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The operational and safety effects of heavy duty vehicles platooning

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THE OPERATIONAL AND SAFETY EFFECTS OF HEAVY DUTY VEHICLES PLATOONING

By

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DEDICATION

This thesis is dedicated to my family: for their kindness, devotion, and their endless support.

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It would not have been possible to finish this work without the full support I had from my professors. I am especially indebted to Dr. Thobias Sando, professor in the Civil Engineering department, and Dr. Murat M Tiryakioglu, a professor in the School of Engineering, who have supported me to achieve my career goals and who were patient enough to grant me the necessary academic knowledge to seek those goals.

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LIST OF ACRONYMS

ACC	Adaptive Cruise Control
ANOVA	Analysis of Variance
CACC	Cooperative Adaptive Cruise Control
COM	Component Object Model
COMPANION	COoperative dynamic forMation of Platoons for sAfe and energy-optImized goods transportation
DLL	Dynamic-Link Library
DOE	Design of Experiment
DR	Deceleration Rate
EDM	External Driver Module
EPA	Environmental Protection Agency
FFS	Free Flow Speed
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
HDVs	Heavy Duty Vehicles
HMI	Human Machine Interface
ICT	Information and Communication Technology
ITS	Intelligent Transportation System
MOVES	MOtor Vehicle Emission Simulator
PATH	Partners for Advanced transportation TecHnology
PET	Post-Encroachment Time

SSAM	Surrogate Safety Assessment model
SSM	Surrogate Safety Measures
TTC	Time To Collision
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
VISSIM	Verkehr In Städten – SIMulationsmodell (German)

ABSTRACT

Although researchers have studied the effects of platooning, most of the work done so far has focused on fuel consumption. There are a few studies that have targeted the impact of platooning on the highway operations and safety. This thesis focuses on the impact of heavy duty vehicles (HDVs) platooning on highway characteristics. Specifically, this study aims at evaluating the effects of platooning of HDVs on capacity, safety and CO_2 emissions.

This study is based on a hypothetical model that was created using the VISSIM software. VISSIM is a powerful simulation software designed to mimic the field traffic flow conditions. For model validity, the model outputs were compared with recommended values from guidelines such as the Highway Capacity Manual (HCM) (Transportation Research Board, 2016).

VISSIM was used to obtain the simulation results regarding capacity. However, in addition to VISSIM, two other software packages were used to obtain outputs that cannot be assessed in VISSIM. MOVES and SSAM are two simulation software packages that were used for emission and safety metrics, respectively. Both software packages depended on input from VISSIM for analysis.

It was found that with the presence of HDVs in the model, the capacity, the emission of CO2, and the safety of the roadway would improve positively. A capacity of 4200 PCE/h/ln could be achieved when there are enough HDVs in platoons. Furthermore, more than 3% of the traffic flow emission of CO_2 reduction is possible when 100% of the HDVs used in the model are in platoons. In addition to that, a reduction of more than 75% of the total number of conflicts might be obtained.

Furthermore, with the analysis of the full factorial method and the Design of Experiment (DOE) conducted by using Excel and Minitab respectively, it was possible to investigate the impact of the platoons' factors on the highway parameters. Most of these factors affect the parameters significantly. However, the change in the desired speed was found to insignificantly affect the highway parameters, due to the high penetration rate.

Keywords: VISSIM, MOVES, SSAM, COM-interface, HDVs, Platooning, Number of Conflicts.

CHAPTER 1: INTRODUCTION

I. Background

Heavy-duty vehicles (HDVs) make transferring and shipping goods possible. They are essential to the world economy, as they play a key role in transporting freight using surface transportation. However, HDVs have adverse effects on highways, such as congestions, traffic accidents, emissions pollution, etc. In spite of continuous endeavors from public authorities to enhance the roadway infrastructure, the burden on infrastructure, energy usage, and the environment is on the rise. This is due to the in the demand for road freight transport (Van Arem, Van Driel, & Visser, 2006)

According to the Environmental Protection Agency (EPA), more than 28% of total U.S. greenhouse gas emissions come from the transportation sector (EPA, 2018). Reducing pollutant emissions to reach the respective national ambient air quality standard by 2020 is one of the main objectives of EPA. The efficiency and improvement of freight transport trigger the attention of public authorities, transport planners, researchers, and automotive manufacturers because the freight transport by HDVs is one of the main policy areas for enhancement of overall energy efficiency.

A “cooperative system” is one of the benefits of innovations of the Information and Communication Technology (ICT) and applications for Intelligent Transportation Systems (ITS). To enhance the performance of the traffic system, this cooperative system uses vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication (Farah et al., 2012). Due to its positive effect on traffic safety, many studies have been committed to investigate the improvement and implementation of a cooperative system. There are other expected benefits from the cooperative system, such as the improving traffic flow and alleviating some environmental effects.

Vehicle platooning, which is known as convoy driving, is the formation of a sequence of trucks with small gaps between each, following a leading truck, referred to as the leader. Platooning of HDVs a highway, as illustrated in Figure 1, is a method of reducing fuel consumption and enhancing transport efficiency. To illustrate, platooning provides a safe driving experience for the trucks on the roadway by relieving the drivers from the main tasks, saving energy through fuel conservation, and reducing CO_2 emission. Besides, the small time gap between vehicles saves space on the highway, so that the highway section can accommodate more vehicles, which increases the road capacity and reduce the congestion (Mesa-Arango & Fabregas， A., 2017).

Figure 1. A platoon of three HDVs operating on a highway (Al Alam, 2011).

Furthermore, according to the Federal Highway Administration, in 2009, 168 billion gallons of fuel were consumed by vehicles, while 20% of that consumed fuel was diesel (FHWA, 2019). By using HDVs platooning, fuel saving may reach up to 20% due to small time gap that causes significant air-drag reduction, and therefore, reduces fuel consumption (Browand, McArthur, & Radovich, 2004). Giving that the demand for freight transportation has been growing every year, HDV platooning has already been considered as an effective way of reducing environmental impacts. It is expected to be implemented in several states in the near future (Lockwood, 2016). Therefore, an extensive study of the effect of the HDV platooning on the highway`s parameters should be carefully analyzed.

Due to the complexity of platooning and the fact that it is a new innovation, many states are cautious about allowing HDV platooning to be driven on its roads (Autonomous Vehicles | Self-Driving Vehicles, 2019). In 2012, only six states passed the legislation for autonomous vehicles to be used within their interstate highways. The State of Florida, for example, did not consider permitting autonomous vehicles until 2016 with some limitations and requirements. In item 316.0895 of the Florida legislation, the minimum safe distance between trucks is 300 feet. However, item 316.85 stated that whoever has a valid driver license can operate an autonomous vehicle in autonomous mode on the state roads, if the vehicle is equipped with autonomous technology, such as adaptive cruise control (ACC). Furthermore, item 316.0896 illustrates some limitations on using platooning on Florida highways, such as submitting insurance to the Department of Highway Safety and Motor Vehicles with an amount of five million dollars (Florida legislature, 2019).

II. Platoon Formation

There are several types of platoon formations. However, since the main idea for platooning is to save fuel, the formation must be studied for precision. It is necessary because of the potential waste of time and fuel can make these formations pointless. Platoon formation could be done either at the beginning of the trip, which is the easiest way, or by forming while trucks are in different positions on the network. However, it is hard to coordinate the trucks while they are in different positions when relying on Vehicle-to-Vehicle (V2V) communication. For that, another party must be involved to make the platooning possible. The responsibility of the party is to coordinate all of the trucks into one platoon and make the necessary communication with the leader of HDVs through Vehicle-to-Infrastructure (V2I) communication to ensure the success of the platooning process (Liang, Martensson, & Johansson, 2013).

When trucks are in different positions formation of platooning could be done in one of three ways. The first is called catch up, where the following truck has to speed up to catch up with the first truck, while the first truck maintains the same speed until the required gap between them is achieved. This method may consume more fuel if it is not done correctly. It is essential that the acceleration is done in a way that the fuel consumed to catch up does not exceed the fuel that same HDV would consume if it were acting as a free agent. This method depends mainly on the distance of the trip of the HDVs. It is assumed that the acceleration would fall within the maximum and minimum comfortable acceleration and deceleration (2.93ft./s^2,-4.4ft./s^2) since the desired distention for the platoon is not known (Van Arem, Van Driel, & Visser, 2006). The second method is called deceleration, where the truck in the front would reduce its speed while the following truck maintains its speed to allow the following truck to reach the required gap between them. However, that could be considered a waste of time but would guarantee less fuel consumption for the whole platoon. The third and most suitable method is a combination of the first two methods. It is done by reducing the speed of the leader truck by a reasonable speed and speeding up the following truck to the desired speed to reach the desired gap distance with the help of the coordinator. The first two ways use (ACC) while the third one uses Cooperative Adaptive Cruise Control (CACC) (Van Arem, Van Driel, & Visser, 2006).

III. Research Objectives

Platooning studies have been conducted for the past 50 years. However, the majority of those studies have been devoted to the implementations and the development of the platooning system. Very few studies have been conducted to investigate the impact of platooning on traffic flow. Those studies focused mainly on cars platooning without concentration on environmental impacts. HDV platooning impact on traffic flow (such as capacity, safety, and greenhouse emissions), still have been insufficiently studied (Mesa-Arango & Fabregas, 2017). Insufficient information has been found regarding the impacts of HDV platoon operations on traffic flow on highways. Apart from fuel saving, there are many topics regarding HDV platooning that need to be investigated.

For the sake of understanding the HDV platooning impact on highway parameters, this thesis is based on designing and simulation of HDV platooning, using primarily utilizing VISSIM software. The study focusses on the impact of HDV platooning on highways regarding the capacity, safety, and greenhouse gas emissions. Additionally, the study will investigate the significance of other HDV platooning variables on highway parameters: percentage of trucks of the traffic flow, percentage of platoons, the time gap, the speed of the platoons, and the number of trucks within a single platoon.

IV. Thesis Limitations and Framework

This thesis is based on simulation and modeling. The study uses a hypothetical model. For simplicity, the model does not include ramps. In order to neglect the effect of the ramps on the highway movement, such as weaving. Besides, there were assumed only two vehicle types available in the traffic mix of the highway: passenger cars and trucks. The characteristics of heavy-HDV (such as refrigerator trucks), were chosen for the simulation and analysis. Heavy-HDVs have a weight of more than 33,000 lb. (class 8). This thesis did not investigate the formation of the platoon effect on the highway movement. During all the simulation runs, it was assumed the platoon formation was created before entering the hypothetical model. Furthermore, in the study of the effect of HDV platooning on emission, MOVES simulation software was used. For accurate results, the effect of air drag reduction should be taken into consideration. However, MOVES does not have an input for air drag calculations. Therefore, the reduction of fuel consumption of HDV platooning was used, based on ITS energy project (Tsugawa, 2013), to estimate the reduction of air drag. Furthermore, it is preferred that trucks drive in the outer lane, it was assumed that the platoons would be driven in the right lane and would not be allowed to use the left lane or do a lane change during the simulation.

This thesis aims to study the HDV platooning effects on traffic flow parameters on the highway. The outline of this thesis will discuss the implementation of the simulation and the steps of collecting the results in a few chapters as follows:

Chapter 2: Background

This chapter defines HDV platooning parameters, mentions some of the benefits of truck platooning, and illustrates the related work about HDV platooning, such as studies related to fuel saving and the formation of HDV platooning.

Chapter 3: Methodology

This chapter explains the simulation software packages that were used. It includes defining properties and operations of HDV platoons, modeling of ACC/CACC systems considering the acceleration capability, and how they have been used within VISSIM, SSAM and MOVES software. Furthermore, it describes the methodology that was used to collect and analyze the outcomes.

Chapter 4: The Impact of HDV platooning on Traffic Flow Parameters

This chapter presents the outcomes that were collected from the simulations and discusses the impact of HDVs on capacity, safety and the greenhouse emissions based on the outcomes. It compares the results of different scenarios of different percentages of HDV platoons' impact on highway traffic flow parameters.

Also, five factors of HDV platoons were statically analyzed to investigate which of these factors have a significant impact on the rate of change on traffic flow parameters. The analysis of the "factorial method" was implemented to discuss the impact. The five factors chosen are as follow: the percentage HDVs trucks from all the traffic flow within the simulation, percentage of HDV platoon from all trucks, the time gap between HDVs within the platoon, and the desired speed of traffic flows , and the number of HDVs within a platoon.

Chapter 5: Overall Conclusions and Future Work

This chapter summarize the thesis work, and the thesis steps with some concluding remarks, and gives some recommendations for future work.

CHAPTER 2: BACKGROUND

I. Heavy Duty Vehicle Development

Truck platooning involves the formation of a sequence of trucks with a small time gap between each other, following a leading truck, referred to as the leader. The following trucks instantly mimic the movement of the leader. The main idea of platooning is to provide a safe driving experience for the trucks on the roadway, save energy through fuel conservation, and reduce CO_2 emission. Additional benefits are the increase in roadway capacity and congestion reduction (Mesa-Arango & Fabregas, 2017).

Since the 1970s, ITS research has been attracted to vehicle platooning topics, with some general interest about severe traffic around major urban centers. The concept of fully automated vehicles traveling in platoons using electronic coupling began in the 1970s (Garrard, 1979). One of the pioneering studies in platooning was conducted by the California Partners for Advanced transportation TecHnology (PATH) initiative which started in 1986. At the beginning of the project, the interest was only on cars platooning. However, the HDV became a part of the plan later, with the main objective of enhancing traffic conditions in California. The focus for platooning research has since shifted from cars to HDVs, specifically aiming at reducing the aerodynamic resistance (Shladover et al., 1991). The experiment was done in San Diego in on an empty freeway with two lanes, and with platooning of three to eight automated trucks with the speed of about 96 km/h (60 mi/h) with each truck weighing 25 ton. The platooning was driving with a gap distance of 6.3 m to see the effect of the aerodynamic on fuel saving. California PATH gave indications that a traffic volume of 1800 to 2000 veh/h/ln could be doubled or tripled if there were 100% of HDV platooning only in the freeway (Van Arem, Van Driel, & Visser, 2006).

Another valuable project that started in 2013 was known as the COoperative dynamic forMation of Platoons for sAfe and energy-optImized goods transportatioN (COMPANION). The European Commission sponsored the COMPANION initiative. The main objective was to investigate the risk of changing the regulation to allow shorter time gaps within HDV platoons. Taking into consideration traffic information and weather conditions, the project was aimed at establishing a dynamic coordination system. The idea of forming a platoon developed organically within the project. HDVs within Such a platoon might not necessarily to have the same origin or destination for HDVs within the platoon. Furthermore, the projects aimed to study the capability of the Human-Machine interface (HMI).

II. Related Studies

There are many studies conducted on platooning, either car platooning or HDV platooning. In this section, three studies are explored regarding the three parameters of this analyzed in this thesis. Starting with capacity, Zhao and Sun (2013) conducted a study that focused on vehicle platooning and car-following behaviors on capacity. In addition, Van Nunen, Esposto, Saberi, and Paardekooper (2017) discussed the safety of HDVs from the perspectives of roadway breaks and slopes. In addition, the emission of CO_2 was studied on real HDV platooning in Energy ITS project in 2009 (Tsugawa)

III. Effect of Car Platooning on Capacity

While car platooning has become an interest of the majority of the automobile industry, the absolute result of platooning impact on traffic flow capacity remains unclear. In Simulation Framework for Vehicle Platooning and car-following behaviors, Zhao (2013) researched and discussed the effect of passenger cars on roadway capacity. The goal of Zhao's study was to model a simulation framework of CACC platoon by using the application programming interface in microscopic-traffic simulation. Six vehicles equipped with CACC in a platoon were simulated to study the interaction of the platoon in traffic stream and to microscopically study the shockwave reaction of the interaction. It was assumed that vehicles equipped with CACC do not change lanes during the simulations. The results indicated that the platoon increased the lane capacity significantly at higher penetration rates of CACC vehicles. However, platoon size had little impact on traffic capacity.

like the above study, this thesis uses a simulation model for the outcomes. However, this thesis investigates the effect of HDVs instead of passenger cars. Likewise, just as the study did not car include lane changing, this thesis includes the assumption of no HDV platoon lane change.

IV. Implementation of HDVs with Safety

The safety of roadways is one of the main factors that concerns traffic engineers. There is one study that investigated HDV platooning safety during the formation of the platooning (Liang, Mårtensson, & Johansson, 2016). The study was conducted to illustrate the effects of slope and break on the safety of the platoon. It was proposed that two-layer control architecture for HDV platooning aimed to safely and fuel-efficiently coordinate the vehicles in the platoon. The proposed layers were responsible for the real-time control of the vehicles and the inclusion of preview information on road topography. The study showed that the proposed layer would give safer conditions to control the platoon and would save about 12% of gasoline compared to using a standard platooning controller.

