Master's thesis
Investigation of freeway cross sectional designs with different soft separation techniques using driving simulator

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Prof. dr. Tom BRJ S

Co-supervisor:
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Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences
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PREFACE

Master Thesis is the final part of Transportation Science of Master program. Starting from proposing a topic, doing a literature review, conducting research to answer the proposed research questions. In my last year of Master’s Program, I put a lot of time and enjoyed performing my research. I present this dissertation with pride.

First, I would like to thank my mentor, Mr. Hammad Hussain Awan for helping me a lot in every aspect of the study and driving simulator studies. Without his help and advice, the simulation experiment would have been too complicated to analyse.

Other Thank goes to Prof. Dr. T. Brijs and dr ir. A. Pirdavani, my supervisor and co-supervisor respectively, who provided critical feedback during the defence of the first part of this thesis and kept me advised about the experiment and report writing in the second part of the thesis. Without their help, quality of the research was not possible.

I would like to thank, Miss Katrine Declerercq who helped me a lot in statistical analysis for this study and Mr. Thiago Gentil Ramires and Miss. Ana Julia Righetto for helping me to conduct the statistical analysis.

Last of all, I want to thank all of my friends and family, who supported me, showed interest in my project and helped me by participating in my experiment. They helped me to find the motivation to put as much effort in the thesis as I could. Without their help, I would not have been able to present this report with a satisfied feeling.

I hope you enjoy your reading.
SUMMARY

This thesis illustrates a study that was performed to assess the soft separation effects on the highway. The aim of this study was to test new types of separation on highways and figure out the most effective soft separation.

Different operational characteristics of express and local-lanes have been studied in the past, but none of them are about the consequences of obstructed traffic flow in express lanes. Hence, a new study investigating the effects of obstructed traffic flow in express lanes needed to be conducted. People who had an idea of European driving culture and having a valid driving license (European/non-European) were selected as test subjects in this study.

A total number of eight scenarios were designed with two types of traffic jam conditions. The design of express and local lanes are adopted from the real-life example of different types of soft separation installed between express and local lanes. An accident was created at a particular point in express lanes in each scenario where participants were supposed to wait for two and a half minutes. Two different traffic conditions were proposed to check their effects on driving behavior. In the first condition, no cars from the queue crossed the soft separation during the period in which traffic jam was induced (Condition A). In the second condition, few cars from the queue crossed the separation (condition B). The traffic intensity on adjacent lanes was kept low to increase temptations of the drivers to cross the soft separation.

Safety aspects were also considered for the test subjects. A with-in subject design was used to conduct the experiments on a driving simulator. To maintain the standards of a driving simulator, a full randomization was applied so that every test subject encountered a unique sequence of scenarios. The set-up of the study was to test how participants behave when they have a traffic jam in express lanes but at the same time; they have an opportunity to cross the separation which is not allowed in a legal manner. All eight scenarios had the same virtual environment of a highway but with four different types of separations.

The study also included short questionnaires before and after the experiment. In the first questionnaire, test subjects were asked information regarding their age, gender, driving experience, etc. In the post questionnaire, participants were asked to indicate their level of temptation to cross when stuck in a traffic jam by classifying them as high, average, low or none in both traffic conditions. Later data collected from this questionnaire is analysed statistically to show the significant difference between types of separation, traffic conditions, age and gender on crossing behaviour and level of temptations of the test subjects.

Overall, tubular delineators were found the most useful type of soft separation because it got the lowest crossing subjects and lowest in the level of temptations also.

Keywords: Soft separation, driving simulator, express lanes, temptations, crossing behaviour.
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1 INTRODUCTION

For past few decades, many types of researches have been conducted to investigate the safety of various highway designs. Elements for designs include cross-sectional design, delineators, roadside features, pavement conditions and lane marking. Studies indicate that improvement in highway design has reduced crashes (Hadi, Aruldhas, Chow, & Wattleworth, 1995). Cross section of a freeway is an area acquired between the right-of-way lines, cutting them upright in the direction of travel along with the road. While designing the cross-section, strong elements such as roadway’s safety, operations and the free flow of traffic are considered (Hancock & Wright, 2013).

Road agencies in developed countries are now looking for solutions to utilize their existing facilities than constructing new infrastructure to avoid high maintenance cost. The concept of managed lanes is widely used to overcome this problem. They are also known by the names of express and local lanes, High occupancy vehicle (HOC) lanes, High occupancy toll (HOT) lanes and carpool lanes. Managed lanes are separated from adjacent general purpose lanes using different techniques. Reason to provide these separate lanes is to improve the quality of travel and increase the free flow of traffic along with reducing the travel time. Another important aspect to be considered is safety while separating these lanes as the design speed on these lanes can be different from each other.

Managed and general purpose lanes are called express and local lanes when traffic is separated based on the destination to travel. There are various methods to separate express and local lanes. Most important of them are:

1) Hard separation
2) Soft separation
3) Pavement marking

Hard separation includes concrete barriers and iron fencing. This type of separation separates express and local lanes using physical barriers. These physical barriers include iron fence and concrete barriers. Benefits of using hard separation decrease toll escaping, controlled entry and exit points and ensure high speed in parallel flow. One of the main disadvantages of hard separation is diverging of traffic from express to local lanes in case of blockage on express lanes due to limited access points. In the case of blockage on express lanes results in the formation of long ques. Special measures and emergency services are required immediately to restore traffic flow on express lanes. This could result in increased travel time which annuls the purpose of express lanes.

Netherland road agencies have used hard separation on their highways and they are facing such problems. Hence, they are looking for a flexible and safe
method of separation which is easier to be cross in the case of a blockage in express lanes. Soft separation includes tubular delineators and various type of pavement markings. In this study, we will be using solid double line and crosshatch marking to separate the traffic between express and local lanes.

This study focuses on four different methods of separations including:

1) Solid double line
2) Crosshatch marking
3) Tubular delineators
4) Vegetation or grass strips

First, three separation techniques are commonly used in some areas, but using vegetation or grass strip is not that common. In my study, the effectiveness of vegetation strip will be analyzed and compared with above mention techniques.

Human behavior is one of the most important factors which needs to be considered during the process of road design. Reason for considering human behavior while designing the road is that most of the accidents are caused due to human error (Parasuraman & Riley, 1997).

Conducting this study in real life would be time-consuming, costly and could risk in property damage or human casualties. The driving simulator is an effective and very efficient tool to conduct this type of study because it costs low and ensures driver’s safety. Hence a driver simulator is used to carry out this study. First, the scenarios will be designed on the driving simulator with four different types of soft separations. In the next step, quantitative data will be collected through the results obtained from driving simulator study and lastly, qualitative data will be collected through questionnaires.

Furthermore, this study includes problem definition, research questions, and objectives of this study, brief methodology including scenario designs and experiment details and detailed literature view regarding any previous studies done on the subject.
1.1 Problem Statement

Hard separation is currently being used to separate express and local lanes in Netherlands. Traffic gets blocked when there is an incident in express lanes due to no escape point, whereas, maneuvers across the hard separation are not possible. This results in waiting in long queues and an increase in traveling time of the travelers. It is costly and time-consuming to adopt counteractive measurements in case an accident occurs. Because of these problems, the Dutch road agency is looking for a solution that plays an alternative role for hard separation and discourages unimportant maneuvers. Furthermore, drivers will feel safe to cross the separation in the case authorized by the highway authorities.

1.2 Objectives

Express lanes are used to separate the traffic with regards of approaching destination. People use express lanes to reach their destination in less travel time. And in the case of traffic jam in those lanes, it takes hours to manage or clear the area. Soft separations will play the same role as hard separations are playing now a day. But its physical properties can be different than the hard barriers. Objectives of this study is:

- The most suitable and efficient type of soft separation that in the case of traffic jam in express lanes, it discourages the maneuvers across the separation.

1.3 Research Questions

Two conditions have been proposed to evaluate the temptations of drivers to cross the separation between express lanes and local lanes. There are four types of separations used in experiment which include solid double line, cross hatch marking, tubular delineator and vegetation strip. The following research questions are addressed in this research study

1. Is there any difference in crossing behavior of drivers when they see other cars changing lanes from express lanes to local lanes when there is very less traffic on local lanes?
2. Is there any significant difference in actual crossing temptation to cross above mentioned four proposed soft separation techniques?
3. Which separation type is most effective?


2 LITERATURE REVIEW

This study has a new research question, so it is expected to find some mature information or literature on this topic. Firstly, we plan to study on different soft separation techniques, are these separations really apply in the world, and their effects, then various studies per different soft separations, then we are planning to study about driving simulator so that it can help in making designs and to conduct the experiments. And study regarding soft separation will be done in various contexts regarding safety, social, or other related sciences.

