CLASSIFICATION AND THE STUDY OF IMPACTS ON FUEL ECONOMY OF HEAVY-DUTY VEHICLES

BY

NAZAM ALI

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (ENGINEERING AND TECHNOLOGY)

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THAMMASAT UNIVERSITY
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A Thesis Presented

By

NAZAM ALI

Submitted to
Sirindhorn International Institute of Technology
Thammasat University
In partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE (ENGINEERING AND TECHNOLOGY)

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JUNE 2018
Acknowledgements

I am grateful to The Almighty ALLAH (SWT), for opening up the horizons of light to me, as HE is the beginning and end of one’s success.

I am very much obliged to my family for their continuous support and believe in me in times whenever I need them as a pillar of strength. I would like to pay my sincere and profound gratitude to my advisor Assoc. Prof Dr. Mongkut Piantanakulchai for improvising and shaping my ideas throughout my graduate studies. I accord my acknowledgment to him for his expertise, guidance, support, encouragement and stimulating discussions during research meetings. My deep thanks are due to him for his moral and humane support to achieve this goal where I am now. I would like to extend my acknowledgement to my committee members Asst. Prof Dr. Teerayut Horanont and Asst. Prof Dr. Surachet Pravinvongvuth for the valuable comments and discussions in shaping my ideas into final research product.

I am indebted to all my lab fellows, brothers, sisters and friends being with me in difficult situations. Last but not the least important, I owe more than an acknowledgement to my elder brothers Hafiz Muhammad Riaz and Azam Ali for their financial support and taking care of family during my stay abroad.

I am also very much grateful to Sirindhorn International Institute of Technology, Thammasat University for providing me Excellent Foreign Students (EFS) Scholarship to support my financial needs during graduate studies at this Institute of global repute.
Abstract

THE STUDY OF EXTRA FUEL CASES, DRIVERS’ ECO-DRIVING MOTIVATIONS AND IMPACTS OF DRIVING PATTERNS ON FUEL CONSUMPTION

by

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The demand of fuel consumption in transportation sector is increasing and will continue to increase even with the advances in technology. The rising prices of fuel in transportation operations have drawn the attention of the logistics managers to control and reduce the amount of fuel used in either way. The drivers are an important component of the transportation sector who contribute a major role in fuel-saving options. The study of the driver’s motivations, strategies and driving patterns on fuel consumption and fuel-control has become inevitable to explore. A multi-dimensional approach to identify extra fuel usage, drivers’ intentions to comply with fuel-saving behaviors, and modeling of fuel consumption based on driving patterns of heavy-duty vehicles is requisite of the time to explore the multi-fold dimensions related with fuel consumption in transportation sector.

This thesis consists of mainly three parts. In the first part, a fuel management policy is proposed to classify cases of extra fuel consumption to accurately identify the blamed-party who is responsible for extra fuel consumption. An Incident Scenario Matrix Approach (ISMA) is designed with three main blamed-parties; self-
blame, other-blame and circumstance-blame with definite factors as driving behavior, driving conditions, vehicle and accessibility to classify extra fuel consumption cases in logistics firms working with fixed fuel policy. This study can be used as a milestone as a fuel policy for logistics firms working with similar fuel control policies.

In the second part, eco-driving motivations of Thai drivers to adopt eco-driving behaviors are observed according to their marital status and education level. The response is recorded in self-scoring fashion with three different goals (1) changing driving behaviors to become eco-drivers after necessary information about eco-driving (2) adopting eco-driving behaviors when they are asked to be in competition with fellow drivers, (3) and impacts of reward or penalty system on their behavioral response to act as eco-drivers. Correlation and ANOVA testing are performed to find the best combination of motivational goals to become eco-driver in different goals and change in behavioral response. The difference in behavioral response is also calculated to check if it is statistically significant or not. Results showed that young and educated drivers manifested strong motivations to become eco-driver in given contextual goals.

In the last part, impacts of driving patterns of heavy-duty vehicle drivers on fuel-consumption are discussed. The parameters which are included in driving styles are; distance travelled, instantaneous speed, speed profiles, braking patterns, accelerating patterns, and engine idle time. Three different kinds of trucks are included in the study to observe the effects of defined parameters on fuel consumption. The attempts to develop regression modals with acceptable $R^2$ value and $p$-value are made to observe the impacts of these parameters on fuel-consumption in real-world driving conditions.

**Keywords**: Incident Scenario Matrix Approach, Blamed-party, Eco-driving, Thai Drivers, Fuel-consumption, Driving Patterns, Instantaneous Speed, Hard Braking, Hard Acceleration, Engine Idle Time, Fuel-modeling,
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Chapter 1
Introduction

1.1 Background

1.1.1 Why Fuel-saving is Important?

As the world is moving towards globalization, the demand of transportation industry in increasing unprecedentedly. With the rise of transportation sector, the need to save fuel is much important than ever before. According to the report published by The International Energy Agency (IEA), the consumption of fuel by transportation sector is more than the quarter of the total energy production (Borger & Mulalic, 2012). According to an estimation, the fuel consumption in the global transportation is expected to increase 60 million barrels in 2035, which would account 61% of the total fuel production (Ma, Xie, Huang, & Xiong, 2015). The amount of fuel consumed is increasing day by day due to the higher demand of logistics operations. Figure 1.1 shows the statistics of the type of energy usage over the years which shows an abrupt increase in the usage of fuel (EIA, 2012).

![World energy consumption by fuel-type](EIA, 2012)

The trucking companies are using millions of liters of fuel on daily basis which amounts millions of dollars, so fuel saving is the prime concern for most of the logistics...
operations. Reducing fuel-usage has direct footprints on the operational cost in the transportation sector for economical operations. One of the most important challenges for most of the trucking firms of this generation is to address the fuel-concern in their operations to improve the sustainability of their economy. Fuel-consumption is the main concern for most of the policy makers, vehicle manufacturers, logistics managers, and company owners. By regulating the fuel-consumption, the stakeholders can address the issues related with energy security and environment (Greene et al., 2017). Logistics managers need fuel-consumption information for making informed decisions about their logistics operations.

From ergonomics point of view, understanding the relationship between drivers, vehicles, motives, attitudes and driving styles, could significantly improve the negative impacts of fuel on environment and economy. Apart from that, sustainability is also an ever-increasing threat to our global village which needs to be addressed on priority basis to reduce the menaces of extra fuel use on environment.

Under the dual pressure of energy and environmental crises, the emergence of multiple technologies, control strategies, concerned attitudes, and eco-fuel modeling is necessary in the transportation field to reduce the vehicles fuel consumption and emissions.

### 1.1.2 Energy Control Policies

Different logistics firms use different approaches in minimizing the fuel-usage in their operations. Those strategies can be of tactical, operational or strategical nature or maybe the combination of above strategies. Most of the strategical strategies include selection of suitable vehicles assigned for specific trips, incorporation of fuel-efficient vehicles in their fleet, vehicle configurations, and vehicle maintenance. The tactical strategies may include the selection of the roads with less slopes, road type, traffic congestions ahead, and payload of the vehicle. While, the operational strategies include the idle timing of the vehicle engines, cruise speeds, use of electrical appliances (i.e., air conditioning), and driving behavior of the drivers (Sivak & Schoettle, 2012a). Some of the after mentioned benefits of these mixed control strategies may include; reducing downtime, reducing operating expenses, reducing insurance costs, superior route planning, and reduction in the maintenance costs. It may include; the re-routing of their
operations, reduced paperwork, identifying the poor driving behaviors, engine idling control, and well-organized dispatching schedules. Some very dominant fuel-control strategies include the fixed fuel policy, educating and training drivers about eco-driving behaviors, and closely monitoring the behaviors of the drivers. These strategies are discussed in details in our study.

1.1.3 What is Eco-driving?

Eco-driving is a concept used to describe the economical and energy efficient usage of the vehicles. In actual meanings, it is a driving strategy that is adopted to travel the same distance at the lowest possible use of fuel. It encompasses reduced use of fuel, road safety, comfort, and efficiency of the system while optimizing the operations (Beloufa et al., 2017). It can be seen as an economical and environmentally friendly method which can result in the reduced use of fuel and environmental emissions.

Eco-driving can also be considered in the broader sense as the strategic decisions (vehicle maintenance, selection of vehicle, and various fuel-control policies), tactical decisions (re-routing of the operations, re-scheduling the deliveries, consideration of vehicle loads), and operational decisions (driver behaviors) that can lead to the reduced fuel-consumption, emissions, and improved safe operations (Sivak & Schoettle, 2012b).

Eco-driving is also a generic term that may be used to describe the optimal and energy-efficient usage of the vehicle. It includes the decisions and behaviors opted by the drivers which can lead to the reduced use of fuel for said operations.

The specific measures taken by the driver in pre-trip, on-trip, and post-trip phases which can reduce the emissions and fuel are also termed as eco-driving behaviors (Ayyildiz, Cavallaro, Nocera, & Willenbrock, 2017). It can also be mentioned as the obeying of traffic rules and regulations, exercising sustained awareness in driving operations, closely observing other users while driving to make safe trips, and adopting position to smoothly adapt one’s behavior to avoid accelerating and decelerating (Nègre & Delhomme, 2017). Eco-driving is also termed as the set of behaviors and styles adopted by the driver to make fuel-efficient trips (McIlroy & Stanton, 2017). Some of the such behaviors which are included in eco-driving may incorporate avoiding harsh acceleration and deceleration, early gear changing,
minimized usage of the electrical appliances and air conditioning, and reduced use of higher speeds (Barkenbus, 2010).

Eco-driving mainly consists of the general driving techniques that can be fruitful in saving fuel and emissions. It can be an attempt to change the driving styles of the drivers such as; (a) avoid fast driving; avoid frequent braking and accelerating; shifting gear at early stage to keep engine speed lower; maintaining cruise speed; and maintaining the condition of the vehicle perfect (i.e., checking tire pressures, changing oils etc.). It may include the additional rules which can be applied while driving in congested situations, such as anticipating traffic flow when accelerating and slowing down of the vehicles smoothly when intend to stop (Barth & Boriboonsomsin, 2009).

So, eco-driving is an important tool which can be used to reduce the amount of fuel in defined trips and can be employed by logistics managers for efficient and economical operations.

1.1.4 Driving Patterns as Determinants of Fuel-consumption

Road transportation is a major consumer of fuel and shares a great amount of total energy production. Fuel-consumption is mainly dependent upon driving characteristics which are called are driving patterns. These driving patterns are the main parameters that can be used to measure their quantification effects on fuel-consumption. The study of these driving patterns includes diverse factors; such as Instantaneous speed, instantaneous speed, acceleration, deceleration, traffic conditions, engine condition, road slope, engine torsional speed. The relationship between fuel-consumption and these driving parameters can be used to have an insight into different levels of fuel-consumption (Wang, Fu, Zhou, & Li, 2008). These driving patterns provide insightful information regarding the fuel-consumption rates. Ericsson Eva (Chi, Wang, & Ouyang, 2015) explored sixty-four parameters and concluded that nine of them having great influence on fuel-consumption. The Vehicle Specific Power (VSP) based approach was investigated by H. Christopher Frey et al (C. C. Rolim, Baptista, Duarte, & Farias, 2014) in order to investigate the sensitivity impact of the fuel-use to acceleration patterns. Michel Andre et al (Pasaoglu, Honselaar, & Thiel, 2012) suggested that the acceleration and Instantaneous speed has significant impacts fuel and emission modeling. Some of the driving pattern parameters can be listed as;
Instantaneous speed, average driving speed, maximum speed, average acceleration, average deceleration, average time of micro-trip, average length of micro trip, acceleration root mean square, percentage of idle time, percentage of acceleration time, percentage of deceleration time, percentage of constant-speed time (Chi et al., 2015).

1.2 Problem Statement

The demand of fuel consumption in transportation sector is increasing and will continue to increase even with the advances in technology. According to an estimation, the total amount of fuel consumption per day will reach 60 million barrels which is 61% of the total amount of fuel produced in the world (Ma et al., 2015). The rising prices of fuel in transportation operations have drawn the attention of the logistics managers to control and reduce the amount of fuel used in either way. The drivers are an important component of the transportation sector who contribute a major role in fuel-saving options. The study of the driver’s motivations, strategies and driving patterns on fuel consumption and fuel-control has become inevitable to explore. The urgent need to address the concerns of the logistics managers is very much important for reducing the menaces of fuel consumption. A multi-dimensional approach to identify extra fuel usage, drivers’ intensions to comply with fuel-saving behaviors, and modeling of fuel consumption based on driving patterns of heavy-duty vehicles is requisite of the time to explore the multi-fold dimensions related with fuel consumption in transportation sector.

1.3 Purpose of the Study

The purposes of the study are manifold; introducing the fuel-control policy based on fixed fuel, understanding the motivations of Thai drivers to adopt eco-driving in different contextual scenarios and fuel-modeling based on real-world driving patterns for heavy-duty vehicles. The main purposes of conducting this study include; the study of the management, responsive or investigative measure which can be used to get an idea for fuel-saving strategies and getting insight of fuel-consumption dependencies.

The introduction of the fuel-control policy based on the fixed fuel policy is an important contribution to highlight the blamed-party responsible for high fuel-usage.
The inclusion of several factors and blamed-parties give guidelines in making any individual accountable in case of extra fuel-consumption. Moreover, that study can be used as a milestone in addressing the concerns of the drivers as well as logistics managers in predicating accurate blamed-party.

While, self-reported response of Thai drivers was recorded to get the understanding of eco-driving behavior of Thai community drivers. In that study, Thai drivers were categorized into two different main groups based on their marital status and education level. The impacts of these definite factors of their willingness were recorded in order to understand which factors are the most influential in behavioral response change.

