reduce road collisions.

Crash Modification Factors and Crash Reduction

The crash modification factors CMFs play a crucial role in determining the frequency of accidents.

A study by (Edara, 2016) on the application of work zone CMFs reported that countermeasures for work zone areas allow predicting the changes in crash frequency. The CMFs for the I-70 in Indiana demonstrated that increasing the shoulder width by 1ft reduced the number of annual crashes by 0.043.

The wider shoulder widths allow the errant drivers to recover in case of an accident. The study proposed that the CMFs may be utilized to schedule lane closures. When implementing a countermeasure, it is expected that the number of crashes will be reduced.

The study by (Fitzpatrick 2008) found that accidents were reduced on the rural and urban freeways in Texas. The CMF equations were created specifically for urban and rural areas with rigid barriers and without barriers.

In the same way, (Lord, 2007) reported on the CMFs for the rural frontage road segments. When the roads were one-way, 41 accidents were reported. After making the roads two-way, the traffic crashes were reduced by 0.0721. Number of severe crashes were less compared to the typical one-way rural frontage roads.

Driving Simulator to Define Crashes

In recent years, driving simulators have become a popular tool applied to the traffic research field for studying the complex interaction between motor vehicles, drivers, and roadways. The driving simulators can be used to determine risks associated with traffic crashes and to estimate the subjective risks of the driving simulator crashes.

According to Dixit, using the driving simulator gives people a variety of choices so they can overcome risky choices that they can experience on the road. However, the use of the driving simulator is restricted by the surrounding environment. The experimental design included several scenarios so that participants can enhance their perception towards risk and make safer choices. One of these scenarios is directing the participant to make a left-hand turn, while there is a possibility of crashing with oncoming traffic (Dixit ,2013).

The study of Guo, illustrates that new technologies such as the driving simulator are helpful tools in examining the interaction between the driver, the vehicle, and the other environmental conditions. The driving simulator allows studying driver's behavior pertaining using a multi-lane freeway interchange which poses a considerable safety and operational challenges to the drivers in real life. The study used a UC-win software and three-dimensional driving environment. Based on the simulation data, it was found that the diverging and merging areas, commonly associated with interchanges, are prone to accidents (Guo, 2013).

(Jamson, 2010) evaluated the road safety treatments using robust driving simulators. The study developed 20 diverse speed-reducing treatments. It was deduced from the simulation that reducing speed was associated with increased awareness to risk. The drivers who were approaching intersections demonstrated improved speed adaptation. The outcomes of this study are useful to road safety implementing authorities. The driving simulations can be used to overcome methodological challenges in the real world.

(Bella, 2008) used driving simulator to research speed in two-lane roads. Forty-five drivers used the interactive fixed-based driving simulator and their speed behavior was significantly different to the actual speed behavior in the field. Higher speeds were recorded in the simulator environment.

