Master's Thesis
석사 학위논문

Intelligent Transportation System:
Route Guidance, Driving Behavior, and Eco-driving

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Department of Information and Communication Engineering

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Advisor : Professor Park, Taejoon
Co-advisor : Doctor Son, Joonwoo

by

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A thesis submitted to the faculty of DGIST in partial fulfillment of the requirements for the degree of Master of Science in the Department of Information and Communication Engineering. The study was conducted in accordance with Code of Research Ethics[1]

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[1] Declaration of Ethical Conduct in Research: I, as a graduate student of DGIST, hereby declare that I have not committed any acts that may damage the credibility of my research. These include, but are not limited to: falsification, thesis written by someone else, distortion of research findings or plagiarism. I affirm that my thesis contains honest conclusions based on my own careful research under the guidance of my thesis advisor.

Intelligent Transportation System:
Route Guidance, Driving Behavior, and Eco-driving

Jeong-il Son

Accepted in partial fulfillment of the requirements for the degree
of Master of Science.

12 . 03 . 2013

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ABSTRACT

There have been numerous modern technological advances that have changed life for many people. Transportation fields are evolving, too. This thesis suggests intelligent transportation systems (focused on general vehicles) using smart sensors, high-powered computers, and advanced communication technologies. This thesis divided into three parts. The first part is the study on route guidance systems. Existing general route guidance systems focused on shorter travel time and distance. However, it is not the most important element in deciding a route. Thus, this study aimed to quantify the quality of alternative routes by explicitly considering route travel time variability. The second part is the study on driving behaviors. This study aimed to propose a new index to capture drivers' aggressiveness by analyzing inter-vehicular dynamics data and to demonstrate how the proposed index would work using real world driving behavior data obtained from four distinctive groups. The final part is the study on eco-driving. The proposed system in this study can offer a recommended speed to drivers and volume of traffic to traffic light control system. This can make an improved traffic environment. This system can reduce fuel consumption and CO2 emissions.

Keywords: route guidance, driving behavior, eco driving

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Chapter 1. Introduction

We live in an age of high technology. Many smart sensors can gather information in different ways. The advanced communication technologies transmit the information in real-time, and high-powered computers can process large amounts of information. Technology can help people develop more efficient and more intelligent systems. This thesis focuses on general vehicles adapted to the transportation system to make a more efficient and safer system. Transportation systems have many issues such as environmental pollution, traffic congestion, traffic accident, etc. The object of this study is to develop a reliable intelligent transportation system using advanced technologies. This study selects three issues in transportation systems. First is the route guidance issue. Drivers want to find the optimal route. However, the significance of the optimal route is ambiguous because drivers have their own best elements to find the optimal route, including travel time, friendly route, safe route, etc. This study offers information to quantify the quality of alternative routes. Drivers can select their preferred route. The second issue is driving behavior. All drivers have their own style of driving. Some drivers are aggressive. They generate dangerous situations on the road. If we have information about the driving behavior of a specific group, it can help people make the roads safer. Therefore, we analyze four groups that were segmented on the basis of age and gender, and then obtained the aggressiveness level of each group. The third issue is eco-driving. Vehicle emissions are the main cause of global warming, which is itself, one of the worst environmental problems. This study reduces fuel consumption and emissions by improving traffic flow at intersections. We use advanced technology to resolve the three issues in the transportation system. This thesis makes two suggestions: improved transportation systems and the potential collaboration between advanced technology and the transportation system. The proposed systems in this thesis are developed using various new technologies.

This thesis has covers the three main issues mentioned above and is therefore composed of three parts: route guidance system, driving behavior, and eco-driving.

The first part is the research about route guidance systems. Travel time data becomes widely available with the deployment of location-based technologies including GPS-equipped vehicles and cell phones, Bluetooth readers, Dedicated Short Range Communication devices, etc. This change has made a shift in the existing distance or historical speed-based route guidance to travel time-based route guidance. For example, commercial GP-based navigation systems utilize real-travel time data to update en-route guidance. However, the variability of link travel times is not explicitly considered. This part explores route viability using real-time link travel time data obtained from Dedicated Short Range Communication (DSRC) devices in Daegu City, South Korea. The purpose of this study is to quantify the quality of alternative routes by explicitly considering route travel time variability. To demonstrate the practical implication of the proposed route viability, a few origin and destination pairs are selected, the distributions of shortest travel time routes (i.e., the best and the second best routes) are generated, and the viability of the shortest routes are compared on the basis of the viability index. It is found that the shortest route based on average travel time is not always the best route due to travel time variability; such a viability index helps travelers understand the quality of the routes.

The second part is the research about driving behavior. Understanding drivers' aggressiveness can be useful for many aspects ranging from negotiating insurance premiums to determining appropriate perception-reaction time for driver specific warnings. Most studies have used (i) survey questionnaires asking about the crash experience, citations, and driving behaviors, and/or (ii) analyzed individual vehicular data such as maximum deceleration rate and highest speed. This study proposes a new index that captures drivers' aggressiveness based on inter-vehicular dynamics data. The proposed index based on the time-to-collision and deceleration rate difference is applied to real world vehicular dynamics data obtained from drivers participating in driving tests. The proposed index clearly shows that younger female drivers are the most aggressive, followed by younger male drivers. Responses of survey questionnaire data from the participants are compared with the proposed index. The results indicate that the index does not appear to match well with some drivers, implying that questionnaire responses might not be the best indicator for capturing drivers' aggressiveness. However, responses on unintentional violation and ideal safe driving speed support the proposed aggressiveness index.

Finally, we study eco-driving system. Nature-friendly systems have become major issues in the transportation system. Increasing vehicle fuel consumption and emissions are aggravating global pollution. Fuel consumption and emissions are influenced by acceleration, stop-and-go times, idle time, etc. To reduce the pollution from automobiles, the elements that increase fuel consumption and emissions should be eliminated. This study proposes a traffic light cycle and vehicle velocity control system using Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communication for reducing fuel consumption and emissions. The proposed system has two phases. In the first phase, the vehicles calculate the optimal speed for driving safety and eco-driving. The optimal speed is calculated by driving pattern and traffic signal information. In the second phase, the traffic light control system calculates the improved cycle, and this system will support smooth traffic flow. The improved traffic light cycle is suggested by collecting traffic flow data. Simulation results indicate that the proposed system can reduce fuel consumption and emissions. The nonstop passing rate at intersections is increased and accelerating rate, idle time, and stop-and-go times are all decreased. Consequently, fuel consumption and emissions are greatly reduced.

We explained more detail about the three issues in the next sections. The route guidance issue is presented in Section 2. In Section 3, driving behavior issue is explained using survey questionnaires and real driving data. The eco-driving issue is presented in Section 4. This section will show a bi-level programming model using traffic light cycle control and vehicle speed control. Section 5 concludes this study.

Chapter 2.

Quantifying Route Quality through Viability Indices using Actual Travel Time Data

2.1 Introduction

A route guidance system typically provides travelers with the shortest route based on link cost such as distance, historical speed, or real-time travel time so that travelers can arrive at their destinations as early as possible. Studies have shown that route guidance systems are effective in improving travel time [1]. In practice, when multiple routes or an alternative route are considered, existing route guidance systems mostly rely on average travel times without explicitly considering variability in link or route travel times. In many cases, travel time reliability is a more important factor than average travel time. For example, consider that there exists two routes to an airport, and assume that route 1 has a faster average travel time but much wider variability than route 2. A traveler would prefer to take route 2 if route 1 travel time variability would possibly make him/her miss the flight. In addition, one might ask how much route 1 is better than route 2 if a traveler does not have to catch a flight, or how viable is route 2 when compared to route 1. In general, a route guidance system only provides a "recommended route" without providing viability of the next best route. Indeed, a main reason that this has not been practiced in the real world is in part due to a lack of available link/route travel time data.

In recent years, link travel time data have become widely available through the deployment of various location-based technologies. One example is a Dedicated Short Range

Communication (DSRC) system deployed in Daegu City, South Korea. The DSRC uses two-way wireless communications between the onboard equipment (OBE) installed within the vehicle and the roadside equipment (RSE) installed at the roadside infrastructure. Each vehicle equipped with OBE sends its information (i.e., randomly generated unique vehicle ID and time stamp) whenever it passes RSE. Thus, the link travel time between RSE locations can be obtained by matching the vehicle IDs and time stamps. Given that Daegu City has over 10% of its vehicles equipped with DSRC, the sample size for estimating average link travel time is more than adequate. A study found that a sample of about 5% is more than enough to estimate average travel time for any given link [2].

The purpose of this study was to quantify the quality of alternative routes by explicitly considering actual route travel time variability. The travel time data was obtained from Daegu City and used to generate the distributions of route travel times of the best and next best routes, and the route viability was calculated on the basis of overlaps between the two distributions. The remainder of this thesis is organized as follows: the travel time data in Daegu City section presents the background of Daegu City, the DSRC system deployed and the travel time to be used in this study. The methodology section discusses proposed route viability indices based on the probability of one route being better than the other using the travel time distributions. The implementation and results section presents case studies of three selected origin destination pairs to demonstrate how the proposed route viability indices can be calculated and the results can be informed to travelers. Finally, the concluding remarks section summarizes the findings of this study and gives recommendations for future research.

2.2 Travel Time Data in Daegu City

Daegu is one of the largest cities in South Korea. The abrupt growth after the economic recession in South Korea changed the paradigm and modernized the big business cities with a fast-paced lifestyle. These changes created greater traffic mobility challenges across larger cities as people use urban transport facilities in a greater magnitude these days to save time. Traffic management thus plays a vital role in providing time-effective, cost-effective and secure urban mobility around these larger cities where a day-to-day voyage is now always in the fast-lane.

To meet the needs of urban mobility in Daegu City, the Ministry of Land, Transport and Maritime Affairs invested about 4.2 billion Korean WON (about 4 million dollars) to introduce an Advanced Traffic Management System that provides commuters with real-time traffic information to help reduce traffic congestion [3]. The goal of this traffic management system was to provide innovative services that relate to different modes of commutations to give commuters flexibility, keep them well-informed, and help them to take safe and coordinated travel routes for daily life mobility. Similarly, Intelligent Transportation Systems (ITS) were deployed around the Daegu Metropolitan Area where the first phase was utilizing a web-based service for travelers (http://car.Daegu.go.kr/) providing transportation network congestion levels as shown in Figure 2.1 The web-based service also provides CCTV camera footage and the maps of VMS deployed.

Figure 2.2 shows the Daegu network used in this study. The locations of the roadside equipment (RSEs) deployed in the City are shown in red dots. Daegu City currently archives a short span of time (about a month) worth of individual DSRC communications data during peak hours. Thus, this study focused on the afternoon peak hours between 5 PM and 7 PM. The raw data was processed using a MATLAB code that parses randomly assigned vehicle IDs, time stamps at a given RSE, and then matches the vehicle IDs between adjacent RSEs, and finally retrieves travel times between RSEs by subtracting time stamps.