Unlike the above study, this thesis investigates the safety of the highway traffic flow with the implementation of HDV platooning. Furthermore, the thesis aims to include the factors that have the most significant impact on highway safety.

V. CO_2 Emission within Energy ITS

Another significant HDV platooning study was “Energy ITS.” Energy ITS started in Japan in 2008 after CO_2, which is one of the main elements that causes global warming, had reached high levels of emission in Japan’s environment. In 2011, it was found that around 28% of the CO_2 emissions nationwide comes from the transportation sector (Tsugawa, 2013). More than 6% came from trucks (Tsugawa, Jeschke, & Shladover, 2016). The main objective of “Energy ITS” was to save energy by reducing energy consumption and preventing global warming with automated driving. In 2008, ”Energy ITS” conducted an experiment on three trucks driving in a platoon on a roadway with their speed set around 80 km/h (50 mi/h); gap distance varied between 4.7m and 20m (15.42 ft. and 65.62 ft.). Figure 2 represents the fuel saved after running the experiment on unloaded trucks with a constant speed of around 80 km/h (50 mi/h). The figure shows that the mean of the fuel saving was around 16% when the gap distance was 4.7m (15.42 ft.) and 13% when the distance was around 10m (32.82 ft.). CO_2 emission reduction was measured, and the experiment showed that up to 4.8% of the CO_2 emissions were reduced when the gap was 4m (13.12 ft.) and 2.1% when the gap was 10m (32.81 ft.) (Sadayuki, 2013).

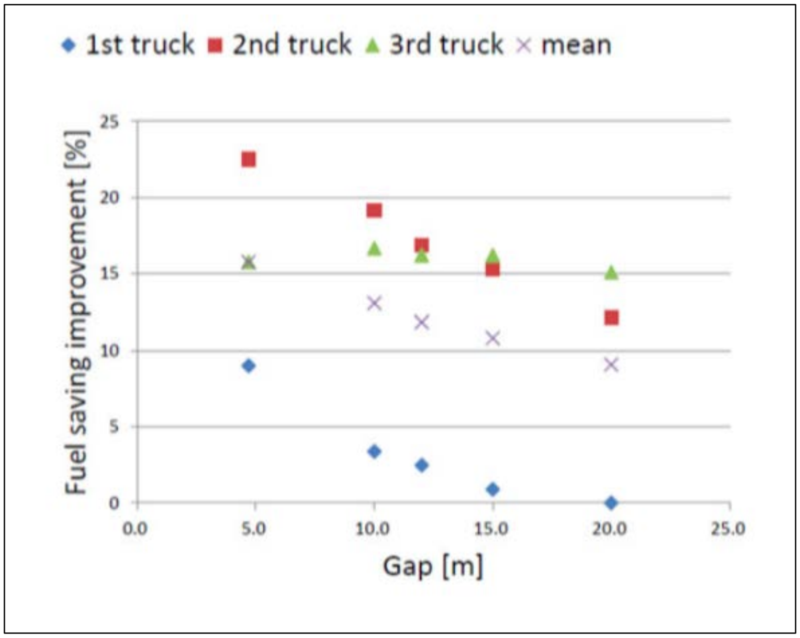


Figure 2. Fuel saving improvement in ITS project (Tsugawa, 2014).

VI. Summary

In this chapter, the relevant literature about HDV platooning was reviewed, including the development of HDV platooning and HDV platoon parameters. The work of this thesis extends HDV platooning on detailed modeling in microscopic simulation and the formulation of a microscopic study on the effect of HDVs on highway parameters, in particular, highway capacity, safety, and greenhouse emissions.

CHAPTER 3: MODELING

This chapter illustrates the methodology that was used in this study. It is divided into three main sections. The first section presents the principles of HDV platooning, while the second section discusses the simulation process. The third section shows the calibration and validation of the simulation model. The three software packages used in this study are VISSIM, MOVES, and SSAM. The last two software packages depend on the outcomes of the first one. They were used to study the impact of HDV platooning on capacity, emission rate, and safety.

I. Heavy Duty Vehicles Platoon Operations

This subsection describes the operation of HDV platooning and the software packages used. Additionally, it highlights the method of connection and communication between HDVs in platoons.

A. The Operations of HDVs

HDV platooning consisted of a group of HDVs driving close to each other and being controlled as one unit, i.e., all vehicles in the platoon mimic the lead vehicle. The HDV platoon was modeled as a platoon class/structure, which represents a group of HDVs with the platooning capability. The traffic model implemented has the ability to mirror the driving behaviors (operations) of an HDV platoon. It includes the acceleration, deceleration, maintaining the time gap, and other advanced operations. The concept of HDV platoon model is illustrated in Figure 3.

A single platoon includes a platoon leader and one or more followers. The first vehicle, referred to as the leader, is operated and driven entirely by a human driver. The rest of the platoon is equipped with human drivers, but an autonomous driving system will take over the longitudinal driving tasks. The drivers of the followers can take control when they want to join or leave the platoon.

As shown in Figure 3, the HDV platoon consists of three main properties: platoon leader ID, platoon speed, and the list of HDV platoon members. Since the speed of the trucks within the same platoon may be different, the speed of the platoon is related to the leader's speed. Each vehicle in the HDV platoon has its information stored in the HDV platoon members list.

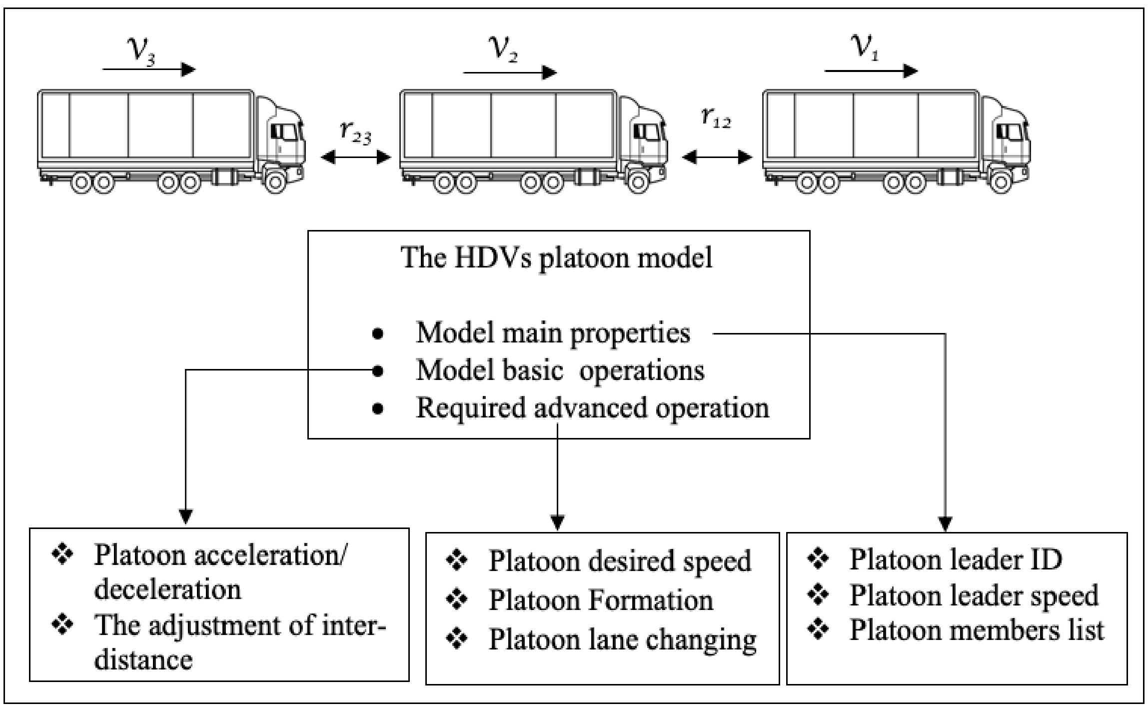


Figure 3. The HDV platoon model with its properties and operations.

In the study, all HDV platoons are initiated and operated by the platoon leader. It is the primary job of the leader to accelerate, decelerate, and maintain the platoon in the required lanes. For example, when a platoon reaches congestion, the leader makes the decision to change the lane or keep using the same lane for the whole platoon. For safety purposes, it was assumed that platoons would drive only on the outer lane to allow free agent vehicles (especially passenger cars) to drive in the inside lane -- the fast lane.

B. Platooning System

In the late 1970s, the concept of fully automated vehicles traveling in platoon using electronic coupling emerged (Caudill & Garrard, 2010). With the development of HDV platooning, the concept of Adaptive Cruise Control (ACC) has become an essential part of the platoon. Another advance system of ACC was joined and named Cooperative Adaptive Cruise Control (CACC). This section discusses the implementation of these systems and how they can affect the HDV platoons.

1. ACC System

When an HDV joins a platoon, an autonomous driving system, ACC, will take over the longitudinal driving tasks. ACC is a radar-based system, which is designed to enhance the driving by relieving the driver from the main tasks, such as adjusting the time gap, and the desired speed (Van A., et al., 2006). The system was designated to slow down when a follower reaches a certain set distance and increases the speed when the proceeding vehicle disappears (e.g., changing lane).

Van Arem, Van Driel, and Visser have proposed an equation (see Equation 1) for the acceleration demand (2006), which is based on relative speed and deviation of current distance from the desired vehicle gap.

$$a_{acc} = k_v \cdot (v_p - v) + k_d \cdot (r - rref) \quad (1)$$

The values of kv and kd are control parameters that must be empirically configured, while the values of v_p and v are the velocity of the proceeding vehicle and controlled vehicle respectively. The distance between the two vehicles is referred to as r. and $rref$ is the the least of r_{min} (2) and r_{system} (0.5 × desired speed)

.

ACC depends on vehicle-to-vehicle (V2V) communications, to get the acceleration /deceleration of the proceeding vehicle. Figure 4 illustrates the usage of both the ACC and CACC system within the platoon. On-board radar and sensors (ACC system) can measure the relative speed and gap between vehicles.

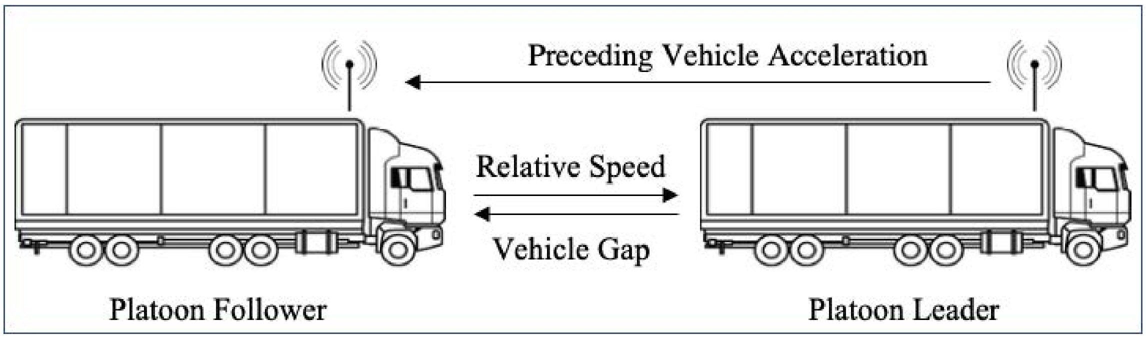


Figure 4. An example of 2-HDV platoon using ACC/CACC system.

It could be said that ACC is designed mainly for driving comfort, with a minimum of 1.4 seconds of time gap time required for ACC (Vahidi & Eskandarian, 2003). The acceleration variance of the platoon can be reduced by more than 50% (Minderhoud & Bovy, 2001). However, if the target time gap in a platoon is too large, then the capacity of the roadway may be decreased (Zwaneveld & Van A., 1998). At the same time, if less than 10% of ACC is presented in the traffic flow, there will be no effect of platooning on capacity (Davis, 2004).

2. CACC System

CACC is an advanced and improved extension of ACC. It uses the technology of V2V communication as a method of connection. Besides the relative speed and vehicle spacing that ACC can achieve, the CACC system can obtain the acceleration and deceleration of the proceeding vehicle, as shown in Figure 4. CACC uses this information to achieve the required small time gap while maintaining stable platooning. Ploeg (2011) investigated and evaluated the CACC on a six-vehicle platoon. This study showed that 0.5 seconds of time gap could be achieved with V2V communication using the CACC system. This small time gap can be achieved by maintaining a stable platoon (Ploeg et al., 2011).

Equations 2, 3 and 4 are used in the simulation model for this thesis. These equations were used by (Van Arem et al., 2006) to achieve the minimum stabled time gap of 0.5 seconds in platoons.

$$a_{ref} = min\,(a_{ref\_v}, a_{ref\_d}) \quad (2)$$

$$a_{ref_v} = k \cdot (v_{int} - v) \quad (3)$$

$$a_{ref\_d} = k_a \cdot a_p + k_v \cdot (v_p - v) + k_d \cdot (r - r_{ref}) \quad (4)$$

Equation 2 is used for the acceleration of the following HDVs to catch up with the HDVs upstream and join or form a platoon, keeping the time gap of 0.5 seconds. It takes the minimum between Equation 2 and 3. In those equations, k = 1, v_{int} and v are the intended velocity and the current velocity of the following HDVs respectively. $K_a = 1$, while k_v and k_d values are 0.58 and 0.1 respectively. Where v_p is the velocity of the predecessor HDVs and r is the net distance between the two HDVs, r_{ref} is the maximum value between r_{min} and r_{system}, where $r_{min} = 2$ and $r_{system} = 0.5 \cdot v$.

In this thesis, the CACC System is used as the default connection between the vehicles in the platoon. The reason for this assumption is that ACC connection showen in previous studies, that it does not have a significant effect on the traffic flow regardless of the set time gap between the vehicles (Van A. et al., 2006).

III. Simulation Software

This thesis is conducted based on three main simulation software: VISSIM, MOVES, and SSAM. This section is divided into three subsections. Each section explains and clarifies how the software works and how they have been used for the study. First, VISSIM was used to build a hypothetical model that has defined characteristics to measure the effect of HDV platooning on capacity. Secondly, MOVES is an EPA simulation software designed to measure the effect of traffic movement on the environment. Finally, SSAM was designed by FHWA to investigate the safety of traffic movement. The validity of these software packages was investigated by different studies (Huang, Liu, Yu, & Wang, 2013).

A. VISSIM

VISSIM is a powerful traffic simulation tool that is used in the analysis of the transport system. The software has been used in different ITS-based vehicle studies. Precisely, it provides a high profile of microscopic details of the simulated traffic flow. VISSIM mirrors the traffic pattern of medium traffic flow. Since VISSIM has the ability to mimic the psychophysical car-following model and lane-changing model to determine longitudinal and lateral driving behaviors of passenger vehicles, VISSIM is used as the backbone of this thesis. It is used to analyze the mixed traffic movement to obtain capacity data for different scenarios. Besides, VISSIM model is used to simulate the traffic movement to study the effect of HDVs on safety and emission as explained below. VISSIM COM server interface is used to perform the HDV platoon behavior, especially when VISSIM does not permit such a small time gap. The COM interface enables users to access and reshape traffic driving behavior. The interaction between COM interface and VISSIM can be seen in Figure 5.

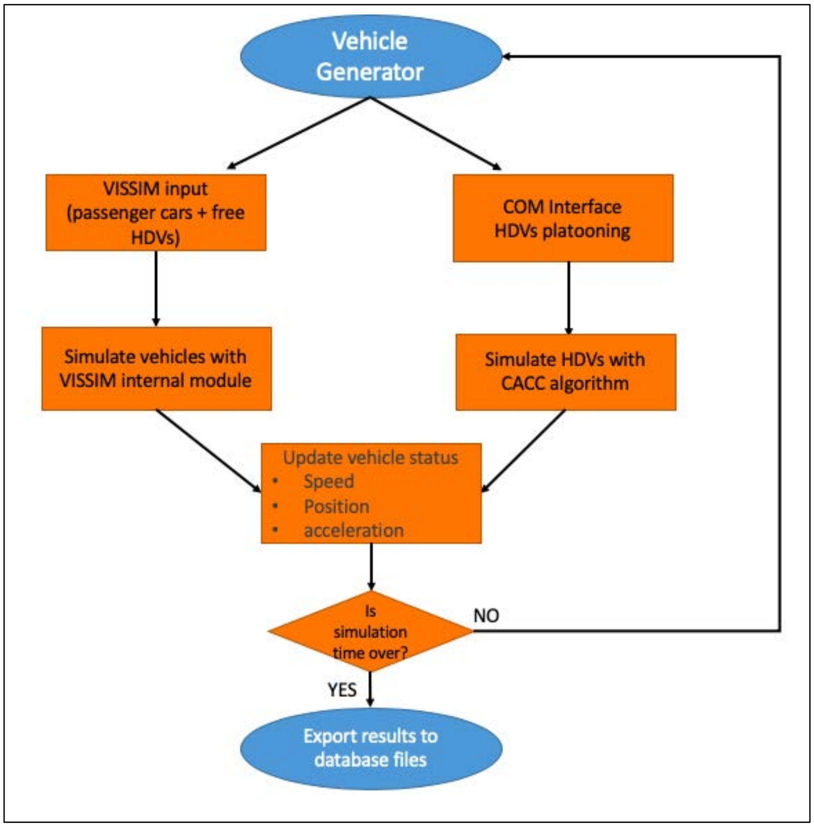


Figure 5. The interaction between VISSIM and COM interface.

