

A COMPUTATIONAL ANALYSIS OF DRIVING VARIATIONS ON DISTRIBUTED MULTIUSER DRIVING SIMULATORS

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Abstract

This paper describes and analyzes an automated driver's assistance system built for two goals: (1) to test how a voice based command (GPS) system and/or traffic lights influence the possible driving variations at T-intersections and (2) to reduce the number of traffic accidents. This computational study was conducted on a multi user driving simulation environment at Linköping University, Sweden. A total of 48 persons (groups of 4 persons took part in 12 experiments) participated in this study. We selected Post Encroachment Time (PET), speed and acceleration as conflict indicators at the T-intersection to analyze the behavior of the drivers. One of the hypotheses before the conducting experiments, stated that there is no difference in incident rate (PET values) at intersections between sessions based on the voice based command (GPS) assistance system, traffic lights and sessions based on the baseline condition. Another hypothesis referred to the same average variation values in the speed and the acceleration values corresponding to the PET values. We carried out several experiments to verify the validity of our hypotheses. The use of voice based command (GPS) assistance system and traffic light in an automated driver's assistance system do not seem to have an effect on the driving behavior. It suggests that the driving behavior of the participants was robust across all experimental hypotheses. The ecological validity of the simulator and awareness of the unreal consequences might have lead to this experimental outcome. The validity of the hypotheses can help out in the evaluation and development of an automated intelligent vehicle safety system keeping in view the current safety requirements.

Keywords: Simulators, Computational Analysis, Distributed Systems, Driving Variations.

1. Introduction

With the increase in the traffic density on the roads the risks of traffic accidents are increasing day by day. The probability of an accident to occur depends on driving variations between different drivers. Many factors like mood, velocity, situation and environment determine the driving variations. These variations generate a need for research studies related to the driving safety and development of an intelligent vehicle safety system. *An accident refers to a situation that results in a collision between two or more vehicles, while an incident is a near-accident; situations where two or more vehicles are spatially and/or temporally close to a collision.* By an article from the Ministry of Interior in Sweden, almost every fifth casualty is at an intersection, whereas two-third of all accidents that lead to serious injuries takes place in or near an intersection [8].

There are a number of techniques like field studies (also called 'simulations'), surveys or interviews for collecting traffics information. Our study to determine the driving variations at the intersections which may lead to an accident, was conducted with the use of a multi user distributed automated driver's assistance system and a set of questionnaires. The system here consists of simulator, people and some external parameters like voice based command system and traffic light. The real life consequences lead to the development of the simulated system. The questionnaires helped to identify the personality traits. We used a Post Encroachment Time (PET) algorithm as discussed in section 2.2.2 to calculate and classify the difference in time between two vehicles approaching an intersection in a simulated environment under the use of the voice based command (GPS) system and traffic light. Due to the high rate of accidents at the intersections our research focuses on the Sävenäs T-intersection in Gothenburg which we have simulated in order to conduct the experiments. The major project is

subdivided into three parts; one part analyzes the driving patterns of the Sävenäs intersection by recording the real intersection with video cameras; the second part let subjects drive at the intersection with an instrumented vehicle equipped with eye-tracking device, a GPS and a radar to study the drivers point to attraction; and the third and the final part is a set of simulated studies using the voice based command (GPS) system and traffic light in a distributed multi user driving simulator at Linköping University (LiU) Sweden. The challenge before the analysis was to develop the automated driver's assistance system and the required sessions using a simulator scripting language.

A detailed background about the types of simulators, conflict indicating variables and the data analyzer is given in section 2. In section 3 we describe the experimental setup and the hypotheses. In section 4 we present the method we followed for the experimentation. The experimental results are provided in section 5. We then present our analysis in section 6 and end this paper with a conclusion and future work in section 7.

2. Background

According to SIKAs research [18] (the Institute for Communication Analysis Sweden) in 2006, the most number of road traffic accidents occur at intersections in most parts of the world. The statistics of the road traffic accidents at intersections appear in a single category although they can be categorized into two major classes at intersections.

The first class is known as *Crossing Path Collisions*. Crossing Path Collisions (Figure 1) can occur when two vehicles have been traveling on different roads and with crossing paths as shown below. They are 27% of the total accidents at intersections.