2.1 Managed lanes

To increase the freeway capacity, roadway agencies are facing challenges such as rising construction cost, the limitation for right-of-way, environmental regulations, etc. To solve these problems, transportation agencies are seeking for solutions to manage the demand on existing freeway facilities efficiently. Managed lanes are becoming popular countermeasure that aims most efficient use of freeway facilities by blocking access to certain vehicle classes that is parallel to existing general purpose lanes.(Liu et al., 2011). The concept of managed lanes was introduced around 30 years ago; managed lanes are used as congestion management strategy to maintain mobility of trip and to improve the moving capability within a metropolitan area. Managed lanes are also classified as HOV lanes, High Occupancy Toll (HOT) lanes, carpool lanes, etc. In most countries, general purpose lanes and managed lanes are known as express or local lanes, and traffic is being separated from the base of destinations. Uninterrupted passage towards distant destinations is provided by express lanes. Implementation of managed lanes improves the freeway capacity. The important factor about the increase in crash rate between general purpose lanes and HOV lanes is mainly because of the speed difference between two lanes. (Cooner & Ranft, 2006). Managed lanes play an integral part in urban mobility. (Cooner & Ranft, 2006). There are many positive examples regarding managed lanes that carry high volumes of traffic including buses and commuters, but on the contrary, it got some criticism as well (Jon Obenberger, n.d.). Congestion in general purpose lanes adversely affects the traffic in managed lanes.(Brewer, 2014).

In the US, most of the particular use freeway lanes which are mostly specified as carpools or toll-paying commutes or sometime both, are physically separated through some sort of barriers. Along the route, there are only selected access points through which cars can go in and out. The open area for crossing can be open for almost 400m or so. Setting a limit for this area is supposed to reduce the turbulence on the road that may occur if these roads don’t have these barriers and vehicles can enter or exit at any point on this road. Cassidy and Kim termed managed lanes and general purpose lanes as special and regular lanes respectively. They found that sometimes access points are the reasons for
bottlenecks. And the reason they gave is that when there is congestion on regular lanes, drivers try to seek refuge by crossing towards marked lanes. If the road has a particular physical space for entering the cars, degradation of congestion can occur due to vehicle maneuvers. This results in even worse when there are no limitations between special and regular lanes. He gave Suggestions for increasing the length of access points from 400m to 700m according to the circumstances (Cassidy, Kim, Ni, & Gu, 2015).

Some of the communities offer the opening length between 396m to 610m, and the recommended buffer width could be 1.2m or greater, it depends on the situation or traffic load on the specific road. Operations were recorded on five different sites to assist the guidance material. Results measured that while entering or exiting the managed lane, and the origin of lane for the vehicles, a large number of maneuvers about 7% was recorded for those vehicles which were passing the slow-moving vehicles. Almost 9% has been registered for those entering the HOV lanes, and about 8% was recorded who were exiting the HOV lanes and crossing the solid white markings. Percentage of the breach was increased about 15% during the period of low speed (less than 64 km/h) or high speed (greater than 96km/h). Maneuvers in consent in the lane marking were different by the length of opening access points. The rate of compliance was higher for long access opening points (457m) and less for shorter opening access points (354m). (Fitzpatrick, Brewer, & Park, 2008).

Having a limited roadway space and increasing congestion on that caused by growing demand, transport agencies are looking for the solutions and seeking for the innovative ideas so that they don't have to build new highway lanes which are even costly and unfeasible; instead, using the same infrastructure in creative ways which shows commitment to addressing the problems. Managed lanes are one of the solutions which provides such mechanism to utilize the current infrastructure. HOT lanes and HOV lanes are considered special purpose lanes which allow engineers to manipulate roadway parameters such as vehicle composition, driver behaviour or varying level of service, etc. (Hlavacek, Vitek, & Machemehl, 2007). In this study, effects of congestion in express lanes on driver's behavior will be investigated.

### 2.2 Separations Techniques

Transportation agencies have been able to understand pros and cons of express and local lanes due to increase number of installation of these lanes. To separate express lanes with local lanes, there are several methods. One of the common methods of separation is hard barriers which are commonly made up of the concrete and other method is soft separation which is usually made up of plastic or pylon or pavement marking. (Davis, 2011). The methods described have their own benefits and limitations, such as, it is considered as safest as the
frictional effects between express lanes and local lanes are minimized, but on the other side in exceptional circumstances, drawback of hard separation is notable when there is an accident on express lanes while having hard separation on them. For example, at the point of access, there is a traffic jam, these hard barriers would result in long queues. And in some cases, solving this problem on the spot may result in high cost or need some special equipment to address the problem. To lower this effect, soft separation can be used or pavement marking instead. (Davis, 2011). In a variety of traffic-related applications, flexible pylons are getting popularity. They are less rigid and enable drivers to enter in case of emergency, and can provide positive control over pavement markings to flow the traffic uninterruptedly. When they are used as a channelizing device on the road, their effectiveness is also concerned. Maintenance cost may be high because motorists usually strike flexible pylons. And on the other hand, broken pylons are also not safe for motorists. Implementation guidelines for pylons are less because their durability can also be tested through some standards. (Kuchangi et al., 2013).

Most of the soft separation between managed lanes and general purpose lanes are painted stripes or narrow buffer which are at least 0.6m in width. This results in congestions on some spots and hypothesized as an adverse effect on managed lanes. (Liu et al., 2011).

This study includes the separation techniques used in industry and focusing on different factors affecting soft separation choices. Pros and cons of each separation type would be discussed below. (Davis, 2011). Type of Separation selection is an important task as this needs to focus on many different factors including right-of-way, cost, access points, etc. some of them are described below:

2.2.1 Factors Effecting in Selection of Separation Techniques

Each project or location has its own characteristics and properties. Many different types of factors can affect the selection of separation techniques, some of them are:

**Right-Of-Way** - Different separation types require a different area for right-of-way due to future expansion or in need for additional shoulder room in it. Points, where express lanes are constructed, are the biggest in the area as more space is required to establish this lane. Reason behind this is to provide a proper combine formation and to separate express lane from local lanes and vehicles as well. Due to this, a typical type of separation is needed within an immobile right-of-way. (Davis, 2011)

**Cost** - separation techniques have varied cost effects, some of them cost higher in initial installation while some of them cost little in initial, but they have high
maintenance cost afterward. Hard barriers are the most expensive after that tubular delineators and pavement markings in the last. Tubular delineators are considered to have the highest maintenance cost they tend to get extricated from misbehaving vehicles. (Davis, 2011).

**Access Points** - Number of access points depending on the separation type used. There can be multiple access points from local lanes or direct access from the intersection. The decision can be made on the point that how much interaction between these two lanes or how often merging occur between these lanes.

**Express Lane Roadway Characteristics** - following can be identified as express lane operation:

- Reversible – both directions of traffic is followed by the same lanes but in different time of the day. Barriers are a must in this operation to separate the express lanes from local lanes because of the safety of incoming traffic. (Davis, 2011).
- Parallel flow – as stated before, a destination for both lanes are in the same direction, and this is the most common type of operation. Meanwhile this is how high occupancy vehicle lanes are operated today. Transport agencies prefer this process to convert the existing lane into the express lane because they don’t need additional right-of-way. And these lanes can be separated through different pavement markings or tubular delineators.

### 2.3 Types Of Separation

As discussed above, there is a different kind of techniques to separate express and local lanes. Some of them are discussed below along with their advantages and disadvantages.

#### 2.3.1 Hard Barriers

Most planned express lane projects re-involving some sort of congestion pricing using continuous rigid barriers for lane separation.(Hlavacek et al., 2007). Any hard or rigid physical expedient between lanes and mostly used and can be found across the country as a separation tool. To resist lane changing maneuvers, rigid barriers are used. This separation method is considered as a least pardoning for vehicles and can cause damage if jammed. On the other side, it prevents car entering or exiting from local lanes to express lanes causing discomfort to express lanes. This separation would require additional right-of-way within an existing highway design. (Davis, 2011). This separation technique has its own advantages and disadvantages described below:
<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• It lessens toll escaping.</td>
<td>• Event management can take a long time due to physical restriction between lanes.</td>
</tr>
<tr>
<td>• Its maintenance cost is low.</td>
<td>• If there is an incident in express lane, its impact will be high due to obstruction</td>
</tr>
<tr>
<td>• It limits the violators and access points can be controlled.</td>
<td>• Highest cost of installation than any other method.</td>
</tr>
<tr>
<td>• Access points can be controlled physically.</td>
<td>• Vacation of lanes in case of an accident is difficult.</td>
</tr>
<tr>
<td>• It can allow high speed in parallel flow operations.</td>
<td>• Special vehicles and machinery are needed to vacate the area of the incident.</td>
</tr>
<tr>
<td>• This technique can separate express lanes from the incidents occurs in local lanes.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. below will help to understand the concept of rigid barriers more easily. Rigid barriers are considered safe if new construction is done. If there are a limited number of access points, rigid barriers are found helpful. And, helps to control the aggressive drivers.