Another purpose of the study was to investigate the impacts of real-world driving patterns on fuel-consumption for heavy-duty vehicles in Bangkok area. As fuel-consumption is an important concern for most of the logistics managers; so it is extremely urgent to develop effective and actual fuel evaluation system for urban transportation. It is important to study the fuel-consumption of different kinds of vehicles with different properties and driving patterns (i.e., acceleration, deceleration, speed, and idle time).

1.4 Significance of the Study

With the advances in technology, our world has become a global village. Fuel-consumption in the global transportation is increasing and will continue to increase in coming years. According to estimation, the daily fuel-usage in the world is expected to reach 60 million barrels in 2035 amounting 61% of the total fuel output (Ma et al., 2015). Under the dual pressure of increased energy requirements and environmental concerns, it’s much needed to address the energy black holes and come up with multiple energy control strategies to minimize the menaces of extra fuel-consumption. This study is an attempt to address management fuel-control policies, response behavior of Thai drivers in participating and adopting eco-driving behaviors and impacts of driving styles (DS) on fuel-consumption. Logistics companies are becoming more concerned about fuel-consumption than ever before, they started implementing new fuel-control strategies. In this study, we propose a fuel-control policy by accurately predicting the
blamed-party which can be the possible responsible for extra fuel-usage. This study can address the concerns of the logistics managers and drivers working with fixed fuel policy. Moreover, the study of the responsive behavior against eco-driving attitude can be used as guidelines in introducing incentive systems for drivers, thus improving the overall cost of logistics operations. It has been investigated (Ma et al., 2015) that driving styles can affect 30% of the fuel-consumption, so it’s of most priority to model fuel-consumption based on driving patterns for eco-routing and re-scheduling of logistics operations. This study can be used to highlight the impacts of accelerating and decelerating patterns on fuel-consumption, which can be used in designing fuel-efficient driving styles.

1.5 Scope of the Study

The data is collected from a leading logistics firm from Thailand. The company used the policy of fixed fuel, giving an estimated amount of fuel to the drivers before they are asked to make a trip. This fuel control strategy was employed to force the drivers to drive at optimum driving styles while lowering the fuel-consumption. The data of the time span of three years from 2014 to 2016 was included which have the cases of extra fuel consumption with possible reasons of blamed-party.

Driver from the same company, eighty-seven (87) in number were included to record the response of the drivers regarding their adopting behavior of eco-driving in three different contexts i.e., changing driving behavior to adopt eco-driving based on information about eco-driving, adopting eco-driving when they are asked to be in competition with fellow drivers, and the impact of reward or penalty on their willingness to become eco-drivers.

To evaluate the impacts of driving patterns on fuel-consumption, three different kinds of vehicle (6W-NGV, 18W-NGV, and 18W-Diesel) were included for a time span of approximately eight weeks. The real-world driving behaviors such as distance travelled, instantaneous speed, number of hard braking, number of hard accelerating, and vehicle idle time were the core parameters to quantify their impacts on fuel-consumption. The total distance travelled within this period by study vehicles was 169345.65 km and most of the trips were made around Bangkok area.
Chapter 2
Literature Review

2.1 Increasing Energy Requirements

The efficient logistics operations are of prime concern for most of the fleet operators. With the increased globalization effect, transportation sector has high demand of fuel and it is continuing to be increased for upcoming years. According to an estimation, the daily fuel-consumption of the transportation alone is expected to be raised up to 60 million barrels per day in 2035. This amount of fuel amounts for the 61% of the total oil production (Ma et al., 2015). Fuel-consumption is a relevant indicator for evaluating the transport sustainability of logistics operations. Currently, transport sector id using 45% of the total energy produced (Ayyildiz et al., 2017) which amounts for 30 % of the total environmental emissions which was 22% in 1990. Because of the increased pressure imposed by the increased energy requirements, it has become inevitable for logistics companies to address the energy and environmental concerns. There are various ways to address these menaces such as; introduction of multiple technologies, inclusion of power-train optimization technologies being used in hybrid vehicles. Numerous studies have proved that the driving patterns can also contribute the significant reduction in energy consumptions by various means. The difference in energy consumption is estimated to be 30% in urban driving cycles and 20% in high-speed driving cycles (Ma et al., 2015). With this high amount of fuel requirements, logistics managers have started finding ways and means to lower the fuel-usage in their logistics operations. Drivers are also one of the important components which are equally co-responsible of this high fuel-consumption. Therefore, most of the logistics companies have employed different strategies to control extra fuel-usage (i.e., introducing fixed-fuel policy), training and educating their drivers to adopt eco-driving, and finding eco-driving styles based on real-world driving styles. With the increased density of vehicles all around the globe, the declining in the natural fuel resources have increased the demand for better fuel-consumption for road transportation. The high fuel-consumption have forced the researchers to develop more fuel-efficient power train technologies and innovate new aspects to save fuel. It is much evident from the
previous research that actual fuel-consumption can be improved by eco-driving. Eco-
driving habits have positive dimensions on fuel-consumption and significantly improve
driving styles (Beusen et al., 2009; Pampel, Jamson, Hibberd, & Barnard, 2015;

2.2 Fuel Control Strategies

Different researchers investigate different fuel-control strategies; which have
positive dimensions on driving styles and fuel-consumption. Some of the very common
fuel control strategies include; giving an estimated and calculated amount of fuel for
each trip, vigilance of fuel-theft activities, up gradation of technological advancements
in the fleet, and moderating the driving behavior of drivers using trainings or incentive
systems.

With technological advancements, the fuel-consumption can be reduced
significantly but it requires a lot of investment as capital cost in establishing the
modernization of operations. It is been investigated that advances in technology can
increase the efficiency of the logistics operations on average of 29% (Michaelides,
2010). The main factor to keep in mind is that the inclusion of new technology in the
system can lead to incurring a huge amount of investment which can prove
uneconomical for logistics companies. Keeping in mind the increased demand of
transportation due to its globalization effect, researchers started seeking out the ways
and means with less investment which can reduce the fuel consumption and improve
the efficiency of the fleet operations.

For example; modeling of the driving behavior can improve fuel from 5 to 25%
(average 10%) depending upon the aggressiveness index and driving behaviors (Beusen
et al., 2009; Díaz-Ramírez et al., 2017; Michon, 1985; Pampel et al., 2015). Eco-driving
is also an emerging dimension which has some significant impacts on fuel-control. It
finds the ways to use the minimum amount of fuel for the assigned trip. Basically, it
includes the decisions made by the on-trip drivers to minimize the amount of fuel used.
Different studies showed that eco-driving is of great importance which can have
positive impacts in reducing fuel. (C. Rolim, Baptista, Duarte, Farias, & Pereira, 2016)
investigated that eco-driving feedback can reduce the fuel-consumption by 8% for
female and 4% for male drivers for a time period of 6 months. Learning eco-driving using instructional videos and interactive guidance system in a driving simulator result in 12.38% and 7.42%, respectively (Beloufa et al., 2017).

Fuel-modeling is also an option for re-routing and driving style modifications, which can be used as a fuel control policy (Martinelli et al., 2018). The impacts of driving patterns on fuel-consumption are inevitable to understand with the growing energy requirements in the transportation sector. With the uprising globalization of the transportation sector, the energy requirements are increasing day by day. According to the report published by The International Energy Agency (IEA), the fuel-consumption by the transportation sector was one-third of the total energy production in the world (Borger & Mulalic, 2012).

The development of different fuel-control strategies is very much important to control the rising demand of energy consumption. Fuel-modeling is an important energy control strategy for effective control of fuel-saving. It’s an important tool to revise the fuel-efficient driving styles to optimize the logistics operations.

### 2.3 Eco-driving Techniques

Eco-driving is the most cheaper option among the available alternative in reducing fuel-consumption (Ayyildiz et al., 2017). Different researcher have discussed the benefits and different strategies of eco-driving owing to its positive dimensions on fuel-economy (5-25%; average 10%) (Alam & McNabola, 2014; Dogan, Steg, & Delhomme, 2011; Lai, 2015a; Larsson & Ericsson, 2009; Linda & Manic, 2012; C. Rolim, Baptista, Duarte, Farias, & Shiftan, 2014; Schall & Mohnen, 2015, 2017; Zhao, Wu, Rong, & Zhang, 2015) and environment [13]–[22]. However, very limited number of studies have been conducted in order to know the understanding of the drivers as eco-driver (Dogan et al., 2011; Lauper et al., 2015; McIlroy & Stanton, 2017; Nègre & Delhomme, 2017; Pampel et al., 2015). These studies discussed different aspects of eco-driving in different contextual scenarios. For example, Dogan et al. (Dogan et al., 2011) investigated the goals of drivers on safety, time saving and fuel saving; McIlroy and Stanton (McIlroy & Stanton, 2017) uses an online questionnaire survey to know the knowledge and understanding of UK drivers of eco-driving based on their...
demographic features; while, Delhomme (Nègre & Delhomme, 2017) discussed French drivers’ self-perception of being eco-driver according to their concern for environment, understanding of their eco-driving concepts, and their driving behaviors.

2.4 Fuel-modeling

Basically, models for calculation of fuel-consumption are categorized into micro, meso and macro models based on the scope of their usage and defined parameters. Macro models are usually used to estimate the overall fuel-consumption for a large region and long period (i.e., one month) of time. While, meso models are essentially developed based on the average speed. The typical meso models are fuel-consumption models based on correction factors and the Vehicle Special Power (VSP) bin distribution [3]. Micro models are developed using instantaneous traffic parameters (i.e., speed, acceleration, idle time etc.). The parameters incorporated in micro models are usually collected by GPS devices and there are broadly three methods to develop these models; statistics, regression and derivations based on power requirements [3].

Over the past years, several studies have investigated that traffic conditions, vehicle characteristics, and driving styles were the core factors affecting fuel-consumption [4], [5]. Some of the researches showed that the driving styles affect the fuel-economy, together with some other influence factors. These derived factors, usually termed as driving patterns are used to explain their impacts on fuel-economy [6]. So, it has been observed that the influence of these driving patterns such as speed, acceleration, deceleration, engine idle time, traffic conditions, and road grade etc., on fuel-economy is significant [5]. Ericsson Eva [6] explored the influence of sixty-four driving pattern parameters on fuel-consumption and concluded that nine of them were of great importance in terms of their impacts on fuel-economy. He modeled a regression equation to predict fuel-consumption based on nine parameters having great impacts on fuel-economy. Similarly, H. Christopher Frey et al [7] and Haikun Wang et al [8] analyzed the impacts of acceleration on fuel-use for conventional vehicles and concluded that fuel-economy is very sensitive to driving styles. The difference in fuel-consumption caused by different driving styles can be approximately 30% and 20% in urban and high-speed driving cycles, respectively [9].
2.5 Conclusion

Keeping in view of the importance of the fuel-consumption, it is very much important to cover the maximum aspects of fuel-control strategies. This study provides an overview of different fuel-control strategies along with fuel-modeling. The fuel strategies include the policy of identification of correct blamed-party in case of extra fuel-consumption in logistics operations. The behavioral response of Thai drivers is also recorded in different contexts to adopt eco-driving behavior. Fuel-modeling using real-world driving patterns is also done to investigate the impacts of different driving variables on fuel-consumption. In broader sense, this study covers the management, behavioral and modeling approach to investigate the determinants of fuel-consumption.
Chapter 3
Incident Scenario Matrix Approach (ISMA) to Classify Cases of Extra Fuel-Consumption

3.1 Introduction

According to the report published by The International Energy Agency (IEA) in 2004, transportation sector consumes more than one quarter of the total energy consumption in the world (Borger & Mulalic, 2012). Logistics companies have been using the fuel amounting millions of dollars, according to an estimation the daily fuel consumption by the transportation sector will reach up to 60 million barrels by 2035 (Ma et al., 2015). Under the high pressure of meeting energy requirements, trucking companies have started finding ways to lower the use of fuel in their operations. One of the effective ways to control the extra usage of the fuel is to control the behavior of the drivers. Reducing fuel-consumption is the main concern of most of the logistics companies. Because reducing fuel have direct footprints on the operational cost of the logistics operations. There are a lot of factors which govern the fuel-consumption such as area terrain, vehicle weight, vehicle age, traffic conditions, weather conditions, driving styles, and vehicle condition etc. The fuel-consumption of the vehicle is also mainly affected by the ambient temperature, quality of the fuel used, usage of the vehicle and cumulative mileage the vehicle is driven (Greene et al., 2017). In the same way, the fuel-consumption of the vehicle driven on the long routes is twice as compared to the fuel-consumption of the vehicles driven on the short routes in connected environment. The impact of payload on fuel-consumption is also significant, for example a 40-tonne articulated truck which is moving at the speed of 60 mph for a distance of 100-mile consumes four times more fuel than an average car running in the similar traffic conditions (Mohamed-Kassim & Filippone, 2010).

As it is evident from the literature above, some of the factors that may lead to extra fuel-usage are relevant to drivers and some of them are not directly related to drivers. Eco-driving is relatively an emerging field of research in which drivers adopt economical manners to save fuel. It has been investigated that eco-driving can improve fuel-consumption form 5-25% (with an average of 10%) (Stillwater, Kurani, &
Mokhtarian, 2017a). In the broader context, eco-driving considers the strategic, tactical, and operational decisions that can enhance the fuel-consumption. Some of these decisions include re-routing, re-scheduling, vehicle payload, and driver’s behavior. Some of the factors that affect fuel-consumption are mentioned in Table 3.1 with their percentage impacts. It is very important to note that vehicle type, the condition of the engine, the pressure in the tires, and road profile grade also accumulate significant change in fuel-consumption. While, the engine idling and excessive use of electrical appliances such as air-conditioning can account for 5-25% of the change in fuel-consumption. Similarly, the aggressiveness in the driving styles can accumulate up to 30% extra fuel-usage in the normal traffic conditions. On the same way, the fuel-consumption change 20-40% in the free and congested traffic conditions. The impact of engine idling is variable with the amount of time it is left running (Sivak & Schoettle, 2012a).

Table 3.1: Summary of the key factors affecting fuel-consumption in percent (Sivak & Schoettle, 2012a).