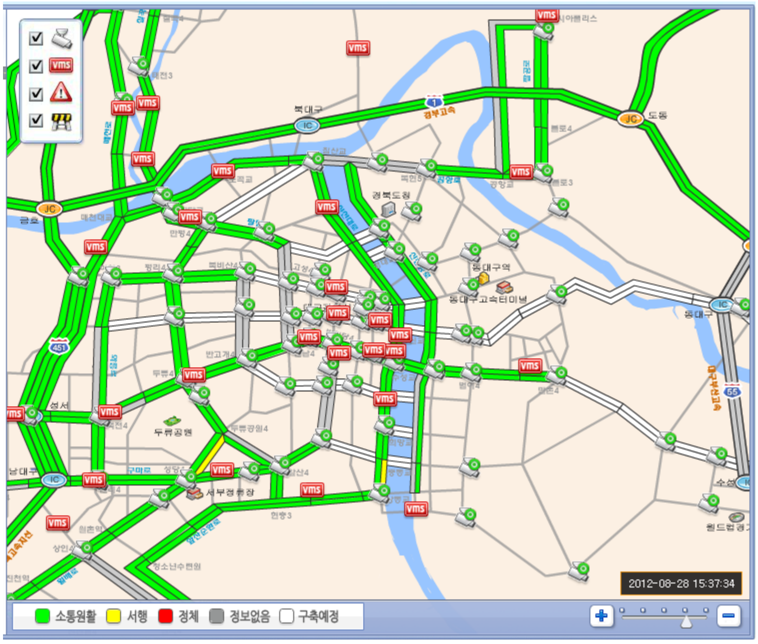


Figure 2.1 Web-based Traveler Information System in Daegu City

Figure 2.2 Daegu City Network with the RSE Locations (Red Dots is RSE)

2.3 Methodology

In this thesis we propose two route viability indices utilizing the distributions of the two routes' travel times. The first is called the 'dominancy index', and is the probability that the superior route is faster than the inferior route, while the other is called the 'beat the average index', and is the probability that the inferior route is faster than the average of the superior route. It is noted that superior and inferior routes are defined on the basis of average travel time.

To describe the proposed indices, the following two routes between origin node 25 and destination node 28 are considered.

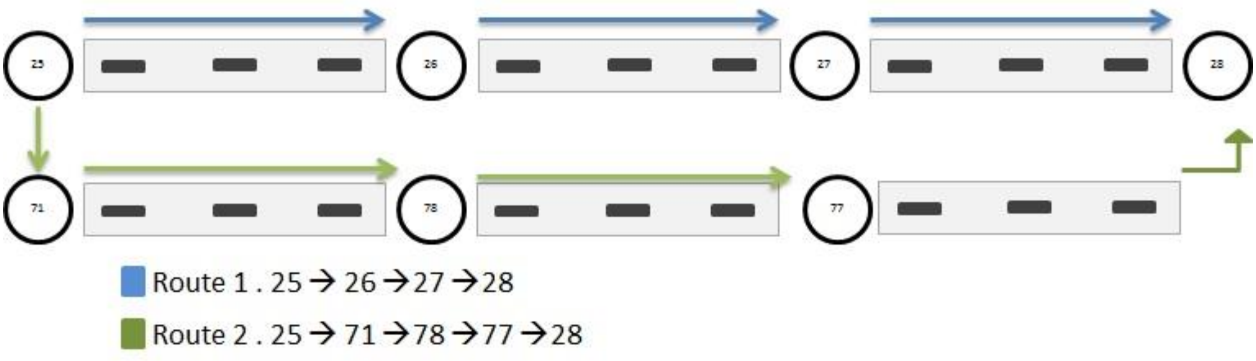


Figure 2.3 Two Routes between Node 25 and Node 28

It is assumed that route 1 is superior to route 2 in terms of average route travel time.

- Route 1: superior route having shorter average travel time
- Route 2: inferior route having longer average travel time

As shown in Figure 2.4, the dominancy index indicates how good the superior route is compared to the inferior route. When there is no overlap between the two route travel time distributions (Figure 2.4 (b)), the superior route completely dominates the inferior route with a dominance index of 1. If an overlap exists, the probability shown in Figure 2.4 (a) represents the dominancy index. Similarly, the beat the average index represents the probability that the inferior route can be better than the average of the superior route as shown in Figure 2.5.

In order to demonstrate the practical implications of these two indices, three representative origin-destination pairs were chosen from the Daegu network. For each of these three pairs, two alternative routes were generated. It is noted that one can generate two best routes using K-shortest path algorithms using average link speed. In this thesis, two routes between the origin and destination were identified on the basis of network knowledge. For example, one is a habitual route and the other is an alternative route to a commuter.

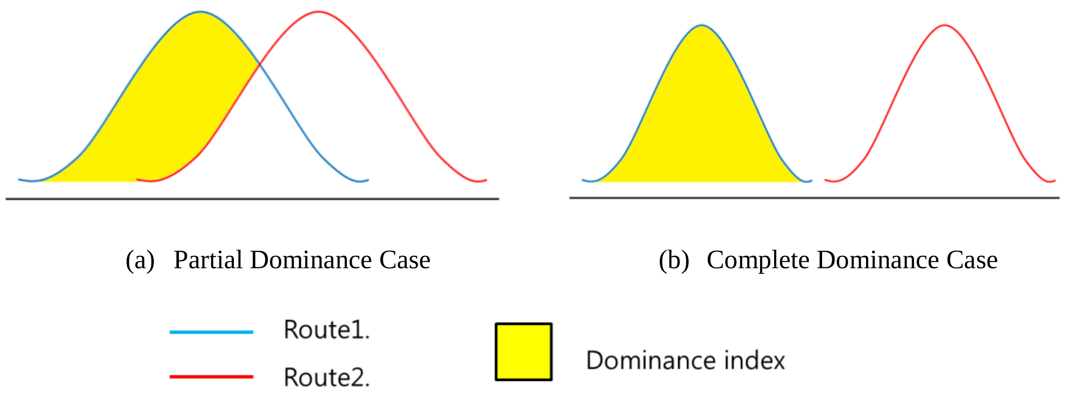


Figure 2.4 Dominance Index shown as Probability being a Superior Route is better than an Alternative Route

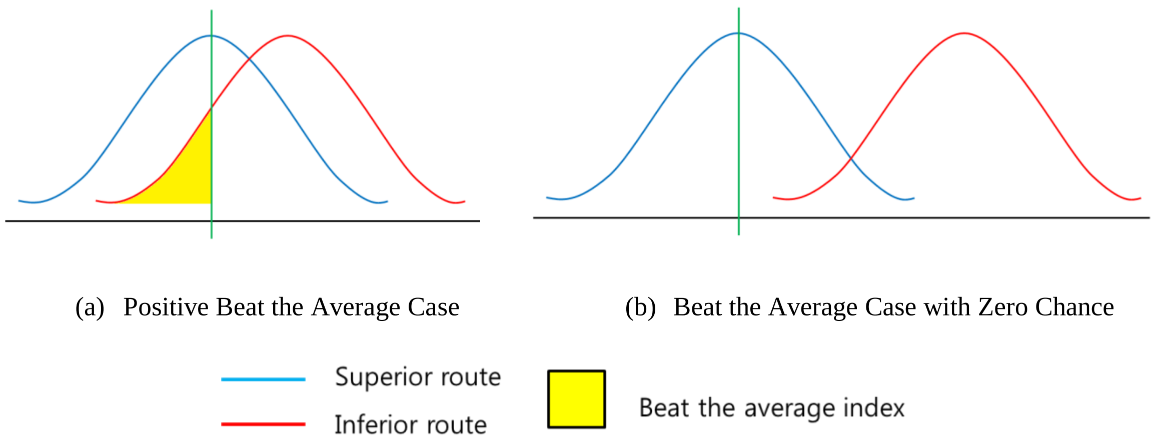


Figure 2.5 Beat the Average Index shown as Probability being an Inferior Route is better than the Average of a Superior Route

2.4 Implementation and Results

As noted, the proposed route viability indices were implemented on three sets of origin destination pairs within the Daegu City network. For each origin and destination (OD) pair, two alternative routes were identified and the distribution of each route travel times was developed. Both route travel time distributions were plotted together. From the distributions, the dominancy index and the beat the average index were calculated.

2.4.1 OD Pair 1

Two viable routes between node 2 and node 14 are shown in Figure 2.6. As noted, these two routes are those that a typical traveler or commuter would take as his or her primary and secondary routes. The travel time distributions were developed by analyzing only vehicles that pass through the entirety of the routes during the PM peak hours between 5 PM and 7 PM over a one month period. It is noted that the amount of data used for the analysis is likely to be more than enough to ensure the distributions were formed in reasonable shapes. It is also noted that a much shorter interval such as 5 or 10 minutes of real-time data on the very same day or historical average, if appropriate, should be used in real world implementation.

2.4.1.1 Dominancy Index

As shown in Figure 2.7, route 1 is superior to route 2. Thus, the dominancy index is the probability that route 1 travel time is absolutely better than that of route 2 (see Figure 2.4). In this OD pair 1, the dominancy index is 25.4 (or the probability of route 1 being absolutely better than route 2 is 25.4%) as shown in Figure 2.8.

2.4.1.2 Beat the Average Index

As noted, this beat the average index presents the probability of the inferior route being better than the average travel time of the superior route. In this OD pair 1, the beat the average index is 36.2 (or the probability that route 2 travel time is faster than the route 1 average travel time is 36.2%).

Figure 2.6 Origin Destination Pair 1 between Node 2 and Node 14

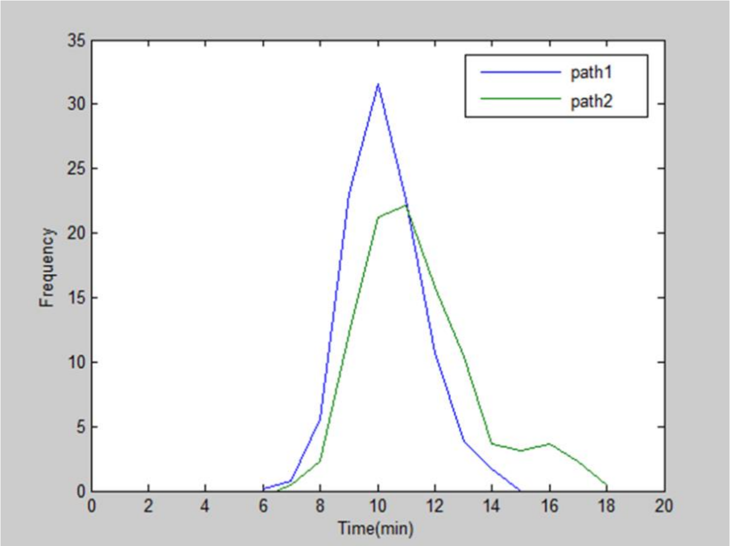


Figure 2.7 Route Travel Time Distributions of OD Pair 1

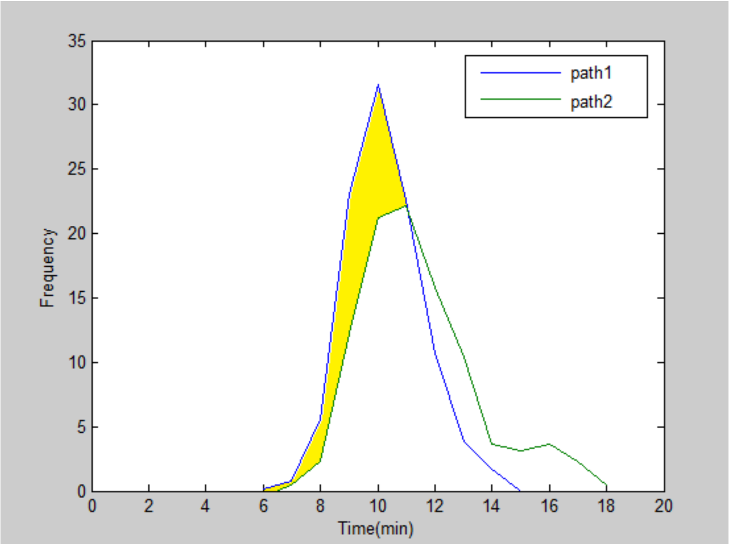


Figure 2.8 Dominancy Index for OD Pair 1 (Yellow-shaded Area)