Figure 1. Hard Barriers (“Precast Concrete Projects | Seminole Precast Manufacturing,” n.d.)
2.3.2 Tubular delineators

Tubular delineators (Figure 2) are painted series of plastic pylons which discourages illegal crossings. As they have some physical properties, and drivers are not pleased to cross the physical barriers. This method shares many features with rigid barriers (Hlavacek et al., 2007). Tubular delineators are used on roadways in various applications. This may include road separation, access management, etc. concerns regarding tubular delineators is that if a car hit the pylons, it will be unsafe for motorcyclist because result from the hit will be broken pylons or exposed nails. This may lead to long-term maintenance cost. (Kuchangi et al., 2013). They are considered as soft separation methods and can be applied to different applications. These plastic pylons are installed with less spacing between each other, and they are crossable. This approach does not physically separates the express lanes from local lanes but gives more relaxation to express lane drivers when local lane is jammed or slowed. Initial installation cost is much lower that the rigid barriers but it frequent maintenance cost need to focus when selecting this type of separation. (Davis, 2011). Advantages and disadvantages of this method are described in Table 2:

Table 2. Benefits and disadvantages of Tubular Delineators (Davis, 2011)

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The right-of-way is not needed to install this method.</td>
<td>• This separation can easily Cross.</td>
</tr>
<tr>
<td>• They are easy to mount.</td>
<td>• Regular maintenance is required.</td>
</tr>
<tr>
<td>• Low initial cost.</td>
<td>• Roadway wreckage can be created quickly.</td>
</tr>
<tr>
<td>• Access points can be controlled.</td>
<td>• Execution areas are difficult to create.</td>
</tr>
<tr>
<td>• Physical separation can be provided.</td>
<td></td>
</tr>
</tbody>
</table>
2.3.3 Pavement markings

Pavement markings (Figure. 3) are used as a separation method which does not deliver any kind of physical barriers but play a role in physical separation. (Kuchangi et al., 2013). They are mostly used to separate express lanes from local lanes and considered as buffer separation type having non-physical properties. They usually require a large area for separation and clear and wide strips to explain the lane difference. A violation can be done easily in this type of separation because of no physical barriers among them. Sometimes, these separations are the cause of confusion among the drivers because of no physical separation. To remove this confusion, lane markings should be clear with signing and messages. If local lane is slower or jammed, express lane also gets slower due to maneuvers from local lanes into express lanes. (Davis, 2011). Advantages and disadvantages of this separation type are:
Table 3. Advantages and Disadvantages of Pavement Markings (Davis, 2011)

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• They are easy to <strong>install</strong>, and initial cost is low.</td>
<td>• Lack of physical separation.</td>
</tr>
<tr>
<td>• Emergency vehicles can access area easily in case of an <strong>incident</strong>.</td>
<td>• Illegal maneuvers are hard to control.</td>
</tr>
<tr>
<td>• The <strong>right-of-way</strong> is not required to install this separation.</td>
<td>• In the case of taking the left exit, express lanes may have to emerge with local lanes.</td>
</tr>
<tr>
<td>• Access points can be easily adjusted even after installation.</td>
<td>• In the case of an incident, local lanes are not separated from express lanes and can easily enter or exit from it.</td>
</tr>
</tbody>
</table>

2.4 Driving Simulator Studies

The worth of driving simulator has demonstrated in several types of research. (Bella, 2009). The driving simulator is considered as a reliable tool to conduct driver behaviour study in realistic mode and low cost. Data collection is easy in driving simulator and safety is highest for drivers. Experiments can be carried out in a controlled environment. (Bella, 2009). Field studies are defined as complex data collector because it needs the presence of data collector on experiment site. And it’s hard to develop controlled environment in the field study. (Bella, 2009). This study will also use a fixed-base driving simulator as a tool to perform its experimentations. There are many studies previously conducted on a driving simulator to examine human behaviours because it is considered as a handy tool to investigate one’s behaviour in short time.

There was a study conducted on the driving simulator by Francesco Bella and Roberta Russo about the behaviors of drivers defining valid driver assistance system, in which they studied about two rural roads of 8.5km and having a cross section of 10.5m. A total number of four scenarios were designed with an average traffic volume of 350 vehicles per hour to 900 vehicles per hour. The speed of vehicles was different in four scenarios. The study was conducted to analyse human behaviour while having car-following maneuvers. New collision warning algorithm was developed on the basis of driver’s risk perception. (Bella, 2009).

The researcher investigated driving performance while approaching a horizontal curve on a 2-lane rural road using a driving simulator. Results indicated
that the 85th percentile of acceleration and deceleration rates of each driver express the actual driving performance in the tangent actually. Benedetto conducted a study to validate the driving simulator for road geometry. The study demonstrated that a geometric design is not considered safe without consideration of the human factor, and a driving simulator approach is safe as it does not involve any physical damage to property or people (Godley, Triggs, & Fildes, 2002).

Approximately 30% of automotive crashes result from rear-end collisions. In this regard, rear-end collision avoidance systems (RECASs) offer a practical approach for helping drivers avoid such accidents. For evaluating the efficacy of RECAS, two experiments have been performed which use a motion-based driving simulator of high-fidelity. The first trial revealed that distracted drivers were able to respond quickly towards early warnings than late or no warnings, which avoided chances of collision. On the contrary, a no-warning condition increased the number of crashes which are seen to get reduced 80.7% in early warning RECAS. As the severity of any collision is proportional to the kinetic energy generated, the early warning system reduces this severity by 96.5% compared to 87.5% in a late warning system which reduces the number of accidents to 50%.

On the other hand, in the second experiment, analysing the braking process revealed that warnings reduce the time required for releasing the accelerator, thus providing an overall benefit. Warnings do not, increase the speedy application of the brake but increase the maximum deceleration and affecting its overall mean value. Such experiments and results lay a foundation for a computational model of driver's performance for extrapolating the findings and identifying the most appropriate parameter settings. Potential applications of these results include methods for evaluating collision warning systems, algorithm design guidance, and driver performance model input (Lee, McGehee, Brown, & Reyes, 2002).

The research project was done to calibrate and validate the driver simulator for the European Interuniversity Research Centre for Road Safety. This was done for the design and verification of the usefulness and appropriateness of temporary traffic signs on highways. It included the following steps:

a) A survey based on calculating speed measurements on highways near to work zone,

b) In the light of driver simulators and driving tests, a reconstruction of the reality in a virtual space,

c) For validating the simulator, a statistical analysis of the field speeds and the speeds from driving simulations has also been done.

The work zone used as a case study has its location on Highway A1 going from Milan to Naples, in Italy. A laser speed meter was used for calculating the speed measurements in the transition, activity and termination area, as well as area speeds, were shot from overhead with a camera. The analysis was performed
using bilateral Z-test for nonmatched samples and was done to determine the difference in response of the drivers when occurred in driving simulator compared to the reality. The results revealed that speed differences between the real situation and those measured with the simulator were not statistically significant (Bella, 2005).

Besides, another research project was conducted to validate the interactive fixed-base driving simulator of the Interuniversity Research Center for Road Safety (CRISS). This was done for enabling its use when designing deceleration in lanes, as a function of the lane length. This research was developed in two phases with the first one being a field study carried out on a real highway. This was taken up for studying driver’s behavior in deceleration lanes with three different lengths. The second experiment was done using the driving simulator of CRISS where 42 drivers drove in the simulator on three different configurations of the deceleration lane. With this, an analysis was made for the trajectories and speeds in the field and simulator. The results revealed that the trajectory in the field is developed within the same phases as in simulation. Speeds in the virtual reality space are greater as compared to those in the field. This is assessed before arriving at the deceleration lane and was determined from knowing that no inertial force on the driver is forwarded in the driving simulator, and also the inability of the driver to recognize roadway scenario long distances ahead. Once in the deceleration lane, a better perception of the situation is achieved, and as a result, speeds were seen similar to that of the field data. No relation between the deceleration rates and the lane length were found in reality as well as in driving simulator (Bella, Garcia, Solves, & Romero, 2007).

Within this study, we will also use the driving simulator as an experimental tool to observe driver’s behaviour in case of a road block on express lanes and influence of different soft separation methods.
3 METHODOLOGY

This section of the report explains what research methodology has been adopted while doing this research. It includes the working of a driving simulator, STISIM software, and explanation of designed scenarios including solid double line, crosshatch marking, vegetation/grass strips, and tubular delineators. Afterward, the test situations, questionnaires, pilot study, the structure of experiment and data collection methods have been discussed.

3.1.1 Driving simulator

A driving simulator was used as an experimental tool in this study to conduct the experiments to examine the driving behaviors of participants towards a different type of separations. The reason why it was used because it is one of the most reliable tools to analyze human behavior at a low cost and exterminates different legality issues of conducting this tests on actual roads. Also, to avoid human casualties and injuries.

The driving simulator used consisted of a real car “Ford Mondeo” with a projected screen in front. This car is fixed-based and includes power steering, accelerator, brake pedal, transmission. All internal functions of the car except indicators were idle. Audio feedback was provided through speakers such as the sound of traffic, environment and participant’s car. Visual feedback was also provided through a projected screen in front which is 180° curved, having rear view mirror image and side mirrors image on it. Images were presented at 60 Hz refresh rate. Three projectors projected the image at a resolution of 1024 x 768 pixels on the curved screen placed in front of the car. However, the only limitation regarding this simulator was that kinetic feedback was not possible because the participants were performing these scenarios in an idle car.