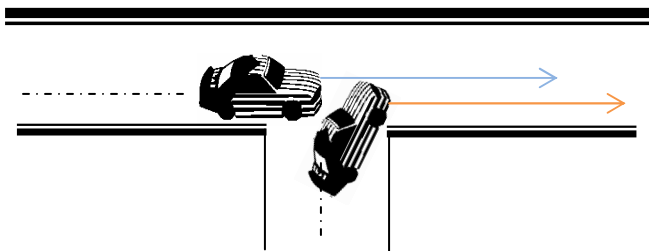


Figure 1: Crossing Path Collision

The second class (Figure 2) is known as *Turning Path Collisions*. They can occur where two vehicles have originally been traveling on the same road, in the opposite or same direction, and one or both vehicles have begun executing a turn as shown below. They are 16% of the total accidents at intersections.

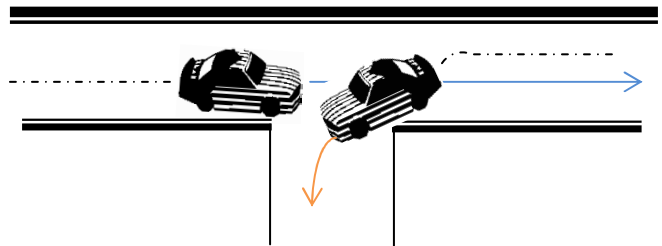


Figure 2: Turning Path Collision

These two categories can be shown diagrammatically as in Figure 3 [18]. There may be some accidents which may not belong to either class of accidents at intersections.

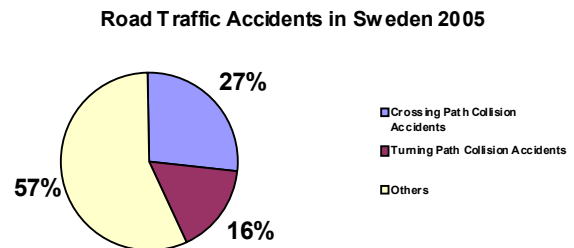


Figure 3: Road Traffic Accidents in Sweden 2005

The high frequency of accidents at intersections show there is a need for research and development of a system that could help in the prevention of such accidents. The need for a simulation based experimentation and research has evolved due to zero risk for the injuries. Simulators can be very efficiently used to create a close to real controlled environment to analyze the required things.

2.1. Types of Driving Simulators

There are two types of simulated environments, (1) a moving based simulator and (2) a fixed-based simulator [15]. We have used the fixed-based simulator for our research work. We developed and tested the automated driver's assistance system simulated using a voice based command (GPS) system and traffic light.

2.1.1. Moving Based Simulators

A moving based simulator gives feedback from the steering wheel and the chair about how the car is moving in the simulated world.

2.1.2. Fixed Based Simulators

This simulated environment gives no feedback from the steering wheel and the chair.

A validity study made by Reed and Green [15] on fixed-based simulators and comparison with real world cars shows that fixed-based simulators have been found to be less precise than actual vehicles or moving-based simulators, mainly due to the lack of motion queues.

The degree of the simulator's validity can vary depending on the nature of study and ecological validity of the simulator. *Ecological validity* of a simulator is the ability of simulators to tell us how real people operate in the real world. Advanced and expensive simulators may seem to be the best option but depending on the hypotheses and the goal of study one may be able to use a simpler simulator with less ecological validity and still get good results. More advance simulators should be used in those cases where the main focus is to get the realistic feeling of driving and that the ecological validity must be high. Whereas if the main focus is on the behaviors in a driving environment, then a less advance simulator might be suffice [17].

In our case we need to test the voice based command (GPS) system and traffic light on a simulated automated driver's assistance system and to reduce the number of road traffic accidents. A driving simulator with less ecological validity was adequate for carrying out the experiments for our research tasks.

2.2. Conflict Indicating Variables

Conflict indicator variables are a set of factors which can be used to identify the circumstances where an accident is about to be happen. For the analysis work, these variables have a lot of importance in order to draw useful outcomes.

The usefulness of these variables can be classified by evaluating the following three criteria [25]:

1. Indicators should complement accident data and be more frequent than accidents.
2. Indicators have a statistical and causal relationship to accidents.
3. Indicators have the characteristics of 'near-accidents' in a hierarchical scale that describes all severity levels of driver interaction with accidents at the highest level and very safe passages with a minimum of interaction at the lowest level.

We selected the Post Encroachment Time (PET) variable in order to analyze the driving variations in an automated driver's assistance system with the voice based command (GPS) system and traffic light at a T-intersection.