Figure 1. Illustration of the driving simulator system

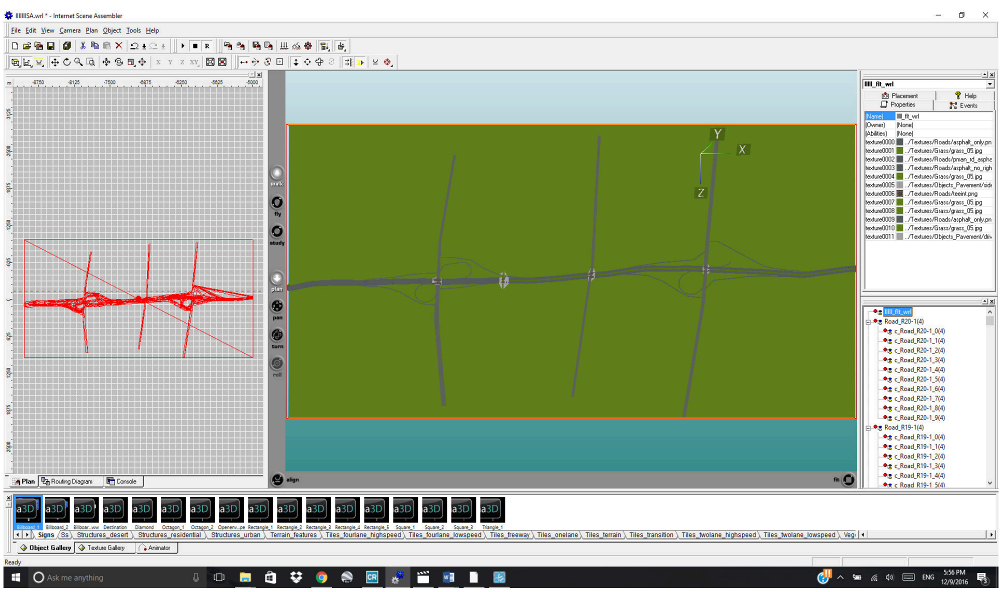

Figure 2. Interface for final modeling in ISA

Effect of Speed in Snow and Ice

A driver's choice of speed limit may be influenced by various factors. Friction is a key concept in understanding car crashes. According to a study conducted by Qin (Qin, 2006) snowstorm may pose a threat to the roadway systems. It was revealed that crash count was inversely related to the amount of deicing material. It implies that increased presence of ice resulted in multiple crashes because of reduced friction. In such a situation, reducing travel time can pose a real threat to the lives of drivers.

Figure 3. Different environments in I-69 highway clear, rain, cloudy and snow weather

Furthermore, the weather and climate contribute to various hazards in road transport. (Rowland, 2005), reviewed the interaction between weather related events and roadway systems. Ice and snow increase crash risk. Previous studies indicate that drivers find it hard to adjust their speeds in snowy and icy weather conditions. This is due to reduced road friction, road obstruction, and reduced visibility distance.

Similarly, a study by (Hjelkrem, 2016) concluded that precipitation and surface conditions were significantly related. Based on the Chosen Risk Index, the study results indicated that car and truck drivers perceived the highest risk when driving on snow-covered roads. Ice and snow alter the friction between the road and tires.

METHODOLOGY

In this study, the simulator scenarios were designed for a highway segment on I-69 in Flint, Michigan. This highway has been identified as the location of a number of crash clusters. Most of these crashes happened because of the weather and road surface conditions.

Crashes and incidents in this area have a proportionate impact on transportation in this heavily traveled corridor. A prototyping approach was used in the driving simulation laboratory at Lawrence Technological University to simulate approximately 4 km of I-69 between the Exit 138 and Exit 139.

The driving simulator is designed to contain a variety of driving scenes with the ability of creating different road and weather conditions as shown in figure 1. The vehicle of the simulator has the main features of a real vehicle (a Ford Fusion) and it is comfortable for human use. It includes a steering wheel, and brake and accelerator pedals.

The aim of this experiment is to create a design of several scenarios capable of testing drivers' behavior. A process was created in such a way that the driving simulator can be used to test how drivers function with weather and road condition schemes on the selected highway segment. Virtual traffic environment simulation and virtual road design are as shown in figure 2. This model was created using provided AutoCAD civil 3D design will facilitate using the Presagis Creator road tools.

Figure 3 shows a snapshot of different environments in the I-69 highway settings with clear, rain, cloudy, and snowy weather. The dynamics of the simulator itself can be modified by the application software SimCreator which is graphical simulation, and modeling system.