3.1.2 Driving simulator program

It is an open software platform combining human factors and applied physics. STISIM is adaptable, flexible, reliable and helps in producing valid results.(“Car Driving Simulator & Software for Occupational Therapy, Research, Training,” n.d.). STISIM 3 was used to make scenarios for the driving simulator. One of the major benefits of using this software was that it provides a large variety of road designs, dynamic (vehicles, pedestrians, and animals) and static objects (buildings, trees and street lights). It also offers vast range of data collection variables that were very helpful in interpreting the human behavior of the person performing this experiment.
3.1.3 Design of scenarios

Four different highway designs were programmed in STISIM. These designs were distinct from each other regarding the method of separation i.e. crosshatch marking, tubular delineators, solid doubled line and vegetation/ grass strip. The scenarios contained all necessary aspects to give it a look and feel of a real-life situation and helped the participants to imagine if they were driving in real life. Each scenario was 5500m long. Roadway consisted of four lanes with an equal width of 3.5m each. On either side, shoulders were given to the road having 1m of internal shoulder and 1.8m of external shoulder (“Traffic signs manual: Chapter 5 - traffic-signs-manual-chapter-05,” n.d.).

Lane markings were also placed with the width of 0.15m each, length of 3m and gap of 6m between each lane marking from center to center (“Traffic signs manual: Chapter 5 - traffic-signs-manual-chapter-05,” n.d.). The scenario included a 300m Service lane where participants were supposed to start the experiment. At 200m, an arrow marking on the road was placed that informed participants about the merging of service lane into freeway. A cantilever gantry signboard was set at 500m before the opening of the access point, Figure 4, which informed participants about the entrance to express lanes.

![Figure 4. Access Ahead Sign Board](image)

After 600m a speed limit sign of 120 was provided on the left side so that participants must respect the speed limit on express lane. At 800m, a double overhead signboard (Figure. 5) was placed to inform the participant about the lanes they needed to travel to accomplish the given task. Names of destinations were put in such a manner so that the participants should travel in the express lane to reach the required destination.
A variable sign overhead was placed at 2700m to warn the participants about the accident (Figure 6) in the express lane. An artificially created crash was set up at 3700m on the left-most lane where participant was supposed to wait for 120 seconds.

After 200 seconds, the right lane of the express lane was opened for the traffic while the left lane remained closed.

At 5000m there was a sign board indicating the end of a test drive (Figure 7) was placed so that participant can get an idea that after 500m, the scenario was going to end.
The scenario finally ended after 500m. Street lights on the left side of express lanes were installed after every 200m. However, trees and buildings were placed randomly across the whole scenario. (Figure. 8)

**3.1.4 Solid double line**

The width of one line is 0.3m and space between two lines are 0.2m. (Davis, 2011) which makes total area of 0.8m on road. Design of the scenario is shown in the picture below. (Figure. 9)

![Figure 9. Solid Double Line Scenario](image)

**3.1.5 Vegetation/Grass Strips**

Separation method was provided in the scenario using vegetation/grass strips in between express lanes and local lanes (Figure 10). Each is having width of 4ft. (Davis, 2011).
3.1.6 Cross Hatch Markings

Crosshatch markings were used having same properties as above mentioned scenarios and it contains lane marking 4ft as same as vegetation strips and inside having markings of 0.2m width at 45 degrees of angle with the longitudinal distance of 2.3m between each strip (Figure 11) ("Traffic signs manual: Chapter 5 - traffic-signs-manual-chapter-05," n.d.).

3.1.7 Tubular Delineators

Tubular delineators were used to separate express lanes with local lanes having the height of 3m from the ground, and lateral position is in the center of median (Figure 12). The distance between each tubular delineator is 3m. (Davis, 2011).
3.2 Traffic conditions

In real life, traffic jams could be very time-consuming. Since participants should not be made to wait for hours in a traffic jam, duration of traffic jam was decreased. There could be various reasons that can provoke the drivers to maneuver across the separation. As duration of traffic jam was decreased, many of these provocative reasons did not influence the driver’s behavior. One of the reasons that can raise driver’s temptation to cross or make him cross the separation can be less or no traffic in adjacent local lanes. Less or no traffic on adjacent lanes might initiate the thoughts in driver’s mind that he is wasting his time for nothing and should cross the separation to complete his journey. Another reason that can cause increased temptations in driver’s behavior might be that the driver observes another car(s) crossing the separation and he would try to do the same. The crossing of other cars might be a reason for some people as it looks justified as they are stuck while there is no traffic on adjacent local lanes.

Four different types of separation were tested for following two conditions of this study:

- **Condition A**: In the first situation, traffic resumes after 120 seconds along with all cars in the queue. But none of the cars in que crossed the separation. But on the adjacent, there was less or no traffic. It was observed that whether participants crossed the separation or not.

- **Condition B**: In the second situation, while waiting for the clearance of congestion, after 100 seconds, one car from the que crossed the separation, and after 110 seconds another vehicle crossed the separation. After that, it was observed whether participant crosses separation in this drive or not.
3.2.1 Pilot Testing

After finalizing all the scenarios, a pilot test was conducted by the experts of a driving simulator. Any flaws remaining in the scenario were highlighted and corrected before carrying out real experiments. As a result, pilot testing helped the experimenter to finalize the scenarios for real experiment. Furthermore, five experts were invited to test the scenario and the changes they advised were completed shortly.

3.2.2 Method of Experimentation

Final simulation contained 8 scenarios in which conditions were tested twice using different situations. Before conducting the experiment, a full randomization of the scenarios was required so that participants get familiar with the driving simulator and its working conditions. Following sections discuss in detail about the participants, randomization of experiments, test drive, and experiment.

3.2.3 Participants

49 participants took part in this study. But three of them got simulator sickness, so their data was not considered in the results. Furthermore, while scanning the data, two outliers were also observed. Those participants who were driving abnormally were described as outliers. So, their data was also not considered in the final analysis.

Hence a total number of valid participants are 44 for this study. Of which 53% are male, and 47% are female. The average age of all participants was 27.65 with a range from 20-49. Participants were invited with the help of Hasselt University and Transport research center IMOB by sending emails.

3.2.4 Randomization of experiments

It is possible that participants may adopt the behavior of scenarios and can judge the next scenario by analyzing the experience of previous scenarios. For example, if a participant passes the experiment with crosshatch marking with no vehicle moved and then next with crosshatch marking with car moved while waiting in congestion, he or she will be able to predict the next sequence of events about to happen in the scenarios. This behavior of learning can influence the study negatively and can cause biased results. Hence, the order of scenarios was randomized to mitigate this effect.

Each participant drove a unique sequence of scenarios. Unfortunately, STISIM DRIVE 3 does not have any built-in function for randomization. So, "https://www.randomizer.org" was used to transform a series into randomized
form. By doing this, it was ensured that every participant would receive a unique sequence while giving the experiment. Randomized sequence sheet is attached in Annexes.

3.2.5 Test Drive

A short test drive was provided to the participants to get familiar with the driving simulator. In some cases, participants needed some time to adapt speed perception, or some participants needed some time to get used to the acceleration or brake pedals or estimation of distances. A scenario resembling the real experiment was played for the participants so that he or she can expect what they are going to have in following scenarios. A scenario with no accident was presented to the participant but with the same traffic load and road design so that participant will have an idea of the scenarios. Furthermore, the person conducting the experiment was answering through microphone towards any question raised by the participant during the test drive.

3.2.6 The experiment

The experiment was conducted in four parts:

1. Introduction & Pre-questionnaire
2. Test drive
3. Experiment study
4. Post-questionnaire

Some information regarding the experiment was given in the introductory part, and a pre-questionnaire was given to the participant which included socio-demographic data including age, gender, and past driving experiences.

The second stage of the experiment was test driving in which participants were asked to drive a scenario which was not a real experiment but mostly related to that so that they had an idea of experiment that what experimenter was expecting from them. In the start of each test scenario, participants were told that experimenter would not go to record your data.

The third phase was the experiment study in which they were given 8 scenarios entirely randomized than others and in a different order. They were asked to drive as they do in real life. Destination, which participants should follow was described before the experiment.

Fourth and the last part of the study was post-questionnaire. After completion of experiment study, participants were provided by the questionnaires, asking about the scenarios they drove and what they perceived about the
experiment. How much tempted they were to change the lane just in case if they did not cross the lane during congestion.

3.2.7 Data Collection

There are two types of data collected in STISIM.

1. Time based
2. Distance based

This study has used time-based approach to collect data. This method helped the experimenter to obtain data in the continuous form of time series. Because in this study, the participant should wait for at least 2 minutes in congestion, cars will be idle on that point, so STISIM will help the experimenter to obtain data in smaller time frames. On the other hand, distance-based approach is not feasible because on the same situation where cars are not moving, no distance will be covered by the participants, and hence no informative data will be collected on that points.