A number of conflict indicator variables are explained as under:

2.2.1. Time to Collision (TTC)

Hayward (1972) defined TTC as: "The time required for two vehicles to collide if they continue at their present speed and on the same path" [10]. TTC continue to decrease if there is no change in speed and path.

2.2.2. Post Encroachment Time (PET)

PET is measured in situations where two road-users, not on a collision course, pass over a common spatial point or area with a temporal difference that is below a predetermined threshold [1] (typically 1 to 1.5 seconds). PET is also known as the *incident rate* at intersections.

The main difference between PETs and TTCs is the absence of the collision course criterion i.e. even if no collision occurs; the PET value can be calculated. PET's can be more easily extracted using photometric analysis, video or simulated environment, than TTC as with TTC relative speed and distance data is required.

Small PET values indicate that two vehicles have a short distance to one another, whilst zero PET values indicate a collision between two vehicles. Thus PET is a measure of how nearly a collision has been avoided. These considerations led us to adopt PET as our measure of when an incident has or may have occurred, and thus we can draw conclusions about driving behavior in intersections.

2.3. Data Analyzer Study

The simulator was configured so that it collected the relevant data for this project. During the session all four simulators did record all real time data that was defined in the configuration.

To analyze the data we constructed a java based data analyzer program. The analyzer was based on the data analyzer platform being developed by the previous group [2] working on this project.

The main functionalities of the analyzer were as follows:

1. Raw data files from our four simulators were read by the analyzer.
2. The data was put into a stack if there are two cars meeting at an intersection.
3. The PET, Speed and Acceleration values were calculated from the relevant data in the stack.

4. A human readable output file was generated with all the information about a particular incident.

3. Experimental Setup

In this study, we have manipulated the voice based command (GPS) system and the Traffic Light to see the changes in the respective PET, speed and the acceleration values to ascertain whether these factors may contribute to accidents at intersections. Four hypotheses have been formulated in relation to the aims and goals of this study.

3.1. Implementation

The first goal in carrying out the research was to develop an automated driver's assistance system and the required scenarios with voice based commands and traffic light on a driving simulator. The implementation was carried out using the STSoftware scripting language.

The Figure 4 shows the simulated world being developed using the stRoadDesign scripting language. The simulated world was built on top of the automated driver's assistance system with GPS and the traffic light capabilities. The simulated world depicts the Sävénäs intersection (Figure 6) in the real life scenario.

Driver's behavior and Driving Patterns, such as speed, acceleration, lane position, distance to intersections and PET were logged with the help of the scripting language from the automated driver's assistance system and were then analyzed as described earlier in section 2.3.

The simulator application, the scripting language and the data processing tool were developed by the Dutch company STsim and the graphics engine was based on the Open Scene Graph high performance 3D open source graphics tool kit.

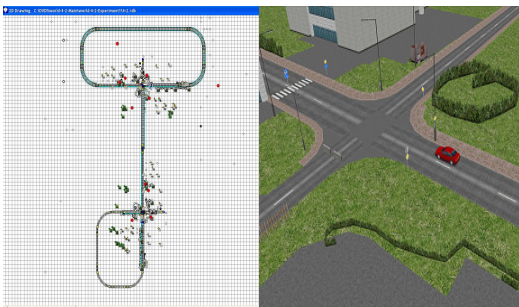


Figure 4: Simulated World.

3.2. Hypotheses

1. The first very important hypothesis is that there is a difference in incident rate at intersections between

sessions based on the voice based command (GPS) assistance system, traffic lights and baseline condition (without GPS and traffic light).

H0: There is no significant difference in incident rate in intersections between sessions based on the voice based command (GPS) assistance system, traffic lights and baseline condition.

HA1: There is a significant difference in incident rate in intersections between sessions based on the voice based command (GPS) assistance system, traffic lights and baseline condition.

To assess that there are differences in the incident rate at intersections, we implemented a guiding mechanism to follow like a voice based command (GPS) system and traffic light. We used the combination of the GPS and the traffic light in one of the scenarios, used the traffic light and GPS separately in two of the scenarios and didn't use anything in one the scenarios known as the baseline condition. The difference in the traffic systems will hopefully show a significant difference in the PET value that would lead to a rejection of the null hypothesis.

2. The second hypothesis is the average PET value across the four different scenarios.

H0: The average PET value will be the same across all the four sessions.

HA1: The average PET value will be lowest in the GPS and Traffic Light session.

HA2: The average PET value will be lowest in the baseline session.