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect on fuel-consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle type</td>
<td>38%</td>
</tr>
<tr>
<td>Out-of-tune engine</td>
<td>4-40%</td>
</tr>
<tr>
<td>Tires with 25% higher rolling resistance</td>
<td>3-5%</td>
</tr>
<tr>
<td>Tires underinflated by 5 psi</td>
<td>1.50%</td>
</tr>
<tr>
<td>Improper engine oil</td>
<td>1-2%</td>
</tr>
<tr>
<td>Route type</td>
<td>Variable</td>
</tr>
<tr>
<td>Road grade profile</td>
<td>15-20%</td>
</tr>
<tr>
<td>Congestion condition</td>
<td>20-40%</td>
</tr>
<tr>
<td>Engine idling</td>
<td>Variable</td>
</tr>
<tr>
<td>Driving at high speeds</td>
<td>30%</td>
</tr>
<tr>
<td>Not obeying cruise control</td>
<td>7% (while at highway speed)</td>
</tr>
<tr>
<td>Using air-conditioner</td>
<td>5-25%</td>
</tr>
<tr>
<td>Aggressive driving</td>
<td>20-30%</td>
</tr>
</tbody>
</table>

Different logistics firms adopt different fuel-control policies. One of these fuel-saving strategies is fixed fuel-policy in which the driver is given an estimated amount of fuel before he is asked to make any trip. In this study a case study from a leading
logistics firm within Thailand has been presented which is using similar kind of fuel control strategy. The name of the firm is kept anonymous keeping in view the Standard Operating Procedures (SOPs) relevant to the privacy of the firm.

According to the policy opted by the firm, if the amount of fuel used in the trip exceeds the given estimated amount of the fuel, the driver is held responsible every time. A closer dialogue with the company revealed that they introduced this policy because of two obvious reasons;

(1) To prevent the fuel-theft activities by the drivers when they are asked to dispatch the consignments to far-off places.

(2) To force the drivers to drive at optimum conditions in an economical manner to reduce the extra fuel-usage and improve fuel-consumption.

As a result of this policy, the company drivers’ dissatisfaction level started increasing and they started switching their jobs. The company need to address their concerns to avoid any point of conflicts between drivers and company management.

So, in the proposed study, authors presented the Incident Scenario Matrix Approach (ISMA) to accurately identify the responsible party who is responsible for extra fuel-usage. ISMA can be used to classify the cases of extra fuel-consumption as well to lower the dissatisfaction level in drivers and encourage them to drive in a more responsible manner.

3.2 Methods and Data Collection

Different logistics companies adopt different strategies to control fuel-consumption. Among these strategies, fixed fuel policy is one of them. Actually, in this policy the driver is given a fixed amount of fuel for each trip that he is advised to make. If the amount of given fuel is not sufficient to accommodate that trip then an extra amount of fuel is required to complete that trip. This extra amount of fuel amounts extra operational cost on logistics companies. In this study, a methodology is developed to predict the possible responsible party for extra fuel consumption. An Incident Scenario Matrix Approach (ISMA) is used in classifying the blamed party with actual reasons behind each case of extra fuel usage. Basically, the blamed parties are categorized into three different types namely self-blame, other-blame and circumstance-blame. If the
reasons of extra fuel usage come under the category of self-blame, then driver should be held responsible. But if it comes under the umbrella of other-blame, then company itself or some third-party logistics should bear the extra charges. But, if the possible reasons fall under the section of circumstance-blame, then nobody should be held responsible and company should accommodate extra fuel charges. The possible factors accumulating extra fuel-usage include driving behavior, driving conditions, and vehicle. This study can be used to classify cases of extra fuel-consumption in logistics firms which work on the principle of fixed fuel to save fuel.

3.2.1 Participants-oriented Approach

Several meetings between the researchers, company management and the drivers took place. In these meetings the researchers presented the preliminary scope and purposes of the study. the concerns of the company management and the drivers were listened carefully to devise a midway to accommodate their issues. One of the purposes of these meetings was to have a common knowledge of the problems and how the company can address the encountered challenges. For example, one of the problems highlighted by the drivers was that driving in the highly connected tight environment may lead to extra fuel usage when driving in the congested traffic in main cities. Also, the drivers complained the wrong registration of extra fuel-consumption cases against them which leads to increased dissatisfaction among drivers. After a comprehensive discussion with the company management and the drivers, the development of an approach which can address the concerns of the company as well as of drivers was agreed to be devised.

3.2.2 Procedure

The data of the registered cases for the period of three years from 2014 to 2016 was collected. The data was in the form of a form which include some basic information such as; the date and time when the case was registered, the name of the driver on route, driving experience of the driver, truck number, truck type (including the size and fuel-type), origin of the trip, destination of the trip, and the history of the registered cases against that particular truck driver. The possible reasons of extra fuel-usage were also mentioned by the investigative team on the forms against each registered case.
detailed process showing the classification of extra fuel-consumption cases predicting the blamed-party is shown in Figure 3.1.

Based on the actual reasons of extra fuel-consumption registered cases, ISMA is devised with eighteen possible scenarios. In ISMA, the blamed-parties are divided as; self-blame, other-blame, and circumstance-blame with definite factors as driving behavior, driving conditions, and vehicle. According to our approach, if the reason falls in the category of self-blame only in that case the driver should be held responsible but if the possible reasons don’t fall in the category of self-blame then the driver should be given a safe way to continue his job with convenience and much disturbance. A careful consideration is kept in view while designing these incident scenarios so that all the valid concerns of the company management and drivers should be addressed in the best possible manners. In each factor, one known and one unknown reason is included. In the data analysis, the dispatch distance is also kept in mind and it has been investigated the registered cases increase with increase in distance. It may be inferred that drivers are involved in fuel-theft activities.

Figure 3.1: The flow chart showing the classification process
3.3 Incident Scenario Matrix

As per the design of ISMA, if the possible reasons of extra fuel-consumption fall in the category of self-blame, then driver is responsible but if it comes in the category of other-blame or circumstance-blame, then third-party logistics or company should be held responsible. The detailed description of the ISMA is illustrated in Table 3.2.

Table 3.2: Description of the Incident Scenario Matrix

<table>
<thead>
<tr>
<th>Factor</th>
<th>Reasons</th>
<th>Blamed Party</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Other-blame</td>
<td>Self-blame</td>
</tr>
<tr>
<td>Driving behavior</td>
<td>Management advised to deliver the consignment faster by taking longer route leading to increase in fuel consumption</td>
<td>Aggressive behavior of driving with abrupt change in speeding, braking, accelerating and gearing</td>
</tr>
<tr>
<td>Driving behavior</td>
<td>Driving in big city with connected tight environment</td>
<td>Driving the wrong route and not sure how long it takes to find the right way</td>
</tr>
<tr>
<td>Driving condition</td>
<td>Frequent short trips within a city affects MPG value, since engine doesn’t operate efficiently</td>
<td>More time spent running idle engine, driving at higher speeds &amp; using electrical accessories (e.g., air conditioner)</td>
</tr>
<tr>
<td>Driving condition</td>
<td>Slow moving vehicle in front blocks your path in sloppy areas and you can't speed up though you have honked the horn</td>
<td>Changing dedicated route without having knowledge of the traffic conditions ahead</td>
</tr>
<tr>
<td>Vehicle</td>
<td>Poorly tuned engine &amp; bad or worn out tires contribute to poor fuel economy</td>
<td>Timely communication of maintenance information &amp; excessive running of air conditioning</td>
</tr>
<tr>
<td>Vehicle</td>
<td>Aging of the engine sensors may lead to poor fuel-consumption</td>
<td>Engaging all four wheels makes the engine work harder and increases transfer case and poor fuel economy</td>
</tr>
</tbody>
</table>
The data collected from the company was analyzed and carefully studied to devise the Incident Scenario Matrices (ISMs). While devising the ISMA it was made sure that the reasonable concerns of the company management and drivers should be addressed in the best possible means. In eighteen designed scenarios, three blamed-parties are developed with define factors that can lead to extra fuel-consumption with one known and one unknown reasons. Some of the incident scenarios are listed here, i.e., driving in the tight connected environment and got stuck in traffic. Abrupt change in climate / weather conditions etc. which may lead to extra fuel-consumption. The accurately identified party in case of ISMA has to bear the cost of extra fuel in order to release the burden of extra fuel-filling by the driver in every case.

3.4 Analysis and Results

In the time span of three years, a total of twenty-five cases of extra fuel-consumption were registered against drivers. By careful considerations and keeping in view the literature review (Table 3.1), ISMA was developed to identify the main blamed-party responsible for extra fuel-filling (Table 3.2).

![Figure 3.2: Frequency of the incidents by scenario-type](image-url)
Based on the ISMA classification, most of the cases fall in the category of circumstance blame which were registered against drivers. Apparently, the driver is responsible in the least cases. The results showed that around seventy-six (76%) of all the cases registered against drivers, they don’t fall in the category of self-blame (Figure 3.2). While, the twenty-eight (28%) of the registered cases fall in the section of other-blame. A significant number of cases around forty-eight (48%) fall in the category of circumstance-blame. The classification of the registered cases with respect to Incident Scenario Matrix is shown in the Figure 3 with respect to the blamed-party in each case.

![Figure 3.3: Frequency of incidents by Trip-distance](image)

It is very much important to consider that the ratio of the registered cases increase as the distance of dispatching consignments increase. The highest frequency of reported cases which is around forty-eight (48%) is when the distance exceeds 1000 Km. It is very interesting to observe that the frequency of reported cases decreases (20%) when the trip distance is less than 500 Km. So, it can be inferred from the reported cases, that maybe drivers are involved in fuel-theft activities when they are advised to make longer trips as the number of registered cases of extra fuel-consumption also increases. ISMA is very much useful in highlighting the blamed-
parties in logistics firms working under similar kind of fuel-control policies. The frequency of the incidents reported with respect to distance is illustrated in Figure 3.3.

The frequency of the reported cases with respect to prevailing factors that may lead to extra fuel-consumption are highlighted in Figure 3.4. It is evident from the Figure 5 that in the maximum number of reported cases driving behavior is the main contributing factor which is a cause of extra fuel-cases. While, in the least number of reported cases, the responsible factor is driving condition constituting around twenty-four (24%) of the total case reported (Figure 3.4). The combined effect of driving conditions and vehicle constitute the number of reported incidents almost equal to driving behavior. So, it can be made conclusion that driving behavior accounts significant impacts on extra fuel-usage.

3.5 Limitations

There are still some limitations in this study, for example how different incident scenarios are designed based on the factors measure with reported cases against each blame party. Some other factors that may lead to extra fuel-usage can also be included
to create more specific incident scenarios to address each possible measures of extra fuel-consumption. However, it is important to note that in our analysis we did classification of incident scenarios with general and most obvious reasons which may not be feasible to apply under challenging working environments. Some of the other factors which may be included to create scenario specific incidents such as; outbound and inbound weights, accessibility to the destination locations, the frequency and rate of vehicle utilization, and tonne kilometer which can be the possible reasons behind extra fuel-consumption.

3.6 Acceptance Response of Fixed-Fuel Policy by Questionnaire

A questionnaire was designed to record the response of the drivers against company’s fixed fuel policy. There were total of twenty-five (25) questions included in that questionnaire and it was translated into Thai language so that drivers can understand it easily. It takes around twenty (20) minutes to fill the questionnaire. Each question was having four (4) options ranging from strongly disagree to strongly agree and yes to no. Some of the questions included in the questionnaire are;

(1) Are you satisfied with company’s fixed-fuel policy?
(2) Do you that driving according to fixed-fuel policy will help you in improving your driving behavior?
(3) Do you think that company gives you enough fuel for making trips?
(4) Do you think that factors leading to extra fuel-consumption are beyond your control?
(5) Do you think that company should give you extra fuel in case if you need more fuel in particular trip?
(6) Do you think that driving in free style will help you in improving your fuel-economy?
(7) What do you think that obeying company’s fixed-fuel policy will help you in saving-fuel?
(8) Do you think that company should prefer safety and time-saving instead of fuel-saving?
(9) Do you think that company is satisfied with your current driving style?
The response of the drivers against these questions was very much in alignment with the defined factors which leads to extra fuel-consumption. A huge number of drivers sixty-seven (67%) percent responded that company should not adopt fixed fuel policy. While seventy-two (72%) percent of the drivers think that driving at their own free style will be more fuel-efficient. Almost more than half of the drivers (57%) showed their manifestations to take the longer route to avoid congestions while saving fuel. Around eighty-nine (89%) of the drivers having of the view that company should provide extra fuel if there is extra consumption due to some unexpected events. The main concerns of the drivers were that there are so many unexpected events that may happened during consignment delivery that can leads to extra fuel-usage. The vague and diverse factors which are difficult to identify and attribute to specific individual may cause the extra fuel consumption in logistics operations. It can be seen from above response of the drivers that they manifested very negatively about acceptance of fixed fuel policy. While, company was much concerned and serious to save fuel, so it opted a great deal to address the concerns of both sides. Several meetings, were arranged between researchers, drivers and company management to find an in-between way to address the concerns of both parties. It was mutually agreed upon that a well-established mechanism should be devised which can cover the main apprehensions of either side.

Based on the extensive literature review and the reports of the registered cases of extra fuel-consumption were studied. A conclusion was drawn to categorize the extra fuel cases into three different types such as; self-blamed, circumstance-blamed, and other-blamed based on the most direct responsibility or negligence of the individuals or circumstances occurred. So, the development of Incident Scenario Matrix was accepted by both sides to resolve the most direct disagreements between drivers and company management.