The validity of the VISSIM model was tested to insure the legitimacy of the simulation outcomes. The method of validity is illustrated, with details, in the HDV Platoon Model section (page 28).

B. MOVES

The MOtor Vehicle Emission Simulator (MOVES) is a state-of-the-art modeling framework. It was designed to allow easier incorporation of large amounts of in-use data from a variety of sources (Hall & Noel, 2014). MOVES was designed and tested by the

United State Environmental Protection Agency (EPA), and its primary purpose is the development of a new emission factor and inventory model for free source emissions. According to the EPA website, MOVES was defined as the "state-of-the-science emission modeling system that estimates emissions for mobile sources at the national, county, and project level for criteria air pollutants, greenhouse gases, and air toxics" (EPA, 2017). Air pollution modelers within the U.S. at local levels can use the model. To run MOVES, users must provide or create a run specification (RunSpec) that describes the nature of the project, and input databases (county or project scale) that relate to the project data. The process of using MOVES is illustrated in Figure 6.

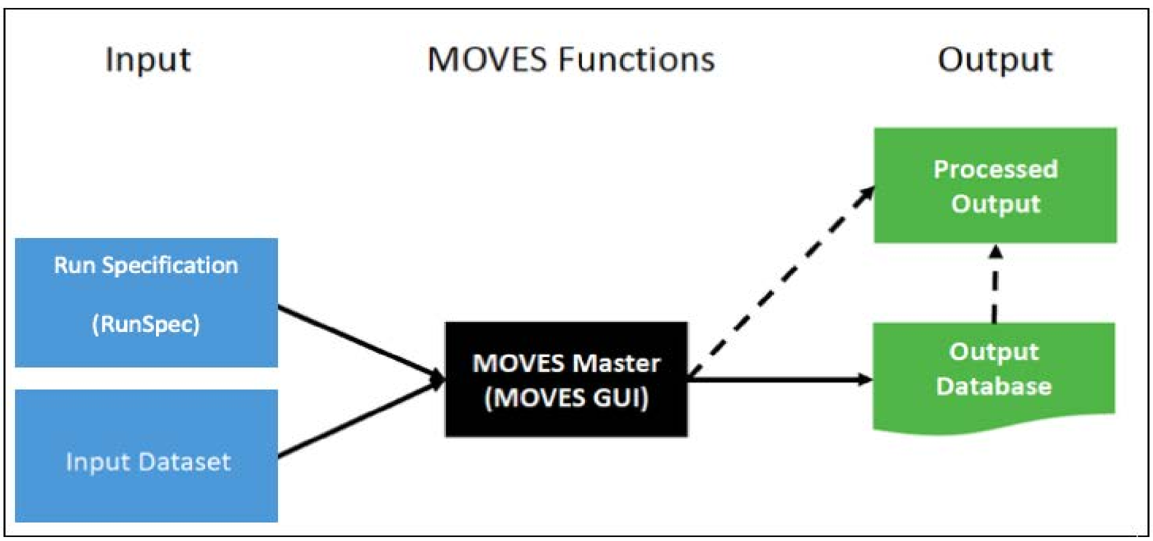


Figure 6. The process of data input in MOVES.

The Graphical User Interface (GUI) is the gate for the user to choose the input and output characteristics of the project, such as the type of greenhouse emission, the place and time of the year the project is conducted, etc. In another words, the nature of the project data must be inserted in the GUI, and the simulation movement output must be inserted in the template format Excel files provided by MOVES in County Data Manager (CDM). It can be said that CDM is a tool that facilitates the process of entering data into a county input database. CDM enables the user to input the project data by creating a template of tables, and the user can insert data in those templates. There are two types of templates available in CDM. Either CDM gives the user default data in the templates based on the choices made in GUI, and the user has the choice to edit them or use them as they are, or CDM would give the user Excel templates and the user has to fill the required cells with the project data (Figure 7).

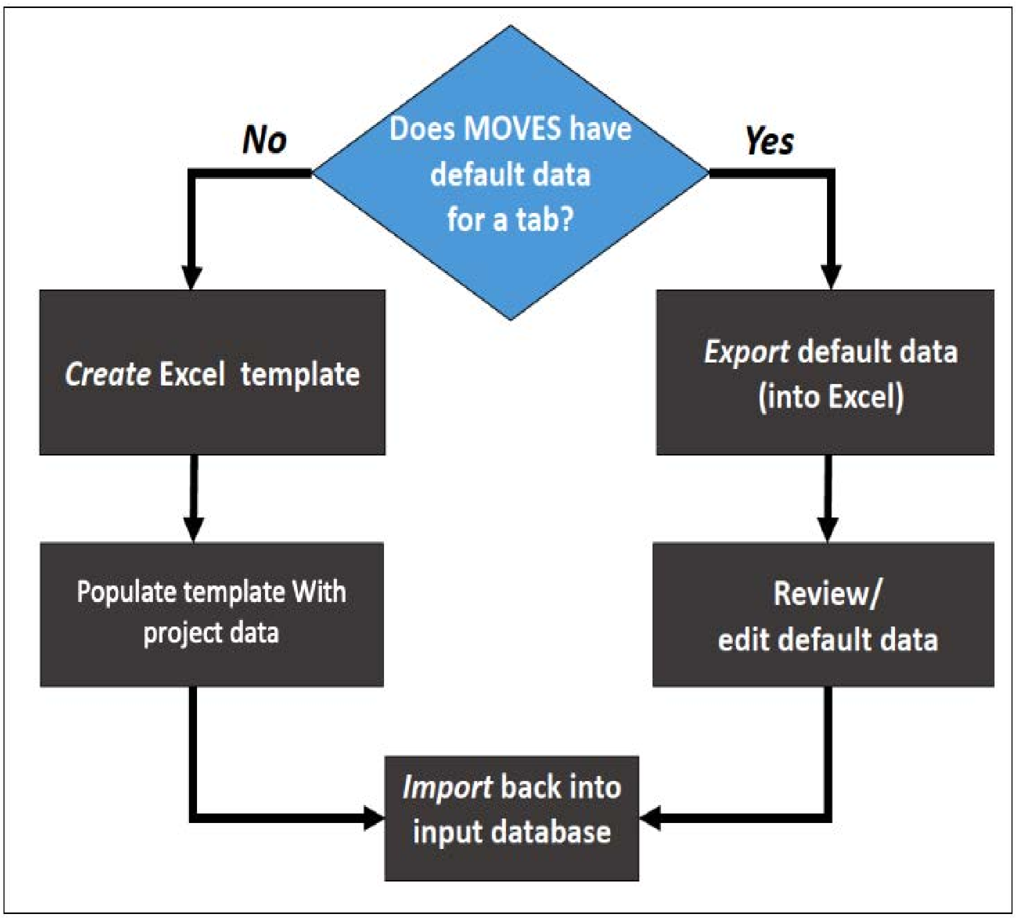


Figure 7. Data entering options in CDM.

In MOVES templates, the default values were used in the study in all of the tabs within CDM, except in fuel, average speed distribution, and Vehicle VMT tabs. In those three tabs, the input was based on the results that were collected from VISSIM from the different scenarios conducted. In addition, MOVES simulated the input data within the template files, as shown in Figure 8, to get the final emissions amount per gram, kilogram or ton, as requested by the user, for a variety of greenhouse gases.

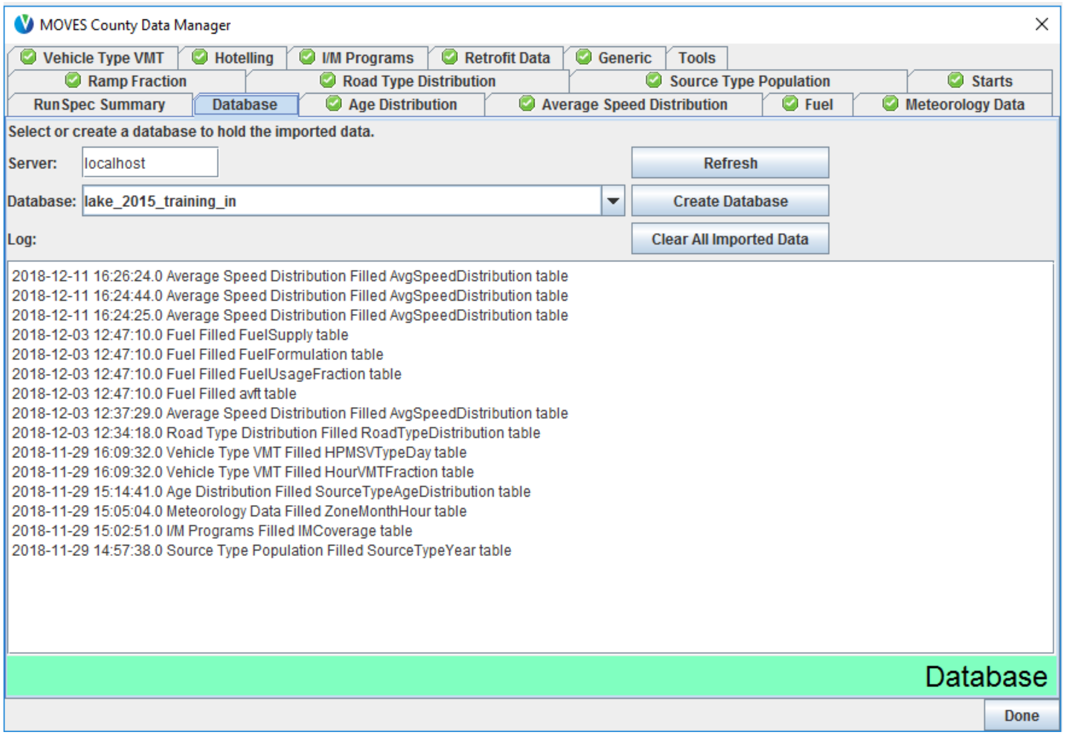


Figure 8. The input data in CDM within MOVES (MOVES, 2014).

According to the EPA around one-fourth of the gas emission in Tte U.S. comes from the transportation sector, and more than 80% of that is CO_2 (EPA, 2017). Therefore, it was the main interest of this thesis to study the impact of HDV platooning on gas emissions and compare the impact of moving trucks that were not platooning.

MOVES uses MySQL as a relational database management system based on Structured Query Language (SQL). Many applications use MySQL, including but not limited to data warehousing, e-commerce, and logging applications. However, the primary use of MYSQL is for web database management (Lehmann, 2010). MySQL is mainly used to communicate with a database, and it is the standard language for relational database management systems. MYSQL statements are used to perform tasks such as updating data in a database or retrieving data from a database. It was used in this study to analyze and group the results that were found from MOVES and to compare the final CO_2 emissions in different scenarios.

C- SSAM

For the effect of the HDV platooning on the overall traffic safety, the same model of VISSIM was used with the addition of another simulation software called Surrogate Safety Assessment Model (SSAM). Crashes are rare events, which means it takes a long time to collect enough data to make reliable inference on the safety condition. Besides, from the limitations in the data collection, assessment of traffic safety from traffic accidents cannot be categorized as active safety management. The use of traffic safety indicators, known merely as Surrogate Safety Measures (SSM), can increase the probability of evaluating traffic safety changes more efficiently and in a shorter time (Peng, Abdel-Aty, Shi, & Yu, 2017). SSAM uses the outcomes of VISSIM simulations through trajectory files and uses those outcomes in analyzing, and calculating several parameters to indicate the safety of the simulation (Figure 9).

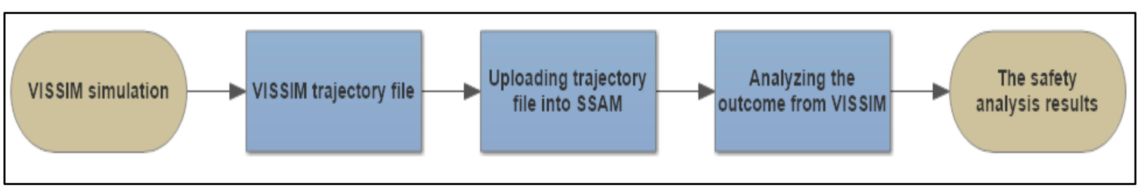


Figure 9. The process of SSAM outcome with VISSIM trajectory file.

SSAM considers the conflicts as risks. It defines the conflicts as three different conflicts based on the degree between the two vehicles as shown in the next figure.

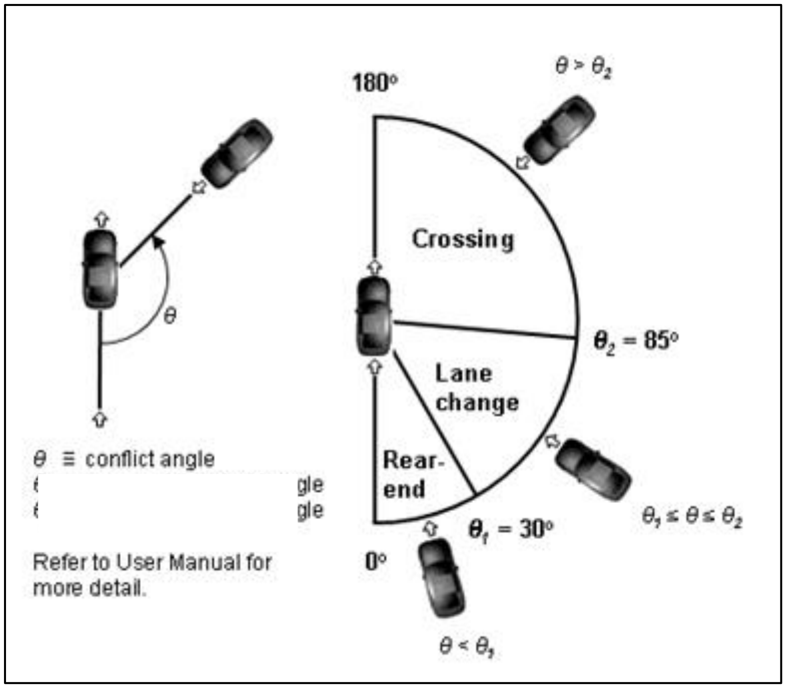


Figure 10. The three different types of conflicts (SSAM, 2008).

SSAM uses many variables to check the safety of the roadway, and the most important ones will be discussed in the following points.

1. Time to Collision (TTC)

In 1971, the term Time to Collision (TTC) was used for the first time and has been commonly applied since then (Peng, Abdel-Aty, Shi, & Yu, 2017). We can define TTC as the time that remains until a collision would have occurred between two vehicles if the collision course and speed difference of the vehicles are maintained (Minderhoud & Bovy, 2001). In other words, the larger the TTC value, the safer the vehicles (Peng, Abdel-Aty, Shi, & Yu, 2017). Figure 11 illustrates the concept of TTC through vehicle trajectories.

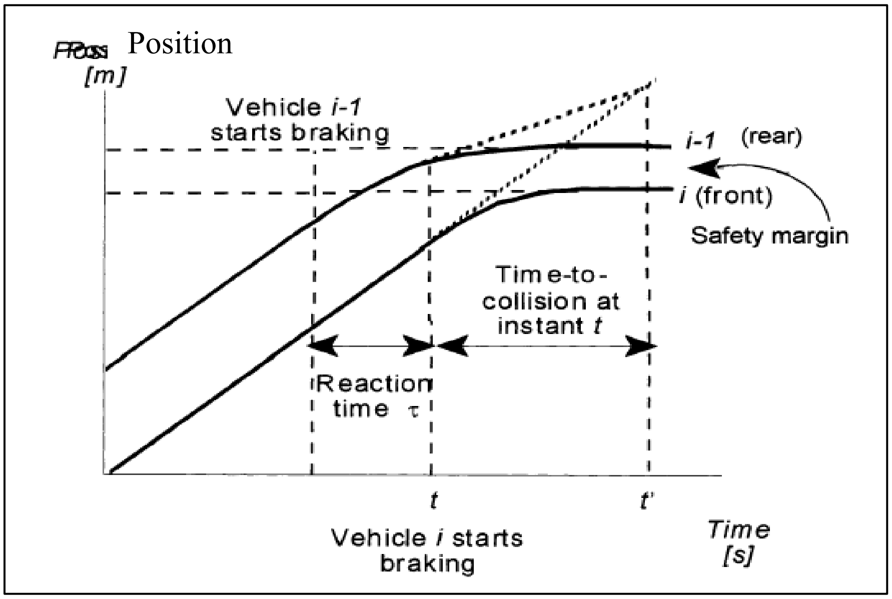


Figure 11. Vehicle trajectories describing TTC (Minderhoud & Bovy, 2001).