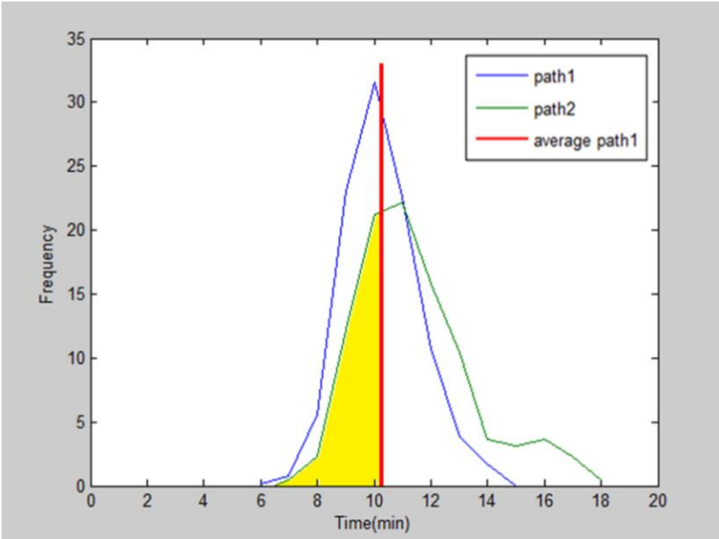


Figure 2.9 Beat the Average Index for OD Pair 1 (Yellow-shaded Area)

2.4.2 OD Pair 2

As shown in Figure 2.10, two viable routes between node 28 and node 36 are shown. Again, these are two alternative routes for typical travelers.

Unlike the OD pair 1 in Figure 2.7, OD pair 2 has slightly distinctive average travel times. That is, the superior route average travel time and its travel time distribution are quite better than those of the inferior route.

Figure 2.10 Origin Destination Pair 2 between Node 28 and Node 36

2.4.2.1 Dominancy Index

As shown in Figure 2.11, route 2 is superior to route 1. In this OD pair 2, the dominancy index is 64.5 (or the probability of route 2 being absolutely better than route 1 is 64.5%) as shown in Figure 2.12.

2.4.2.2 Beat the Average Index

In this OD pair 2, as shown in Figure 2.13, the beat the average index is 5.8 (or the probability that the route 1 travel time is faster than the route 2 average travel time is 5.8%).

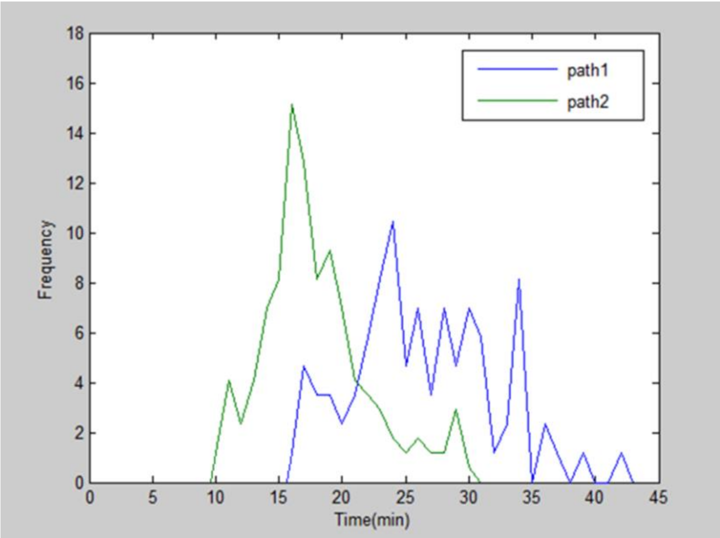


Figure 2.11 Route Travel Time Distributions of OD Pair 2

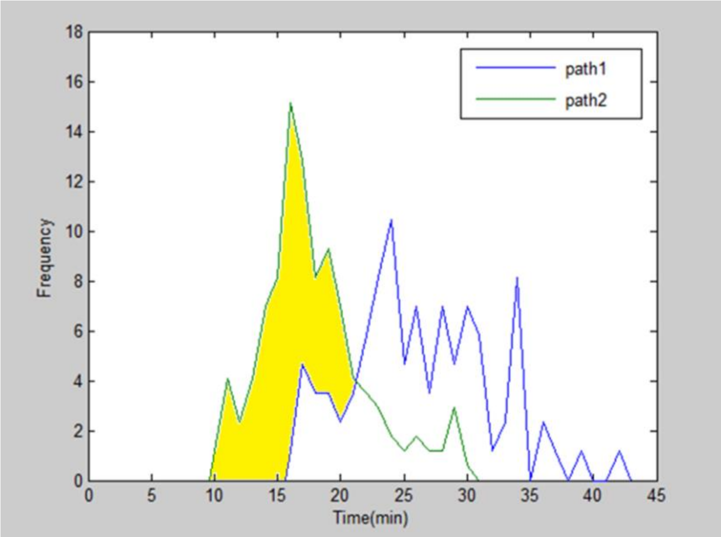


Figure 2.12 Dominancy Index for OD Pair 2 (Yellow-shaded Area)

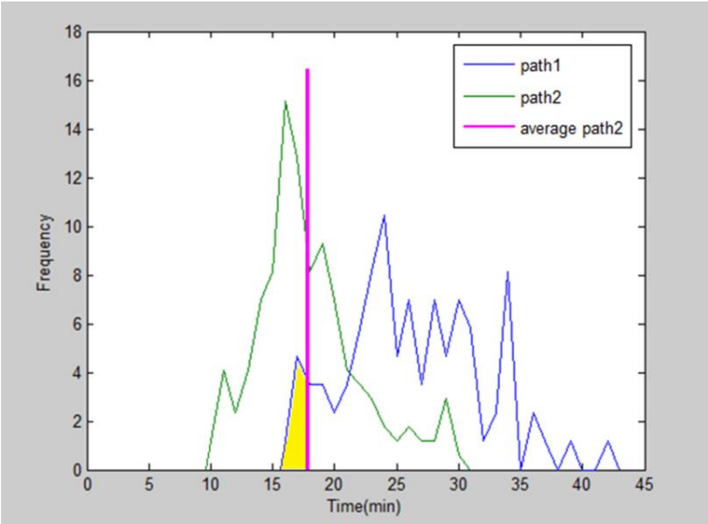


Figure 2.13 Beat the Average Index for OD Pair 2 (Yellow-shaded Area)

2.4.3 OD Pair 3

As shown in Figure 2.14, two viable routes between node 25 and node 28 are shown. Again, these are two alternative routes for typical travelers.

As shown in Figure 2.15, the superior route average travel time is much shorter than that of the inferior alternative route average travel time. The travel time distributions suggest that the superior route dominates the inferior route.

Figure 2.14 Origin Destination Pair 3 between Node 25 and Node 28

2.4.3.1 Dominancy Index

As shown in Figure 2.15, route 1 is superior to route 2. Thus, the dominancy index is the probability that the route 1 travel time is absolutely better than that of route 2 (see Figure 2.4). In this OD pair 2, the dominancy index is 100 (or the probability of route 1 being absolutely better than route 2 is 100%) as shown in Figure 2.16.

2.4.3.2 Beat the Average Index

This beat the average index presents the probability of the inferior route being better than the average travel time of the superior route. In this OD pair 3, as shown in Figure 2.17, the beat the average index is 0.0 (or the probability that the route 2 travel time is faster than the route 1 average travel time is 0.0%).

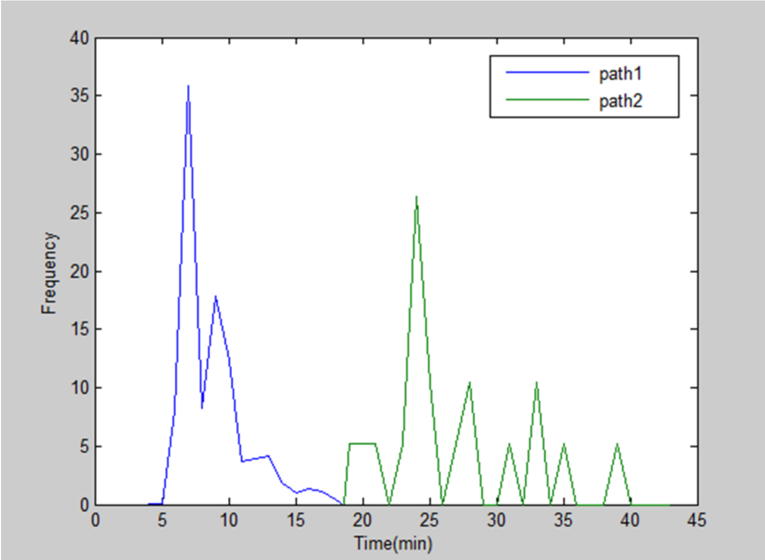


Figure 2.15 Route Travel Time Distributions of OD Pair 3

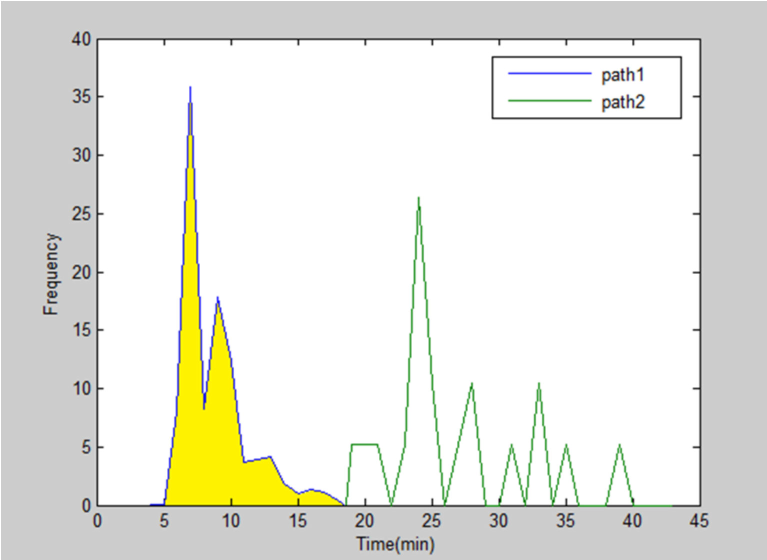


Figure 2.16 Dominancy Index for OD Pair 3 (Yellow-shaded Area)

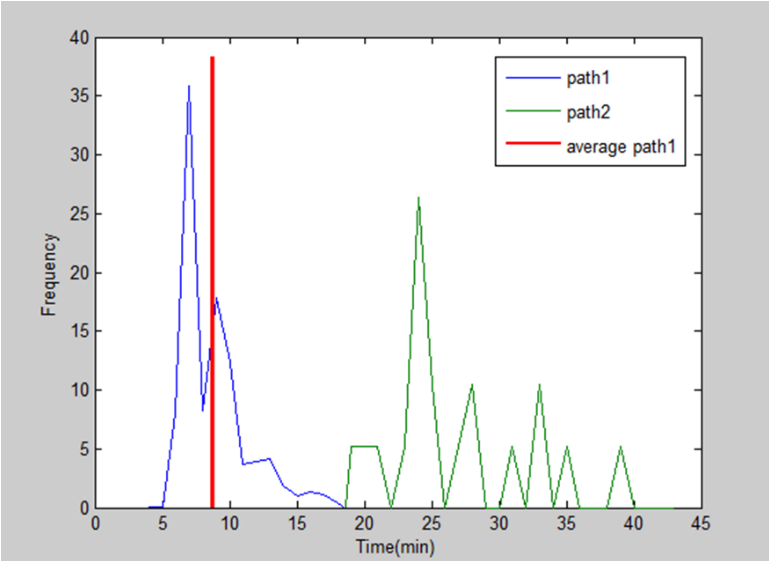


Figure 2.17 Beat the Average Index for OD Pair 3 (Yellow-shaded Area)

2.5 Summary

This thesis proposed route viability indices (i.e., dominancy index and beat the average index) and demonstrated their usages through three selected origin and destination pairs from Daegu City using actual route travel time distributions. The case studies showed that the indices adequately reflect the variability of travel times and provide more informative knowledge on the alternative routes (in terms of how good the superior route is or how good the next best route is). The case studies also showed the importance of utilizing travel time variability as the simple average-based travel time does not provide necessary information for making the most appropriate decision.