3.7 Discussions and Conclusion

The classification for cases of consumption of extra fuel can be used by the logistics firms working with similar kind of fuel control policies. The increase in dispatch distance leads to increase in registered case, which is an indication that drivers may indulge in fuel-theft activities. For vigilance of fuel-theft activities, the authors
recommend the use of anti-theft protection system that is the simplest and inexpensive solution to address this issue. There are a number of sensors available in the market which can serve the purpose. However, the company may introduce standard range of fuel-consumption (MPG) value keeping in view the area terrain, traffic conditions and some other factors. If the drivers succeed in securing the marked value of fuel-consumption, they must get some incentives which can boost their confidence in favorable working environment.

This study, however, gives the general guidelines to the logistics managers and company management about fuel-control policy who are working with fixed fuel-policy. They can accurately predict the responsible party who is reasonable of extra fuel. For the continuation of this study, some more factors can be incorporated in developing specific incident scenarios to closely address the concerns of the drivers and company management.
Chapter 4  
Self-scored Manifestations of Thai Drivers to Adopt Eco-driving Behaviors in Different Motivational Contexts

4.1 Introduction

Eco-driving is an emerging field of research in the transportation sector. Many researchers around the globe have started studying this interesting area of research due to its positive footprints on fuel-consumption and environmental emissions. In the broader sense, eco-driving is set of behaviors and styles adopted by the drivers to lower the menaces of fuel-related and environment-related concerns. Among other many factors, drivers are the important part and parcel of the transportation sector having significant impacts on fuel-consumption. To improve the role of drivers in fuel-consumption, many logistics firms have started involving their drivers. Due to their major role economically and ecologically in the transportation industry, they are advised to become more responsible and attractive drivers in terms of optimum operations (Xu et al., 2017). Eco-driving includes all the strategic, tactical and operational decisions that a driver make to improve the safety and fuel-consumption in on-road operations. Some of the core decisions which are included in eco-driving strategy are; selection of the vehicle type, vehicle models, vehicle maintenance, tire pressures, and engine oils that have direct impacts on fuel-consumption (Sivak & Schoettle, 2012a).

Among all other available strategies, eco-driving is relatively cheaper option to save fuel because it needs only management prospective in making timely decisions (Ayyildiz et al., 2017). Many researchers have discussed the benefits of eco-driving on fuel-consumption as well as on environmental emissions and investigated that fuel-consumption can be improved from 5 to 25% (average 10%) (Ando, Nishihori, & Ochi, 2010; Ayyildiz et al., 2017; Boriboonsomsin, Vu, & Barth, 2010; Ericsson, Larsson, & Brundell-Freij, 2006; Lai, 2015b; Larsson & Ericsson, 2009; Stillwater, Kurani, & Mokhtarian, 2017b; Strömberg & Karlsson, 2013; Thijssen, Hofman, & Ham, 2014; Vaezipour et al., 2017; Walnum & Simonsen, 2015; M. Zhou & Jin, 2017). Until recent,
the most of the studies focusing eco-driving have described the ways, strategies, management prospective, and benefits of eco-driving and very limited studies addressed the concept of drivers about eco-driving and its implications (Dogan et al., 2011; McIlroy & Stanton, 2017; Nègre & Delhomme, 2017). The influence of these goals; safety, time saving, and fuel saving was investigated on driving behavior (Dogan et al., 2011). The knowledge and understanding of UK drivers about eco-driving was also recorded with an online questionnaire according to their demographic features (McIlroy & Stanton, 2017). (Nègre & Delhomme, 2017) collected the self-reported perception of French drivers to check their concern about their saving environment, knowledge and understanding about eco-driving, and their driving behavior. As mentioned in the previous literature, there has been a lack of recording the motivations of drivers to adopt eco-driving in different contextual scenarios such as; (1) changing driving style as eco-driver based on information received about eco-driving, (2) competition with fellow drivers to become eco-driver, (3) impacts of penalty or reward system on their behavioral change to become eco-drivers especially in Thailand.

In this study, the behavioral response of Thai drivers is recorded to observe if there is any statistically significant difference between their response based on their marital status, education levels, age, and driving experience in different contexts. ANOVA and post-hoc testing was performed to analyze the change in behavioral response. The response was collected on the scale from one (1) to five (5) representing strongly disagree to strongly agree, respectively.

4.1.1 Benefits of Eco-driving

The eco-driving has very positive footprints on fuel-consumption as well as operational cost of transportation, especially if the vehicles are driver-dependent. The positive dimensions of eco-driving can be observed in any prospects either by choice or by necessity.

Eco-driving can significantly reduce the Greenhouse Gas Emissions (GhGE) which are directly related with the amount of fuel consumption (for combustion engines). The average reduction of fuel is 10% (range:5-25%);(Mensing, Bideaux, Trigui, & Tattegrain, 2013) caused by eco-driving techniques. Other than the environmental emissions, it can also result in reduction in environmental emissions
other than exhaust, such as the particular matter (PMx) which are emitted by the tire-road and brake-pad contact. Eco-driving can be a significant tool to reduce the wear and tear caused by the high speeding and heavy braking and accelerating (Kumar, Pirjola, Ketzel, & Harrison, 2013).

The cost saving benefits of eco-driving cannot be nullified as they are very much important to consider. It affects the purchase of the fuels and overall drop the cost of car fuel costs (Barkenbus, 2010; calculated that it can improve the cost of fuel from $214 to $428 per year). Because, the smooth driving of the vehicle can reduce the wear and tear of the engine and vehicle itself.

One of the benefits of eco-driving with respect to comfort level are also important to mention here, because more noise by the vehicle engine can be inconvenient for the passengers as well as other vehicle drivers nearby: the noise caused by the engine of a car running at the speed of 4000 rpm is equal to the noise caused by the engines of the 20 vehicles running at the speed of 2000 rpm (Barić et al., 2013). This factor is very much important to consider when you drive through residential areas.

Eco-driving can also help in creating a standard way of living and it can be sustained by the social norms about the new environmental concerns. It’s been investigated that females are more environmentally conscious than men and they have more stronger relationship between environmental attitude and knowledge of eco-driving (McIlroy & Stanton, 2017).

Apart from all these benefits of eco-driving, only few drivers maintain the eco-driving behavior and most of them forget to practice these styles after some time or completely abandon it (Beusen et al., 2009). With the passage of time, they use it very less and less in their everyday driving (af Wählberg, 2007). (Pampel et al., 2015) investigated that when drivers are asked to drive normally, they don’t follow eco-driving and they follow their own self-developed ideas to driver, which are called as mental models.

In this study, we did not focus on real eco-driving techniques or its benefits rather we evaluated the eco-driving motivations of Thai drivers to practice eco-driving in different contexts. Some information about eco-driving was given to the drivers before recording their response. This study should provide new avenues into eco-driving knowledge and understanding of drivers.
4.1.2 Research Hypothesis

The response of the people is different in different situations. (Pampel et al., 2015) described that the driver’s behaviors are different when their response is collected in a simulator study and reported that when drivers are asked to drive normally, they don’t follow their driving styles which are called mental models. In this study, it is hypothesized that the response of Thai drivers would be greatly different according to their marital status, education levels, age and driving experience. It is also hypothesized that single, educated, and senior drivers would show strong manifestations to become eco-driver in given contexts.

4.2 Methodology

4.2.1 Participants

The drivers from one of the leading logistics firm were included in our study to get their behavioral response. Fortunately, we received very positive cooperation from the company management and drivers because of the involvement of local Thai undergraduate students from Thammasat University. A four-member group of students along with the company management was requested to help in facilitating the drivers in filling questionnaire forms. The forms were made very easy to understand by the drivers; however, the students were deployed in helping explaining any questions if the drivers may ask during filling of questionnaire forms. The first section of the questionnaire survey was dedicated to get the demographic features of the participants.

The drivers were divided into single, married, and in-relationship drivers according to their marital status while the categorization according to their education was followed as per the levels defined by the Thai Education Commission such as primary schooling, secondary schooling, high schooling, and university level education. They are grouped into three different types based on their age; less than 30-years, 30-50 years, and more than 50-years. While, based on the driving experience they were grouped as; less than 5-years, 5–10-years, and more than 10-year experience. A total of 87 drivers were engaged in filling the questionnaire forms and there was only one (1) female driver. Due to very less percent of female drivers, the effect of gender
on eco-driving motivations was neglected in this research study. The details of the demographic features of Thai drivers are summarized in the following Table 4.1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. of participants</th>
<th>%</th>
<th>Variable</th>
<th>No. of participants</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td>High school</td>
<td>20</td>
<td>22.9</td>
</tr>
<tr>
<td>Male</td>
<td>86</td>
<td>98.8</td>
<td>University level</td>
<td>3</td>
<td>3.4</td>
</tr>
<tr>
<td>Female</td>
<td>1</td>
<td>1.1</td>
<td>Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marital status</td>
<td></td>
<td></td>
<td>&lt;30</td>
<td>9</td>
<td>10.3</td>
</tr>
<tr>
<td>Single</td>
<td>21</td>
<td>24.1</td>
<td>30-50</td>
<td>73</td>
<td>83.9</td>
</tr>
<tr>
<td>Married</td>
<td>54</td>
<td>62.0</td>
<td>&gt;50</td>
<td>9</td>
<td>10.3</td>
</tr>
<tr>
<td>In relationship</td>
<td>12</td>
<td>13.7</td>
<td>Driving experience</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education level</td>
<td></td>
<td></td>
<td>&lt;5</td>
<td>15</td>
<td>17.2</td>
</tr>
<tr>
<td>Primary school</td>
<td>21</td>
<td>24.1</td>
<td>5-10</td>
<td>45</td>
<td>51.7</td>
</tr>
<tr>
<td>Secondary school</td>
<td>43</td>
<td>49.4</td>
<td>&gt;15</td>
<td>27</td>
<td>31.0</td>
</tr>
</tbody>
</table>

### 4.2.2 Procedure

A number of meetings happened between the company management, the drivers, and the researchers. During the meetings, the company management was given an overview about the purpose of the study and basic methods of the data analysis. The questionnaire forms were translated both in Thai and English to get the response of the exact nature. Also, during the filling of the questionnaire forms, the drivers were given some of the basic information of eco-driving and group of undergraduate students was deployed to explain the basic questions to the drivers. The questionnaire form was divided into three different sections;

1. Changing driving behavior to become eco-driver according to given information.
2. Changing driving behavior to become eco-driver when they are asked to be in competition with fellow drivers.
3. Changing driving behavior to become eco-driver when they are subject to penalty or reward system based on their driving styles.

The average time consumed in filling the questionnaire survey was 20 minutes. The company management was offered ice-cream to each participant driver who took...
part in this study. The drivers were divided as single, married, and in-relationship drivers based on their marital status and primary schooling, secondary schooling, high schooling and university level according to their education level. Similarly, they were also divided into three groups based on their age and driving experience in each case. The results were reported in two different sections. In the first section, self-reported scores were presented in the tabular and well as graphical form. In the second part, One-way ANOVA and post-hoc comparison testing is performed if the difference in their behavioral response is statistically significant or not.

4.2.3 Measures

The response was collected in three different motivations with the help of a questionnaire form. Five-point Likert scaling system was adopted to record the response against each section from one (1) to five (5) with strongly disagree to strongly agree, respectively. The demographic features of the drivers were also asked at the start of the questionnaire.

Changing driving styles (S1). In the first part, the questions related to the change in driving behavior according to the information of eco-driving were included. For instance, some of the questions asked were;

1. Do you think eco-driving will make you a better driver?
2. Do you consider that your current driving style is not eco-driving and you need to improve it?

Competition with fellow drivers (S2). The second section of the questionnaire include the response of the drivers when they were asked to be in competition with fellow drivers in accordance with the necessary instructions provided about eco-driving. Some of the questions which were included in the questionnaire are listed as follows here;

1. Do you agree that putting in competition with fellow drivers will help you in improving your driving behavior to become eco-drivers?
2. Do you agree that scoring drivers according to their performance will improve eco-driving styles?

Penalty or reward systems (S3). The last part of the questionnaire included questions when the drivers were asked subject to penalty or reward systems based on their driving
behaviors. Some of the questions as some examples are listed as follows which the part of this section was;

1. Do you want company to introduce penalty or reward system to improve eco-driving?
2. Do you agree that on poor performance you are ready to receive written warnings?
3. Do you agree that firing from job on poor driving performance is a justifiable act?

4.3 Results

In this study, the results are reported in two parts. In the first part, self-reported scores of Thai drivers are reported according to their willingness. In the second part, the statistical analysis is conducted including Pearson correlations and ANOVA testing. Pearson correlations tell us the combination of best motivations in which drivers manifested strong desire to adopt eco-driving while ANOVA testing is performed to check if the impact of the behavioral response between different group of drivers is statistically significant or not.