3. The third hypothesis is related to the changes in the speed when meeting another car at an intersection in all the four sessions.

H0: The speed is the same in all the four sessions.

HA1: The speed is not the same in all the four sessions.

4. The fourth hypothesis is related to the changes in the acceleration when meeting another car at an intersection in all the four sessions.

H0: The acceleration is the same in all the four sessions.

HA1: The acceleration is not the same in all the four sessions.

The PET, speed and acceleration data was calculated in each condition to see if there is a difference in driver behavior at intersections. If such a difference is found, then we can reject the null hypothesis. If the difference is in the anticipated direction, we can support our alternative hypothesis that people tend to be speed up or slow down to avoid collision at an intersection.

4. Method

The automated driver's assistance system was deployed on four multi-user driving simulators. The voice based command system and the traffic light was used in some scenarios (Table 2). There were four experimental sessions; each session lasted for approximately two and a half hours. The total experimentation period lasted for two weeks.

A total of 48 participants were having a valid driver's license. The mean and standard deviation of the participants' age and driving experience in years is also calculated (Table 1).

	Women	Men
Mean, age	23.28	26.85
Standard deviation, age	2.36	9.51
Mean, Driving experience	4.33	1.93
Standard deviation, experience	8.74	9.59

Table 1: The mean and standard deviation of participants' age and driving experience in years.

4.1. Simulated Scenario Design

There were four driving simulators installed at the Department of Computer and Information science at Linköping University. No driver was able to see the other driver (Figure 5).



Figure 5: The driving simulator at IDA.

This driving simulator was able to extract and capture the driving patterns of the real and autonomous drivers.

4.2. The Simulated Environment

The road slopes around the actual Sävenäs intersection (Figure 6) could not be implemented in the simulated world due to the limitations in the simulator. The other elements of the intersection were represented in a realistic manner.



Figure 6: The Sävenäs intersection.

There were four different scenarios in our study, in which a driver was analyzed. There were a total of four real and eight autonomous cars making a grand total of twelve cars in a single scenario. The driving speed was 50 km/h for the autonomous cars and the speed limit was the same for the real drivers. Scenarios were designed to find the changes in the behavior of the driver. The proposed scenarios are shown in Table 2.

	With Traffic Light	Without Traffic Light
With GPS	A	B
Without GPS	C	D

Table 2: Summary of Scenarios used for experimentation.

The order of scenario presentation was shuffled across all the 12 experimental groups (Table 3). This was done to decrease the perplexing variable of driving the same session before another.

Experimental group	Scenarios Order
1	ABDC
2	BCDA
3	CDAB
4	DABC
5	ACBD
6	CBDA
7	BDAC
8	DACB
9	ADCB
10	DCBA
11	CBAD
12	BADC

Table 3: The order of scenarios.

4.2.1. Tasks and Procedure

In each session the participants were assigned a task to generate a purpose for their driving and to make them more eager to explore the world. The task was different in each of the four sessions. The drivers had to collect a number of signs (words) collectively forming a sentence. The sentence is a part of a song which was tokenized randomly.

A group of four participants were called upon on a single occasion. The participants had to start off with a practice session lasting 10 minutes so that they can get familiar with the driving environment. The main experimental trial consisted of 4 sessions each lasting 10 minutes. The total time for the experiments was about 2 hours and 30 minutes including a break in between the experiments.

5. Results

This section presents the simulator data containing PET, Speed and Acceleration. Chi Square-test and within subject Analysis of Variance (AVONA) test on the PET, Speed and Acceleration data were conducted. The data for PET values above 10 seconds is not being included in the analysis.

5.1. Scenarios

There were a total of 244 incidents at an intersection within the four sessions. The graph is shown in Figure 7.

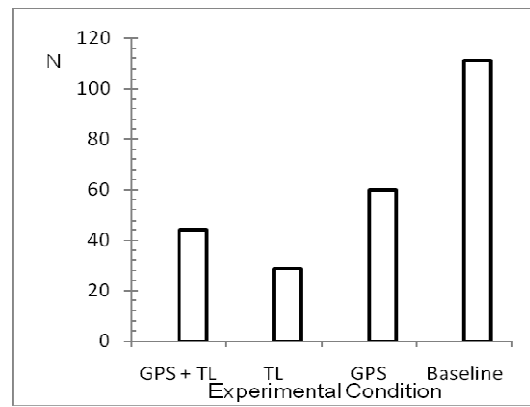


Figure 7: Total Number of Incidents in all four sessions.