Future research should consider developing an algorithm that identifies the best and next best routes that are acceptable by travelers. While K-shortest path algorithm that finds up to K paths can be used for this purpose, it is generally understood that K-paths, often sharing too many common links, do not serve as realistic/viable alternative paths. In addition, the real-time traffic data along with the wireless communications based technology (a.k.a., connected vehicle technology) can help deploy a feedback-based route guidance system by incorporating planned routes as well as real-time updates on en-route changes.

Chapter 3.

Capturing Drivers' Aggressiveness from Inter-Vehicular Dynamics Data

3.1 Introduction

In transportation research, drivers' aggressiveness has been an important factor determining operational control strategies as well as safety enhancement. For an operational control example, a distribution of drivers' aggressiveness could affect the installation of permissive left turn phase – this is because the gap acceptance (i.e., drivers' aggressiveness) determines available capacity during the permissive left turn phase. An additional operational control example includes the determination of a yellow light change interval at traffic lights. In terms of safety enhancement, understanding drivers' aggressiveness can be useful for making the enforcement intensity decision to improve compliance on the posted speed limit, or for providing driver-specific warnings/guidance for crash impending conditions. Thus, researchers relied on the driving behaviors implied from the number of citations and crash experience, or stated driving behaviors such as how they would drive in certain conditions that are obtained from survey questionnaires [6], [7], [8]. Given that these self-reported survey questionnaires might often be unreliable, researchers analyzed actual driving data using deceleration rates and/or speeds. However, none of the research efforts used inter-vehicular dynamics data for measuring drivers' aggressiveness.

The objective of this thesis is to propose a new index to capture drivers' aggressiveness by analyzing inter-vehicular dynamics data and to demonstrate how the proposed index would work using real world driving behavior data obtained from four distinctive groups. The remaining thesis is organized as follows: Section 2 presents the data used in this study, while section 3 describes the procedure used in quantifying drivers' aggressiveness from inter-vehicular dynamics data as well as a driving behavior questionnaire. Section 4 discusses the results from the proposed index and two other aggressiveness measures, and is followed by concluding remarks in Section 5.

3.2 DATA

3.2.1 Subject

Table 3.1 Participants Overview

	Young Adult		Late Middle Age	
Gender	Male	Female	Male	Female
# Subject	13	13	13	13
Age*	27.54 (2.90)	30.46 (3.10)	60.69 (1.89)	57.08 (2.06)
# Naturalistic Driving	7	6	6	7

* Note. Means with Standard Deviations

Atotal of 52 young and late middle age (LMA) adult drivers participated in the study (see Table 3.1) and met the following criteria: age between 25 and 35 or between 55 and 65, drive on average more than twice a week, and be in self-reported good health. Half of the participants were not considered for the proposed aggressive index, because they were supported by advanced driver assistance systems that had affected their driving behaviors.

3.2.2 Instrumented Vehicle

The experiments were conducted using a full size sedan that is instrumented for collecting time-synchronized data. The DGIST instrumented vehicle equipped with six video cameras (two focused on the driver and four focused on the road for environment monitoring), high speed and low speed Controller Area Network (CAN) logger, lane position and headway recorder, driver gaze tracking system, and physiological measurement system. The DGIST-designed custom monitoring software ran separately on four windows-based PCs and synchronized by storing the measurement data with master time that was sent by a main control PC [9].

3.2.3 Data Collection Procedure

Upon completion of informed consent and a questionnaire about safe driving (safety protocol), participants received about 20 minutes of urban and rural road driving experience and adaptation time on the instrumented vehicle. The main driving experiment began when the participant was confident in safe driving with the instrumented vehicle. During the main data collection session, each participant drove 5.5 km of rural road (about 10 minutes), 7.9 km of urban road (about 25 minutes) and 36 km of highway (about 20 minutes). The rural road had a speed limit of 70km/h with one lane each way; the urban road had a speed limit of 60km/h with two to four lanes each way, and the highway had a speed limit of 100km/h with two lanes each way.

3.2.4. Driving Behavior Data

The instrumented vehicle collected various data during the main data collection session. These include vehicle speed, acceleration, engine torque, gear shifting, leading vehicle speed, and distance to the leading vehicle.

3.2.5 Questionnaire Data

Each participant answered a safe driving related questionnaire covering intentional violation, unintentional violation, and self-reported driving behavior. The violation related questions were derived from the Manchester driver behavior questionnaire (DBQ) [8]. Each question used 0-to-4 rating scale. The questionnaire consists of questions about participants' crash history and usual driving habits. In this study, the Questionnaire was used to compare driver's self-reported aggressiveness with the proposed aggressiveness index.

3.3 Procedure for Quantifying Aggressiveness

As noted, understanding drivers' driving behaviors is one of the key elements in improving transportation system operations. Thus, past studies quantified drivers' aggressiveness by analyzing the driving behavior questionnaires and/or the actual driving behaviors [10]. With the best of the authors' knowledge, none of those studies utilized inter-vehicular dynamics data in quantifying drivers' aggressiveness. This is in part because the past studies could not have measured adjacent vehicles' movements. When the driver's aggressiveness is tied to assessing safety or possibly insurance premiums related to traffic crashes, it is critical to consider inter-vehicular dynamics for a proper assessment. Thus, the transportation research community realized the need to utilize inter-vehicular dynamics data in quantifying safety using surrogate measures such as time-to-collision. For example, a recent study proposed potential rear-end crash triggers based on the time-to-collision and deceleration rate difference between two adjacent vehicles using actual crash data obtained from a Minnesota freeway segment [11].

3.3.1 Proposed Aggressiveness Index

This study proposed an aggressiveness index based on these two crash triggers. The index and the two crash triggers are explained as follows:

3.3.1.1 Time to Collision Measure

The time-to-collision (TTC) measure calculates the amount of time taken for the two adjacent vehicles to run into each other when the two vehicles maintain their current speeds on the same path. Obviously, the TTC can only be calculated if the following vehicle travels at a higher speed than that of the leading vehicle. In this study, the TTC is calculated using the equation below [12]:

$$TTC = \frac{Gap\ Distnace}{V_{Following} - V_{Leading}}$$

Where,

TTC: Time to collision (in seconds).

Gap Distance: The difference of following and leading vehicles' distance at a given time (in feet).

$V_{Following}$: Following vehicle speed (in feet per second).

$V_{Leading}$: Leading vehicle speed (in feet per second).

3.3.1.2 Deceleration Rate Difference Measure

While the time-to-collision measure identifies the following vehicle driver's aggressiveness, it often misclassifies a safe condition as unsafe. This happens when the leading vehicle accelerates and the following vehicle decelerates, even though the very moment the TTC might indicate an unsafe condition. It is noted that the unsafe condition caused by the following driver's inattention typically shows the following vehicle driver's positive acceleration and the leading vehicle driver's deceleration behaviors. Thus, the deceleration rate difference (DRD) measure is added to capture unsafe/aggressiveness driving behavior of the following vehicle driver. The equation for calculation of DRD is as follows:

$$DRD = A_{Following} - A_{Leading}$$

Where,

DRD: Deceleration rate difference (in feet per second squared).

$A_{Following}$: Following vehicle acceleration (in feet per second squared).

$A_{Leading}$: Leading vehicle acceleration (in feet per second squared).

Threshold values are needed to indicate the conditions of an unsafe event. This study adopted the values calibrated from real world inter-vehicular traffic data including actual crashes [11]. The threshold values for TTC and DRD are 2.5 seconds and 15ft/sec^2 (4.572m/sec^2), respectively.

3.3.1.3 Proposed Aggressiveness Index

In this thesis, a driver's aggressiveness was assessed using our newly proposed index that quantifies the percent of cases exceeding both the time-to-collision threshold and the deceleration rate difference threshold. Thus, the index represents a driver's aggressiveness using the percentage of time that the driver puts himself/herself into unsafe conditions. The equation for the index calculation is as follows:

$$Indext = \frac{the\ number\ of\ events\ exceeding\ TTC\ and\ DRD\ thresholds}{total\ number\ of\ events\ considered} \times 100$$

3.3.2 Drivers' Aggressiveness from Driving Behavior Questionnaire

3.3.2.1 Radar Chart based Aggressiveness Analysis

To compare aggressiveness among the groups as well as drivers within the group, the study identified several questions from the questionnaire and plotted them on a Radar Chart. The selected questions are:

- How safe do you think your driving habit is? (preq35)
- How well do you obey the speed limit? (preq36bc)
- Have you ever raced with other cars? (preq36w)
- How many times did you have collision accidents in the last 5 years? (preq38)
- How many times did you pay a speeding fine? (preq39)
- How many times did you pay a traffic signal violation fine? (preq40)
- How many times did the police give a fine and a warning to you? (preq42)

It is noted that first three questions (i.e., Questions 35 and 36) could be subjective, while the other questions (i.e., Questions 38, 39, 40, and 42) are objective.

3.3.2.2 Quantifying Aggressiveness based on Intentional and Unintentional Violations

This approach classifies drivers' aggressiveness into intended and unintended factors. The questions in the driving behavior questionnaire were divided into intended and unintended violations as shown in Table 3.2.

Table 3.2 Questions for Measuring Intentional and Unintentional Violation

No	Intentional Violation	Unintentional Violation
1	Drove through a light that was already red before you entered an intersection.	Fail to notice ‘Red’ light, almost hitting a car that has the right of way.
2	Drive very close to the car in front of you as a signal that they should go faster or get out of the way.	Fail to notice pedestrians crossing when turning onto a side street.
3	Ignore speed limits late at night or very early in the morning.	When you back up, you hit something that you did not observe before but was there.
4	Become impatient with a slow driver in the left lane and pass on the right.	You intend to drive to destination A, but you ‘wake up’ to find yourself on the road to destination B, perhaps because B is your more usual destination.
5	Get involved in spontaneous or spur-of-the moment races with other drivers.	

3.4 Results and Discussion

This section presents analysis results and discussion.

3.4.1 Proposed Driver’s Aggressiveness Index

As noted, among the 52 drivers who participated in the driving tests, inter-vehicular driving data obtained from 26 drivers who did not receive any driving assistance were used in the calculation of the proposed driver’s aggressiveness index. The index is calculated for each participant and summarized by the group as shown in Table 3.3.

The results seem plausible as the younger female group was the most aggressive drivers, followed by the younger male group drivers. For the late middle aged group, the male drivers were more aggressive than female drivers, which also makes sense. Statistical analyses using the student t-test at 95th percentile confidence showed that the difference between the male and female drivers in each group is not statistically significant with p-values of 0.12 for younger drivers and 0.34 for late middle aged drivers. In addition, the difference between the younger and late middle aged groups is not statistically significant with a p-value of 0.10.