4.3.1 Eco-driving Scores

The eco-driving scores which are purely based on the self-reporting of Thai drivers are presented in this section. The manifestations of Thai drivers in three contexts are evaluated. Three contexts which are included in this study are; (1) changing driving behavior to become eco-driver based on information of eco-driving, (2) competition with fellow drivers to become eco-drivers and, (3) impacts of penalty or reward contexts on eco-driving. Drivers were given the choice of self-scoring according to their free will to rate their behavioral response in each context and the results were reported in self-scoring system. The results of the mean scores and standard deviations by each group of drivers are shown in Table 4.2.
The self-scoring system of Thai drivers reported that among the group of drivers with respect to their marital status, single drivers manifested strong inclinations to adopt eco-driving behavior based on their manifestations. The global score of single drivers is 12.07 (Table 4.2), which is the highest among other married and in-relationship drivers. The global score is the sum of all average scores by each driver group in given motivations. To be more precise, single drivers showed highest motivations in changing their driving behaviors to adopt eco-driving (score 4.21), and least motivations when they are asked to be in competition with fellow drivers (score 3.81). The self-scored rating of single drivers is 4.05 (Table 4.2), when they are asked subject to the penalty or reward system to adopt eco-driving behaviors. The motivations showed by the married drivers are also higher in changing their driving behaviors (score 4.00) and least when they are to be in competition with fellow drivers to adopt eco-driving (score 3.79). In-relationship drivers are the least scorer in the group of drivers with respect to marital status with average global score of 10.51 out of 15.00. However, they also manifested strong intentions to change their driving behaviors (score 4.00), while they manifested least motivations when they are asked to be in competition with fellow drivers (score 3.74). The least inclination of in-relationship drivers may be subject to their more mental engagement in their personal relationships which can hinder their motivations to become eco-drivers. However, it is worth-noting that the drivers with respect to their marital status performed better when they are asked to change their driving behavior based on information about eco-driving and they showed least motivations when they are asked to be in competition with fellow drivers. Another

Table 4.2: The global, mean scores, and of Thai driver's self-scoring

<table>
<thead>
<tr>
<th>Marital Status</th>
<th>Education Level</th>
<th>Age (years)</th>
<th>Driving Experience (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td>Married</td>
<td>In relationship</td>
<td>Primary school</td>
</tr>
<tr>
<td>Global score</td>
<td>12.07</td>
<td>11.77</td>
<td>10.51</td>
</tr>
<tr>
<td>Changing driving behavior</td>
<td>4.21</td>
<td>4.00</td>
<td>3.63</td>
</tr>
<tr>
<td>Competition with fellow drivers</td>
<td>3.81</td>
<td>3.79</td>
<td>3.12</td>
</tr>
<tr>
<td>Penalty or reward system</td>
<td>4.05</td>
<td>3.98</td>
<td>3.75</td>
</tr>
</tbody>
</table>
point, the single driver outperformed among married and in-relationship drivers in almost all contextual scenarios (Table 4.2 and Figure 4.1).

The eco-scores of educated drivers are good as compared to the less educated drivers (Table 4.2). The drivers with high school level education showed strong motivations to adopt eco-driving (with global score 12.78) with respect other driver groups categorized with respect to education levels. The drivers with less education manifested lower motivations to adopt eco-driving. The drivers with primary schooling showed strong motivations in changing their driving behavior to adopt eco-driving according to the information provided about eco-driving (score 4.00). The motivations of the primary schooling drivers are lower when they are asked to be in competition with fellow drivers (score 3.74). The drivers with secondary school level education also showed least manifestations to become eco-drivers with average global score of 11.14. Likewise, drivers with primary schooling education, drivers with secondary schooling education also showed strong desire to change their driving styles to become eco-drivers as per information of eco-driving by changing their driving behavior to become eco-drivers (score 3.89). It is evident from Table 4.2 and Figure 4.2, the drivers with high school education are the top scorer to adopt eco-driving behavior based on their self-reported inclination with an average global score of 12.78 (Figure 4.2). Contrary
to the response from other driver groups, the drivers with high school education level showed strong motivations to adopt eco-driving behavior when they are asked to be in competition with fellow drivers (score 4.39) and impacts of penalty or reward system on their behavioral response (score 4.38), respectively. They showed least motivations to change their driving behaviors based on eco-driving information (score 4.01) (Figure 4.2 and Table 4.2).

![Figure 4.2: Intentional manifestations of Thai drivers between education levels and eco-driving scale](image)

While, the behavioral manifestations of drivers with university level education are also higher as compared to drivers with primary and secondary school education. They scored second in rank after drivers with high school education with average global score of 12.33 (Table 4.2). The highest motivations showed by university level education drivers are when they are subject to penalty or reward system to adopt eco-driving behaviors (score 4.27). Like other drivers, they showed least motivations when they are asked to be in competition with other colleague drivers (score 3.93).

The self-scoring system of Thai drivers reported that among the group of drivers with respect to age, senior drivers (more than 50 years old) manifested strong inclinations to adopt eco-driving behavior based on their manifestations. To be more precise, senior drivers showed highest motivations in changing their driving behaviors
to adopt eco-driving (score 4.36), and least motivations when they are asked to be in competition with fellow drivers (score 3.93). The self-scored rating of senior drivers is 4.13 (Table 4.2), when they are asked subject to the penalty or reward system to adopt eco-driving behaviors. The motivations showed by the middle aged drivers (30-50 years old) are higher in penalty or reward systems (score 3.98) and least when they are to be in competition with fellow drivers to adopt eco-driving (score 3.81). Young drivers (less than 30 years old) manifested strong intentions to change their driving behaviors (score 4.27), while they manifested least motivations when they are asked to be in competition with fellow drivers (score 3.60). However, it is worth-noting that the drivers with respect to age-grouped performed better when they are asked to change their driving behavior based on information about eco-driving and they showed least motivations when they are asked to be in competition with fellow drivers. Another point, the senior drivers outperformed among young and middle-aged drivers in almost all contextual scenarios (Table 4.2 and Figure 4.3).

![Figure 4.3: Intentional manifestations of Thai drivers between age and eco-driving scale](image)

The self-scoring system of Thai drivers reported that among the group of drivers with respect to driving experience, drivers with 5-10 years of driving experience manifested strong inclinations to adopt eco-driving behavior based on their
manifestations. To be more precise, they showed highest motivations in penalty or reward systems to adopt eco-driving (score 4.18), and least motivations when they are asked to change their driving behavior (score 3.95). The self-scored rating of senior drivers is 4.04 (Table 4.2), when they are asked subject to the penalty or reward system to adopt eco-driving behaviors. The motivations showed by less experienced drivers (less than 5-years’ experience) are higher in changing their driving behavior (score 4.12) and least when they are to be in competition with fellow drivers to adopt eco-driving (score 3.72). More experienced drivers (greater than 10 years’ experience) manifested strong intentions to change their driving behaviors (score 3.96), while they manifested least motivations when they are asked to be in competition with fellow drivers (score 3.68). However, it is worth-noting that the drivers with respect to driving experience performed better when they are asked to change their driving behavior based on information about eco-driving and they showed least motivations when they are asked to be in competition with fellow drivers. Also, drivers with 5-10 years’ experience outperformed among other types of drivers in almost all contextual scenarios (Table 4.2 and Figure 4.4).

Figure 4.4: Intentional manifestations of Thai drivers between driving experience and eco-driving scale
It’s worth mentioning that almost all group of drivers showed strong motivations to adopt eco-driving behaviors by changing their driving behaviors (Figure 4.1, 4.2, 4.3 and 4.4). On the other hand, they showed least motivations, they are asked to be in competition with other fellow drivers (Table 4.2). So, it can be concluded that inherent inclination of competition is lower in drivers while they are ready to change their driving styles when they are asked to change their driving styles.

4.3.2 Statistical Analysis of Behavioral Response

The two types of statistical analysis are presented in this study. In the first place, the Pearson correlation analysis is conducted to find the best combination of motivations to find which has strong relationship with each other and can work best in predicting the self-reported response of Thai drivers about eco-driving. In the second part of this section, ANOVA testing is conducted to find out if the behavioral response showed by different group of drivers is statistically significant or not subject to the variables of marital status and education of Thai drivers.

It is very much evident from Table 4.3 that the correlation relationship between penalty or reward system and competition with fellow drivers is of great importance (79%). It can be inferred from this relationship that drivers who are interested in penalty or reward system are also very much interested in competition with other drivers. In the same way, Thai drivers who think about changing their driving behavior based on eco-driving information and drivers who think to change their driving behavior in competition contexts show some common interests of 42%. Pearson correlations between different motivational contexts of adopting eco-driving behavior by Thai drivers are shown in Table 4.3.

Table 4.3: Pearson correlation between different contextual scenarios

<table>
<thead>
<tr>
<th>Changing driving behavior</th>
<th>Competition with drivers</th>
<th>Penalty or reward system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changing driving behavior</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Competition with Drivers</td>
<td>0.42</td>
<td>1.00</td>
</tr>
<tr>
<td>Penalty or reward system</td>
<td>0.57</td>
<td>0.79</td>
</tr>
</tbody>
</table>
The applicability of the One-way ANOVA testing was checked to understand if the difference in behavioral difference between different group of divers is statistically significant or not. After that post-hoc comparison testing was further performed to investigate that difference within different driver groups is statistically significant or not. The alpha value (denoted as $\alpha$ or significance value) is set to 0.05 for performing these tests.

The one-factor ANOVA test results for single drivers showed that the behavioral difference in given contexts with respect to different motivations do not comes in the line that it is not statistically significant $[F (2,60) = 3.009, p\text{-value} = 0.0568, F_{\text{crit}} = 3.15]$. So, there is no point to further perform post-hoc comparison testing. The detailed results of the one-factor ANOVA testing are shown in Table 4.4.

Table 4.4: One-factor ANOVA test results for single with respect to given motivations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$p$- value</th>
<th>$F_{\text{crit}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1.7003</td>
<td>2</td>
<td>0.8502</td>
<td>3.0097</td>
<td>0.0568</td>
<td>3.1504</td>
</tr>
<tr>
<td>Within Groups</td>
<td>16.949</td>
<td>60</td>
<td>0.2825</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>18.649</td>
<td>62</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The one-factor ANOVA test results for married drivers showed that the behavioral difference in given contexts with respect to different motivations do not comes in the line that it is not statistically significant $[F (2,168) = 2.49, p\text{-value} = 0.0859, F_{\text{crit}} = 3.049]$. So, there is no point to further perform post-hoc comparison testing. The detailed results of the one-factor ANOVA testing are shown in Table 4.5.

Table 4.5: One-factor ANOVA test results for married with respect to given motivations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$p$-value</th>
<th>$F_{\text{crit}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1.532632</td>
<td>2</td>
<td>0.766316</td>
<td>2.490714</td>
<td>0.085906</td>
<td>3.049792</td>
</tr>
<tr>
<td>Within Groups</td>
<td>51.68842</td>
<td>168</td>
<td>0.307669</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>53.22105</td>
<td>170</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The one-factor ANOVA test results for in-relationship drivers showed that the behavioral difference in given contexts with respect to marital status comes in the line that it is statistically significant $[F (2,36) = 4.65, p\text{-value} = 0.015, F_{\text{crit}} = 3.25]$. So, further post-hoc comparison testing is performed to check the statistically significant...
difference between different motivations. The detailed results of the one-factor ANOVA testing for in-relationship drivers in given motivations are shown in Table 4.6.

Table 4.6: One-factor ANOVA test results for in-relationship drivers in given motivations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>2.90667</td>
<td>2</td>
<td>1.453333</td>
<td>4.65353</td>
<td>0.01594</td>
<td>3.259446</td>
</tr>
<tr>
<td>Within Groups</td>
<td>11.24308</td>
<td>36</td>
<td>0.312308</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14.14974</td>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further, post-hoc comparison testing performed on each type of motivations to investigate if they are statistically significant or not, revealed that changing driving behavior and competition with fellow drivers’ manifestations are statistically significantly different \( (p\text{-value} = 0.0133) \). While, changing driving behavior and penalty and reward system manifestations are not statistically different \( (p\text{-value} = 0.55) \). Also, it is inferred that competition with fellow drivers and penalty and reward manifestations are statistically significantly different \( (p\text{-value} = 0.0207) \).

The one-factor ANOVA test results for primary school education drivers showed that the behavioral difference in given contexts with respect to different motivations do not comes in the line that it is not statistically significant \[ F (2,63) = 2.86, p\text{-value} = 0.0643, F \text{ crit} = 3.14 \]. So, there is no point to further perform post-hoc comparison testing. The detailed results of the one-factor ANOVA testing are shown in Table 4.7.

Table 4.7: One-factor ANOVA test results for primary school drivers in given motivations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>0.801211</td>
<td>2</td>
<td>0.400606</td>
<td>2.86679</td>
<td>0.064329</td>
<td>3.142809</td>
</tr>
<tr>
<td>Within Groups</td>
<td>8.803634</td>
<td>63</td>
<td>0.13974</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9.60485</td>
<td>65</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The one-factor ANOVA test results for secondary school drivers showed that the behavioral difference in given contexts with respect comes in the line that it is statistically significant \[ F (2,114) = 5.52, p\text{-value} = 0.005, F \text{ crit} = 3.07 \]. So, further post-hoc comparison testing is performed to check the statistically significant
difference between different motivations. The detailed results of the one-factor ANOVA testing for in-relationship drivers in given motivations are shown in Table 4.8.

Table 4.8: One-factor ANOVA test results for secondary school drivers in given motivations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>3.21846</td>
<td>2</td>
<td>1.609231</td>
<td>5.523624</td>
<td>0.005133</td>
<td>3.075853</td>
</tr>
<tr>
<td>Within Groups</td>
<td>33.2123</td>
<td>114</td>
<td>0.291336</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>36.4308</td>
<td>116</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further, post-hoc comparison testing for secondary school drivers performed on each type of motivations to investigate if they are statistically significant or not, revealed that changing driving behavior and competition with fellow drivers’ manifestations are statistically significantly different (\(p\)-value = 0.0019). While, changing driving behavior and penalty and reward system manifestations are not statistically different (\(p\)-value = 0.1837). Also, it is inferred that competition with fellow drivers and penalty and reward manifestations are not statistically significantly different (\(p\)-value = 0.058).

The one-factor ANOVA test results for secondary school drivers showed that the behavioral difference in given contexts with respect comes in the line that it is statistically significant \([F (2,57) = 6.62, p\text{-value} = 0.0025, F \text{ crit} = 3.15]\). So, further post-hoc comparison testing is performed to check the statistically significant difference between different motivations. The detailed results of the one-factor ANOVA testing for in-relationship drivers in given motivations are shown in Table 4.9.

Table 4.9: One-factor ANOVA test results for high school drivers in given motivations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1.876</td>
<td>2</td>
<td>0.938</td>
<td>6.626921</td>
<td>0.002584</td>
<td>3.158843</td>
</tr>
<tr>
<td>Within Groups</td>
<td>8.068</td>
<td>57</td>
<td>0.14154</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9.944</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

So, post-hoc comparison testing for high school drivers performed on each type of motivations to investigate if they are statistically significant or not, revealed that changing driving behavior and competition with fellow drivers’ manifestations are
statistically significantly different \( (p-value = 0.0029) \). While, changing driving behavior and penalty and reward system manifestations are also statistically different \( (p-value = 0.0014) \). Contrary to that, it is investigated that competition with fellow drivers and penalty and reward manifestations are not statistically significantly different \( (p-value = 0.9383) \).