At the time of data collection, different variables were collected to analyze the data statistically in which most important variable was the lane change behavior (Lateral position) of the driver which helped to analyze the results accordingly. Lateral of the car was collected through the driving simulator.

3.2.8 Questionnaires

This study aims to collect both types of data i.e. qualitative and quantitative. For qualitative data, two types of questionnaires are designed to conduct the study.

1. Pre-Questionnaire
2. Post-Questionnaire

In pre-questionnaire, general information is being asked about the participant, their driving abilities, license type, the purpose of driving on highways etc. so that experimenter have an idea about the participant’s driving skills.

In post questionnaires, questions about scenarios were asked that what they think about the study and purpose of study is clear to them or not, etc. which helped the experimenter to analyze qualitative data through that.
4 RESULTS

In this chapter, descriptive and statistical analysis are discussed. Data collected from STISIM was extracted from the STISIM format using the Matlab software. Statistical analysis of the observed differences was carried out in SAS software. Sample population and outlier population is justified later in this part. Furthermore, results from all eight scenarios are discussed. Each of the descriptive studies is warranted through statistical analysis with a confidence level of 95%.

4.1 Participants

Total 49 participants took part in this study. Of which 53% are male, and 47% are female. The average age of all participants was 27.65 with a range from 20-49. Three of the participants got simulator sick. Hence, their data was not considered in the results. Furthermore, while scanning the data, two outliers were also observed. Those participants who were driving abnormally and they were not following the European driving culture, and their values were not even close to the other participants. So, it was decided to exclude their data from the results.

Hence a total number of valid participants are 44 for this study. After converting data from STISIM Drive 3 to excel format through MATLAB, data for the lateral position was extracted. Two types of data were collected using driving simulator and post questionnaires.

4.2 Driving Simulator (Crossing behavior)

Data for the lateral position was obtained through driving simulator which helps to locate the position of the vehicle on the road. By having this parameter, it can be observed that participants have crossed the separation or not. Results are segregated according to the two conditions of a traffic jam.

4.2.1 Condition A

In this part, results are discussed according to the “condition A” in which no cars were crossing the separation during traffic jam.

4.2.1.1 Solid Double Line

Figure 13. Below will help us to understand the lane changing the behaviour of each participant in Solid Double Line. X-axis explains the distance covered by the driver and y-axis explains the lateral position of the vehicle on road. In the scenario, participant started the experiment from a service lane (x-axis 0, y-axis 20-25) after 300m, drivers entered in local lane on highway from service lane (X-axis 0-500, Y-axis 15-20). After covering 1300m in total, there was an access
point in which participants entered the express lanes (X-axis 1600-2200 m Y-axis 10-15). Accident was designed at 3700 m with the lateral position between 5-10. Where participants were supposed to wait. Those participants who crossed the separationsm they changed their lateral position from the block of 5-10 to 10-15 or downwards. Some of the participants changed the lane when they saw the accident and some of them crossed when they saw the variable sign message board. So those participants whom lateral position is changing from block 5-10 to downwards in the graph are considered as the participants who changed the lanes. similarly this explanation refers to all the other figures explained in this part.

![Solid Double Line (Condition A)](image.png)

*Figure 13. Lateral position of vehicles in Solid Double Line (Condition A)*

Figure 13 shows that 13 members out of 44 crossed the separation that makes 29.5% of the total participants. Rest of the participants entered the desired lane and waited for the traffic jam to open in Solid Double Line.

### 4.2.1.2 Crossed Hatch Markings

Figure 14 Will illustrate the lane changing behavior of the participants when the separation type was crosshatch marking.
Figure 14. Lateral position of vehicles in Crosshatch Markings (Condition A)

Figure 14 shows the lane changing behavior of the participants that 7 out of 44 participants crossed the separation when no cars crossed the lane in front of them which makes 15.9% of the participants.

4.2.1.3 Tubular Delineators

Figure 15 Will help to understand the lane change behavior of the participants:
Figure 15 shows the lane changing the behavior of participants that only 5 out of 44 participants crossed the separation which makes only 11.36% of the total participants.

4.2.1.4 Vegetation Strips

Figure 16 Will illustrate the lane changing behavior of the participants.

![Graph showing lateral position of vehicles in Vegetation Strips (Condition A)](image)

*Figure 16. Lateral position of vehicles in Vegetation Strips (Condition A)*

Figure 16 shows that 9 participants out of 44 crossed the vegetation strip separation while no cars crossed the separation in front of them that makes them 20.45% of the total participants.

4.2.2 Condition B

In this part, the second state of traffic jam will be discussed in which some cars were crossing the separation in the traffic jam.

4.2.2.1 Solid Double Line

Figure 17 Will help us to understand the lane changing behavior of the participants.
Figure 17 shows that 7 out of 44 participants crossed the lane in the second situation. Which makes them 15.9% of the total participants. It can also be observed that only one participant didn’t enter the express lane.

4.2.2.2 Crossed Hatch Marking

Figure 18 Will describe the lane changing behavior of the participants:

Figure 18 shows that 9 out of 44 participants crossed the separation which makes them 20.45% of the total participants.
4.2.2.3 Tubular Delineators

Figure 19 Will describe the lane changing behavior of the participants.

![Tubular Delineator (Condition B)](image)

*Figure 19. Lateral position of vehicles in Tubular Delineators (Condition B)*

Figure 19 shows that 6 out of 44 participants crossed the separation which makes them 13.63% of the total participants.

4.2.2.4 Vegetation Strips

Figure 20 Will describe the lane changing the behavior of the participants:

![Vegetation Strip (Condition B)](image)

*Figure 20. Lateral position of vehicles in Vegetation Strips (Condition B)*
Figure 20 shows that 8 out of 44 members crossed the separation which makes them 18.18% of the total participants.

4.2.3 Observations

There are some common considerations for the results while no cars were crossing the lane in front of the participants. Common reasons for crossing this lane was:

1) They didn’t consider Solid Double Line and crossed hatch markings as hard barriers.
2) Didn’t wanted to wait in the que.
3) Crossing the separation of the other cars are one of the main reason to cross the separation described by the participants.
4) Participants who didn’t enter the separation miscalculated the access point, or they thought that there would be another access pint ahead.

Total number of participants who crossed versus those who did not cross the separation can be described in the Figure 21.

![Figure 21](image-url)
4.3 Statistical Analysis for crossing Behavior

To investigate the effects of Separation types, traffic conditions and gender on crossing behavior of participants. The probability of crossing separations is computed using Logistic Generalized estimation equation (GEE).

The GEE logit estimates the logistic regression when there are a dichotomous dependent variable and a set of explanatory variables (“logit.gee,” n.d.). This type of model helps to analyse the data collected in nested longitudinal or repeated measure designs. GEEs use the generalized linear model to estimate more efficient and unbiased regression parameters relative to ordinary least squares regression in part because they permit specification of a working correlation matrix that accounts for the form of within-subject correlation of responses on dependent variables of many different distributions, including normal and binomial (Ballinger, 2004). This methodology is used to analyse the correlated data that could be modeled as a generalized linear model.

The effects of separation type and traffic conditions on crossing behavior were tested statistically using logistic GEE regression model. Types of separation and The traffic situation and gender as explanatory variables and the interaction between both factors.

The table 4 shows that there is no significant effect of separation type ($\chi^2 = 4.54$ (3 df); $P= 0.2088$) and that there is no significant effect of Traffic conditions ($\chi^2 = 0.21$ (1 df); $P = 0.6434$) and no significant interaction between separation type and traffic condition ($\chi^2 = 4.47$ (3 df); $P = 0.2152$), no significant effect of gender ($\chi^2 = 0.01$ (1 df); $P = 0.9133$).

Table 4. describes that the crossing behavior of participants is not dependent on the method of separation or crossing behavior of other vehicles in front of them.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Chi-Square</th>
<th>Pr &gt; ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separation Type</td>
<td>3</td>
<td>4.54</td>
<td>0.2088</td>
</tr>
<tr>
<td>Traffic Conditions</td>
<td>1</td>
<td>0.21</td>
<td>0.6434</td>
</tr>
<tr>
<td>Separation type*traffic conditions</td>
<td>3</td>
<td>4.47</td>
<td>0.2152</td>
</tr>
<tr>
<td>Gender</td>
<td>1</td>
<td>0.01</td>
<td>0.9133</td>
</tr>
</tbody>
</table>

Table 4. shows that none of the four effects (Separation type, Traffic conditions, Interaction between separation type and traffic conditions and gender)
in the model has a significant effect on the crossing. As the P-value is not less than 0.05, it indicates that no variable is significant.

4.4 Temptations to Cross

Participants were asked about the level of their temptations towards crossing of separation. Temptation tendency was divided into four parts i.e. Highly Tempted, average tempted (moderately Tempted), low tempted and Not tempted. Table 5 below shows the different level of temptations of participants in condition A.