Table 3.3 Proposed Aggressiveness Index by Group

	Younger Female	Younger Male	LMA Female	LMA Male
1	1.89	0.62	0.69	0.4
2	3.72	0.45	2.08	2.51
3	2.46	0.97	0.42	0.82
4	1.84	0.63	0.71	0.34
5	1.48	2.69	0.57	1.56
6	0.84	1.87	0.5	2.4
7	2.09	-	-	0.84
Average	2.05	1.21	0.83	1.27

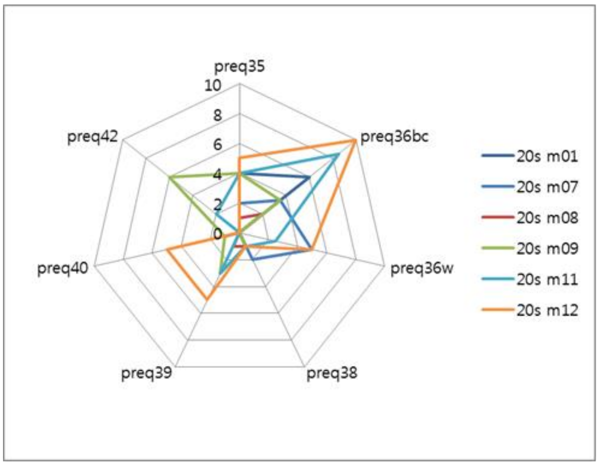
3.4.2 Aggressiveness Obtained from Radar Charts

The proposed driver's aggressiveness index is compared with the points obtained from the radar chart based on the selected driving behavior questionnaire. Figure 3.1 shows these radar charts by each group for all the drivers within the group. Table 3.4 summarized the aggressiveness points by each group. Both Figure 3.1 and Table 3.4 clearly show that younger male drivers are most aggressive, followed by younger female drivers. Two points were made: (1) younger group drivers are more aggressive than late middle aged group drivers, which shows consistent results with the proposed driver's aggressiveness index, and (2) the questionnaire answers show that younger male drivers are more aggressive than younger female drivers, which shows a contradictory result.

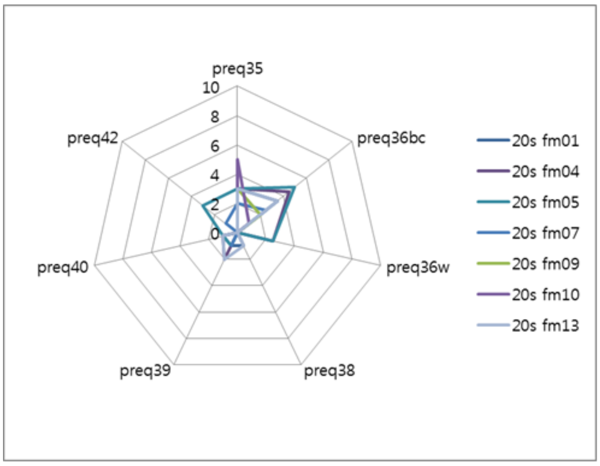
Assuming the responses from the driving behavior questionnaire are often unfaithful for various reasons and the proposed aggressiveness index properly captures actual driving behavior, it can be speculated that younger female drivers do not fully expose their driving behaviors on the questionnaire. This could further indicate that a caution should be made in analyzing driving behavior questionnaires.

Table 3.4 Summary of Radar Chart Aggressiveness Points by Group

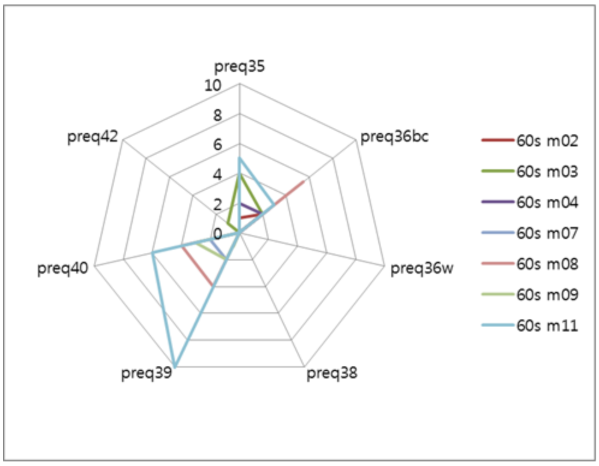
Younger Female	Younger Male	LMA Female	LMA Male
9.43 points	16.5 points	5.50 points	9.14 points



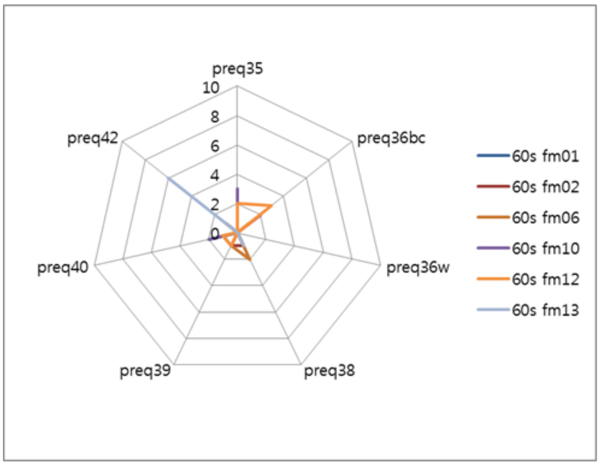
(a) Younger Male



(b) Younger Female



(c) LMA Male



(d) LMA Female

Figure 3.1 By group Result of Survey Questionnaires

3.4.3 Aggressiveness using Intentional and Unintentional Violations, and Safe Driving Speed

Table 3.5 summarized the intentional and unintentional violation points as well as ideal safe driving speed by group. As noted, these points were calculated from participating drivers' responses on the driving behavior questionnaire. It is noted that the intentional and unintentional violation results are mixed. Analysis of variance tests indicated that both unintentional and ideal safe driving do not show statically significant differences among the group, while the intentional violation does show a statistically significant difference due to very high intentional violations shown from younger male drivers. This could have been due to the relatively small sample sizes used in this study.

Based on the results from Table 3.5 and Table 3.3, the following points are made. The proposed aggressiveness index identified younger female drivers as the most aggressive, which is supported by the unintentional violation and ideal safe driving speed (two out of three measures). Interestingly, the ideal safe driving speed supports the ranks of aggressiveness found from the proposed index.

Table 3.5 The Violation Points and Safe Speed of Survey Questionnaires in Each Group

Group	Younger Female	Younger Male	LMA Female	LMA Male
Intentional Violation	0.71	1.34	0.29	0.51
Unintentional Violation	0.54	0.40	0.27	0.21
Ideal Safe Driving Speed (KM/H)	59.23	51.54	45.00	51.15

3.5 Summary

In this thesis, a driver's aggressiveness was quantified using inter-vehicular dynamics data and the proposed driver's aggressiveness index was compared with the driving behavior questionnaire data. This study used 26 drivers in four groups including younger male and female drivers and late middle aged female and male drivers.

The proposed driver's aggressiveness index that is based on the percentage of time exceeding time-to-collision and deceleration rate difference measures was used to analyze the inter-vehicular dynamics data obtained from each participant driving the instrumented vehicle for about 55 minutes. The analysis results based on the proposed index show that younger female drivers were most aggressive, followed by younger male drivers. In order to compare the findings from the proposed driver's aggressiveness index, two analyses were implemented: (i) radar charts and (ii) intentional/unintentional violations and ideal safe driving speed. The radar charts analysis showed contradictory results, indicating younger male drivers were most aggressive, followed by younger female drivers. However, the unintentional and the ideal safe driving speed based analyses results supported findings from the proposed aggressiveness index. Given that the responses from questionnaires are often unfaithful, this study concludes that the proposed driver's aggressiveness index appears to be capturing the participating drivers' aggressiveness.

While a total of 26 drivers' inter-vehicular dynamics data and their driving behavior questionnaire responses were used in the analysis, additional data from a larger number of participants and/or repeated driving data should be considered for validating the proposed driver's aggressiveness index and findings.

Chapter 4.

Vehicles' Speed and Traffic Light Control to Reduce Fuel Consumption and CO_2 Emissions

4.1 Introduction

Currently there is a lot of concern over global warming. Global warming is the rise in the average temperature of the Earth's atmosphere and oceans since the late 19th century and its projected continuation [14]. Recent studies have suggested that global warming is caused by the emission of greenhouse gases. Seventy-two percent of all emitted greenhouse gases is carbon dioxide, 18 percent methane and 9 percent nitrous oxide. Carbon dioxide emissions, therefore, are the largest cause of global warming [15]. Climate disruptions caused by global warming put our food and water supply at risk, endanger our health, jeopardize our national security, and threaten other basic human needs [16]. Some impacts—such as record high temperatures, melting glaciers, and severe flooding and droughts—are already increasingly common. Actually, the oceans have already risen an average of 18cm during the 20th century [17]. The trend, linked to global warming, puts thousands of coastal cities, like Venice, Italy, (seen here during a historic flood in 2008), and even whole islands are at risk of being claimed by the ocean [18]. When sea levels rise rapidly, as they have been doing, even a small increase can have devastating effects on coastal habitats. As seawater reaches farther inland, it can cause destructive erosion, flooding of wetlands, contamination of aquifers and agricultural soils, and lost habitat for fish, birds, and plants. Most climate experts further predict that the warming of the planet will continue and likely will accelerate [18]. Oceans will likely continue to rise as well, but predicting the amount is an inexact science. A recent study says we can expect the oceans to rise between 2.5 and 6.5 feet (0.8 and 2 meters) by 2100, enough to swamp many of the cities along the U.S. East Coast. More dire estimates, including a complete meltdown of the Greenland ice sheet, push sea level rise to 23 feet (7 meters), enough to submerge London and Los Angeles [18].

Transportation is one of the primary contributors to global warming. Transportation now produces the second-largest carbon dioxide emissions, after fossil fuel burning power plants [19]. It is generating more than one-third of all U.S. carbon dioxide emissions and 30 percent of America's total global warming emissions [16]. Especially, cars and light trucks are responsible for more than 60 percent of U.S. transportation emissions. Awareness of global warming is increasing, and much research is being conducted to reduce vehicle fuel consumption and emissions because they greatly affect the problem of global warming. A typical driving trip consists of idling, accelerating, cruising, and decelerating [20], [21]. The proportion of a trip spent in these different stages will depend on the driver's behavior (e.g., aggressive vs. mild driving habits), the roadway type (e.g., freeway vs. arterial), and the level of traffic congestion. Sudden acceleration and deceleration, stop-and-go driving, and long idle time consume more fuel and emit more emissions [22]. In order to reduce the pollution from automobiles, the elements that increase fuel consumption and emissions should be eliminated as much as possible.

In this thesis, we suggest an eco-driving system in arterial roads. The biggest difference between an arterial road and a highway is whether the road has traffic lights or not. The traffic system for an arterial road has to consider traffic lights because traffic lights affect traffic flow more than any other elements. Our system also use traffic lights as one of its main elements. Another element for eco-driving in arterial roads is speed. The driving speed is a core element in both freeways and arterial roads. Speed has an effect on traffic congestion, and then traffic congestion is related to travel time. Traffic lights and speed are key elements on arterial roads. Therefore, we use these two elements for eco-driving.