The one-factor ANOVA test results for young drivers (less than 30 years old) showed that the behavioral difference in given contexts with respect to different motivations do not come in the line that it is not statistically significant \( [F (2,24) = 2.82, p-value = 0.079, F_{crit} = 3.40] \). So, there is no point to further perform post-hoc comparison testing. The detailed results of the one-factor ANOVA testing are shown in Table 4.10.

Table 4.10: One-factor ANOVA test results for young drivers in given motivations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>2.24</td>
<td>2</td>
<td>1.12</td>
<td>2.823529</td>
<td>0.079206</td>
<td>3.402826</td>
</tr>
<tr>
<td>Within Groups</td>
<td>9.52</td>
<td>24</td>
<td>0.396667</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11.76</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The one-factor ANOVA test results for middle-aged drivers (30-50 years old) showed that the behavioral difference in given contexts with respect to different motivations do not come in the line that it is not statistically significant \( [F (2,192) = 1.78, p-value = 0.170, F_{crit} = 3.042] \). So, there is no point to further perform post-hoc comparison testing. The detailed results of the one-factor ANOVA testing are shown in Table 4.11.

Table 4.11: One-factor ANOVA test results for middle-aged drivers in given motivations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>0.94</td>
<td>2</td>
<td>0.499077</td>
<td>1.782826</td>
<td>0.170935</td>
<td>3.042964</td>
</tr>
<tr>
<td>Within Groups</td>
<td>53.79</td>
<td>192</td>
<td>0.279936</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>54.75</td>
<td>194</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The one-factor ANOVA test results for senior drivers (more than 50 years old) showed that the behavioral difference in given contexts with respect to different motivations do not come in the line that it is not statistically significant \( [F (2,24) = 2.82, p-value = 0.079, F_{crit} = 3.40] \).
1.10, \( p\text{-value} = 0.34 \), \( F \text{ crit} = 3.402 \). So, there is no point to further perform post-hoc comparison testing. The detailed results of the one-factor ANOVA testing are shown in Table 4.12.

Table 4.12: One-factor ANOVA test results for senior drivers in given motivations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>0.802</td>
<td>2</td>
<td>0.401481</td>
<td>1.107252</td>
<td>0.346765</td>
<td>3.402826</td>
</tr>
<tr>
<td>Within Groups</td>
<td>8.702</td>
<td>24</td>
<td>0.362593</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9.505</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The one-factor ANOVA test results for less experienced drivers (less than years) showed that the behavioral difference in given contexts with respect to different motivations do not comes in the line that it is not statistically significant \( [F (2,42) = 3.66, \ p\text{-value} = 0.081, \ F \text{ crit} = 3.21] \). So, there is no point to further perform post-hoc comparison testing. The detailed results of the one-factor ANOVA testing are shown in Table 4.13.

Table 4.13: One-factor ANOVA test results for less experienced drivers in given motivations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1.216</td>
<td>2</td>
<td>0.608</td>
<td>2.664441</td>
<td>0.081392</td>
<td>3.219942</td>
</tr>
<tr>
<td>Within Groups</td>
<td>9.584</td>
<td>42</td>
<td>0.22819</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10.8</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The one-factor ANOVA test results for drivers with experience of 5-10 years showed that the behavioral difference in given contexts with respect to different motivations do not comes in the line that it is not statistically significant \( [F (2,132) = 2.29, \ p\text{-value} = 0.104, \ F \text{ crit} = 3.06] \). So, there is no point to further perform post-hoc comparison testing. The detailed results of the one-factor ANOVA testing are shown in Table 4.14.
Table 4.14: One-factor ANOVA test results for drivers with 5-10 years’ experience in given motivations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1.21126</td>
<td>2</td>
<td>0.60563</td>
<td>2.299801</td>
<td>0.104284</td>
<td>3.064761</td>
</tr>
<tr>
<td>Within Groups</td>
<td>34.7609</td>
<td>132</td>
<td>0.26334</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>35.9721</td>
<td>134</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The one-factor ANOVA test results for more experienced drivers (more than 10 years) showed that the behavioral difference in given contexts with respect to different motivations do not comes in the line that it is not statistically significant \[F (2,78) = 2.66, p-value = 0.075, F_{crit} = 3.11\]. So, there is no point to further perform post-hoc comparison testing. The detailed results of the one-factor ANOVA testing are shown in Table 4.15.

Table 4.15: One-factor ANOVA test results for more experienced drivers in given motivations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1.21</td>
<td>2</td>
<td>0.605926</td>
<td>2.665608</td>
<td>0.075891</td>
<td>3.113792</td>
</tr>
<tr>
<td>Within Groups</td>
<td>17.73</td>
<td>78</td>
<td>0.227312</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>18.94</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It’s worth mentioning here that in-relationship drivers, secondary and high school education drivers, has statistically significant impact on their behavioral change in adopting eco-driving behaviors in given contextual scenarios.

4.4 Discussions and Conclusion

In this study, the role of three different contexts about Thai drivers’ self-reported inclination to adopt eco-driving are discussed. These three different contexts include: changing driving behavior to become eco-driver based on the information provided about eco-driving behavior, change in behavioral response of Thai drivers when they are asked to be in competition with fellow Thai drivers, and impacts of penalty or reward system on their behavioral response. The results are reported in self-scoring
system as well as some statistical analysis methods are performed such as Pearson correlations and One-factor ANOVA testing to check the relationship among different behavioral responses and if the behavioral response showed by different group of drivers in given motivations is statistically significant or not.

This study can be proved as a milestone in checking the behavioral response of Thai drivers against eco-driving contexts. According to the literature review, eco-driving is an emerging tool in reducing the menaces of fuel-consumption and environmental emissions, so no such study has been conducted especially in Thailand. In this study instead of focusing real eco-driving, we focused on the behavioral or intentional behavior of Thai drivers for recording their willingness behavior to adopt eco-driving in given contexts. We observed from the given group of drivers that single and married don’t show any statistically significant difference in their behavioral responses in given motivations. While, in-relationship drivers showed that they respond differently in given motivation scenarios. The overall trend of willingness behavior for in-relationship drivers grouped can be generalized as: changing driving behavior > penalty or reward system > competition with fellow drivers. So, it can be concluded that in-relationship drivers showed highest motivations in changing their driving behaviors (score 3.75). So, apparently this strategy can be used to get the best response of eco-driving adopting behavior of in-relationship drivers. As the behavioral response of single and married drivers is not statistically significantly different, so we can’t conclude that which type of motivation will work best for them (Figure 4.1 and Table 4.2, 4.4, 4.5 and 4.6). The impact of education levels on eco-driving behavior is also very important to understand. As it is evident from Figure 4.2 and Table 4.2, 4.7, 4.8 and 4.9, they educated drivers with high school and secondary school education manifested strong motivations to adopt eco-driving in given contexts. Their behavioral response is statistically significantly different in given motivations. Drivers with secondary school education showed highest manifestations to adopt eco-driving in changing their driving behaviors (score 3.89). Their behavioral response is statistically significantly different in changing their driving behaviors and competition with fellow drivers (p-value = 0.00198). While, drivers with high school education also showed statistically significantly different behavioral response when they are asked to change their driving behaviors and competition with fellow drivers (p-value = 0.00295) as well.
as when they are asked to change their driving behaviors and impacts of penalty and reward systems ($p$-value $= 0.00148$). The overall trend of drivers with secondary school education is; changing driving behavior > competition with fellow drivers. On the other hand, the overall trend for drivers with high school education can be; competition with fellow drivers > penalty or reward systems > changing driving behaviors. So, it can be concluded from above results that changing driving behavior and competition with fellow drivers are the best motivations for drivers with secondary and high school education drivers, respectively. On the other hand, drivers with university level education don’t have any statistically significantly different response.

It can also be seen from Figure 4.3, Table 4.2, 4.10, 4.11 and 4.12, drivers with respect to their age manifested strong motivations to adopt eco-driving almost same in given contexts. Their behavioral response is not statistically significant in any motivation types.

It is also evident from Figure 4.4 and Table 4.2, 4.13, 4.14 and 4.15 that drivers with driving experience showed almost similar kind of response in given motivation contexts. Their behavioral response is not statistically significant in any motivation types.

As this study is purely based on the self-reported and self-scored response so there maybe the possibility of biasedness in the results because of the social desirability of Thai drivers. Another important factor is, the numbers of drivers interviewed in this study are very small as compared to the total population of the country, so it is possible that the sample study cannot accurately predict the behavioral response of Thai drivers in particular.

For continuing this study, a greater number of drivers will be included in this study and their response against different company favorable policies will be investigated such as job security, job status about eco-driving motivations.
Chapter 5
Investigation of Fuel-consumption for Heavy-duty Vehicles based on their Driving Patterns

5.1 Introduction

With the rise of transportation sector, the need to save fuel is much important than ever before. According to the report published by The International Energy Agency (IEA), the consumption of fuel by transportation sector is more than the quarter of the total energy production (Borger & Mulalic, 2012). According to an estimation, the fuel consumption in the global transportation is expected to increase 60 million barrels in 2035, which would account 61% of the total fuel production (Ma, Xie, Huang, & Xiong, 2015). The amount of fuel consumed is increasing day by day due to the higher demand of logistics operations. Figure 1.1 shows the statistics of the type of energy usage over the years which shows an abrupt increase in the usage of fuel (EIA, 2012).

The impacts of driving patterns on fuel-consumption are inevitable to understand with the growing energy requirements in the transportation sector. With the uprising globalization of the transportation sector, the energy requirements are increasing day by day. According to the report published by The International Energy Agency (IEA), the fuel-consumption by the transportation sector was one-third of the total energy production in the world (Borger & Mulalic, 2012). The rising amount of vehicle intensity and greater use of vehicles in the household in the recent years, the fuel-consumption has increased unprecedentedly in current decade. According to an article published in Bangkok Post, the daily fuel-consumption in Bangkok is expected to increase by 3.5% from 150 million liters to 155 million liters in 2018 from 2017 (“DOEB spots rising fuel consumption in 2018 | Bangkok Post: business,” n.d.). It has also been estimated that the daily fuel-consumption by the transportation sector of the world is expected to reach around 60 million barrels in 2035, which would be the 61% of the total energy production in this world (Ma et al., 2015). Figure 5.1 shows the type of the energy used as fuel in different sectors in percentage.
Figure 5.1: The percentage of the energy consumption by fuel-type in 2013

The development of different fuel-control strategies is very much important to control the rising demand of energy consumption. Fuel-modeling is an important energy control strategy for effective control of fuel-saving. It’s an important tool to revise the fuel-efficient driving styles to optimize the logistics operations.

In the broader perspective, fuel-modeling is of three different types based on the parameters include and the scope of the study. The important types of fuel-modeling strategies include macro, meso, and micro modeling. Macro-modeling is usually used when we need to model the fuel-consumption for a large area of study with a relatively longer span of time (i.e., longer than one month). Meso-modeling is the category of fuel-modeling which incorporate speed as an important input parameter in predicting fuel-consumption. The famous typical examples which come in the category of meso-modeling are:

1. Fuel models based on correction factors.
2. Fuel models based on Vehicle Special Power (VSP) bin distribution.

While, the micro-modeling is done using the techniques of statistics, regression and derivation of the driving parameters based on power requirements (X. Zhou, Huang, Lv, & Li, 2013).

Various researchers employed different techniques in fuel-modeling but the basic parameters included were speed, acceleration, traffic conditions, and vehicle characteristics (Ericsson, 2000). It’s been investigated that fuel-consumption is
influenced by some of the factors and that factors are known as driving pattern parameters (Ericsson, 2001). So, there is no denial that the impacts of independent driving patterns such as Instantaneous speed, acceleration, deceleration, traffic conditions and road grade are significant on fuel-consumption (Ericsson, 2000). (Ericsson, 2001) investigated the sixty-four (64) different driving patterns and finally made the conclusion that nine (9) of them have significant impacts on fuel-consumption. (Frey, Routhail, Zhai, Farias, & Gonçalves, 2007) and (Wang et al., 2008) suggested that impacts of acceleration are sensitive to fuel-modeling. The detailed difference in the fuel-consumption can be seen in Figure 5.2 as follows:

![Figure 5.2: The difference in fuel-consumption at different roads by different driving styles](image)

Similarly, the fuel-consumption can also be affected by the vehicle characteristics in different road conditions. (Ma et al., 2015) concluded that different driving styles can change the fuel-consumption up to 30% in urban roads and up to 20% in high-speed roads outside the residential routes. The illustration can be seen in Figure 5.3.
(Voort, Dougherty, & Maarseveen, 2001) developed an isoline fuel map using regression techniques for fuel-modeling with vehicle speed, acceleration, and fuel-consumption as modeling input parameters. The fuel-consumption map developed using Isoline technique can be seen in the Figure 5.4.

Figure 5.3: Fuel-consumption percent difference in different road conditions under different vehicle running processes

Figure 5.4: Fuel-consumption map using isoline technique
(Rakha, Ahn, & Trani, 2004) developed VT_micro models to calculate instantaneous fuel-consumption (l/s) using speed of vehicle in km/h and different acceleration values as input. He developed the exponential function with speed and acceleration as input parameters of the regression model. It is interesting to note that he used four values of acceleration (1.8, 0.9, 0.0, and -0.9 m/s²) as input parameters with same speed parameter of the vehicle and concluded that acceleration has significant impact on rate of fuel-consumption as compared to deceleration. Figure 5.5 illustrate the graphical description of the models used developed by the said researcher.