Table 1. Features of driving simulator scenarios for the study

Scenario	Design speed	Direction	Weather	Road surface		Driving simulator scenarios
				condition	μ tire	
Scenario1 S1	80	Eastbound Exit 139-138	Clear	Dry	0.95	Car cutting off the road, object
Scenario2 S2	80	Eastbound Exit 138-139	Cloudy, Rain	Wet	0.55	Slowed dawn, change lane
Scenario3 S3	70	Eastbound Exit 139-138	Clear	Dry	0.95	Car cutting off the road, object
Scenario4 S4	70	Westbound Exit 138-139	Cloudy, Rain	Wet	0.55	Slowed dawn, change lane
Scenario5 S5	70	Eastbound Exit 138-139	Snow	Snow	0.2	Drive in snow weather and snow road condition
Scenario6 S6	70	Eastbound Exit 138-139	Clear	Icy	0.1	Drive in clear weather and icy condition
Scenario7 S7	50	Eastbound Exit 138-139	Snow	Snow	0.2	Drive in snow weather snow condition
Scenario8 S8	50	Westbound Exit 139-138	Clear	Icy	0.1	Drive in snow weather snow condition
Scenario9 S9	40	Eastbound Exit 138-139	Snow	Snow	0.2	Drive in snow weather snow condition
Scenario10 S10	40	Westbound Exit 139-138	Clear	Icy	0.1	Drive in snow weather icy condition

The virtual I-69 highway segment is tested by allowing participating drivers to navigate virtually through driving simulation. For this study purpose, 10 different driving simulator scenarios were developed for the same roadway segment. A description of those scenarios is in table 1:

Following is a description of the perceptual performance experiment including descriptions of participants, experimental design, experimental factors and levels, task selection and implementation, dependent variables, experimental procedures, and statistical analysis. Note that all experimental procedures were approved by the Institutional Review Board (IRB) at Lawrence Technological University to use human subjects in this research project.

Defining Compliance

In this study, test drivers of the scenarios S1 and S2 were asked to drive at speed limit of 80 mph and to choose either the first or the second lane. Test drivers of the scenarios S3 and S4 were asked to drive at speed limit of 70 mph and to choose either the first or the second lane. Test drivers of the scenarios S5 and S6 were asked to drive at speed limit of 70 mph and to choose any lane. Test drivers of the scenarios S7, and S8 were asked to reduce the speed to 50 mph and to choose any lane. Test drivers of the scenarios S9 and S10 were asked to reduce the speed to 40 mph and to choose any lane. Maintaining an end speed close to speed limit and traveling on a designated lane were considered as the compliances. To evaluate driver's compliance to the roadside signs, the study used vehicle speed, x, y position, lane, brake, total tire slide, and crash for analysis.

Table 2. Descriptive statistics of participants.

Driver Characteristics	Classification	Number of Drivers	Proportion
Age	(18-25) (25-30) (31-40) (41-50) (51-60)	2 2 3 1 2	20% 20% 30% 10% 20%
Gender	Male Female	8 2	80% 20%
No. of years of driving experience	Primary (1–5 years) Middle (6–9 years) Senior (≥10 years)	1 3 6	10% 30% 60%
Highway driving mileage per day	0-10 20-40 40-50	3 4 3	30% 40% 30%
Drivers feeling while driving on snowy and icy roads	Less safe Very safe	7 3	70% 30%
Number of times the driver has slid on snowy and icy roads	Sometimes Never Often	6 1 3	60% 10% 30%

Procedure

This pilot study was conducted with ten participants (8 males and 2 females, average age of 35.2). The age of these drivers ranged from 18 to 60. In order to receive feedback on experimental procedure, instructions to participants and questionnaire materials were used. Participants went through the experiment in its entirety and their feedback was also used to clarify unclear task command wording. Participants' demographic information and driving history are summarized in table 2.

In each scenario, the driving simulator records five parameters for each participant. These parameters are position coordinates, speed, brake amount, steering amount, and crashes. Therefore, driving simulator generates a data set for each driver under each scenario. The datasets of drivers are further needed to be refined before being used for data analysis.

Data Collection

Participants were introduced to the driving simulator and were allowed to test drive the simulator to be acquainted with its components and features. This process took from 3-4 minutes as previous studies on driving simulator use have indicated. The duration of each scenario was expected to be 3 minutes actual driving and one minute to load the simulator. The experiment took around 50 minutes to be completed by a driver. Independent variables chosen for this