2. Decelaration Rate

Deceleration rate is the rate at which crossing vehicles must decelerate to avoid a probable collision. Some studies define it as Deceleration Rate to Avoid Collision (DRAC). It is a valuable measure when assessing dangerous maneuvers and the severity of a conflict (Nadimi, Behbahani, & Shahbazi, 2016). For a vehicle traveling in the same path, DRAC can be expressed as in the Equation 5, where X_L is the leading vehicle position, X_F is the following vehicle position, V_F is the following vehicle speed, V_L is the leading vehicle speed, and l_L is the vehicle length. The usefulness of DRAC is limited by the extraction process (of the actual deceleration rates), which is difficult and resource demanding (Archer, 2005).

$$DRAC_t = \frac{(v_{F,t} - v_{L,t})^2}{2(X_{L,t} - X_{F,t} - l_L)} \quad (5)$$

3. Post-Encroachment Time (PET)

This factor is defined as the time between which the arrival of a through vehicle arrives at the point of collision and the end of the encroachment of a turning vehicle. It is contemplated as a further alteration of TTC. It measures situations where two vehicles that are not on a collision course pass over a common spatial point or area with a difference in time that is below a predetermined threshold (Saffarzadeh, Nadimi, Naseralavi, & Mamdoohi, 2012). In other words, PET represents the difference in time between the passage of the offended and conflicted road users over a standard conflict zone. Some literature describes post-encroachment time simply as a potential danger (Nadimi, Behbahani, & Shahbazi, 2016). It is easier to calculate PET than TTC because there is no need for relative speed and distance data in PET (Saffarzadeh, Nadimi, Naseralavi, & Mamdoohi, 2012).

IV. HDV Platoon Model

A. Model Calibration

As was illustrated, this thesis was based on a simulation study. Also, the foundation of the outcomes was based on the VISSIM model simulation. The model used in VISSIM, was a hypothetical model with two lanes of 12 feet width, and with similar characteristics to the base conditions of the typical highway. According to the highway capacity manual (HCM), a highway in its its base conditions when it has the following elements (HCM, 2016):

1. 12 feet lane width with adequate lateral clearances

2. Drivers are in a regular composition and familiar with the roadway
3. No pavement deterioration
4. No work zone or accidents are present
5. Good weather conditions with excellent visibility to the drivers
6. No HDVs in the traffic stream

The model used in VISSIM has the characteristics of a base condition highway, except with the presence of HDVs. To illustrate the model validity, a preliminary model was designed with the whole highway in base condition (without the presence of HDVs). Based on the exhibit 12-4 in HCM, the capacity of highway with the base condition was different based on its Free Flow Speed (FFS) as in table 1:

Table 1. The Capacity of Base Conditions Highway from HCM (HCM, 2016).

FFS (mi/h)	**Capacity of the Basic Freeway Segments (pc/h/ln)**
70	2400
65	2350
60	2300

After conducting the simulations of the preliminary design, the average speed and the capacity of the three simulations for the above FFS are collected as shown in Table 2:

Table 2. The Average Speed and the Capacity of Simulation Runs.

Average Speed (mi/h)	**Capacity of the VISSIM Model (pc/h/ln)**
66.1	2386
62.2	2334
58.4	2289

To clarify the validity of the model, a hypothesis T-test was done on each result of the average speed and the model capacity with FFS and the capacity of basic freeway segments from HCM respectively. The α value was assumed at 0.05. Therefore, the critical value of T = 2.09. Table 3 shows the values and the results of the t-tests conducted:

Table 3. Comparison between VISSIM Model Results and HCM Values.

FFS	Avg. Speed	T-score	HCM Capacity	VISSIM Model Capacity	T-score
70	66.1	1.75	2400	2386	1.90
65	62.2	1.47	2350	2334	1.76
60	58.4	0.99	2300	2289	1.08

For clarification purposes, one example is written to understand the steps used in the hypothesis that the T-test used. When the FFS of a highway in base conditions is 70 mi/h, the average speed of the model was 66.1 mi/h. To show if the two numbers have such a significant difference or not, a null hypothesis (H0) of μ = 70 was assumed. On the other hand, an alternative hypothesis with H1: μ ≠ 70 was assumed as well as the first step. Then Equation 6 was used to find the value of the T-score.

$$T = \frac{x - \mu}{\frac{s}{\sqrt{n}}} \tag{6}$$

With the substitution of parameters, a value of 1.75 results when the standard deviation is about 10.9. We can notice that 1.75 is smaller than the critical value of T, 2.09—the value can be found from the two-tailed T-distribution. Thus, the null hypothesis is accepted: the average speed of the model and the FFS of the highway with the same posted speed are not significantly different. Figure 12 explains the T-distribution for this particular example.

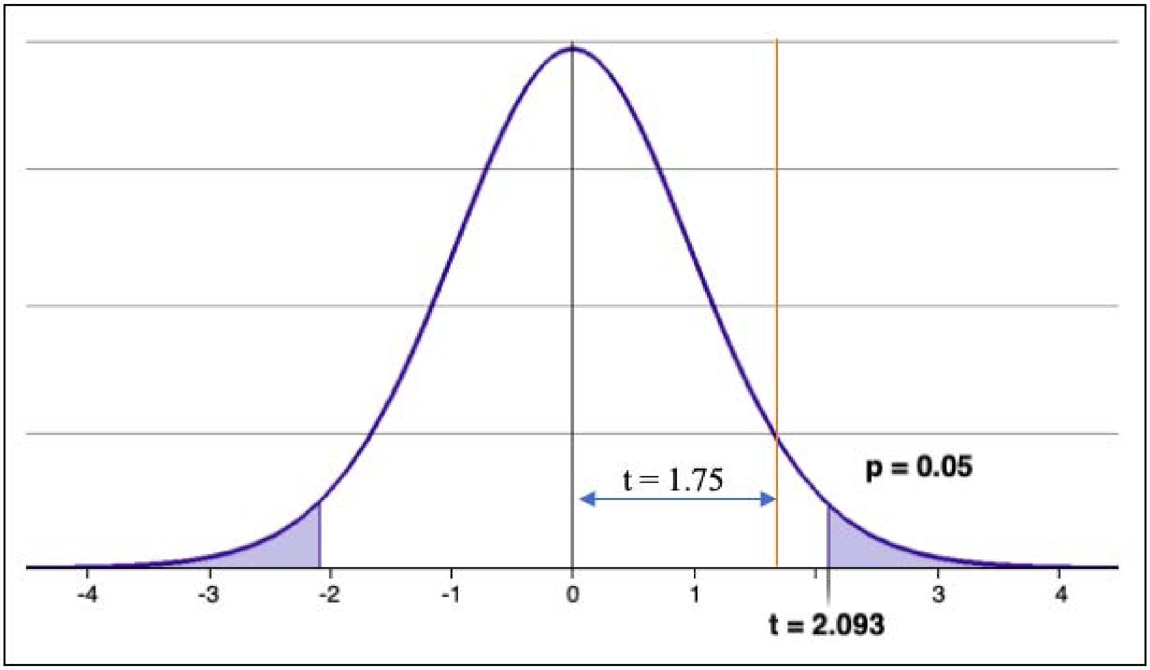


Figure 12. The T-distribution of the difference between the mean of the VISSIM model and HCM values.

Moreover, by choosing the default minimum allowed headway distance after the lane change to be 0.5 sec, it was assured that the vehicles are not within platoons are not poisitioned between the vehicles of the platoon during the simulation runs. Therefore, when the time gap was 0.5 sec within the platoon, VISSIM would not allow such interference.

B. Number of Runs

The number of runs of each simulation scenario is critical. As the user applies a more significant number of runs, the result is closer to the real mean. For that purpose, the Florida Department of Transportation (FDOT), has recommended using the following equation to determine the minimum number of simulation runs for any simulations scenarios:

$$\boldsymbol{n} = (\frac{\boldsymbol{s}\times\boldsymbol{t}_{\propto}}{\boldsymbol{\mu}\times\boldsymbol{\varepsilon}})^{\mathbf{2}} \quad (7)$$

Where *n* is the minimum number of simulation runs, *s* is the standard deviation of the simulation runs (based on previous runs), $\boldsymbol{t}_{\propto}$ is the critical value of the two-sided T-test with 95% confidence level, μ is the mean of the previously conducted runs, and ε is the tolerance error(estimated as 10%). All the simulation runs were conducted using Equation 7 to ensure a sufficient number of runs. For example, when the capacity was measured at 70% of HDVs in platoons, it was found that the number of simulations required was $(\frac{395\times2.09}{3165\times0.1})^2 = 6.81$. Therefore, seven simulation runs were used. The minimum required number of runs was found to be nine, while all the simulations conducted included 20 runs each.

V. Summary

This chapter discussed the operation and the essential factors of HDV platooning systems. It gave an overview of the software simulations that were used (VISSIM, MOVES, and SSAM) with some necessary details to understand the foundation of this study. Since the essential part of the simulation was the VISSIM model, the validity of the model was illustrated by statistical analysis. It was proven that the VISSIM model does not vary from what the HCM presents. The next chapter shows the results of the simulation software of HDV's effect on capacity, greenhouse emissions, and safety of the hypothetical highway model.

CHAPTER 4: HDVS PLATOONING IMPACT ON TRAFFIC FLOW PARAMETERS

This chapter presents the study results. The first and second sections discuss the output of the simulation scenarios on the model capacity. The third and fourth sections present the effect of HDVs on greenhouse emissions, with a special focus on carbon dioxide. The effect of HDVs on highway safety was discussed in the last two sections of this chapter. Each of these sections presents the output of rigorous analyses that include the ANOVA single factor analysis. In this study, ANOVA was used to test the effects of various penetration rates on the means of response variables—capacity, carbon dioxide and conflicts.

I. The Effect of HDVs on Highway Capacity

Many studies have used VISSIM for traffic analysis (Huang, Liu, Yu, & Wang, 2013). The validity of the hypothetical model was discussed in Chapter 3 of this thesis. The hypothetical model used in this study has two lanes of 12 feet width. It has the base conditions of a highway as suggested by HCM. Since VISSIM has some limitations on driving behavior, an External Driver Module (EDM) was needed to control the desired gaps between vehicles and the drivers' behavior. EDM is an interface of VISSIM that provides the option to develop the internal driving behavior by a full user definition for some or all vehicles in the model. A Dynamic-Link Library (DLL) was built to control the platooning behavior during the simulation within the network. Figure 5 (page 20) shows how DLL and COM interfaces integrate with VISSIM, and Figure 13 is a screenshot of the platooning during VISSIM simulation run.

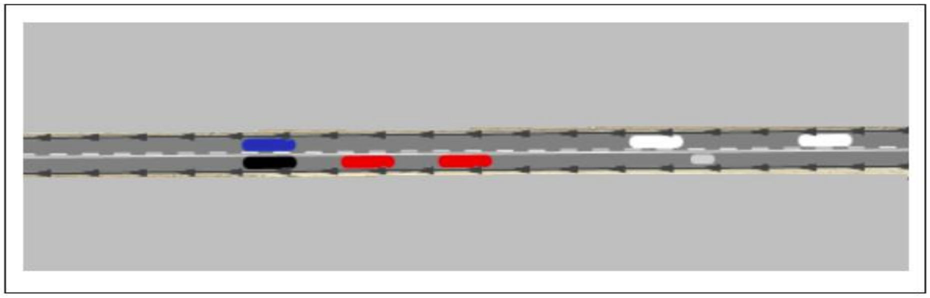


Figure 13. Screenshot of HDV platooning during a VISSIM simulation run.

The results from VISSIM were collected after conducting the simulation several times by changing the penetration rate of HDV platoon in the simulation runs. First, the simulation was conducted without any autonomous HDVs to see the capacity of the road in regular traffic. Then, a number of simulations were conducted with autonomous HDVs present in platoons but with different percentages. Simulations started with 0% of HDVs in platoons and were increased 10% in each simulation until 100% of the HDVs in the simulation were in platoons. Each simulation run was conducted with 20 rounds. Each of the 20 rounds was simulated with a different seed number, so the simulated results of the traffic movement would vary in each of the 20 rounds.

The capacity of each scenario was recorded by an increase in the volume input until the throughput decreased with increasing traffic demand. Figure 14 illustrates that at the input rate of 2750 PCE/h/ln, the maximum capacity was reached at 2570 passenger car equivalent (PCE)/h/ln, for a 40% HDV platoon.

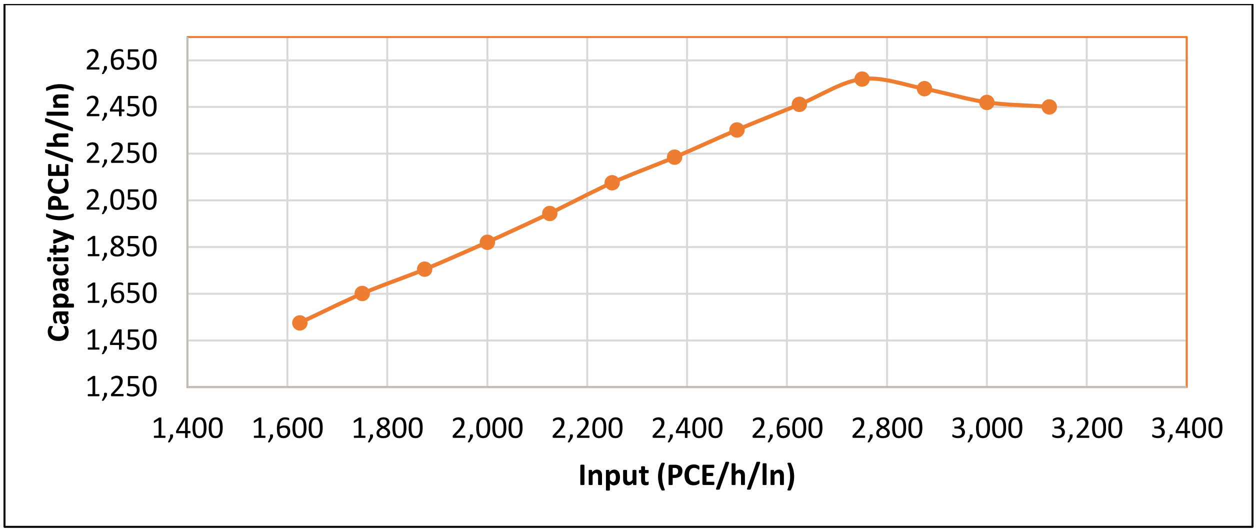


Figure14. The traffic flow (PCE/h/ln) obtained with different input values.

After completing 11 simulation runs, the average capacity of each run was collected. Figure 15 shows that there was an increment in the capacity of the model, where it was 2214 PCE/h at 0% platooning and reached over 4200 PCE/h/ln at 100% penetration rate.

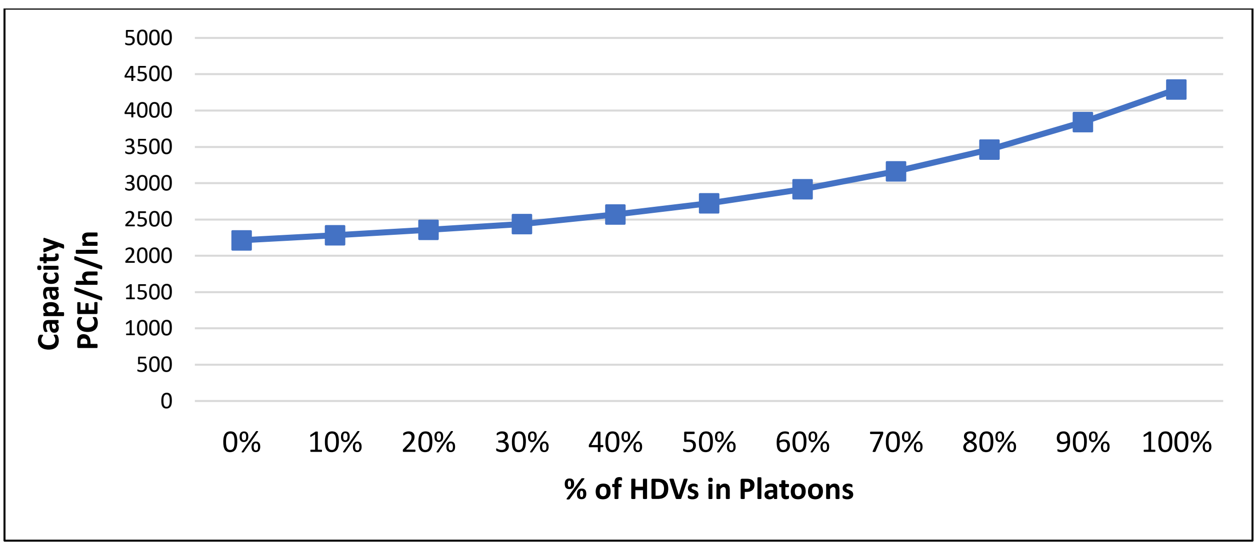


Figure 15. The capacity results with different penetration percentages.