![Figure 5.5: Regression model predictions (fuel-consumption)](image)

The vehicle characteristics, vehicle frontal area and some other parameters were also used to observe their impacts on fuel-consumption and concluded that they have significant impacts on fuel-consumption (Ganti, Pham, Ahmadi, Nangia, & Abdelzaher, 2010).

As it is mentioned above from the literature point of view, most of the researchers included speed and accelerating patterns as determining parameters for fuel-modeling. But, none of the researchers have used hard braking and hard accelerating as defining parameters which can be used for fuel-modeling. In this study, distance travelled, instantaneous speed, hard braking, hard accelerating, and vehicle idle time are used as defining parameters for fuel-modeling using stepwise regression modeling technique.
The quantification effects of the above-mentioned parameters on fuel-consumption are very important to study because of the development of methods and approaches to predict fuel-consumption.

5.1.1 Measures

Based on the literature review, we carefully considered the defined parameters and used these parameters because of their importance in determining fuel-consumption. For example, several researchers used speed as a main determining parameter in predicting fuel-consumption. Depending upon the importance of speed parameter, we included instantaneous speed as a determining factor of fuel-consumption in our study.

Before going in details of the notations used in our study, the description of the terms used are explained in the following table (Table 5.1).

Table 5.1: Terms used in this study along with their description

<table>
<thead>
<tr>
<th>Terms</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v$</td>
<td>Speed of vehicle (km/hr.)</td>
</tr>
<tr>
<td>$\Delta s$</td>
<td>Change in distance (km)</td>
</tr>
<tr>
<td>$\Delta t$</td>
<td>Change in time interval (s)</td>
</tr>
<tr>
<td>$v_f$</td>
<td>Final velocity (km/hr.)</td>
</tr>
<tr>
<td>$v_i$</td>
<td>Initial velocity (km/hr.)</td>
</tr>
<tr>
<td>$a_{av}$</td>
<td>Average acceleration (m/s²)</td>
</tr>
<tr>
<td>$I_t$</td>
<td>Idle time (%)</td>
</tr>
<tr>
<td>$H_b$</td>
<td>Number of hard braking (change in instantaneous speed (km/hr./s))</td>
</tr>
<tr>
<td>$H_a$</td>
<td>Number of hard acceleration (change in instantaneous speed (km/hr./s))</td>
</tr>
</tbody>
</table>

Different researchers used different values as hard braking and hard acceleration incidents based on change in instantaneous speed. There is no thumb rule to define these incidents and each researcher used these set values as per his / her own understanding and desire. Some of the values used by different researchers are shown in Table 5.2.
Table 5.2: Set values of Hard Braking and Hard Acceleration

<table>
<thead>
<tr>
<th>Paper</th>
<th>Set values (m/s²)</th>
<th>Parameter</th>
<th>Study vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Ando &amp; Nishihori, 2012)</td>
<td>1.962 1.962</td>
<td>Hard braking&lt;br&gt;Hard accelerating</td>
<td>Toyota City car</td>
</tr>
<tr>
<td>(C. C. Rolim et al., 2014)</td>
<td>3.04 – 4.41&lt;br&gt;3.33 – 4.41</td>
<td>Hard accelerating&lt;br&gt;Hard braking</td>
<td>Cars</td>
</tr>
<tr>
<td>(Rutty, Matthews, Andrey, &amp; Matto, 2013)</td>
<td>2.97&lt;br&gt;3.47</td>
<td>Hard accelerating&lt;br&gt;Hard braking</td>
<td>Gasoline and hybrid cars</td>
</tr>
<tr>
<td>(Staubach, Schebitz, Köster, &amp; Kuck, 2014)</td>
<td>3.5</td>
<td>Hard accelerating&lt;br&gt;Hard braking</td>
<td>Dynamic driving simulator</td>
</tr>
<tr>
<td>(Klauser, Dingus, Neale, Sudweeks, &amp; Ramsey, 2009)</td>
<td>2.943</td>
<td>Hard accelerating&lt;br&gt;Hard braking</td>
<td>Cars</td>
</tr>
</tbody>
</table>

As it is evident from the above-mentioned literature review, there is no study conducted on hard braking and hard accelerating incident definitions. Most of the previous studies either include cars or driving simulators in defining these parameters. So, in this study we define these hard braking and hard accelerating parameters for heavy-duty vehicles especially for trucks. For the convenience of our analysis, we put these parameters in such a way that (1) if the speed of the vehicle changes more than or equal to 8 km/hr. in time period of one second, it would be regarded as hard acceleration, (2) if the speed of the vehicle changes less than or equal to 6 km/hr. in one second, it would be considered as hard braking. Some of the reasons that our set values are different than previously defined values by other researchers are;

(1) Our study vehicles include heavy-duty vehicles which have not been studied before.

(2) Because of the heavy weights, the inertia of these vehicles is more and it takes more force to stop and start them, so we set these values less than the values set by different researchers.

(3) We believe that it’s easy to accelerate the vehicle as compared to stop it within specified amount of time, that is why we set the value of hard braking less than hard accelerating.
The equations that are used to calculate these values and parameters are shown in as below. However, idle time is calculated in percentage and measured with respect to total distance travelled. The normal red signal timings in Bangkok area is approximately 60 sec, however, if the stopping time is more than one minute that is included and calculated as idle time in these scenarios.

\[ a_{av} = \frac{(\Delta v_f - \Delta v_i)}{\Delta t} \geq -1.66 \text{ m/s}^2 \quad (1) \]

\[ a_{av} = \frac{(\Delta v_f - \Delta v_i)}{\Delta t} \geq 2.22 \text{ m/s}^2 \quad (2) \]

The negative sign at the right-hand side of the equation 1 shows that the speed is decreasing with respect to initial speed (negative acceleration). However, the quantification effects of these calculated parameters are investigated in this study using stepwise regression modeling.

5.2 Methodology

In this study, an attempt to model the fuel-consumption of the heavy-duty vehicles has been made to study the quantification effect of different driving parameters. The driving parameters kept in consideration are distance travelled, instantaneous speed, hard braking, hard accelerating and engine idle time etc. The impacts of hard braking and hard accelerating are investigated with respect to number of these incidents during one-time fuel filling. Three different kinds of trucks are included as study vehicles in this study including 6-Wheeler Natural Gas Vehicles (6W-NGV), 18-Wheeler Natural Gas Vehicles (18W-NGV), and 18-Wheeler Diesel Vehicles (18W-Diesel). The data was collected using Controller Area Network (CAN) technology installed in the study vehicles for a time span of two months. The data contained the information regarding latitude, longitude, distance, speed, and fuel-consumption. The number of hard braking and hard accelerating were recorded as an incident in the SECONLINE system used by the company. Meaning that if the value of the instantaneous speed changes more than the desired set range of value, it was recorded as an incident of hard braking or hard accelerating depending upon increase or decrease in the value of the speed in one second. Attempts to model the impacts of these incidents along with distance travelled, instantaneous speed and engine idle time.
in predicting fuel-consumption is investigated with acceptable accuracies. It has been investigated that accelerating and decelerating patterns (hard braking and hard accelerating) have significant impacts on fuel-consumption. The data was collected in the suburbs of the Bangkok city and purely based on real-world driving patterns by different kinds of vehicles.

Three different kinds of vehicles were selected as study vehicles in our reseach. The vehicles have the characteristics as; 6-Wheeler Natural Gas Vehicles, 18-Wheeler Natural Gas Vehicles, 18-Wheeler Diesel Vehicles. The data was collected for a time span of eight (8) weeks and the modeling was done very carefully in such a way that the parameters which don’t have statistically significant impacts on fuel-consumption were ignored in our analysis. Another selection criteria of our modeling was the best fitting models which can provide the best possible fitting of the data in the modeling process. The collected data contained the information of latitude, longitude, distance, speed, hard braking incident, hard accelerating incident, fuel-consumption and vehicle idle time. The data included was modeled using micro-modeling (stepwise regression) technique and the area of data collection was Bangkok area.

5.2.1 Data Collection

In this study, around forty-trucks were included and data was collected using Controller Area Networks (CAN) installed in these study vehicles. basically, vehicles were of three different types based on their configuration and fuel-types (6W-NGV, 18W-NGV, and 18W-Diesel). The time span of data collection was approximately two months (eight weeks). The collected data contained the information of latitude, longitude, distance, speed, number of hard braking, number of hard accelerations, location, idle time and fuel consumption record. The time period of data collection was between August of 2017 and November of 2017. The data was collected in the suburbs of Bangkok city. The study vehicles were selected carefully keeping in view of their working conditions. The data was collected by using SECONLINE software used by the company for monitoring of their vehicle operations.
5.2.2 Procedure

There were several meetings happened between the researchers and the company management. In these meetings, the researchers explained the scope and purpose of the study and the company was requested to adjust their incident parameters as per requirement of the researchers. The incidents were recorded in their SECONLINE monitoring system containing information of hard braking, hard acceleration, lane changing activity, engine idle time etc. The time period for data collection was almost two months and stepwise regression was performed to calculate the quantification effects of Instantaneous speed, distance travelled, hard braking, hard accelerating, and idle time on fuel-consumption. In the first attempt, all of the variables were included in the analysis, and then the parameters whose impact was not statistically significant were removed.

5.2.3 Modal Development

Human behavior is very complex and difficult to comprehend due to its dynamic and non-linear nature. It is very much difficult to produce same results from human behavior even if all of the conditions are similar. With increased fuel usage in the recent decades, it is an urgent matter to model the fuel for better results. The modeling of effective fuel-consumption evaluation models is very necessary in real-world driving styles of the drivers.

The main purpose of this study is to describe the quantification impacts of described parameters on fuel-consumption for optimization of fuel-modeling. The stepwise regression modeling was chosen for this purpose because of its less complexity and it’s easy to perform modeling approach by changing the values of the input parameters if required. In this modeling approach, the impacts of different independent parameters (X₁, X₂, X₃, … Xₙ) are measured for dependent variable mentioned as (Y). Stepwise regression modeling is primarily based on the Pearson correlation coefficients. The equation form of the simple model of the stepwise regression models is shown in the following equation 3;

\[ Y = \beta_0 + \beta_1 \sum s + \beta_2 \sum (s \ast v) + \beta_3 \sum (s \ast v^2) + \beta_4 \sum H_b + \beta_5 \sum H_a + \beta_6 \sum I_t + \varepsilon \quad (3) \]

Where;
$Y$ is the dependent variable (fuel-consumption);
$s$ is distance travelled (Km);
$v$ is instantaneous speed (Km/hr.);
$H_b$ is number of hard braking in one fuel-filling period;
$H_a$ is number of hard accelerating in one fuel-filling period;
and $I_i$ is engine idle time in one fuel-filling period (minutes);
$\beta_1, \beta_2, \ldots, \beta_6$ are coefficient parameters; and $\varepsilon$ is a random component (the rest of the model);

The stepwise regression modeling was performed using Microsoft Excel software and some of the indices were used to check the applicability and suitability of the devised models such as $R^2$ value and $p$-value. $R^2$ value manifest the accuracy of the data fitting, while $p$-value shows if the proposed model is statistically significant or not and can be used for modeling purpose.

The Global Positioning System (GPS) data was too scattered with uneven timestamp intervals. The time interval duration of data points ranges from one second to several minutes sometimes. So, because of the non-homogeneity of the data, some of the data was filtered and calculations of fuel consumption were carried out for each tank filling. The typical example of the data is shown in the following figure;

![Figure 5.6: Typical example of data](Ref. code: 25605922040224YBC)
The driving variables in each tank filling were used determinants of fuel calculations. This fuel calculated (Predicted fuel consumption) was compared with fuel consumption data provided by the company for each tank filling (Measured fuel consumption). The analysis is carried out and, in each iteration, the best models describing good fit of data and most accurate calculations of fuel-modeling were included in the results sections. The analysis includes many steps and the best describing models were selected. The detailed illustration of the steps adopted in analysis is shown in Figure 5.7.

Figure 5.7: Procedure of step-wise regression modeling using Microsoft Excel

5.3 Results and Discussions

In this study, an attempt to quantify the impacts of driving patterns on fuel-consumption are observed under the given parameters of distance travelled, instantaneous speed, number of hard braking, number of hard accelerations, and engine
idle time. Only the parameters which have statistically significant impact on fuel-consumption are included in the modeling process. The fuel-consumption was modeled using real-world driving pattern parameters and the percentage error between the observed and predicted fuel-consumption lies in the range of 12.02% and 12.85% for 18W-NGV and 18W-Diesel vehicles, respectively. Two of the important parameters or indices considered for selection of suitable mode were $R^2$ value and the $p$-value. $R^2$ gives the idea that the data is fit while $p$-value gives the information about if the parameters are statistically significant or not. For 6-Wheeler NGV truck, the regression analysis is shown in Table 5.3, containing the parameters having significant impacts on fuel-consumption.

Table 5.3: Regression analysis results of 6W-NGV Truck

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Standard Error</th>
<th>$t$ Stat</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0</td>
<td>#N/A</td>
<td>#N/A</td>
</tr>
<tr>
<td>$v \times s$</td>
<td>0.0129</td>
<td>0.0020</td>
<td>6.4311</td>
</tr>
<tr>
<td>$v^2 \times s$</td>
<td>(0.0002)</td>
<td>0.0000</td>
<td>(4.5009)</td>
</tr>
<tr>
<td>$H_b$</td>
<td>1.5461</td>
<td>0.1969</td>
<td>7.8515</td>
</tr>
<tr>
<td>$I_t$</td>
<td>0.0365</td>
<td>0.0108</td>
<td>3.3938</td>
</tr>
</tbody>
</table>

According to the defined parameters which have statistically significant impacts on fuel-consumption, the regression model takes the form (Model 1); analysis shows that distance travelled, instantaneous speed, number of hard braking and engine idle time have significant impacts on fuel-consumption. The proposed model is shown in the following equation.

$$Y = 0.0129 \times v \times s - 0.0002 \times v^2 \times s + 1.5461 \times H_b + 0.0365 \times I_t$$  \hspace{1cm} (Model 1)

It can be defined as that, with respect to model 1, the fuel-consumption will increase by 1.5461 Kg, if there is an additional number of hard braking, provided all other mentioned parameters do not change. It is also evident from Model 1 that increase in idle time leads to increase in fuel-consumption. The fuel-consumption will increase by 0.0365 Kg, if there is an increase of one minute in the idle time duration provided that all other parameters remains constant. The very high value of $R^2$ (0.9789) shows...
that these parameters are the best fit to predict the amount of fuel-consumption. However, the $R^2$ value between the measured and predicted fuel-consumption is 0.8573, which shows that they are in good agreement with each other with an average error of 12.02%.