The objective of this thesis is to propose a new system for reducing fuel consumption and emissions: a dynamic traffic signal control system and recommended velocity using Vehicle to Infrastructure communication (V2I) and Vehicle to Vehicle communication (V2V). V2I and V2V make it possible to realize an intelligent transportation system. The dynamic traffic signal control system can control the volume of traffic on the road. The traffic light is located at an intersection greatly influences traffic flow. This study tries to find the improved signal cycle. The improved signal cycle is to minimize waiting time. In doing so, the decreased idling and travel time is the result. V2V and V2I are used to identify the number of vehicles traveling each way at an intersection and to convey this information to the traffic light control system. The system can compute the improved cycle using the given information. The recommended velocity helps drivers avoid elements that increase fuel consumption and emissions. V2I and V2V communication is important to achieve the goal of eco-driving. Each vehicle notifies its speed to vehicles and traffic lights around them. Also, traffic lights notify their signal cycle to vehicles in the communication coverage area. This information is used to calculate the optimal speed to reduce fuel consumption. The optimal speed helps increase traffic flow by mitigating traffic congestion and increasing the non-stop pass rate. The optimal speed is also used to limit acceleration and deceleration, which helps vehicles obtain effective fuel consumption. In this thesis, we suggest two systems for eco-driving. We used these two systems as a bi-level program concept. A bi-level eco-driving system makes an improved solution to cut fuel consumption and emissions by repeating two-phase. The proposed bi-level system decreased waiting time and the number of stops, and this led to reductions in idle time and sudden acceleration and deceleration. Consequentially, fuel consumption and emissions were reduced. Our proposed scheme is demonstrated to reduce fuel consumption and emissions by 14% over previously proposed.

4.2 Background

4.2.1 Elements Increasing Fuel Consumption and Emissions of Vehicles

One liter of gas can produce three kilograms of global warming emissions [16]. Therefore, vehicles' fuel consumption should be decreased in order to reduce CO2 emissions. It is known that velocity and acceleration and deceleration have had a great deal of influence on fuel consumption and emissions. Because sudden acceleration and deceleration uses more fuel and produces more emissions, much research about eco-driving tries to prevent sudden acceleration and deceleration [22], [23]. Driving too slowly or too quickly is one cause of increased fuel consumption. As traffic congestion causes slow driving velocity, it is important to mitigate congestion [20], [24]. Slow driving speed emits CO2 emissions more than if the vehicle is driving the optimal speed (about 72 km/h) [20]. To cut traffic congestion, many studies suggest allowing traffic to flow at better speeds [24]. Traffic congestion is strongly correlated to travel time. Therefore, travel time is also an important element in eco-driving.

4.2.2 Car-Following Model

The Wiedemann car-following model was originally formulated in 1974 by Rainer Wiedemann [25]. Longitudinal vehicle movement is influenced by vehicles in front in that same lane; the according models are therefore generally called car-following models [26]. A driver is mainly influenced by the first front vehicle. The model hence concentrates on the influence of the first front vehicle, including an option to consider brake lights of other vehicles in front. Car movement is influenced by the perception of the relative movement of the front vehicle, change in distance, and speed difference. When these values reach the threshold, drivers control the movement of their vehicles in order to avoid dangerous situations such as a crash. In this case, it is important that the speed of recognizing the front vehicle changes such as speed difference and distance. The demanded values for movement of vehicles are central in car-following models. Extensive measurements and investigations were undertaken by TODOSIEV (1963), MICHAELS (1965) and HOEFS (1972) aimed at finding the limits of human perception in car-following processes, the so-called thresholds. These investigations form the basis of the car-following model developed by WIEDEMANN (1974).

4.2.3 VISSIM

Traffic simulation is an indispensable instrument for transport planners and traffic engineers [27]. VISSIM is a microscopic, behavior-based multi-purpose traffic simulation to analyze and optimize traffic flows. It offers a wide variety of urban and highway applications, integrating public and private transportation. Complex traffic conditions are visualized in a high level of detail supported by realistic traffic models. VISSIM uses the Wiedemann car-following model.

4.2.4 VT-Micro Model

This thesis uses The Virginia Tech Microscopic Energy and Emission Model (VT-Micro Model) to evaluate the proposed system. This model estimates vehicle pollutants at a second-by-second level of resolution using vehicle speed/acceleration data [28]. The VT-Micro model was developed from experimentation with numerous polynomial combinations of speed and acceleration levels. Specifically, linear, quadratic, cubic, and quartic terms of speed and acceleration were tested using chassis dynamometer data collected at the Oak Ridge National Laboratory.

4.2.5 Related Work

There were many researches to suggest optimal travel speeds and control the traffic light cycle. However, many researches proposed either optimal speed [23], [29], [30], [31] or improved traffic light cycle [32]. They improved performance such as travel time, fuel consumption, emissions, traffic flow, etc. [24] reduced CO_2 emissions using three different strategies: congestion mitigation strategies, speed management techniques, and traffic flow smoothing techniques. [24] shown that CO_2 emissions could be reduced by up to about 20 percent. However, [24] did not use traffic light cycle control because this research is intended for vehicles on high-ways. Our study is intended for vehicles on arterial roads because arterial roads have more congestion than high-ways. [33] proposed a V2I-based traffic management system. It suggested a solution to resolve the problem of regulating traffic in urban areas. Also, it recommended actions to driver in order to avoid accidents. It used only speed control, too. If this study includes traffic light control system, it has better results than current results. Therefore, we proposed the system to combine optimal speed with improved traffic light cycle.

The research [21] to combine optimal speed with improved traffic light cycle exists. However, the research used incorrect elements such as acceleration time and stop times. The acceleration time to reach an optimal speed is fixed as three seconds. Also, all vehicles can stop just one time during a simulation. In this study, we calculated acceleration time using a precise acceleration formula. There is no specific limit for the number of stops. The existing research used fuzzy model in order to compare with their proposed scheme. We, on the other hands, used VISSIM to get the data that was used to compute fuel consumption and CO_2 emissions. The VISSIM used both existing traffic system and proposed traffic.

4.3 Methodology

As mentioned above, this study proposed an eco-driving system using bi-level programming. The bi-level programming consists of two phases: speed control and traffic light cycle control. First, the speed control system suggested a recommended speed to the driver that was calculated utilizing the information from surrounding cars and traffic signal cycles. .

Second, the traffic light cycle control system computes the improved traffic signal cycle. An improved traffic signal cycle is that which makes the least travel time.

In this thesis, we assumes the following:

- All vehicles at an intersection have the device that can communicate with surrounding cars and infrastructures and calculate the recommended speed.
- The traffic signal control system can obtain information about every car that is approaching the intersection from other intersections and that the infrastructure can communicate.

This study calculates the recommended speed utilizing the surrounding traffic light cycle information and cars information such as speed and position. The system needs a communication device to get the information. Also, the device should have the ability to compute the recommended speed. This system offers the improved traffic light cycle that can reduce travel time. The improved traffic light cycle is calculated using information about all vehicles that are entering the intersection.

4.3.1 Speed Control

The first phase is speed control. Speed control is a system that suggests the most effective speed to drivers. In this phase, each vehicle calculates the recommended speed utilizing the information of the traffic light cycle and the surrounding cars. The following information is an explanation of the symbols use to calculate the recommended speed:

- Distance, D;
- Green light cycle C_g, red light cycle C_r, yellow light cycle C_y, and traffic light one cycle C_{total},

  where $C_{total} = C_g + C_r + C_y$;

- Remaining time of green light R_g and remaining time of red light R_r;
- Current speed S_{cur}, maximum speed S_{max}, minimum speed S_{min}, regulation speed S_{reg}, and recommended speed S_{rec}.

We define the total cycle as $C_g + C_r + C_y$. We use the three cycles for the simulation in this study. However, in order to compute the recommended speed, we use just two cycles: C_g and C_r. The C_y is divided into two parts: possible pass period and impossible pass period. The possible pass period is added to C_g, and the impossible pass period is added to C_r.

Every car calculates its recommended speed when it arrives at the position that can obtain the traffic light cycle information. The algorithm for speed control is divided into two parts by the current traffic light state. The following algorithm explains how to calculate the recommended speed.

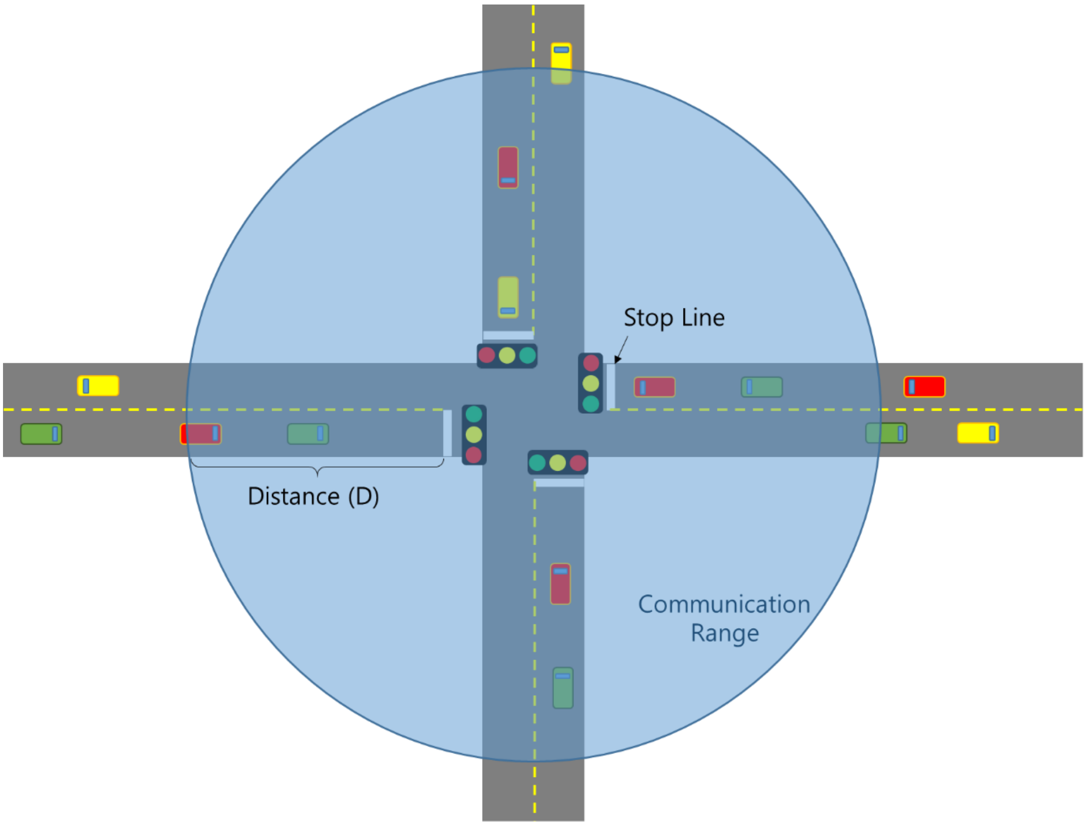
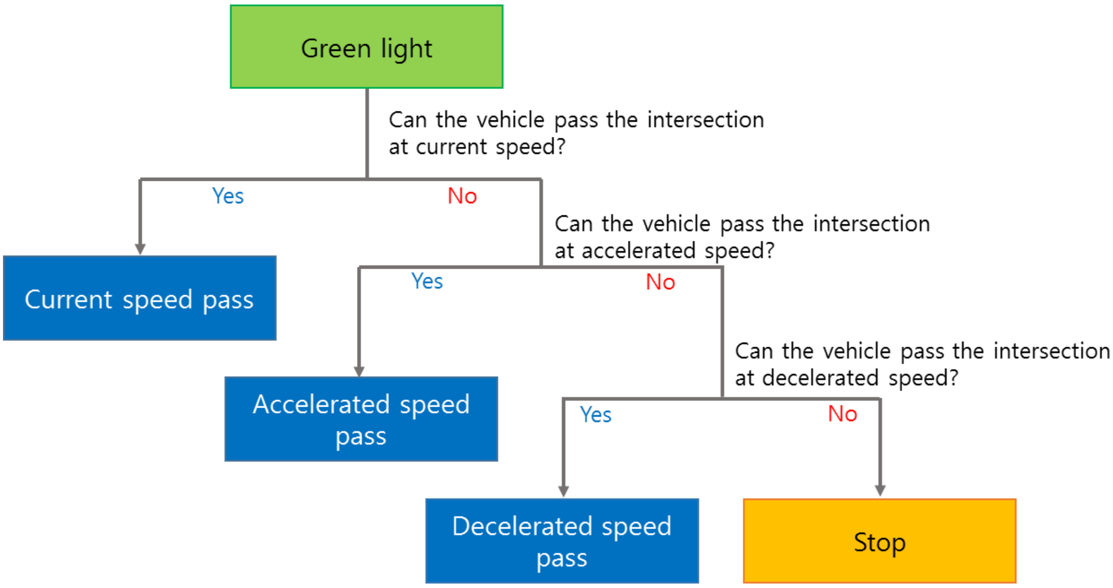
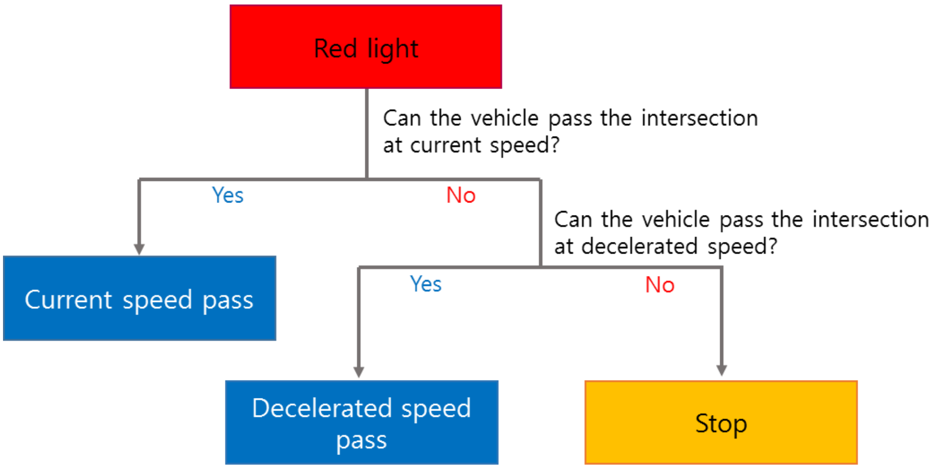