As shown in Figure 15, the capacity increases with the increase of penetration rate of the HDV platooning. Due to the small time gap between the HDVs within a platoon, the capacity of the roadway increases and can accommodate more vehicles. The increase has a similar rate of change until 70% penetration of HDVs. A dramatic increase in capacity occurs when the penetration rate of HDVs in platoons reaches 70%. The percentage of the capacity had increased to around 8% when the percentage of platooning increases from 60% to 70%, and 8.6% when the platooning penetration increased another 10% percent to reach 80%. Around 10% of the capacity had increased when the percentage of platooning reached 90%, likewise at 100%.

This quadratic increment took place since the model started to generate the platoons within a small amount of time when the penetration rate reached 70%. Thus, individual platoons start to be closer to each other, and the model asks them to join any autonomous vehicles within short distance. For that, a number of platoons start to join other platoons which provids more space for other vehicles to be in the model.

An ANOVA single factor analysis was done using Excel. The result of the analysis shows a significant difference in every change in the penetration rate of the platooning. The following table shows the output table of the analysis that was created by Excel:

Table 4. The ANOVA Analysis of HDV Platooning Impact on Capacity.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F-critical*
Between Groups	9.40E+07	10	9.40E+06	5.14E+04	0	1.876216
Within Groups	3.82E+04	209	182.7032			
Total	9.40E+07	219				

The ANOVA analysis uses a theoretical analysis: assuming a null hypothesis that all the means of the groups are equal and an alternative hypothesis that the means are not equal. A confidence level of 0.95 ($\alpha = 0.05$) was assumed. Thus if the analysis P-value is greater than 0.05, then the null hypothesis is accepted; otherwise, it is not. As shown in the previous table, the P-value was too small (close to zero). Therefore, the null hypothesis is rejected and the alternative hypothesis is accepted, which means there is a significant difference with changing the percentage of HDV platooning in the capacity of the model.

Furthermore, it is critical to show that the model is working along with what HCM is suggesting. An example of the relationship between speed and the traffic flow measured to see if it mimics the trend of what the HCM outlines regarding the fundamental traffic flow relationships. According to Exhibit 4-2(Chapter Four, HCM), the fundamental of the relationship between speed and flow rate should be as shown in Figure 16. The collected speed flow rate from the simulation scenario at 30% of platooning is shown in Figure 17.

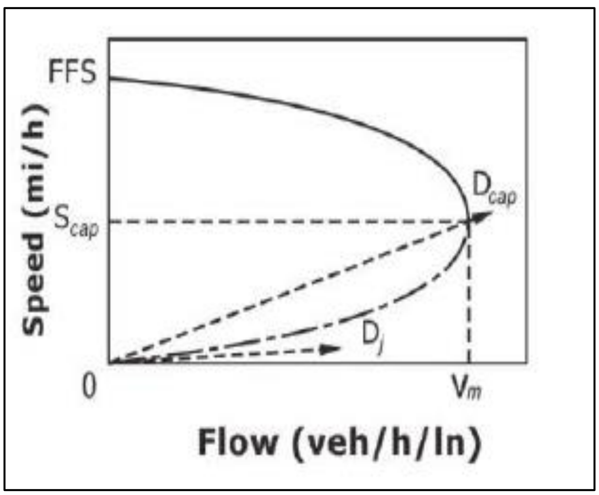


Figure 16. The fundamental relationship between speed and flow (May, 1990 as cited in HCM, 2016).

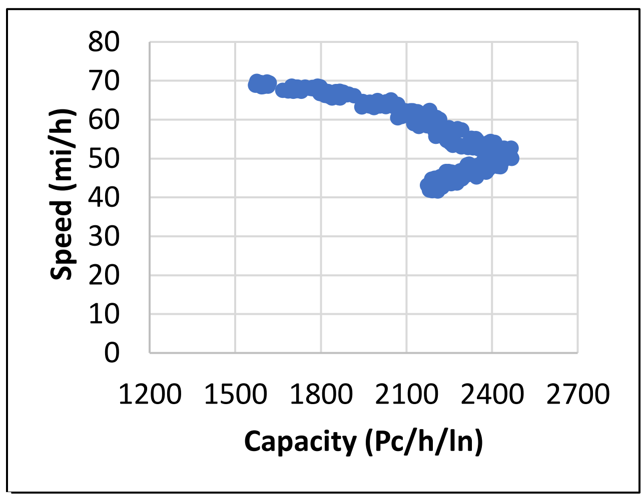


Figure 17. The speed capacity relationship of the model at 30% of HDVs in platoons.

Figure 16 represents few cars in the traffic that the average FFS is as great as possible, and decreasing a little as the capacity increases until the roadway reaches its saturation level. After that, both the capacity and FFS start to decrease, due to the presence of a large vehicles' demand, while the saturation level has been reached. It can be seen that both diagrams reflect similar trends. This gives give an indication of the validity of the model that has been used.

III The Impact Significance of HDV Platoons' Factors on Capacity

There are many factors involved in the formation and the continuity of every platoon. The most believed remarkable factors were chosen for as related to the capacity. Each of these factors have two levels (low and high). The factors included in the study with their levels are as follow:

1. The percentage of trucks in the traffic flow (20%, 80%) and referred to as "Factor A."
2. The percentage of HDVs which are in platoons to all the HDVs within the traffic flow (20%, 80%) and referred to as "Factor B."
3. The time gap between the vehicles in the platoon (0.5 sec, 1.5 sec) and referred to as "Factor C."
4. The desired speed of the traffic flow (50 mi/h, 70 mi/h) and referred to as "Factor D."
5. The number of HDVs in each platoon (3, 5) and referred to as "Factor E."

The level values for "Factor A" and "Factor B" were chosen to be 20% and 80%, to cover most of the results of the analysis and also to be close to the tendency of the results. "Factor C" was chosen based on the minimum gap distance (CACC and ACC) it give to the platoon 0.5 sec and 1.5 sec, respectively. 50 mi/h and 70 mi/h are the low and the high levels for "Factor D," and were chosen based on the minimum and maximum speeds on Florida highways. The "Factor E", the low level was chosen as the number of HDVs in a platoon in the Energy ITS project, which the fuel reduction assumption was based on, and the high level was chosen as the length of a reasonably long platoon.

To understand the impact of the platooning factors on the highway capacity, a full factorial analysis by Excel and Design Of Experiment (DOE) by Minitab were conducted. Thirty-two scenarios were initiated with different values to estimate the response value (the capacity) for each scenario (Table 5).

Table 5. The DOE Scenarios with the Capacity Responses.

A	**B**	**C**	**D**	**E**	**Capacity (PCE/h/ln)**	**A**	**B**	**C**	**D**	**E**	**Capacity (PCE/h/ln)**
20	20	0.5	50	3	**2350**	80	80	1.5	50	3	**3787**
20	80	0.5	50	3	**3100**	20	20	0.5	70	3	**2377**
80	20	0.5	50	3	**3550**	20	80	0.5	70	3	**3110**
80	80	0.5	50	3	**4020**	80	20	0.5	70	3	**3570**
20	20	1.5	50	3	**2214**	80	80	0.5	70	3	**4004**
20	80	1.5	50	3	**2921**	20	20	1.5	70	3	**2218**
80	20	1.5	50	3	**3345**	20	80	1.5	70	3	**2900**
80	20	1.5	70	3	**3340**	80	80	1.5	50	5	**4094**
80	80	1.5	70	3	**3788**	20	20	0.5	70	5	**2569**
20	20	0.5	50	5	**2540**	20	80	0.5	70	5	**3361**
20	80	0.5	50	5	**3351**	80	20	0.5	70	5	**3859**
80	20	0.5	50	5	**3837**	80	80	0.5	70	5	**4328**
80	80	0.5	50	5	**4345**	20	20	1.5	70	5	**2397**
20	20	1.5	50	5	**2393**	20	80	1.5	70	5	**3134**
20	80	1.5	50	5	**3157**	80	20	1.5	70	5	**3610**
80	20	1.5	50	5	**3615**	80	80	1.5	70	5	**4094**

Then an analysis was conducted and it involved the capacity results of the 32 scenarios as responses. This analysis aims to study those responses by comparing each response to the values of corresponding factors. Excel initiated the following table after using hypothetical T-test (Table 6).

Table 6. The Result of the Full Factorial Analysis of the Capacity Responses.

Factors	***Coefficients***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***	
Intercept	3289.92	1700.11	< 0.00001	3285.82	3294.03	**Significant**
A	303.44	156.81	< 0.00001	299.34	307.54	**Significant**
B	534.15	276.03	< 0.00001	530.05	538.25	**Significant**
C	-101.99	-52.71	< 0.00001	-106.10	-97.89	**Significant**
D	1.33	0.69	0.5008	-2.77	5.44	**Not significant**
E	127.83	66.06	< 0.00001	123.73	131.93	**Significant**
AB	-70.02	-36.18	< 0.00001	-74.12	-65.92	**Significant**
AC	-7.00	-3.62	< 0.00001	-11.10	-2.89	**Significant**
AD	-4.71	-2.43	< 0.00001	-8.81	-0.61	**Significant**
AE	11.79	6.09	< 0.00001	7.69	15.89	**Significant**

Factors	*Coefficients*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	
BC	-12.99	-6.71	< 0.00001	-17.09	-8.88	**Significant**
BD	-1.32	-0.68	0.5047	-5.42	2.78	**Not significant**
BE	20.75	10.73	< 0.00001	16.65	24.86	**Significant**
CD	-4.00	-2.07	0.0553	-8.10	0.10	**Not significant**
CE	-3.96	-2.05	0.0573	-8.07	0.14	**Not significant**
DE	0.05	0.03	0.9790	-4.05	4.15	**Not significant**

As shown in the above table, when the P-value (which is the confidence level) is greater than 0.05 (95% confidence level), the analysis rejects the null hypothesis and accepts the alternative hypothesis that the factor or the interaction does not significantly impact the capacity of the highway. The results of the analysis show that all the factors of the platoons are significantly affecting the capacity of the highway when they are adjusted, except “Factor D,” which is the desired speed. The input values for the scenarios were estimated at the level of service E (maximum capacity), which resulted in a traffic flow with less desired speed, due to the congestion on the model. Furthermore, it was noticed from the 32 scenarios, that when a high level of the factors was used, an increase in the capacity of the highway results, except with “Factor C.” When 1.5 sec of time gap was used, that resulted in an increase in the space between the vehicles in the platoon. Therefore, fewer vehicles were occupying the highway.

In addition, a regression equation can be drawn from the above table by taking the coefficients from the table and multiplying them by the factors. This regression equation can be used to predict the capacity of the model with any values of the factors. Equation 8 is the regression equation for the model.

$$\textbf{The capacity } (PCE/h/ln) = 3289.92 + 303.44A + 534.15B - 101.99C + 1.33D + 127.33E - 70.02AB - 7AC - 4.71AD + 11.79AE - 1.32BD + 20.75BE - 4CD - 3.96CE + 0.05DE \quad (8)$$

To evaluate the impact significance of the platoon factor on capacity, or in other words, which factor is more significant than the others, Minitab was used to do DOE. Figure 18 shows the result after the DOE analysis was conducted.

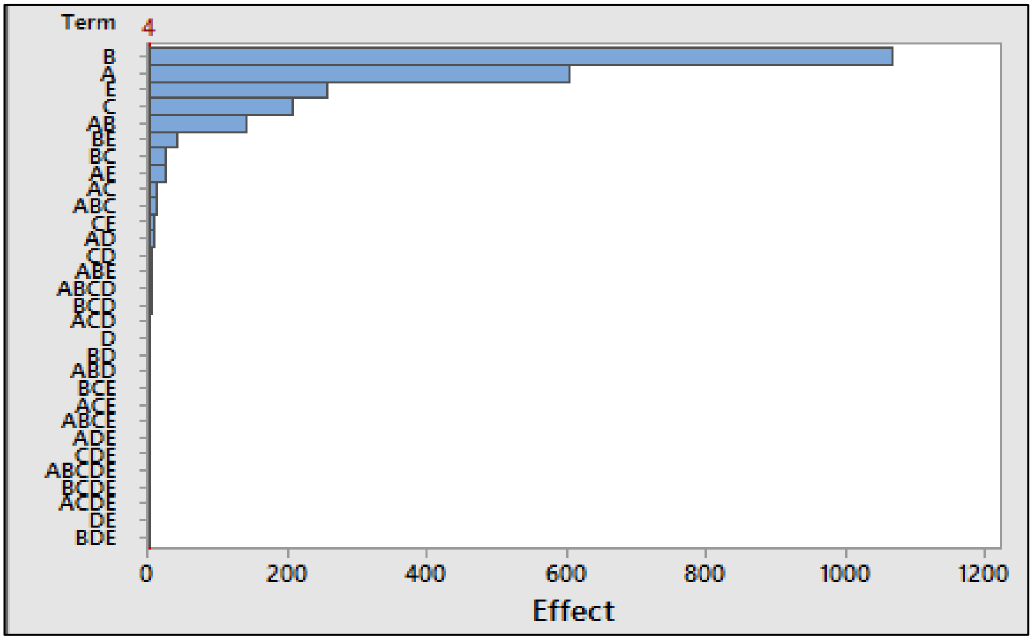
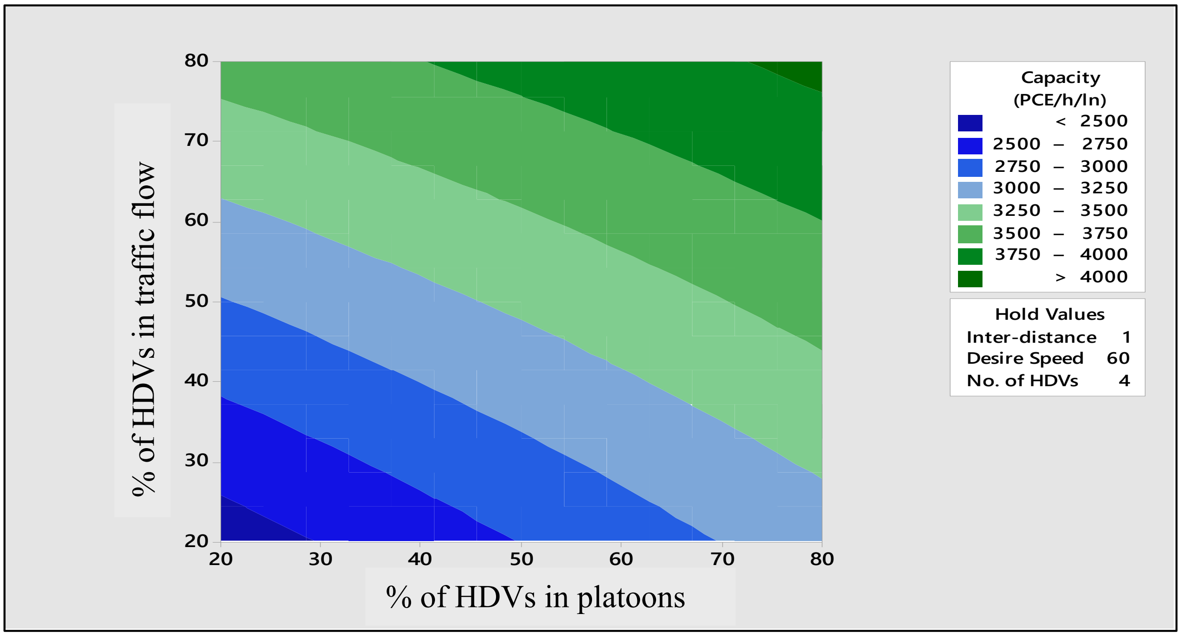
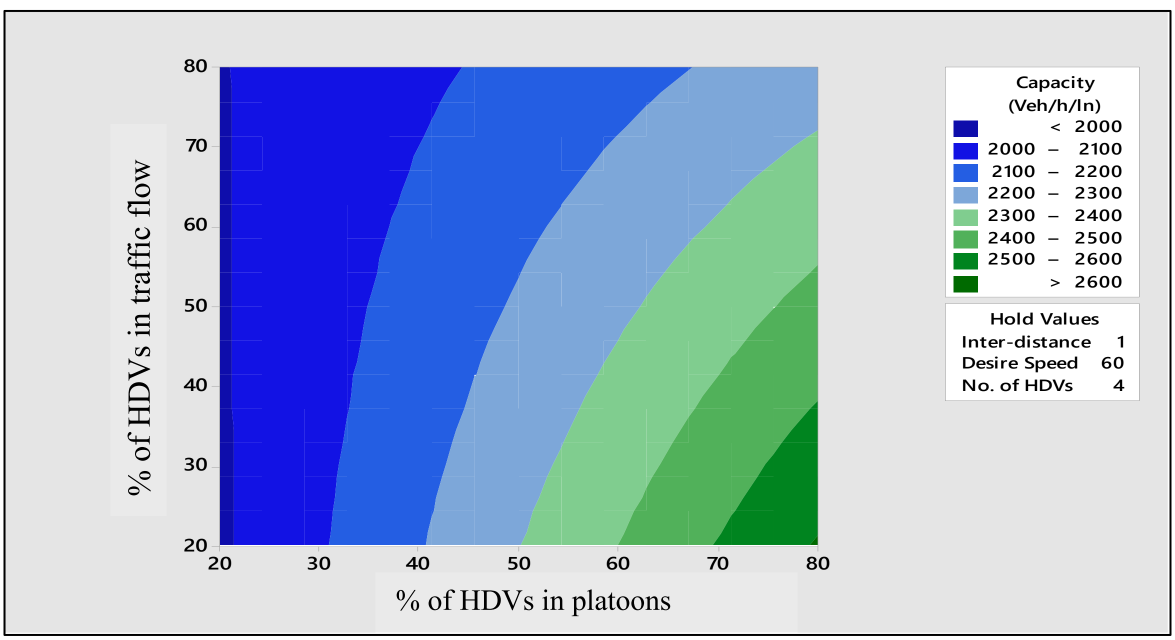


Figure 18. HDV platooning factor impact significance on capacity (Minitab, 2008).