Figure 5.8: Measured Vs. predicted fuel-consumption for 6W-NGV Truck

Figure 5.8 showed the scatter plot between predicted and measured fuel-consumption at 95% of the confidence interval. The modeled fuel-consumption is calculated using step wise regression approach in such a way that the variables which are not statistically significant are removed from the analysis and the $p$-value is checked. If the $p$-value is less than 0.05, then the variable is accepted otherwise it is rejected from the analysis (Model 1). The Figure 5.7 shows the good fit of the model with an acceptable accuracy between the measured and predicted fuel-consumption. It shows that predicted and measured fuel-consumption for 6-Wheeler Natural Gas Vehicles (NGV) are in good fit with each other and modeled equation (Model 1) has the potential to predict fuel-consumption based on the driving patterns of the vehicles operating in real-world driving conditions under the constrained variables mentioned in the analysis. The scattered plot between the predicted and measured fuel-consumption for 6-Wheeler Natural Gas Vehicles takes the form with $R^2$ value of 0.8573 and average error of 12.02%.
The modeled regression equation for 18-Wheeler Natural Gas Vehicles can be illustrated in the following equation and it is very much important to illustrate those four variables of distance travelled, instantaneous speed, number of hard braking and idle time have statistically significant impacts on fuel-consumption. Table 5.4 shows the p-values of the mentioned variables and coefficients all containing variables.

### Table 5.4: Regression analysis results of 18W-NGV Truck

<table>
<thead>
<tr>
<th></th>
<th>Coefficients</th>
<th>Standard Error</th>
<th>t Stat</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>- #N/A</td>
<td>#N/A</td>
<td>#N/A</td>
<td>#N/A</td>
</tr>
<tr>
<td>S</td>
<td>0.4618</td>
<td>0.0300</td>
<td>15.3682</td>
<td>0.0000</td>
</tr>
<tr>
<td>v² * S</td>
<td>(0.0001)</td>
<td>0.0000</td>
<td>(6.5693)</td>
<td>0.0000</td>
</tr>
<tr>
<td>H_b</td>
<td>0.7332</td>
<td>0.0845</td>
<td>8.6761</td>
<td>0.0000</td>
</tr>
<tr>
<td>I_t</td>
<td>0.0073</td>
<td>0.0032</td>
<td>2.2644</td>
<td>0.0243</td>
</tr>
</tbody>
</table>

The equation showing the modeling of 18-W Natural Gas Vehicles can be shown as follows (Model 2):

\[ Y = 0.4618 * s - 0.0001 * v^2 * s + 0.7332 * H_b + 0.0073 * I_t \]  

(Model 2)

The results of the model 2 can be explained in the following manner; the fuel-consumption of the vehicle will increase by 1 0.4618 Kg, if there is an increase of 1-Km in distance travelled by vehicle provided that all other parameters do not change. It is obvious that increase in distance will leads to increase in fuel consumption. Similarly, there would be an increase in fuel-consumption by 0.7332 Kg, if there is increase in number of hard braking by one provided that all other variables remain same. It also reveals that an increase in idle time by one minute will lead to an increase in fuel-consumption by 0.0073 Kg, provided that all other variables do not change. The scatter plot between predicted and measured fuel-consumption is shown in Figure 5.9. The plot shows that there is very good fit of model with the measured value with \( R^2 \) value of 0.9389. The average error between the predicted and measured fuel-consumption is 7.70%. The scattered plot between predicted and measured fuel-consumption can be shown in the following figure.
The regression model for 18-Wheeler Diesel Vehicles contains distance travelled, instantaneous speed and number of hard braking (Model 3). The variables which do not have statistically significant impact on fuel-consumption were rejected from the analysis. The results of the model 3 can be explained in the following fashion: the fuel-consumption of the vehicle will increase by 0.4335 Kg, if there is an increase of 1-Km in distance travelled provided that all other variables do not change. Again, it is understood that increase in distance travelled will be in agreement with increase in fuel consumption. It can also be inferred from Model 3 that an increase in number of hard braking will also accumulate in extra fuel consumption. For example, an increase of 0.4290 Kg in fuel-consumption will happen if there is an additional number of hard braking, provided that all other variables are unchanged. The regression equation developed for modeling of 18-Wheeler Diesel Vehicles can be illustrated in the following form.

\[ Y = 0.4335 \times s - 0.0102 \times v \times s + 0.0001 \times v^2 \times s + 0.4290 \times H_b \]  

(Model 3)
Table 5.5: Regression analysis results of 18W-Diesel Truck

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Standard Error</th>
<th>t Stat</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.0000</td>
<td>#N/A</td>
<td>#N/A</td>
</tr>
<tr>
<td>s</td>
<td>0.4335</td>
<td>0.0281</td>
<td>15.4501</td>
</tr>
<tr>
<td>v * s</td>
<td>-0.0102</td>
<td>0.0007</td>
<td>-15.0951</td>
</tr>
<tr>
<td>v^2 * s</td>
<td>0.0001</td>
<td>0.0000</td>
<td>43.6477</td>
</tr>
<tr>
<td>H_b</td>
<td>0.4290</td>
<td>0.0771</td>
<td>5.5619</td>
</tr>
</tbody>
</table>

Figure 5.10 shows a very good fit of the predicted and measured fuel-consumption for 18-Wheeler Diesel Vehicle. The $R^2$ value of the model is 0.9439. The average error between the predicted and measured fuel-consumption is 12.85%. The scatter plot between predicted and measured fuel-consumption can be illustrated in the following figure.

Figure 5.10: Measured Vs. predicted fuel-consumption for 18W-Diesel Truck

The average error for 6-W NGV, 18-W NGV, and 18-W diesel vehicles is 12.02%, 7.07%, and 12.85%, respectively. The scattered plots between modeled and measured values are shown in Figures 5.8, 5.9, and 5.10, respectively. The models (1, 2, and 3) show that distance travelled, instantaneous speed, number of hard braking, and engine idle timings have statistically significant impacts on fuel-consumption. While, the impacts of hard accelerating are not statistically significant on either of the
vehicle type. Moreover, instantaneous speeds have positive and negative impacts on fuel-consumption based on the range of instantaneous speed values. Instantaneous speeds have negative relationship with fuel-consumption at very low and very high-speed ranges.

5.4 Conclusion

This study showed the application of stepwise regression modeling to characterize the fuel-consumption of heavy-duty vehicles under real-world driving conditions. It is being observed that these driving parameters have significant impacts in predicting fuel-consumption. It is also observed that fuel-consumption is dependent on distance travelled, instantaneous speeds, accelerating, decelerating patterns and engine idle timings. All of these variables have statistically significant impacts on fuel-consumption except number of hard accelerating. These regression equations with acceptable accuracies have the tendency to predict fuel-consumption while the driving pattern variables are observed in real-world driving situations. The inclusion of some other parameters such as engine speed, fuel-type, payload, traffic conditions and the topography of the road structure may increase the accuracy of these models.

5.5 Limitations and Future Work

There are some limitations in this study; the most prominent of them include the detailed information of some of the important factors. The impacts of road gradient information, payload on the vehicles, configuration of traffic signals on the routes, and engine working condition can may improve the accuracy of the proposed models. The inclusion of engine rotation speed and loading information can also be used to predict the fuel-consumption and the impacts of these parameters on fuel-consumption. Moreover, the data used in this analysis was very scattered with so much information missing. The quality of the data was directly attributed to the accuracy of the proposed models.

For the continuity of this work, the impacts of the above-named parameters on fuel-consumption will be observed. In the further analysis, an attempt to develop more
accurate models will be made based on inclusion of more specific information. Most importantly, the impacts of prevailing traffic conditions and loading conditions are inevitable to analyze for fuel-consumption modeling.
Chapter 6
Conclusions and Recommendations

The fuel-consumption is an important and urgent issue to discuss in the recent
decade due to the globalization of the transportation industry. A large amount of the
total fuel produced is used by the transport sector which is a secondary consumer of
energy after industrialization. In the transportation industry, drivers are the important
components who are equally responsible of high amount of fuel-consumption.
According to the research, around 5-25% of the fuel-consumption can be reduced by
moderating the driving styles of the drivers (Sivak & Schoettle, 2012b). So, moderating
fleet operations is becoming the first priority of the fleet managers as well other
stakeholders in transportation sector.

This study is primarily consisting of three sections. In the first section an
Incident Scenario Matrix Approach (ISMA) is designed to accurately identify the
blamed-party for extra fuel-consumption. In the second part, the behavioral response of
the truck drivers is recorded about their motivations to practice eco-driving in three
different contexts. In the last section, the impacts of driving patterns of heavy-duty
vehicles on fuel-consumption are investigated. An attempt to model the fuel-
consumption is made to observe the quantification impacts of Instantaneous speed,
number of hard braking per km, number of hard accelerating per km, and engine idle
time using multi-linear stepwise regression approach.

Incident Scenario Matrix is designed by keeping in view the general causes of
extra fuel consumption and listening the concerns of the logistics managers and truck
drivers. Three main blamed-parties were defined according to the responsible body
against different registered cases of extra fuel. Blamed-parties were mainly of three
kinds; self-blame, other-blame and circumstance-blame. To be exact, eighteen different
scenarios were devised carefully with three definite factors of driving behavior, driving
conditions, and vehicle. According to our approach of classification, if the registered
case falls in the category of self-blame, then driver would be held responsible otherwise
company or third-party logistics have to accommodate the expenditures of the extra
fuel. But, if the extra fuel consumption registered case comes in the category of
circumstance-blame, then company have to bear the expenditures without putting burden on drivers. As per the data collected, around seventy-six (76%) of the registered cases do not come in self-blame. So, the design of ISMA provides an opportunity for the stakeholders to accurately identify the blamed-party who is responsible for extra fuel-usage.

The response of Thai drivers against different eco-driving contexts was recorded based on their marital status, education levels, age and driving experience. Three defined contexts were; changing driving behavior to become eco-driver based on information about eco-driving, adopting eco-driving behavior when asked to be in competition with fellow drivers, and impacts of penalty or reward contexts on eco-driving motivations. The self-reported response of Thai drivers was very interesting and there was statistically significant difference in behavioral response by different group of drivers. The drivers were categorized as single, married and in-relationship drivers based on their marital status. While, education level classified drivers as drivers with primary education, secondary education, high school education, and university level education. Based on the age of the drivers, they were group in three types; less than 30 years old, 30-50 years old, and more than 50 years old. While, driving experience was categorized into three divisions; less than 5 years, 5-10 years, and more than 10 years. The results manifested that in-relationship drivers, drivers with secondary and high school education manifested statistically significantly different behaviors in given motivation. Almost all of them showed strong motivations when they are asked to change their driving behaviors. However, their response when they are asked to be in competition with fellow drivers is poor in all given contextual scenarios.

In the last part of the study, the impacts of the driving pattern parameters on the fuel-consumption of the heavy-duty vehicles were investigated. The core parameters discussed in this study include distance travelled, instantaneous speed, number of hard braking, number of hard accelerating, and engine idle time. The data contained the information of latitude, longitude, speed, distance, location, and fuel consumption records. Data was collected for a time period of two months (i.e., August and September) of 2018. Three different vehicles were selected based on their configuration; 6W-NGV, 18W-NGV, and 18W-Diesel vehicles. The stepwise linear
regression technique was employed to model fuel-consumption. It was observed that instantaneous speed having positive and negative impacts on fuel-consumption depending upon the range of speed. As a general rule, instantaneous speed has negative implications on fuel-consumption when speed range is very low or very high. Otherwise, it has positive impacts on fuel-consumption.

An important point to ponder in our analysis is almost all of the included variables have statistically significant impacts on fuel-consumption. Two indices were defined as criteria to select the regression model, $R^2$ value and $p$-value. $R^2$ value shows the fitness of the data, while $p$-value manifest the significance of the variables on modeling. The results showed that the equations (models) developed using stepwise linear regression approach having acceptable accuracies have the potential to predict fuel-consumption of heavy-duty vehicles in real-world driving patterns.

However, there are still some of the limitations of this study. More number of incident scenarios can be devised with the inclusion of more factors leading to extra fuel-consumption. Some of the factors that can be accommodated for formulation of extra fuel-cases can be payload, accessibility, and fuel-type etc. This study gives the general guidelines for the logistics managers in classifying the extra fuel cases. While, more specific incident scenarios can be designed to make them workable in challenging working conditions. Moreover, the eco-driving response of the drivers was purely based on their self-reported behavioral response which may distort the results because of the social desirability of the drivers. The impacts of many managerial policies such as bonus systems, job security etc. can be investigated. It may reinforce and further clarify the recorded response in given contextual scenarios. For evaluating the impacts of the driving variables on fuel-consumption, the loading information, road slope, traffic conditions and engine condition can be the useful variables included in our study which possibly can increase the accuracy of the proposed models.

This study has manifold objectives to address the fuel-consumption in the transportation sector. It explores from fuel-control policing to fuel-modeling and eco-driving response of drivers to study their behavioral response in different contexts. But, the core purpose of the study includes the limitations of extra fuel usage in logistics operations from management, responsive and modeling prospects. This study can be
proved as a milestone in covering multi-dimensional aspects in fuel-controlling and gives the response of the drivers showing their motivations to practice eco-driving.
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