The null hypothesis was that the number of data points is the same across the four experimental sessions / conditions. This hypothesis states that we expect the experimental manipulations to have no effect on the number of encounters.

As the number of data points is not a continuous measure, we cannot use ANOVA to test the hypothesis so we must use the Chi-Square test. Chi-Square test is better because there are 4 categories and 3 degrees of freedom.

The test statistical value, 62.5 is large. The likelihood of getting this result by chance is extremely small. So the probability of getting these results is less than 0.001 i.e. $\text{Chi-square}(3) = 62.5, p < .001$.

This tells us that there is in fact a statistically significant difference across the four categories. The difference between the number of encounters in the baseline condition and the other conditions is significant.

5.2. Post Encroachment Time (PET)

The null hypothesis states that there is no difference in incident rate (PET values) in intersections between sessions based on the voice based command (GPS) assistance system, traffic lights and baseline condition. Whereas the alternate hypothesis states that there is a significant difference in incident rate in intersections between such sessions. The graph of the results achieved is shown in Figure 8.

A between conditions ANOVA was run to test the null hypothesis that there is no difference in the value of in the value of across the four experiment PET conditions.

The difference between the conditions was not found to be significant, $F(3,240) = 0.32, p > 0.05$. The ANOVA fails to reject the null hypothesis of no difference.

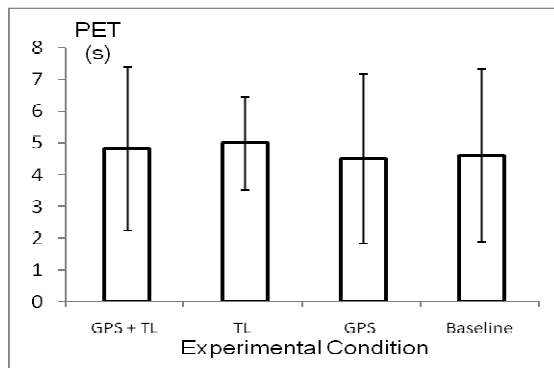


Figure 8: PET variation in all four sessions.

This finding showed that there is no indication in these data that the experimental manipulations influenced the drivers' PET values.

Post-hoc analysis of the Chi-square analysis reveals four cells that contribute disproportionately to the significant difference: There are considerably more PET values than expected in Condition B at 5 and 6 seconds, in Condition C at 1 second, and in Condition D at 3 seconds. In fact, in Conditions A and B, PET values were larger (times were longer, cars were further apart) than in conditions C and D.

5.3. Speed

This value is captured when the vehicle is 5 meters from an intersection. ANOVA was run to test the null hypothesis that there is no difference of values in the four experiments speed conditions.

The difference between the conditions was not found to be significant, $F(3,240) = 1.66, p > 0.05$.

The graph is shown in Figure 9:

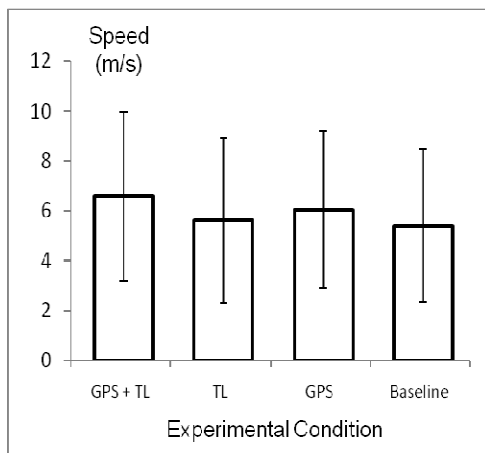


Figure 9: Speed variation in all four sessions.

The ANOVA fails to reject the null hypothesis of no difference. This finding showed that there is no indication in these data that the experimental manipulations influenced the drivers' speed.

5.4. Acceleration

This value is captured when the vehicle is 5 meters from the centre of an intersection. ANOVA was run to test the null hypothesis that there is no difference of values in the four experiments acceleration conditions (Figure 10).

The difference between the conditions was not found to be significant, $F(3,240) = 1.76, p > 0.05$.

The ANOVA fails to reject the null hypothesis of no difference. This finding showed that there is no indication in these data that the experimental manipulations influenced the drivers' acceleration.