Figure 4.1 Communication Range and Distance



(a) The Algorithm when Current Light is Green.



(b) The Algorithm when Current Light is Red.

Figure 4.2 The Algorithm for Speed Control.

4.3.1.1 Current Traffic Light is Green

When the current light is green, we have four cases in the algorithm: current speed pass, accelerated speed pass, decelerated speed pass, and stop.

a. Current Speed Pass: If the remaining green light time R_g is longer than the time T_{cur} that the vehicle spends to pass the intersection at the speed of S_{cur}, the recommended speed is the current speed S_{cur}. The system notifies drivers to keep their current speed.

The expression is as follows:

$D \div S_{cur} = T_{cur}$

If $R_g \geq T_{cur}$**, then**

$$S_{rec} = S_{cur}$$

b. Accelerated Speed Pass: If the remaining green light time R_g is shorter than the time T_{cur} that the vehicle spends to pass the intersection at the speed of S_{cur} but R_g is longer than the time T_{acc} that the vehicle spends to pass the intersection at the speed of S_{max}, the recommended speed is maximum speed S_{max}. The system notifies drivers to accelerate to maximum speed S_{max}. The expression is as follows:

$D \div S_{max} = T_{max}$

If $T_{max} \leq R_g < T_{cur}$**, then**

$$S_{rec} = S_{max}$$

c. Decelerated Speed Pass: If the vehicle cannot pass the intersection at the current speed or maximum speed, the proposed algorithm considers a decelerated speed pass. The decelerated speed pass is to pass the intersection after the next red light (i.e., during the next green light) without stopping but at a speed that is slower than current speed and faster than the minimum speed. When this condition is satisfied, the proposed system notifies drivers to pass the intersection at the recommended speed without stopping. In this case, the recommended speed to pass the intersection when the red light turns green is calculated. The expression is as follows:

$D \div S_{min} = T_{min}$

If $R_g < T_{max}$ **and** $R_g + R_r \leq T_{min}$**, then**

$$\left(\frac{1}{2 \times acc}\right)x^2 - \left(R_g + R_r + \frac{S_{cur}}{acc}\right)x + \frac{{S_{cur}}^2}{2 \times acc} + D = 0$$

*acc = acceleration

$$S_{rec} = x \ (0 \leq x \leq S_{max})$$

d. Stop: If the vehicle cannot pass the intersection at the current speed, maximum speed, or decelerated speed, the vehicle has to stop before the stop line. The vehicle travels at the minimum speed until it stops. The expression is as follows:

If $\boldsymbol{R_g + R_r > T_{min}}$**, then**

$$\boldsymbol{S_{rec} = S_{min}}$$

4.3.1.2 Current Traffic Light is Red

When the current light is red, we have the three cases in the algorithm: current speed pass, decelerated speed pass, and stop.

a. Current Speed Pass: If the remaining red light time R_r is shorter than the time T_{cur} that the vehicle spends to pass the intersection at the speed of S_{cur}, the recommended speed is current speed S_{cur}. The system notifies drivers to maintain the current speed. The expression is as follows:

$\boldsymbol{D \div S_{cur} = T_{cur}}$

If $\boldsymbol{R_r \leq T_{cur}}$**, then**

$$\boldsymbol{S_{rec} = S_{cur}}$$

b. Decelerated Speed Pass: If the vehicle cannot pass the intersection at the current speed, the proposed algorithm considers a decelerated speed pass. A decelerated speed pass will allow the driver to pass the intersection after the remaining red light time (i.e., during the next green light) without stopping at a speed that is slower than the current speed and faster than the minimum speed. When this condition is satisfied, the proposed system notifies drivers to pass the intersection at the recommended speed without stopping. In this case, the recommended speed is calculated to pass the intersection when the red light turns green. The expression is as follows:

$$D \div S_{min} = T_{min}$$

If $R_r \leq T_{min}$, then

$$\left(\frac{1}{2 \times acc}\right) x^2 - \left(R_r + \frac{S_{cur}}{acc}\right) x + \frac{{S_{cur}}^2}{2 \times acc} + D = 0$$

*acc = acceleration

$$S_{rec} = x \ (0 \leq x \leq S_{max})$$

c. **Stop:** If the vehicle cannot pass the intersection at the current speed or at a decelerated speed, the vehicle will have to stop at the stop line. The vehicle travels as fast as the minimum speed until it stops. The expression is as follows:

If $R_r > T_{min}$, then

$$S_{rec} = S_{min}$$

4.3.2 Traffic Light Cycle Control

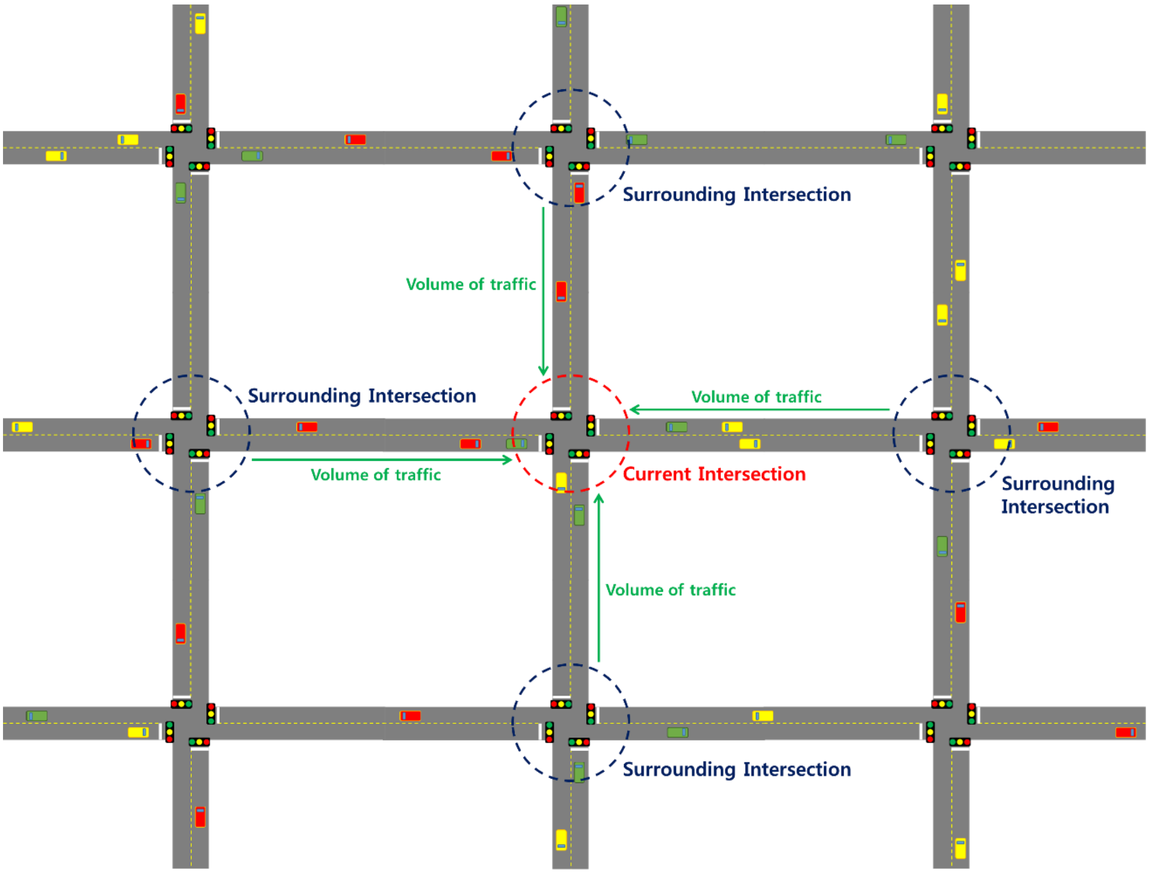


Figure 4.3 Measure Volume of Traffic at Surrounding Intersections

The traffic light cycle control system uses information about the volume of traffic at surrounding intersections, as shown in Figure 4.3, to calculate the improved traffic light cycle. The surrounding intersections transmitted their traffic volume information to the current intersection. The current intersection can predict when the vehicle will arrive. We used this information to compute improved traffic light cycle. When the intersection has different volumes of traffic by direction, our system offer longer green signal to direction that has more vehicles. This helps reduce travel time at the intersection.

4.4 Simulation

In this section, the proposed intersection eco-driving system was implemented on two cases: with all directions at the intersection having the same volume of traffic and with different volumes of traffic. For each case, the simulation results of the existing system and the proposed system were compared.