As is evident from the above figure, all the factors have a significant impact on the capacity of the highway except “Factor D.” (desired speed). “The Effect” that lies on x-axis is a unit less. It is just used to show the proportion of significance of the impact that the factors and their interactions have on the capacity. However, “Factor B” (percentage of HDVs in the traffic flow) has the largest impact on the capacity of the traffic flow. Then “Factor A” (percentage of HDVs in platoons) would rank as the second biggest impact on capacity between those factors. However, this is when the capacity was measured as PCE/h/ln. Which means, every truck was assumed to be equivalent to two normal passenger cars. To understand the difference, the response value was changed to be in veh/h/ln capacity, and it was compared between the capacity as PCE/h/ln and the capacity as veh/h/ln. The two figures (19-A & 19-B) show the actual impact of the "Factor A" and "Factor B." on the capacity.



A



B

Figure19. Contour plot of "Factor A", and "Factor B" VS. A- capacity as (PCE/h/ln), and B-capacity as (veh/h/ln).

As evident from the two figures above, the increase in the percentage of trucks in the traffic flow would increase the capacity as PCE if it is assumed to be equivalent to two passenger cars. However, in the matter of the number of vehicles that can pass through the traffic model, increasing the amount of vehicles in traffic would decrease the capacity.

III. The Effect of HDVs on Highway Greenhouse Emissions

This experiment runs on MOVES was chosen to be an on-road model with project domain. According to FHWA, 26% of the gas emissions within the United States is CO_2, and 90% of that comes from transportation sectors (Schmitt, & Sprung, 2011). Hence, CO_2 was chosen as the primary greenhouse gas emission rate for the same 11 scenarios as in the capacity study. Since the hypothetical model has similar characteristics to I-295 highway, the county of Duval in Jacksonville was chosen to have the default values for the meteorology data and other necessary input values. Either the input values into MOVES were taken from VISSIM simulation runs or the default data given by EPA for the chosen county. It is worth mentioning that in the fuel tab, the fuel usage fraction template was used to estimate the fuel reduction in the platoons according to what the ITS Energy study suggested (Figure 2, page 13). After fulfillment of the MOVES navigation panel and CDM tabs, a simulation run was conducted on MOVES for all the scenarios. The database given in the summary report cannot be changed or added to get the total emissions without using MYSQL. With the help of MYSQL, it was possible to analyze and calculate the total CO_2 emission, and the total energy consumed for all the scenarios, export ingthe results in Excel tables. The following figure shows the CO_2 emission from MYSQL files for the different penetration percentages of HDVs in the platoons:

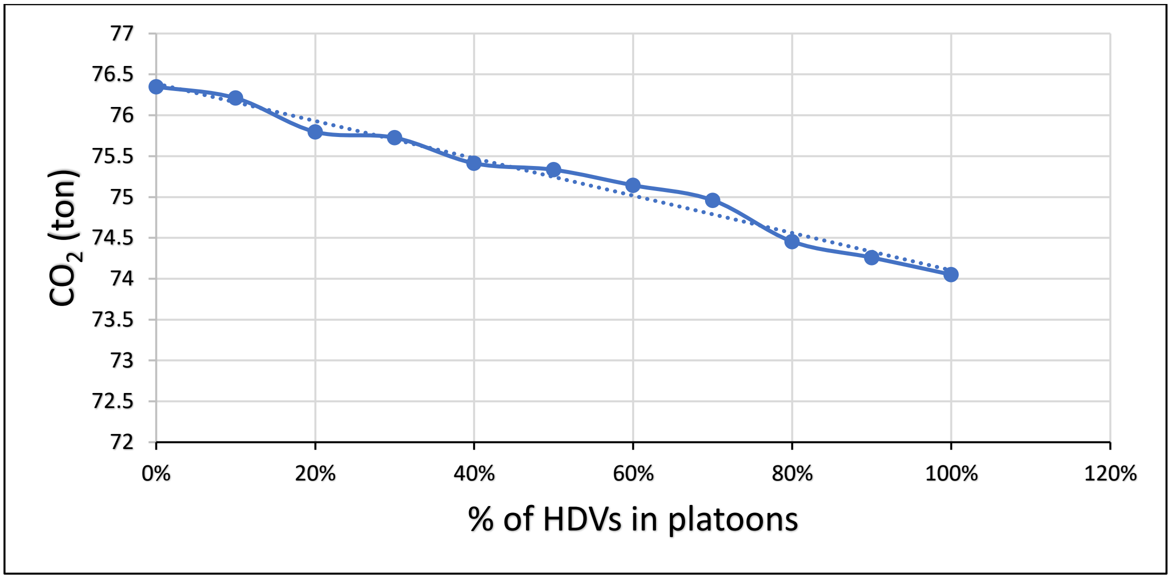


Figure 20. MOVES output of the CO_2 emission rate VS. different percentages of HDVS in platoons.

The general trend shows a decrease in the percentage of the total traffic CO_2 emissions. Since the input of the fuel usage fraction in the fuel tab at CDM was decreasing according to what the study of ITS Energy and based on Figure 2, it is not surprising to see the CO_2 emissions decreasing as well. It must be clear that Figure 20 is shows total traffic emissions at each percentage, not just the platoon itself.

There is a decrease of the total CO_2 emissions as the percentage of HDVs in platoon increases. However, the percentage of change between each percentage and 0% of HDVs in platoons are shown in the following table:

Table 7. The Percentage of Change for CO_2 Emission Compared no Platoons are Presented.

% of HDVS in platoon	CO_2 (ton)	Percentage of change	% of HDVS in platoon	CO_2 (ton)	Percentage of change
0%	76.349		**60%**	75.143	1.58%
10%	76.21	0.18 %	**70%**	74.96	1.82%
20%	75.797	0.72%	**80%**	74.455	2.48%
30%	75.725	0.82%	**90%**	74.259	2.74%
40%	75.412	1.23%	**100%**	74.05	3.01%
50%	75.333	1.33%			

To study if the difference is significant or not between the whole scenarios, another ANOVA single factor analysis is conducted by Excel. Table 8 illustrates the collected results after the ANOVA tests was conducted, showing the factors' impact significance as below:

Table 8. The ANOVA Analysis of HDV Platooning Impact on CO_2 Emission.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Groups	1.17E+08	10	1.17E+07	3550.35	2.58E-227	1.876
Within Groups	6.87E+05	209	3287.91			
Total	1.17E+08	219				

As it has been pointed out, the P-value is much smaller than 0.05. That means, that there was a significant difference between the CO_2 emissions when there were no HDVs in platoons compared to when then platooning of HDVs was introduced in the system. It is essential to say that there was more than 3% of the decrease in the rate of CO_2 emissions between no platooning are presented, and when there is 100% of HDVs in platoons for all the vehicles within the network emission.

IV. The Impact Significance of HDV Platoons' Factors on Emissions

The same five factors were used to study their impacts on highway CO_2 emissions. A full factorial method was conducted with the analysis of the thirty-two scenarios. The response (CO_2 emissions) for the scenarios are as shown in the next table:

Table 9. The DOE Scenarios with the CO_2 Emissions as Responses.

A	B	C	D	E	CO_2 (ton)	A	B	C	D	E	CO_2 (ton)
20	20	0.5	50	3	**68.806**	20	20	0.5	50	5	**68.322**
80	20	0.5	50	3	**148.204**	80	20	0.5	50	5	**146.040**
20	80	0.5	50	3	**66.790**	20	80	0.5	50	5	**64.600**
80	80	0.5	50	3	**139.679**	80	80	0.5	50	5	**131.153**
20	20	1.5	50	3	**69.111**	20	20	1.5	50	5	**68.623**
80	20	1.5	50	3	**149.322**	80	20	1.5	50	5	**147.246**

A	B	C	D	E	CO_2 (ton)	A	B	C	D	E	CO_2 (ton)
20	80	1.5	50	3	**67.888**	20	80	1.5	50	5	**65.805**
80	80	1.5	50	3	**144.400**	80	80	1.5	50	5	**135.976**
20	20	0.5	70	3	**68.954**	20	20	0.5	70	5	**68.469**
80	20	0.5	70	3	**148.523**	80	20	0.5	70	5	**146.354**
20	80	0.5	70	3	**66.934**	20	80	0.5	70	5	**64.739**
80	80	0.5	70	3	**139.979**	80	80	0.5	70	5	**131.435**
20	20	1.5	70	3	**692.60**	20	20	1.5	70	5	**68.771**
80	20	1.5	70	3	**149.643**	80	20	1.5	70	5	**147.563**
20	80	1.5	70	3	**680.34**	20	80	1.5	70	5	**65.947**
80	80	1.5	70	3	**144.711**	80	80	1.5	70	5	**136.268**

As was done with capacity, a regression equation can be generated from the above table by taking the coefficients and multiply them with the values of the factors for each value, to predict the emissions of that scenario in the model.

Furthermore, with the help of Excel, a full factorial analysis was designed. Except for "Factor D," it was found that most of the factors have a significant impact on the amount of CO_2 emissions. The main reason that the penetration rate was at the maximum capacity was found. Therefore, the average FFS of the traffic flow was not what was input as the desired speed. Therefore, the desired speed does not have such a significant impact (Table 10).

Table 10. The Result of the Full Factorial Analysis of the CO_2 Emission Responses.

	Coefficients	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	
Intercept	105235.87	616.57	< 0.0001	104874.04	105597.70	**Significant**
A	37670.16	220.71	< 0.0001	37308.33	38031.98	**Significant**
B	-3089.76	-18.10	< 0.0001	-3451.58	-2727.93	**Significant**
C	924.56	5.42	< 0.0001	562.73	1286.38	**Significant**
D	113.06	0.66	0.517	-248.77	474.88	**Not significant**
E	-1653.96	-9.69	< 0.0001	-2015.79	-1292.14	**Significant**
AB	-1866.06	-10.93	< 0.0001	-2227.89	-1504.24	**Significant**
AC	560.53	3.28	< 0.0001	198.71	922.37	**Significant**
AD	40.47	0.24	0.816	-321.36	402.30	**Not significant**
AE	-997.63	-5.85	< 0.0001	-1359.46	-635.81	**Significant**

	Coefficients	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	
BC	557.91	3.27	< 0.0001	196.09	919.74	**Significant**
BD	-3.31	-0.02	0.985	-365.15	358.51	**Not significant**
BE	-1001.76	-5.87	< 0.0001	-1363.59	-639.94	**Significant**
CD	0.99	0.01	0.995	-360.83	362.82	**Not significant**
CE	18.33	0.11	0.916	-343.49	380.16	**Not significant**
DE	-1.77	-0.01	0.992	-363.60	360.05	**Not significant**

Furthermore, to investigate which factor was more significant than the others, Minitab was used to conduct DOE to analyze these 32 scenarios with their responses. The following figure is the final result of that DOE.

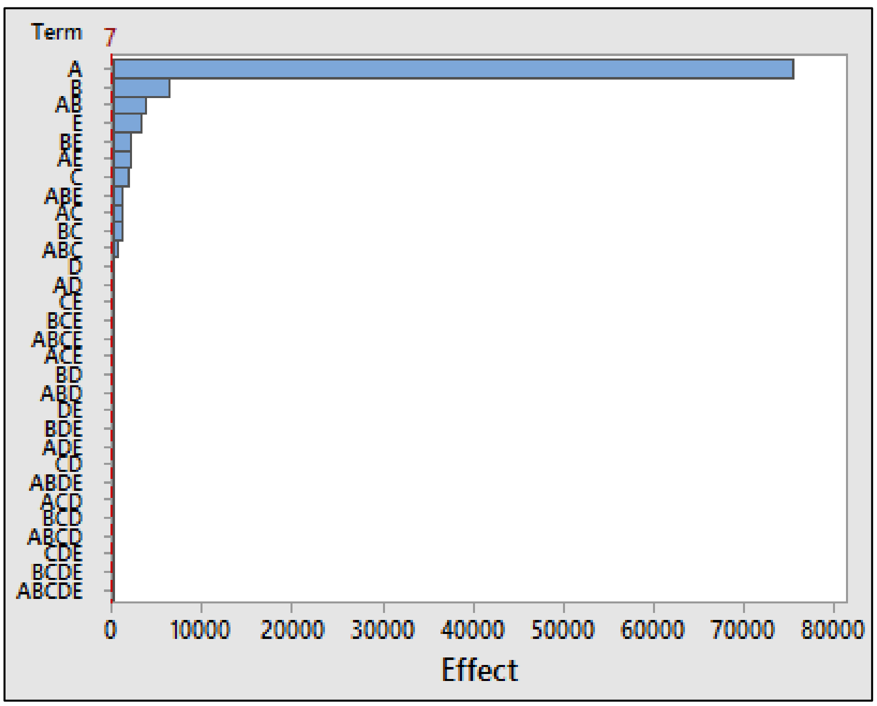


Figure 21. HDV platooning factor impact significance on CO_2 emission rate (Minitab, 2008)

As revealed above, "Factor A" (percentage of HDVs in the traffic flow) shows the most marked difference between its effect and the closest factor to it, which is "Factor B." By looking closely in table 8, the value of CO_2 emission increased to be more than the double when the value of "Factor A" change from the low level to the high level. Moreover, these are reasonable values if we know that an average truck would produce around 1697 g/mile of CO_2 compared to 404 g of CO_2 to a passenger car in average (EPA, 2018). To further illustrate, a counterplot was drawn to illustrate how the emissions would go higher when the percentage of trucks is increased, by comparing between "Factor A" and "Factor B."

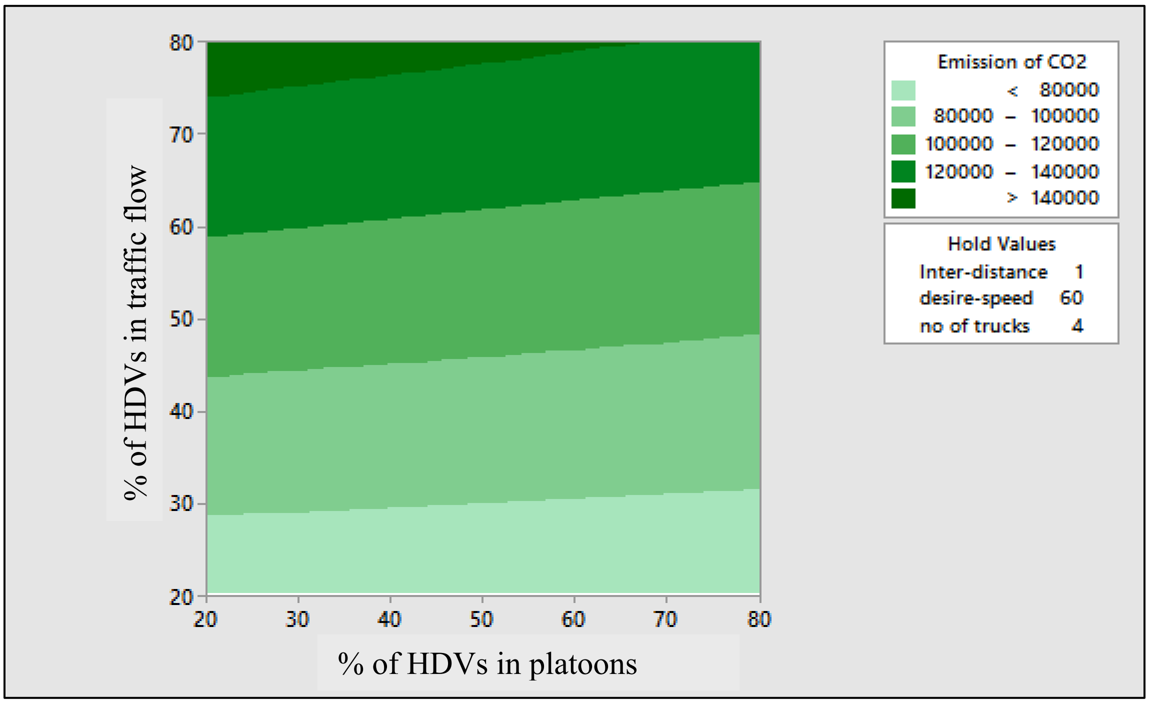


Figure 22. Contour Plot of Emission of CO_2 vs "Factor B" and "Factor A."