Table 5. Level of temptations in Condition A

<table>
<thead>
<tr>
<th>Types of separation</th>
<th>Highly Tempted</th>
<th>Average Tempted</th>
<th>Low Tempted</th>
<th>Not Tempted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Double Line</td>
<td>22</td>
<td>4</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Crossed Hatch Marking</td>
<td>20</td>
<td>9</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Tubular Delineators</td>
<td>6</td>
<td>5</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>Vegetation Strip</td>
<td>12</td>
<td>11</td>
<td>6</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 6 shows the temptations of participants when they saw other cars are crossing the separation in front of them:

Table 6. Level of temptations in Condition B

<table>
<thead>
<tr>
<th>Types of separation</th>
<th>Highly Tempted</th>
<th>Average Tempted</th>
<th>Low Tempted</th>
<th>Not Tempted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Double Line</td>
<td>18</td>
<td>11</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Crossed Hatch Marking</td>
<td>19</td>
<td>10</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Tubular Delineators</td>
<td>11</td>
<td>2</td>
<td>8</td>
<td>23</td>
</tr>
<tr>
<td>Vegetation Strip</td>
<td>11</td>
<td>7</td>
<td>10</td>
<td>16</td>
</tr>
</tbody>
</table>
4.5 Statistical Analysis for temptations

Cumulative logit model for temptation score (High=1, Average=2, Low=3, Not=4) was tested, with Separation Types and Traffic conditions, interaction between separation type and traffic conditions, gender and age category as explanatory variables. This type of model is used when response has more than two categories and if they are in logical order in response. And our data has more than two categories in the form of separation types and age categories. Hence we have to use this model to analyze the results.

4.5.1 Cumulative logit model for temptation

Probabilities for high temptations were computed using cumulative logit model. The table below shows that there is a significant effect of type of separation ($\chi^2 = 21.91$ (3 df); $P < .0001$) and that there is no significant effect of traffic conditions ($\chi^2 = 0.01$ (1 df); $P = 0.9436$) and no significant interaction ($\chi^2 = 3.06$ (3 df); $P = 0.3821$), no significant effect of gender ($\chi^2 = 1.39$ (1 df); $P = 0.2379$) and no significant effect of age factor also ($\chi^2 = 2.96$ (3 df); $P = 0.3971$).

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Chi-Square</th>
<th>Pr &gt; ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of separation</td>
<td>3</td>
<td>21.91</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Traffic Conditions</td>
<td>1</td>
<td>0.01</td>
<td>0.9436</td>
</tr>
<tr>
<td>Separation type*traffic conditions</td>
<td>3</td>
<td>3.06</td>
<td>0.3821</td>
</tr>
<tr>
<td>gender</td>
<td>1</td>
<td>1.39</td>
<td>0.2379</td>
</tr>
<tr>
<td>Age category</td>
<td>3</td>
<td>2.96</td>
<td>0.3971</td>
</tr>
</tbody>
</table>

As the variable of “types of separation” showed the significant effect on the temptations of participants, but there are four types of separations and it is needed to check the individual effect of each type of separation on temptations. That is why cumulative logit model has been applied to estimate the probabilities for each type of separation.

The cumulative logit model is used to estimate the probabilities of 1) high temptation, 2) high or average temptation, 3) high, the average and low temptation for the four scenarios:

<table>
<thead>
<tr>
<th>Least Squares Means</th>
<th>Separation Type</th>
<th>Estimated probabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>High temptation</td>
<td>Solid Double Line</td>
<td>0.4092</td>
</tr>
<tr>
<td>High temptation</td>
<td>Crosshatch Marking</td>
<td>0.4414</td>
</tr>
<tr>
<td>High temptation</td>
<td>Tubular Delineators</td>
<td>0.1600</td>
</tr>
</tbody>
</table>
High temptation | Vegetation Strip | 0.2742
Average temptation | Solid Double Line | 0.5864
Average temptation | Crosshatch Marking | 0.6179
Average temptation | Tubular Delineators | 0.2804
Average temptation | Vegetation Strip | 0.4360
Low temptation | Solid Double Line | 0.7346
Low temptation | Crosshatch Marking | 0.7595
Low temptation | Tubular Delineators | 0.4321
Low temptation | Vegetation Strip | 0.6015

Table 8 shows cumulative estimated probabilities of temptations on all four methods. To get results for each temptation, we should deduct the preceding probability. And to calculate the last temptation, we should subtract last probability from 1. As a whole, above table shows that:

- If the “type of separation” is Solid Double Line then there is 40.92% of chance that the temptation will be high, 17.72% of chance that temptation will be average, 14.82% of chance that temptation will be low and 26.54% of chance that there will be no temptation.
- If the “type of separation” is Crosshatch marking then there is 44.14% of chance that the temptation will be high, 17.65% of chance that temptation will be average, 14.16% of chance that probability will be low and 25.05% of a chance there will be no temptation.
- If the “type of separation” is tubular delineators then there is 16% of chance that the temptation will be high, 12.04% of chance that temptation will be average, 15.17% of chance that temptation will be low and 56.79% of probability that there will be no temptation.
- If the “type of separation” is vegetation strip then there is 27.42% of chance that the temptation will be high, 16.18% of chance that temptation will be average, 16.55% of chance that temptation will be low and 39.85% of chance that there will be no temptation.

From above observations, it is evident that tubular delineator is the most efficient method of separation in restricting drivers to cross the separation. After tubular delineator, vegetation strip is the most useful type of separation. Then crosshatch marking and solid double line.

In order to analyse the difference between the types of separation, these types are compared with each other. To control the overall type-I-error $\alpha$ of 0.05, these comparisons were made at a significance level of $\alpha/6 = 0.0083$ each (Bonferroni correction for multiple comparisons).
### Table 9. Differences of Separation Type Least Squares Means

| Separation Type       | Separation type       | Pr > |z| |
|-----------------------|-----------------------|------|---|
| Solid Double Line     | Crosshatch Marking    | 0.4632 |
| Solid Double Line     | Tubular Delineators   | <.0001 |
| Solid Double Line     | Vegetation Strip      | 0.0078 |
| Crosshatch Marking    | Tubular Delineators   | <.0001 |
| Crosshatch Marking    | Vegetation Strip      | 0.0016 |
| Tubular Delineators   | Vegetation Strip      | 0.0029 |

So, we can conclude that there is a significant difference between all pairs of types of separation except for Solid Double Line and Crosshatch Marking.

Above method was used to calculate estimation for multinomial data. In the next step, multinomial data was converted into binomial data by combining (High tempted and Average Tempted = 1) and (Low tempted and Not tempted = 0). We have reduced our data into two categories to further investigate the significant effect of separation types, traffic conditions, the interaction between separation type and traffic conditions, gender and age group on temptations. As after the conversion of data into two categories, binary logit model can be applied for the analysis.

### 4.5.2 Logit Model For temptation (Binary Data)

Logit model (Table 10) is used to calculate the probabilities of higher levels of temptation. The table below shows that there is a significant effect of separation types only ($\chi^2 = 21.50$ (3 df); $P < .0001$) and that there is no significant effect of others crossing ($\chi^2 = 0.00$ (1 df); $P = 0.9537$) and no significant interaction ($\chi^2 = 3.31$ (3 df); $P = 0.3469$), no significant effect of gender ($\chi^2 = 1.24$ (1 df); $P = 0.2651$) and no significant effect of age factor also ($\chi^2 = 3.37$ (3 df); $P = 0.3387$).

### Table 10. Model For temptation (Binary Data)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Chi-Square</th>
<th>Pr &gt; ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separation types</td>
<td>3</td>
<td>21.50</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Traffic conditions</td>
<td>1</td>
<td>0.00</td>
<td>0.9537</td>
</tr>
<tr>
<td>Separation type*traffic conditions</td>
<td>3</td>
<td>3.31</td>
<td>0.3469</td>
</tr>
<tr>
<td>gender</td>
<td>1</td>
<td>1.24</td>
<td>0.2651</td>
</tr>
<tr>
<td>agecat</td>
<td>3</td>
<td>3.37</td>
<td>0.3387</td>
</tr>
</tbody>
</table>

As the results from table 10. show that only separation types have a significant difference, we calculated their estimated mean independently according to separation type. The estimated probabilities of (High tempted and Average...
Tempted) and (Low tempted and Not tempted) for the four scenarios are given below.

<table>
<thead>
<tr>
<th>Separation Types</th>
<th>Estimate</th>
<th>Mean</th>
<th>Standard Error of Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Double Line</td>
<td>-.4800</td>
<td>0.6177</td>
<td>0.06101</td>
</tr>
<tr>
<td>Crosshatch Marking</td>
<td>-.6970</td>
<td>0.6675</td>
<td>0.06116</td>
</tr>
<tr>
<td>Tubular Delineators</td>
<td>1.1145</td>
<td>0.2470</td>
<td>0.05224</td>
</tr>
<tr>
<td>Vegetation Strip</td>
<td>0.1830</td>
<td>0.4544</td>
<td>0.06444</td>
</tr>
</tbody>
</table>

Data from table 11. shows that there are a 61.77% chances that participants were highly or averaged tempted when the solid double line is used as the separation type. Chances for high and average tempted for other three types of separations are:

1. 66.75% for Crosshatch Markings
2. 24.70% for tubular delineators
3. 45.44% for vegetation strip.
5 CONCLUSION AND DISCUSSION

This thesis was to study useful type of soft separation on the highways to segregate express and local lanes. The concept of express and local lanes are described in previous sections. Literature review pointed out the positive and negative points of hard barriers that they are the cause of high cost and long queues in express lanes. Each type of separation is also explained in the literature part, along with their pros and cons.