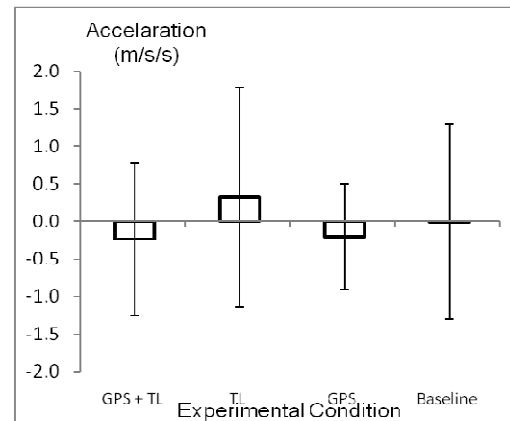


Figure 10: Acceleration variation in all four sessions.

6. Analysis

The primary purpose of this study is to develop an automated driver's assistance system in order to examine the driving behavior at intersections. The use of voice based command (GPS) system and traffic light do not seem to have an effect on the participants' driving behavior. However, this null result is encouraging. It suggests that the driving behavior of the participants in the study was stable enough not to be affected by our manipulations. Driving behavior appears to be robust across experimental manipulations.

The experimental design could have altered the participants' behavior. According to Burgoon et al. [5], expectancy violations can alter the behavior of people. A violation of expectations is created whenever behavior deviates from the expected norm. This may have been the case in the interaction between human-driven and autonomous vehicles.

Our hypothesis was that the participants will meet more frequently in the newly introduced GPS and traffic light system but the results negated our hypothesis. There were more number of incidents in the scenario without both the GPS and the traffic light. The result was quite surprising so the reason behind this could be due the underlying points:

1. The participants and the autonomous cars had to stop on the traffic light which could have been the reason behind the cars not able to arrive at the intersections.
2. The participants' cars had to listen very carefully in the scenarios having GPS, which could have resulted in the slowing down of speed. The results can be verified by comparing the speed and PET results achieved earlier.
3. The distance between the Traffic Light placed and the intersection may be very long. It took more time for a participant to start off from the traffic light and reach the upcoming car at the intersection.
4. Some of the drivers were circling around the same intersection in the scenario without the voice based command system and traffic light.
5. In the baseline experimental scenario the participants were free to roam as they would have liked, this must have encouraged higher incident rate.

Further side effects which may have lead to negate our hypothesis could be:

1. The signs differ in number and text written. This could have also varied the speed and time leading to lower incident rate.
2. The users were placed on different locations in each of the scenarios/sessions. The participants may have to vary the speed accordingly leading to lower incident rate.

The simulator is the core element of this study as its ecological validity is limited and a crucial topic for discussion. The simulator was in general perceived well by the participants. However, a few participants thought that it was unrealistic.

7. Conclusion and Future Work

The claim that changes in the driving environment like voice based command (GPS) system or traffic lights may trigger more PET values on an automated driver's assistance system is proven to be false with the help of

our experiment data. The drivers get more concerned when they have to follow certain commands and route while driving. As a result to this scenario the driving behavior is being altered causing less number of incidents.

Another interesting observation that was deduced during this experimentation is the variation in the speed and acceleration in a particular experimental scenario. The drivers tend to be a lot more careful while driving on slower speed with lower PET values. Whereas, in the scenario without voice based command (GPS) system and traffic light, the drivers tend to drive on higher speeds. This scenario also generated more PET values and had a higher road safety risk.

In this study we have chosen to overlook individual differences, due to the fact that we are interested in representative behavior. However, we could have obtained other interesting results if we would have examined the individual data.

Our study contributes to further research on traffic behavior in intersections, primarily with our chosen experimental method and the data that we have collected. It will be used in the continued research involving the Sävenäs intersection. We have recorded more relevant data variables than we have analyzed, like Distance to Intersection (DTI), Lane Position and Time to Collision (TTC) with respect to the vehicle in front. If the other data variables are also being examined this might give a better picture and explanation of the vehicles meetings at intersections. This may eventually give way for the development of active traffic safety systems that prevent accidents from occurring.

We recommend that further research is required with respect to analyzing different aspects of the bulk of data already collected by the current and the old research groups. An analysis may be conducted between the PET, speed and acceleration data with the questionnaire data collected by the other group. Several other variables may also be considered for identifying new facts and figures.

Our study has also contributed to the understanding and development of simulator-based research for an automated driver's assistance system. The method of choice has illustrated the usability of the simulator and will work as a springboard for this research area. In the future others might be able to implement this study in the real world and compare it with these findings.

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