A close examination, the above figure reveals that with increasing the percentage of the HDVs in platoons, the reduction of the emissions would be small compared to the increase of the emissions if the percentage of the HDVs in the network increased. As a conclusion, it could be said that some of the factors may have a significant impact but not necessarily a positive impact.

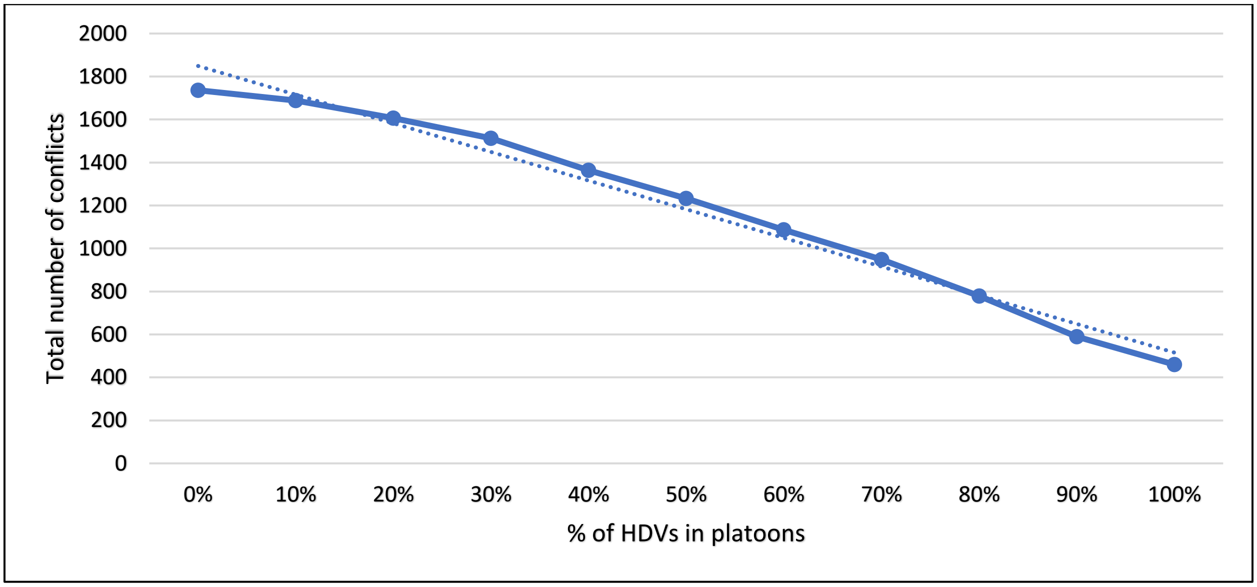
V. The Effect of HDVs on Highway Safety

Simultaneously with each of the 11 simulation runs for the analysis of the capacity, a trajectory file was requested from VISSIM, which is integrated with SSAM. This step was established to see the effect of the existing of platooning on the safety of the roadway. Interestingly, it was found that the risk of getting accidents was decreased with each increment in platooning percentage. Table 11 shows the results for all the 11 simulations, for both type of conflicts and their total as well.

Table 11. SSAM Output of Number of Conflicts.

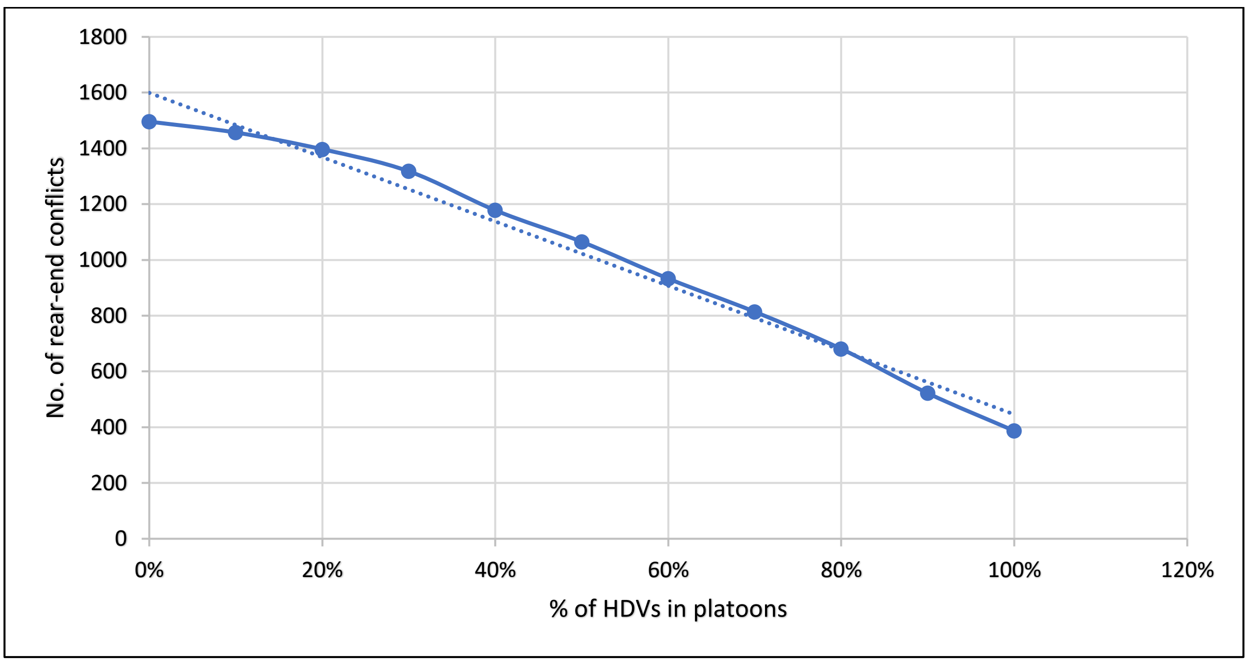
%HDVs in platoon	rear-end	lane-change	Total conf.	% of change
0%	1496	240	1736	
10%	1457	232	1689	**2.71%**
20%	1397	210	1607	**7.43%**
30%	1318	195	1513	**12.85%**
40%	1178	186	1364	**21.43%**
50%	1065	167	1232	**29.03%**
60%	933	154	1087	**37.38%**
70%	814	135	949	**45.33%**
80%	681	97	778	**55.18%**
90%	522	68	590	**66.01%**
100%	414	46	433	**75.06%**

As evident from above table, as the percentage of HDVs in platoons increases, the number of conflicts decreases. The decrease in the numbers of the both conflicts occurs, due to the increase of the number of HDVs in platoon, and since those platoons are not allowed to commit lane changes, the number of the conflicts decreases as well. Figure 23 (A, B and C) are line charts showing how the decrease looks in total, rear-end and lane change conflicts respectively.



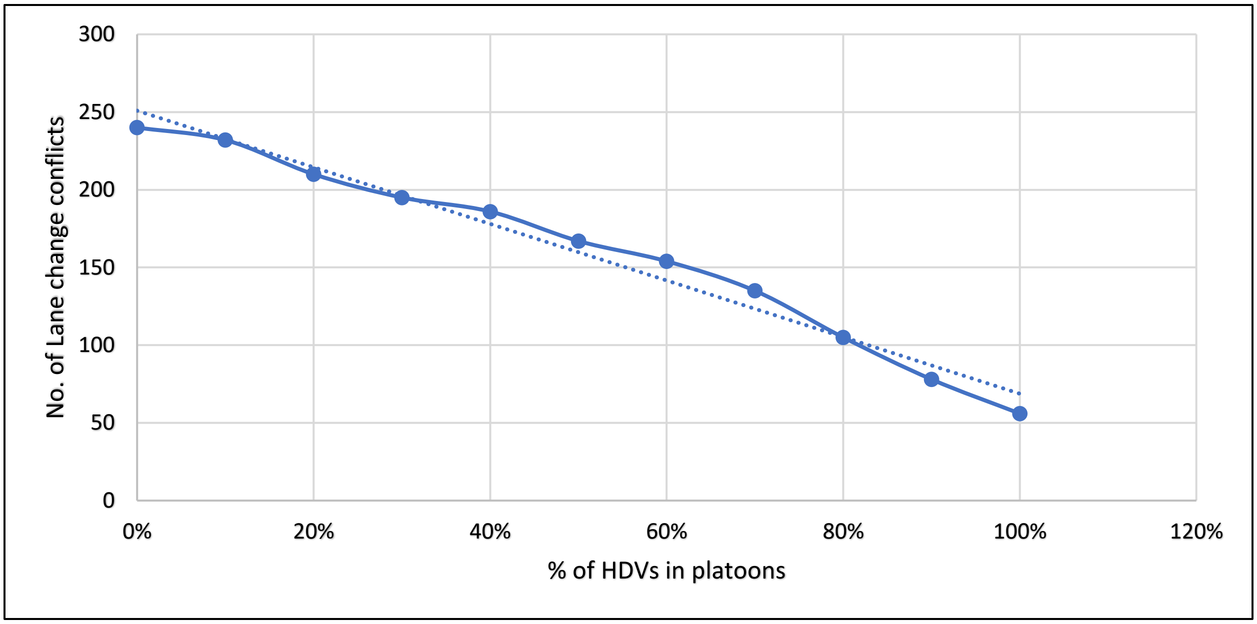
Total number of conflicts
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% of HDVs in platoons

A



No. of rear-end conflicts
1800
1600
1400
1200
1000
800
600
400
200
0
0%
20%
40%
60%
80%
100%
120%
% of HDVs in platoons

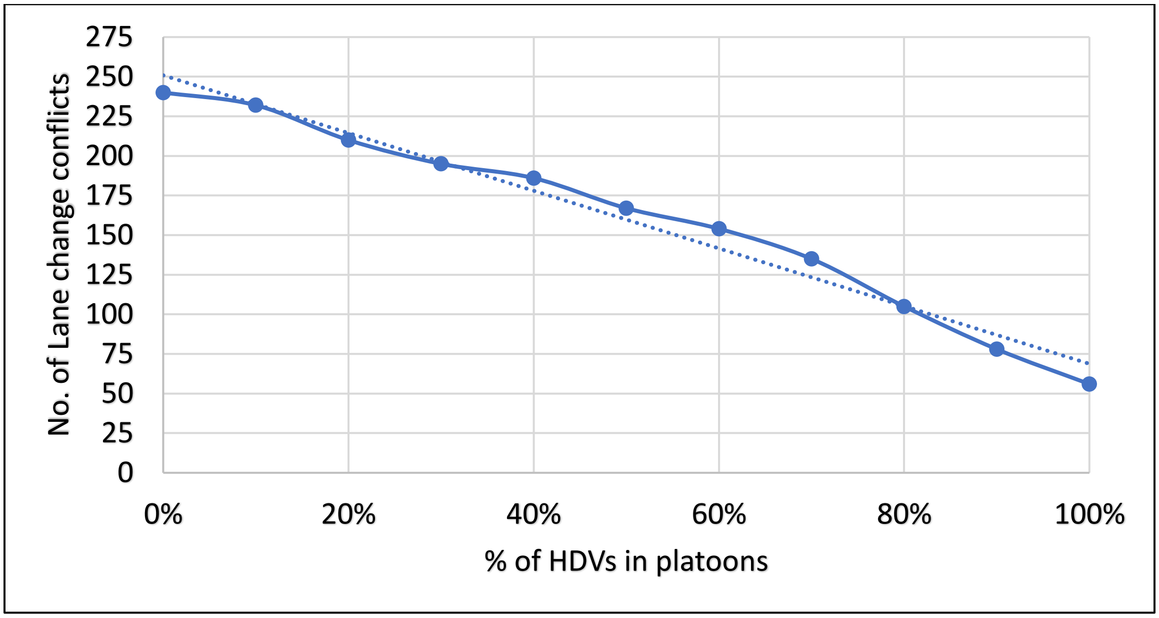
B



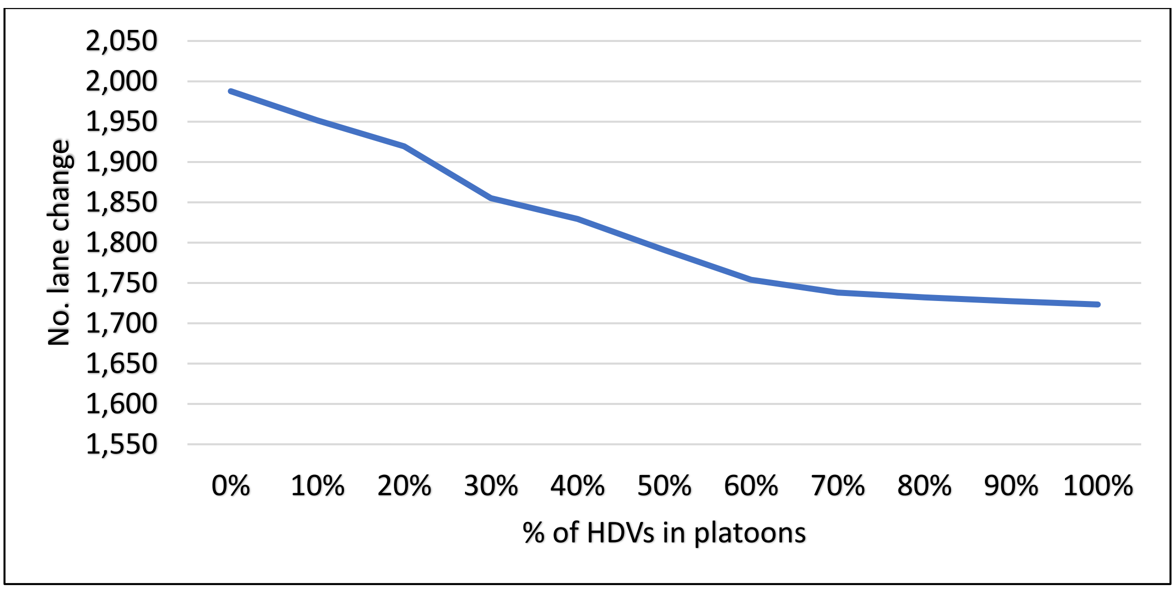
C

Figure 23. Line charts for A) the total number of conflicts, B) the rear-end conflict number, and C) Lane change number of conflicts of all the simulation.

As it is clearly seen, there is a drop in the number of conflicts when there is an increase in the percentage of the platoons. The rear conflict shows a bigger change in the number of conflicts after HDVs in platoons has increased to 20%: then the increase in the number of conflicts starts to increase until 100% of HDVs are in platoons. On the other hand, the number of lane change conflicts shows the same pattern. However, after the platoons percentage reach 70% did the decrease in the number of conflicts become dramatic. The reason is that by increasing the number of platoons on the right lane, it becomes harder for other vehicles to conduct a lane change. To investigate that, the number of lane changes occurred for all the simulation were pulled out of VISSIM to compare them with the lane change conflict number. Figure 24-A shows that the trend of the number of lane change is similar to the number of lane change conflicts as in Figure 24-B. It should be clarified that there are no cross conflicts, because the simulations were on a highway segment, and it does not include intersections.



A



B

Figure 24. A) Percentage of HDVs are in platoon VS. lane change conflict numbers, B) Percentage of HDVs are in platoon VS. lane change numbers.

Furthermore, it is critical to understand that wether the decrease in the number of conflicts and the HDV platoons are related or they are independent of each other. Additionally, it is imperative to see if the difference in the number of accidents is significant or not. Therefore, further analysis was involved in answering these two inquiries.

First, a chi-square test was conducted to see the independence between the number of conflicts and the percentage of HDV platoons. This was done to see the difference between 100% of HDV platoon traffic flow and the normal traffic flow with 0% of HDV platoons. It was hypothesized (Ho) that the two variables are independent. While the chi-square statistically is calculated by using Equation 9:

$$\chi 2 = \sum (O - E)^2 / E \quad (9)$$

Where O represents the observed frequency, E is the expected frequency under the null hypothesis and computed by:

$$\mathrm{E} = \frac{\text{row total} \times \text{column total}}{\text{total sample size}} \quad (10)$$

The value of the test statistic was compared to the critical value of $\chi 2$ with a degree of freedom = $(r - 1)(c - 1) = 1$. The following tables show the observed and predicted values.