Eight scenarios were designed in a virtual world that can be driven using driving simulator with four different soft separation techniques and with two different traffic conditions. The driving simulator program used for designing the virtual world was STISIM Drive 3. This chapter will focus on the findings resulting from the analysis of the data obtained from the simulator and data collected through the questionnaires. The general perception of the participants is also discussed in this part of the report.

5.1 Crossing Behaviour

Crossing behaviour of participants was analysed statistically, out of eight scenarios, four scenarios were dedicated to conditioning. As in which no cars crossed the separation. In this condition, participants who didn’t cross the lane were found highly tempted when the separation type was a solid double line. They were least tempted when the separation type was tubular delineator.

Remaining four scenarios were with traffic condition B in which participants saw other cars from the queue crossing the separation. Only a few participants got tempted when they saw other cars are crossing. Even in tubular delineators, only two participants passed the separation when they saw other cars are crossing tubular delineators. Results were almost the same in temptations that participants found highly tempted in solid double lines and crossed hatch marking and lowest in tubular delineators.

And those who crossed the separation gave the reasons that:

- They did not consider Solid Double Line and crossed hatch markings as physical barriers. Didn’t wanted to wait in the queue.
- Some of the participants who did not enter the express lane were looking for another access point.
- Some of the participants who did not enter the lane miscalculated the access point and crossed that particular area which allows them to enter the express lanes.
- only a few of them gave a reason that when they saw other cars moving, they also changed their lane.
From above observations and statistical analysis, it is concluded that no explanatory variable (Separation type, traffic conditions, gender) has a significant difference on the crossing behavior. Hence, we cannot deduce from crossing behavior analysis, any conclusion regarding which separation method is better among the other.

5.2 Temptations

It was observed that participants were highly tempted when the solid double line and crosshatch markings were used than tubular delineators and vegetation strip. This could be because both tubular delineators and vegetation strip give feelings of physical barriers. A considerable number of participants were highly tempted in vegetation strips also as it will not damage their car. But highest number of participants who were not tempted at all was in tubular delineators. This gives us a conclusion that tubular delineators are the most efficient method of separating express and local lanes in restricting drivers from crossing the separation.

From statistical analysis of temptations tendencies data, explanatory variables such as two traffic conditions, gender, and age had no significant effects on the temptations. It was observed that only the separation types have a significant difference on temptations, by doing further analysis on separation types, it is found that tubular delineators are the most efficient type of separation out of all. This augments our previous conclusion that tubular delineators are the most efficient method of separating express and local lanes in restricting drivers from crossing the separation.
6 FUTURE EXTENSION

This study has a very wide perspective. It has several aspects which are still to be explored. The study conducted can play an important role in serving as the key towards future researches. This study can be extended by investigating the effects of peer pressure on both crossing behaviour and temptations. Design of our study was to check individual’s behaviour on soft separation techniques that whether they cross it or not if exposed to traffic jam in express lanes in a driving simulator. With the same experimental road design and conditions, we can conduct experiments in a way that a driver will have a passenger with them and can find the effects of fellow passenger on motivation level of the driver to cross the separation. From this, we can analyse the behaviour of an individual towards soft separations having a peer pressure on them.
REFERENCES


ANNEXURE

Annexure 1a: Pre-Questionnaire (English)

Pre-Questionnaire

Dear Participant

It would be nice that if you fill this questionnaire per requested from the researcher, if you find difficulties in understanding questions you can always ask the researcher.

Thank you for your Co-operation

*********************************************************

**General Information**

1. Gender
   - O Man
   - O women

2. Date of Birth
   - ...... / ...... / ........ (day/month/year)

3. Residence
   - ............................................. (postcode + city)

4. Profession
   - O Student
   - O full time employee
   - O Part time employee
   - O private Business
   - O Retired
   - O other : ..............................
Driving-Information

6. What type of license do you own and since when?
   - O B Permit
   - O C Permit
   - O D Permit
   since ........... (year!)

7. How many kilometers you drive per year?
   - O 0 to 4.999km
   - O 5.000 to 9.999km
   - O 10.000 to 14.999km
   - O 15.000 to 19.999km
   - O 20.000 to 25.000km
   - O More than 25.000km

8. How many times per week you drive on highways?
   - O Daily
   - O Weekly
   - O Monthly
   - O Annual
   - O Never

9. What is the purpose of using the highway often?
   - O Work
   - O Shopping
   - O Tourism
   - O Other: ..........................

10. When moved you most frequently?
    [Peak hours: from 07:00 to 09:00 and from 16:30 to 18:30]
    - O Outside peak hours
    - O within peak hours

11. Do you wear optical glasses or contact lenses while driving?
    - O Yes
    - O No

12. Will you optical glasses or contact lenses while this experiment?
    - O Yes
    - O No

13. Drive usually manual or through automatic acceleration?
    - O Manual
    - O Automatic
14. Have you ever been involved in an accident?
   - Yes
   - No

15. If yes, then how often? If not, ignore this question.

   - Time with only material damage
   - Time with slightly injured
   - Time with seriously injured
   - Time with killing
Annexure 1b: Pre-Questionnaire (Dutch)

Beste proefpersoon

ID-nr: ......

Gelieve onderstaande vragenlijst in te vullen. Mochten sommige vragen niet duidelijk zijn, kunt u altijd de onderzoeker om hulp vragen.

Bedankt voor uw medewerking.

****************

Algemene informatie

1. Geslacht?  
   O Man  
   O Vrouw

2. Geboortedatum?  
   ...... / ...... / .......... (dag/maand/jaar)

3. Woonplaats?  
   .......................................................... (postcode + gemeente)

4. beroep?
   O Student  
   O full time medewerker  
   O Part time medewerker  
   O Eigen bedrijf  
   O Met pensioen  
   O Ander:.................................
**Rij-informatie**

6. Welk type van rijbewijs bezit u en sinds wanneer?

- O B vergunning
- O C vergunning
- O D vergunning

sinds .......... (jaartal)

7. Hoeveel kilometer rijdt u gemiddeld per jaar?

- O 0 tot 4.999km
- O 5.000 tot 9.999km
- O 10.000 tot 14.999km
- O 15.000 tot 19.999km
- O 20.000 tot 25.000km
- O Meer dan 25.000km

8. Hoe vaak per week rijdt u op snelwegen?

- O Dagelijks
- O Wekelijks
- O Maandelijks
- O Jaarlijks
- O Nooit

9. Wat is de reden van uw verplaatsing??

- O werken
- O winkelen
- O Toerisme
- O Ander: .......................... 

10. Wanneer verplaatst u zich het vaakst?

[Spitsuren: van 07:00 tot 09:00 en van 16:30 tot 18:30]

- O Buiten spitsuren
- O Binnen spitsuren

11. Draagt u een bril of contactlenzen tijdens het rijden?

- O Ja
- O Nee
12. Gebruikt u een bril of contactlenzen tijdens dit experiment?
   O Ja
   O Nee

13. Rijdt u meestal handgeschakeld of automaat?
   O Handgeschakeld
   O Automaat

Verkeersveiligheid

14. Bent u ooit betrokken geweest bij een ongeval?
   O Ja
   O Nee

   ............ keer met enkel materiële schade
   ............ keer met lichtgewonden
   ............ keer met zwaargewonden
   ............ keer met doden
Annexure 2a: Post-Questionnaire (English)

Post-questionnaire

1. What is the purpose of this investigation according to you?
………………………………………………………………………………………………………………………………
………………………………………………………………………………………………………………………………
………………………………………………………………………………………………………………………………

2. Did your driving behaviour in the simulator correspond to your driving behaviour in reality?
   O It was more or less in line
   O It deviated a bit
   O It strongly deviated

3. Signboards, and different information signs were enough visible in the scenario?
   O Yes
   O No

4. Do you have any other remarks regarding the scenario?
………………………………………………………………………………………………………………………………
………………………………………………………………………………………………………………………………

5. Did you notice the variable message overhead signboard?
   O Yes
   O No

6. If yes, what was the information displayed on the variable message overhead signboard?
………………………………………………………………………………………………………………………………
………………………………………………………………………………………………………………………………

7. Were there any difference between the scenarios?
………………………………………………………………………………………………………………………………

ID-nr: …..
8. On what level of temptation, you wanted to change the lane when the traffic was jammed?