Table 12. The Observed Value for Both Conflicts in 0% and 100% of HDV Platoons.

	0% HDVs	**100% HDVs**	**Total**
Rear conf.	1496	414	1970
Lane change conf.	240	46	286
total	1736	457	2193

Table 13. The Predicted Value for both Conflicts in 0% and 100% of HDV Platoons.

	0% HDVs	**100% HDVs**	**Total**
Rear conf.	1507	397	1970
Lane conf.	226	60	286
Total	1736	457	2193

So, the value of $\chi 2$ = $(1570-1496)^2/1321.53+\cdots+(60-46)^2/60=4.697$, is larger than the critical value of $\chi 2$ with 1 degree of freedom, which is 3.84. (It gives us a P-value of 0.03022 which is < 0.05.) Therefore, the null hypothesis is rejected and it is concluded that the conflicts and the percentage of HDV platoons are dependent at 95% of significant level (α =0.05.)

Additionally, it is important to see if the difference between the total number of conflicts without HDV platoons and with the existing of HDV platoons is significant or not. To do so, a T-test was used to compare the mean of two independence samples, with a null hypothesis (Ho) : $\mu_d = 0, where\ \mu_d = \mu_1 - \mu_2$,

The alternative hypothesis (H1): $\mu_d < 0$

Since $t = \frac{D-\mu_d}{Sd/\sqrt{n}}$ (11)

Where D = the mean of the difference between the samples results = 1276, α = 0.05,

$Sd = 198\ , and\ n = 20$

Therefore, $t = (1736 - 460)/(\frac{198}{\sqrt{20}}) = 28.82$

The t critical value from t table = 1.96, and since the t-value is higher than the T-critical value, then the hypothesis was rejected. Therefore, the means of both samples are not equal. Therefore, there was a significant difference between the total number of conflicts in the scenario where there are no HDV platoons and 100% of HDVs.

VI. The Impact Significance of HDV Platoons' Factors on Safety

To understand the effect of the platoon parameter impact on the safety of the highway, a full factorial method was created to study that impact. The same thirty-two scenarios conducted on capacity and emission studies were used for the safety factor.

Table 14. The DOE Scenarios with the Number of Conflicts as Responses.

A	B	C	D	E	No. of conflicts.	A	B	C	D	E	No. of conflicts.
20	20	0.5	50	3	**1654**	80	80	0.5	70	3	**412**
20	80	0.5	50	3	**995**	20	20	1.5	70	3	**1984**
80	20	0.5	50	3	**1002**	20	80	1.5	70	3	**1209**
80	80	0.5	50	3	**410**	80	20	1.5	70	3	**1212**
20	20	1.5	50	3	**1973**	80	80	1.5	70	3	**504**
20	80	1.5	50	3	**1202**	20	20	0.5	50	5	**1412**
80	20	1.5	50	3	**1206**	20	80	0.5	50	5	**849**
80	80	1.5	50	3	**501**	80	20	0.5	50	5	**855**
20	20	0.5	70	3	**1663**	80	80	0.5	50	5	**350**
20	80	0.5	70	3	**1000**	20	20	1.5	50	5	**1684**
80	20	0.5	70	3	**1008**	20	80	1.5	50	5	**1026**
80	20	1.5	50	5	**1029**	80	80	0.5	70	5	**351**
80	80	1.5	50	5	**427**	20	20	1.5	70	5	**1694**
20	20	0.5	70	5	**1420**	20	80	1.5	70	5	**1032**
20	80	0.5	70	5	**853**	80	20	1.5	70	5	**1034**
80	20	0.5	70	5	**860**	80	80	1.5	70	5	**430**

If the similar scenarios were compared, it would be clearly seen that the increase of the time gap would increase the number of conflicts. The reason behind that is when the distance increases, the chance of the free agent vehicles to conduct a lane change becomes more significant, especially when there is too much traffic. In our scenarios, it was assumed that the penetration rate happened at the maximum capacity of the roadway (approximately 2625 PCE/h/ln.) Therefore, vehicles tended to change its lane more frequently, and it was possible to go between the vehicles of the platoon since the distance was considered sizable.

Furthermore, to understand the significance of each factor, the following table was created by the regression analysis by Excel:

Table 15. The Result of the Full Factorial Analysis of the Number of Conflicts as Responses.

	Coefficients	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	
Intercept	1038.78	1274.58	< 0.0001	1037.04	1040.52	**Significant**
A	-316.84	-388.77	< 0.0001	-318.58	-315.11	**Significant**
B	-314.34	-385.70	< 0.0001	-316.08	-312.61	**Significant**
C	95.41	117.06	< 0.0001	93.67	97.14	**Significant**
D	2.84	3.49	< 0.0001	1.11	4.58	**Significant**
E	-82.16	-100.81	< 0.0001	-83.89	-80.42	**Significant**
AB	15.53	19.06	< 0.0001	13.79	17.27	**Significant**
AC	-25.97	-31.86	< 0.0001	-27.71	-24.23	**Significant**
AD	-0.91	-1.11	0.284	-2.64	0.83	**NOT Significant.**
AE	24.97	30.64	< 0.0001	23.23	26.71	**Significant**
BC	-26.97	-33.09	< 0.0001	-28.71	-25.23	**Significant**
BD	-0.91	-1.11	0.284	-2.64	0.83	**NOT Significant.**
BE	24.72	30.33	< 0.0001	22.98	26.46	**Significant**
CD	0.34	0.42	0.679	-1.39	2.08	**NOT Significant.**
CE	-7.53	-9.24	< 0.0001	-9.27	-5.79	**Significant**
DE	-0.22	-0.27	0.792	-1.96	1.52	**NOT Significant.**

All the factors have a significant impact on the safety of the highway when their values are changed. However, some factors have more vital significance than others. To study which factors show more impact than others do, Minitab was used to design DOE. Figure 25 is the result of that experiment, and it shows high and similar impact for “Factor A” and “Factor B.”

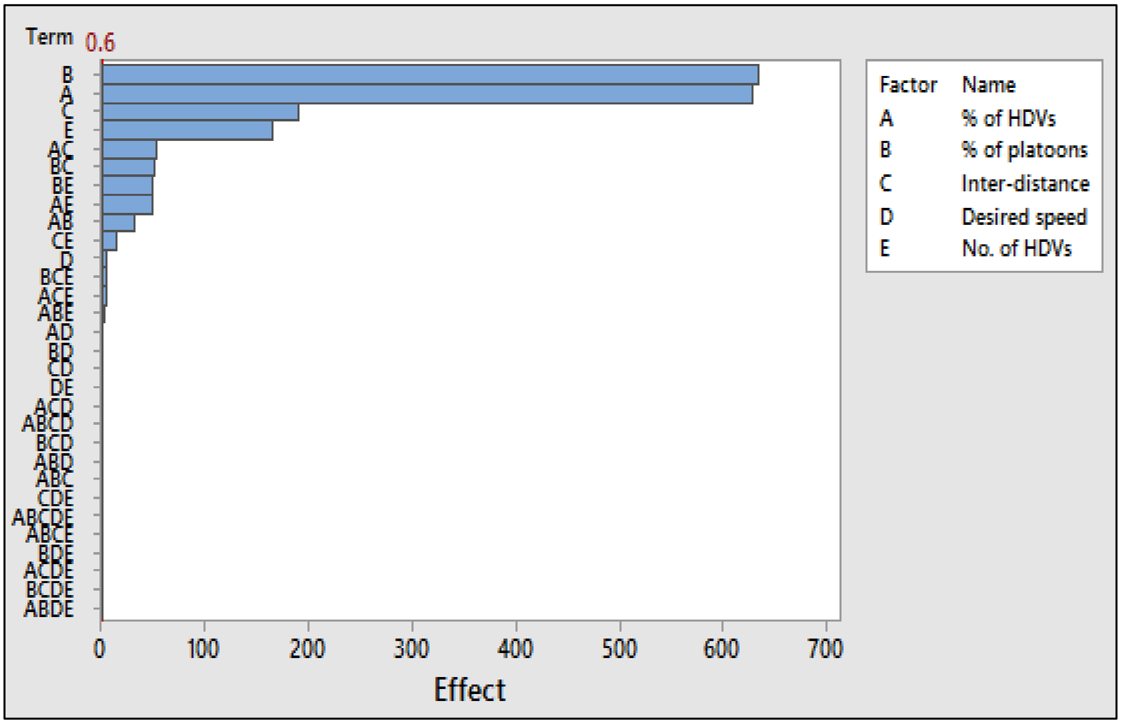


Figure25. Chart of the effects of the platooning factors on highway safety.

If we compare the results found in the above figure to the table (14), we will find similar results. "Factor D" for instance, has shown some significance, but, if we look in Figure 25, we will find that the significance is not as significant as other factors. The reason that Factor D (desired speed) has some significance, is due to the fact that the numbers of the conflicts "as a value" is less than in capacity and emission outputs. For more clarification, the next figure shows how the change in the number of conflicts happened due to "Factor D" compared to "Factor A."

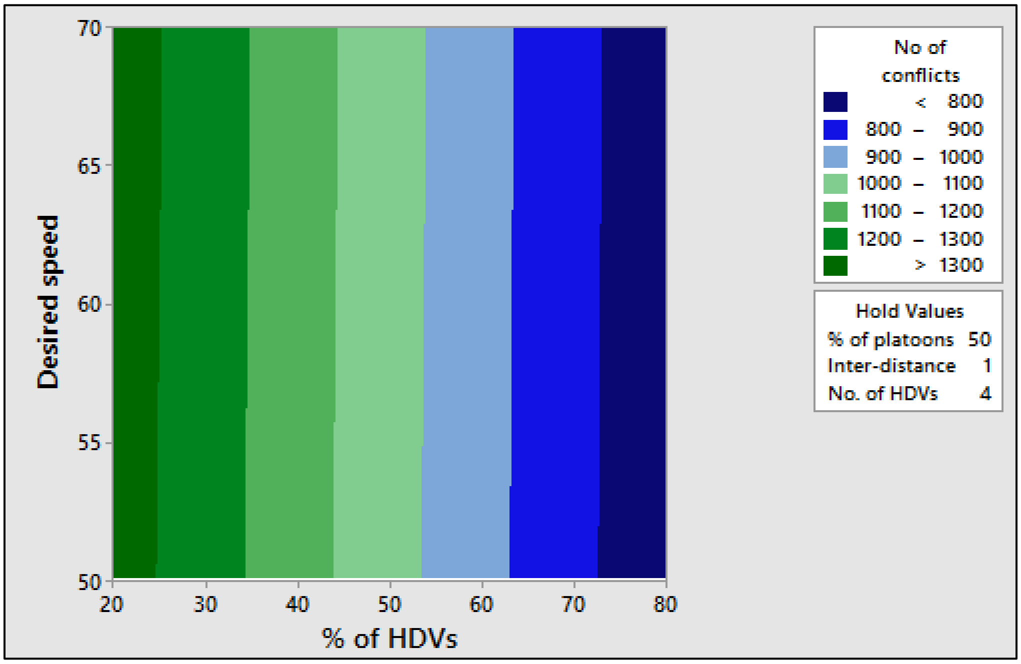


Figure26. Contour plot of total number of conflicts VS desired speed and the percentage of HDVs.

As evident from the above figure, "Factor D" (desired speed) does not show as much significance as "Factor A" does. If the full factorial was with bigger dataset, for example 64 instead of 32, we may see that "Factor C" is insignificant.

VII. Summary

In conclusion, platooning has appositive impact on all of the highway parameters. The simulation output showed an improvement in the overall capacity of the model in PCE/h/ln. The significance of value changes from one parameter to another. Generally, as we increase the umber of HDV platoons, and decrease the time gap, the capacity of the highway would increase. On the one hand, the percentage of the HDVs in the traffic flow impact positively if we want to measure the capacity as PCE/h/ln. On the other hand, the same factor would affect negatively if we measure the real number of vehicles pass through the section as was discussed in Figure 19.

Furthermore, 100% of HDV platooning would decrease the emissions rate of the overall traffic emissions about 3% when comparing if there were not any platooning on the traffic. This is mainly based on the consumption reduction in the HDVs platoons when the HDVs are driven in such a close distance. The increase in “Factor C” would negatively affect and increase the CO_2 emission.

Moreover, the penetration of HDV platoons decreases the number of conflicts in highway traffic, as the output of SSAM suggests. Since the distance between the vehicles of the platoons is such a small distance (0.5 sec), the lane change number decreases. That leads to a decrease in the number of lane change conflicts. Also, the number of penetration in the scenarios is the same, and with increasing the number of HDVs in platoons, the possibility of rear-end conflicts decreases. However, with increasing the distance between the vehicles in the platoon, the free agent vehicles tend to perform a lane change between the vehicles of the platoon, which increase the number of lane changes as well.

Chapter 5: OVERALL SUMMARY AND RECOMMENDATIONS

This study is based on a hypothetical model that was created by VISSIM software. This model was the backbone of this study and its output. The model was considered to have the characteristics of the base condition highway corresponding to what HCM suggests. Different statistical methods investigated the validity of this model and compared it the expected values of HCM. In addition to VISSIM, MOVES, and SSAM are two simulation software packages that used to obtain the CO_2 emissions and the safety results, respectively. These two software packages are dependent on the model created by VISSIM.

To investigate the effect of the platoon's factors effect, a full factorial method was created, after conducting thirty-two simulation scenarios. The factors were chosen to be: A) The percentage of HDVs in the traffic flow; B) The percentage of platoons; C) The time gap; D) The desired speed of the traffic flow; E) The number of HDVs in every single platoon.

By the end of this study, it was found that as the percentage of HDVs in platoon increased, the highway parameters would be positively affected. Furthermore, increasing the number of HDV in platoons, the highway traffic parameters would be enhanced is discussed with details in Chapter 4. Additionally, most of the chosen platoon factors have a significant impact on the highway parameters, except for the desired speed due to the high penetration rate used.

It is worth to mentioning that most of the studies conducted on platooning, have been mostly concerned with the reduction of fuel consumption, which has been considered the main idea behind the creation of platoons in the first place. This thesis focuses mainly on the effect of the HDV platooning on the highway parameters. In addition, it investigates the impact that those platoons' factors have on the parameters. As was mentioned, this thesis was based on a verified hypothetical model. Several assumptions were involved for the simplicity and clarification purposes. However, it was recommended that future work be done in the conduction of similar study using a real highway data as an input. In addition, the limitation of the model could be reduced to enhance the model results.

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VITAE

AHMED ALZAHRANI

Objective

Joining an extraordinary university to expand my knowledge in transportation engineering and to explore, discover and develop significant contributions to my career and the transportation sector.

Education and Training

University of North Florida | Jacksonville, FL
Master of Science in Transportation Engineering
2019

- Currently enrolled with 3.71 as a GPA
- Major in Transportation Engineering
- Thesis: The Effect of Truck Platooning on Highway Parameters.
- A Member of Institute of Transportation Engineers (ITE)

King Abdul Aziz university | Jeddah
Bachelor of Science in Civil Engineering
2013

- Graduated at 2013 with 3.312 of GPA
- Saudi Society of Civil Engineering (SSCE) Member

Experience

University of North Florida | Jacksonville, FL
Graduate Student
08/2017 - Current

- Attended in- Conferences, workshops, and Participation: had the chance to attend TRB in Washington D.C. in 2019, the FSIT conference that was held in Fort Lauderdale in 2018, the Florida Automated Vehicle summits in 2017 and 2018.
- A participant with a paper at the Florida Automated Vehicle Summit 2018, entitled "Truck Platooning Effect on Highway Parameters."

King Abdul Aziz University | Jeddah, Makkah
Teaching Assistant
04/2014 - 08/2016

- Teaching Experience: worked as a teaching assistant at KAU and was responsible for developing lesson plans, lectures, problem sets, and final exam questions, as well as the syllabus for a new degree program. Collaborated with teacher to devise and implement developmentally appropriate lessons aligning with school's philosophy and mission.

Saudi Electricity Company (National Grid) | Jeddah, Makkah
Field Engineer
01/2014 - 08/2014

- Worked as a site and quality control engineer. My main duty was the supervision on the construction of electricity stations and its safety.
- Hired and supervised subcontractors to improve production and ensure safety requirements were met.

Certifications

- AutoCAD certification with Grade (Very good) from KAU.
- Certified from American Concrete Institute (ACI), as concrete field-testing technician grade 1.
- English language program graduate at UNF

Skills

- Professionalism in transportation software such VISSIM and MOVES.
- Professionalism in SoliedWork, AutoCAD and STAADPro, software.
- The ability of teaching, tutoring and counseling.
- Good experience in communication skills.

Summery

Reliable graduate student eager to prove himself as a transportation engineer. With his experience in teaching and research, his aspiration and goals are limitless to have an impact in transportation sector.