   O Solid double line  
   \textit{Highly tempted, average tempted, low tempted, no temptation}

   O Cross Hatched Markings  
   \textit{Highly tempted, average tempted, low tempted, no temptation}

   O Tubular Delineators  
   \textit{Highly tempted, average tempted, low tempted, no temptation}

   O Vegetation/Grass Strip  
   \textit{Highly tempted, average tempted, low tempted, no temptation}

9. When you saw cars crossing the jammed traffic and crossing through other lanes, how much you were tempted to change the lane then?

   O Solid double line  
   \textit{Highly tempted, average tempted, low tempted, no temptation}

   O Cross Hatched Markings  
   \textit{Highly tempted, average tempted, low tempted, no temptation}

   O Tubular Delineators  
   \textit{Highly tempted, average tempted, low tempted, no temptation}

   O Vegetation/Grass Strip  
   \textit{Highly tempted, average tempted, low tempted, no temptation}

10. What made you cross the separation? (Brief reasoning)

   ……………………………………………………………………………………………………………………………

11. Any other suggestions you want to give?

   ………………………………………………………………………………………………………………………………………
Annexure 2b: Post-Questionnaire (Dutch)

Nabevraging

1. Wat is het doel van dit onderzoek volgens u?

2. Heeft uw rijgedrag in de simulator komen overeen met uw rijgedrag in werkelijkheid?
   - O het was min of meer in lijn
   - O het afgeweken een beetje
   - O het sterk afgeweken

3. Borden, en verschillende informatie tekenen waren genoeg zichtbaar in het scenario?
   - O ja
   - O nee

4. Heb je andere opmerkingen over het scenario?

5. Merkte u de variabele bericht overhead bord?
   - O ja
   - O nee

6. Zo ja, wat was de informatie die wordt weergegeven op de variabele bericht overhead bord?

ID-nr: ....
7. waren er geen verschil tussen de scenario's?

8. op welk niveau van verleiding, die u wilde veranderen van de baan, wanneer het verkeer vastgelopen was?
   O gesloten dubbele lijn...
   Zeer geneigd, gemiddelde verleiding, lage verleiding, geen temptation
   O Cross-gearceerde markeringen...
   Zeer geneigd, gemiddelde verleiding, lage verleiding, geen temptation
   O buisvormige afbakeningstekens...
   Zeer geneigd, gemiddelde verleiding, lage verleiding, geen temptation
   O vegetatie/gras Strip...
   Zeer geneigd, gemiddelde verleiding, lage verleiding, geen temptation

9. toen je zag de auto's het vastgelopen verkeer oversteken en oversteken via andere rijstroken, hoeveel u waren geneigd om te veranderen de baan dan?
   O gesloten dubbele lijn...
   Zeer geneigd, gemiddelde verleiding, lage verleiding, geen temptation
   O Cross-gearceerde markeringen...
   Zeer geneigd, gemiddelde verleiding, lage verleiding, geen temptation
   O buisvormige afbakeningstekens...
   Zeer geneigd, gemiddelde verleiding, lage verleiding, geen temptation
   O vegetatie/gras Strip...
   Zeer geneigd, gemiddelde verleiding, lage verleiding, geen temptation

10. wat maakte je Kruis de scheiding? (Korte redenering)

11. eventuele andere suggesties die u wilt geven?
Annexure 3: Scenario Randomizer

Scenario Randomizer
Results:

<table>
<thead>
<tr>
<th>Set</th>
<th>1= SDL</th>
<th>2=SDL1</th>
<th>3=CHM</th>
<th>4=CHM1</th>
<th>5=TD</th>
<th>6=TD1</th>
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<tr>
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<td>5</td>
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</table>
Annexure 4: SAS Input

%LET PATH = D:\Studenten\Shah Rukh Sajid;

PROC IMPORT OUT= WORK.ShahRukh
    DATAFILE= "&PATH\Post Questionnaire Analysis_final.xlsx"
    DBMS=EXCEL REPLACE;
    RANGE="Sheet1$A4:AV49";
    GETNAMES=NO;
    MIXED=YES;
    SCANTEXT=YES;
    USEDATE=YES;
    SCANTIME=YES;
RUN;

proc format;
    value temptfmt 1 = 'High temptation'
        2 = 'Average temptation'
            3 = 'Low temptation'
                4 = 'No temptation';
    value temptbin 1 = 'High or Average'
        0 = 'Low or No';
    value methfmt 1 = 'Closed Double Line'
        2 = 'Crosshatch Marking'
            3 = 'Tubular Delineators'
                4 = 'Vegetation Strip';
value agefmt 1 = '20-26'

2 = '27-32'

3 = '33-38'

4 = '39-44'

5 = '45-50';

run;

data temptations;

set ShahRukh;

array no_oth{4,4} F9-F12 F14-F17 F19-F22 F24-F27;

array oth{4,4} F29-F32 F34-F37 F39-F42 F44-F47;

array xing{4,2} F13 F33 F18 F38 F23 F43 F28 F48;

rename F1 = PersonID;

rename F5 = YearOfBirth;

rename F6 = age;

if F3 = 1 then gender = 'M';

else if F4 = 1 then gender = 'F';

if 20 LE F6 LE 26 then agecat = 1;

else if 27 LE F6 LE 32 then agecat = 2;

else if 33 LE F6 LE 38 then agecat = 3;

else if 39 LE F6 LE 44 then agecat = 4;

else if 45 LE F6 LE 50 then agecat = 5;

if F7 = 1 then crossed = 1;

else if F8 = 1 then crossed = 0;
temptation = .;

do i = 1 to 4; /* runs over 4 methods */

method = i;

others = 0;

crossing = (xing[i,1]=1);

if crossing then temptation = 1; /* If crossing, that is considered as highly tempted */

else do j = 1 to 4; /* runs over 4 categories of temptation */

if no_oth[ij] = 1 then temptation = j;

end;

output;

temptation = .;

others = 1;

crossing = (xing[i,2]=1);

if crossing then temptation = 1;

else do j = 1 to 4;

if oth[ij] = 1 then temptation = j;

end;

output;

drop F2 i j F9-F48;

format method methfmt. temptation temptfmt. agecat agefmt. ;

run;

data temptations;
set temptations;
if temptation IN (1,2) then Tempt0_1 = 1;
if temptation IN (3,4) then Tempt0_1 = 0;
format Tempt0_1 temptbin.;
run;

data crossing;
set ShahRukh;
array xing[4,2] F13 F33 F18 F38 F23 F43 F28 F48;
rename F1 = PersonID;
rename F5 = YearOfBirth;
rename F6 = age;
if F3 = 1 then gender = 'M';
ext if F4 = 1 then gender = 'F';
if 20 LE F6 LE 26 then agecat = 1;
ext if 27 LE F6 LE 32 then agecat = 2;
ext if 33 LE F6 LE 38 then agecat = 3;
ext if 39 LE F6 LE 44 then agecat = 4;
ext if 45 LE F6 LE 50 then agecat = 5;
if F7 = 1 then crossed = 1;
ext if F8 = 1 then crossed = 0;
do i = 1 to 4;
method = i;
do j = 1 to 2;
others = j + 1;

if xing{i,j} = 1 then crossing = 1;
else crossing = 0;

output;

end;
end;
drop F8-F48 i j;
format method methfmt. agecat agefmt.;
run;

ODS RTF file="&PATH\AnalysisCrossing_19MAY2017.rtf";
/

title "Model for probability of crossing";
proc genmod data = crossing descending;

class personID method others gender agecat;

model Crossing = method|others gender agecat/type3 dist=binomial link=logit;

repeated subject=personID;
run;
/*
title "Model for probability of crossing";
proc genmod data = crossing descending;

class personID method others gender;

model Crossing = method|others gender/type3 dist=binomial link=logit;

repeated subject=personID;
run;

/*

title "Model for probability of crossing";

proc genmod data = crossing descending;

class personID method others agecat;

model Crossing = method|others agecat/type3 dist=binomial link=logit;

repeated subject=personID;

run;

*/

ODS RTF CLOSE;

ODS RTF file="&PATH\AnalysisTemptation_19MAY2017.rtf";

title "Cumulative Logit Model for Ordinal response Temptation";

proc genmod data = temptations rorder=internal;

class personID method others gender agecat;

model Temptation = method|others gender agecat/type3 dist=multinomial link=cumlogit;

repeated subject=personID;

lsmeans method/mlink diff;

run;

ODS RTF CLOSE;

ODS RTF file="&PATH\AnalysisTemptation_Binary_19MAY2017.rtf";

title "Logistic Regression Model for probability to show high or Average Temptation";

proc genmod data = temptations descending;

class personID method others gender agecat;
model Tempt0_1 = method|others gender agecat/type3 dist=binomial link=logit;

repeated subject=personID;

lsmeans method/Il link diff;

run;

ODS RTF CLOSE;
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Investigation of freeway cross sectional designs with different soft separation techniques using driving simulator

Richting: Master of Transportation Sciences-Traffic Safety
Jaar: 2017

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Voor akkoord,

Sajid, Shah Rukh

Datum: 2/06/2017