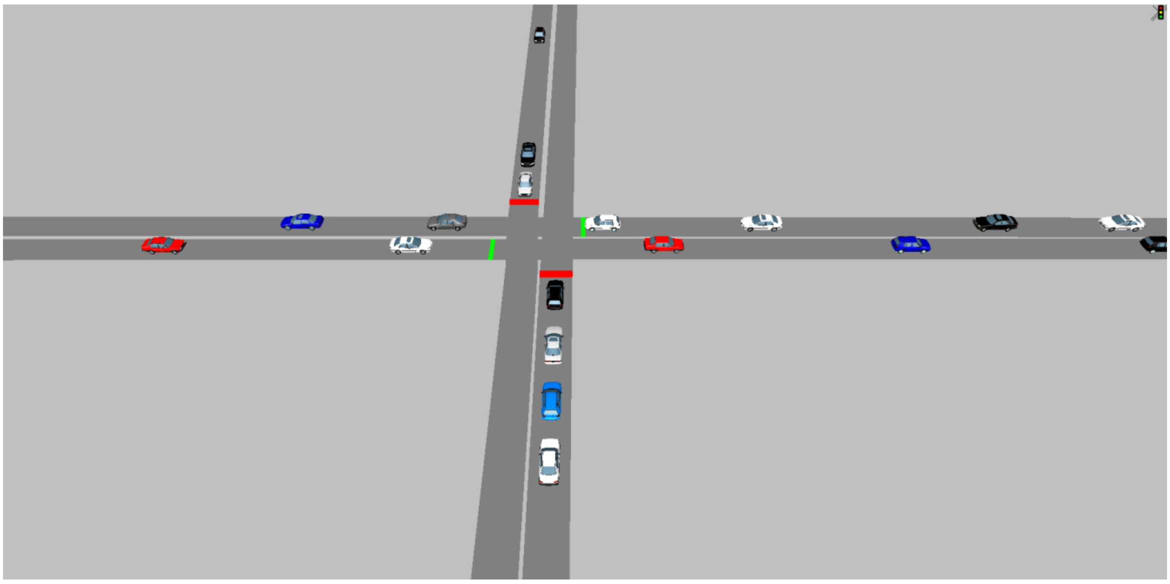


Figure 4.4 VISSIM Simulation

4.4.1 Simulation Environment

In this thesis, we used VISSIM to evaluate the performance of the proposed system. For the simulation, we assume some simulation environment as below:

- An intersection has four directions.
- An intersection is two-way, with two lanes.
- Vehicles can only travel straight at intersections (no left-turn and no right-turn).
- In the simulation, the speed limit is 70km/h. However, the vehicle can drive up to 80km/h because drivers usually exceed the speed limit in the real world.
- The minimum speed is 20km/h.
- In this thesis, we used one intersection. A yellow signal is set to be 3 seconds, and a green signal is set to be at least 10 seconds and at the most 60 seconds. Also, a red signal is set to be based on an opposite green signal.
- The communication range is 300m. Thus, all vehicles can receive the traffic signal cycle information 300m in front of the stop line.
- The measuring range D of fuel consumption and CO_2 emissions to evaluate this system is 300m, the same as the communication range.
- The simulation time is one hour. (We simulated vehicles passing an intersection for one hour.)

The reason for the measuring range of 300m is that it is possible to control the speed of vehicles in the communication range. When simulating the proposed system, every car receives traffic signal information in the communication range. After that, each vehicle computes the optimal speed for eco-driving using the proposed algorithm. If the state of the vehicle can apply to the recommended speed, the vehicle's speed will be controlled according to the algorithm. On the other hand, if it cannot apply the recommended speed, the vehicle moves using the Wiedmann car-following model in VISSIM.

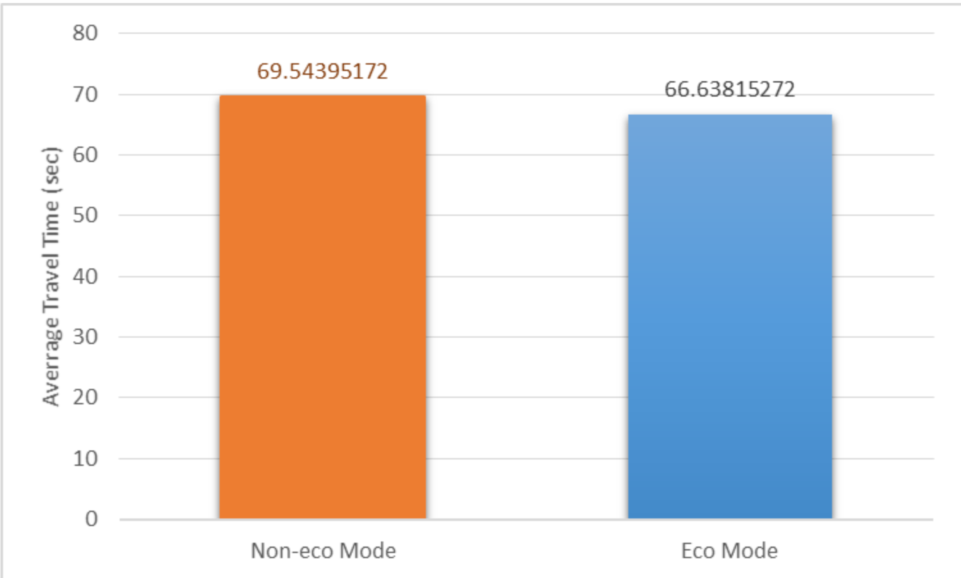
4.4.2 Simulation Result

In this section, we analyze and evaluate the simulation results. The proposed system to reduce fuel consumption and CO2 emissions generated a recommended speed and an improved traffic light cycle for eco-driving. We gained simulation results using the VISSIM, and then will discuss the results.

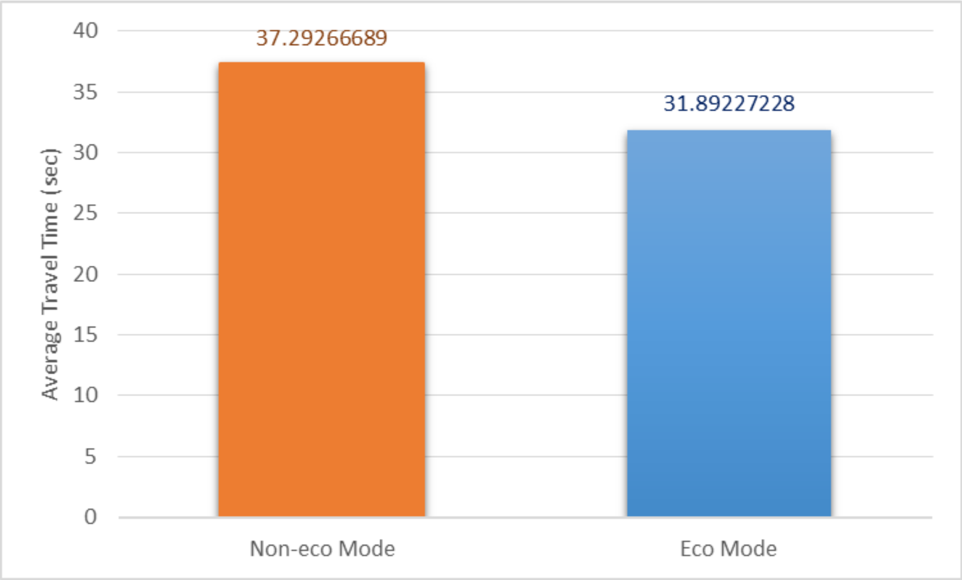
The results consist of the three items: average travel time, non-stop pass rate, and fuel consumption and CO_2 emissions.

4.4.2.1 Average Travel Time

The average travel time from communication range (300m in front of the stop line) to the stop lines is shown in Figure 4.5. Figure 4.5 shows that the proposed system has a shorter travel time than the existing system. Also, when the intersection has different volumes of traffic by directions, the system has better performance in terms of average travel time.



(a) When the Intersection has Same Volumes of Traffic by Directions
(All directions have 1000 vehicles for an hour)



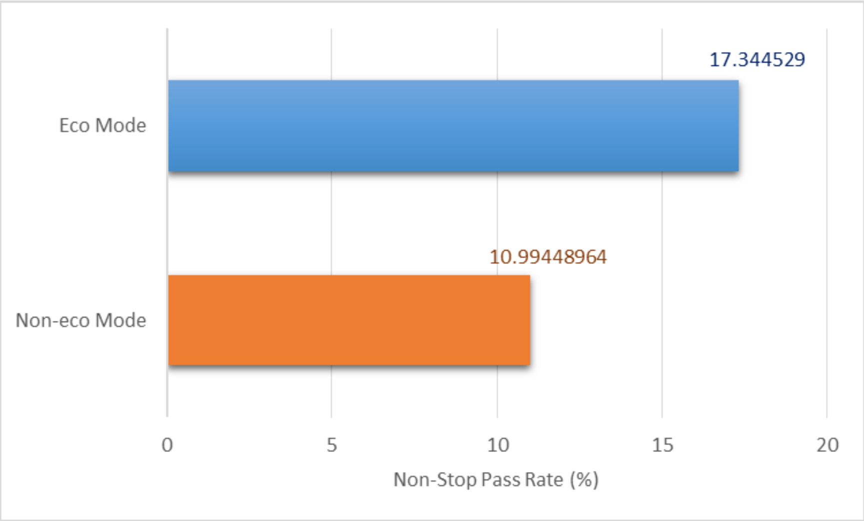
(b) When the Intersection has Different Volumes of Traffic by Directions

(The one direction has 1000 vehicles and the other direction has 600 vehicles for an hour)

Figure 4.5 Average Travel Time

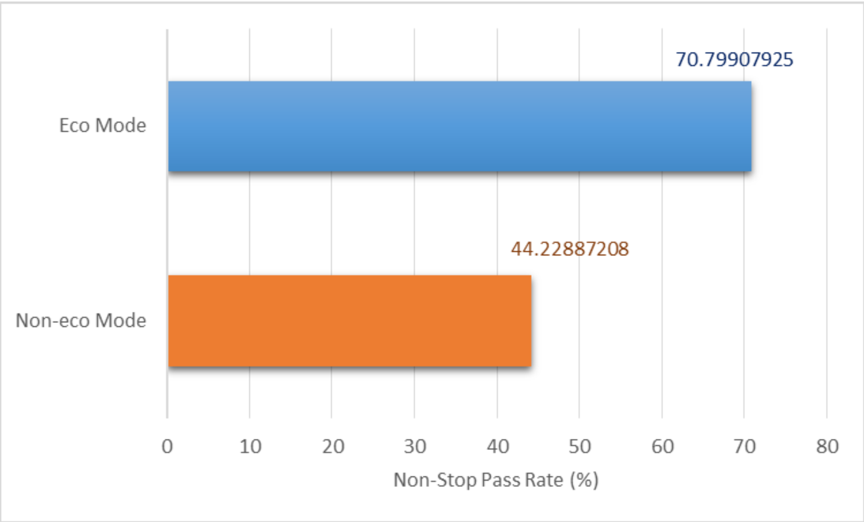
4.4.2.2 Non-stop Pass Rate

The non-stop pass rate is shown in Figure 4.6. Figure 4.6 indicates that the proposed system has a higher non-stop pass rate. Non-stop pass rate, in common with average travel time, has better performance when the intersection has different volumes of traffic by direction. If non-stop pass rate is improved, waiting time is reduced. As a result, the average travel time is also reduced. Therefore, the non-stop pass rate is also an important element for eco-driving.



(a) When the Intersection has Same Volumes of Traffic by Directions

(All directions have 1000 vehicles for an hour)



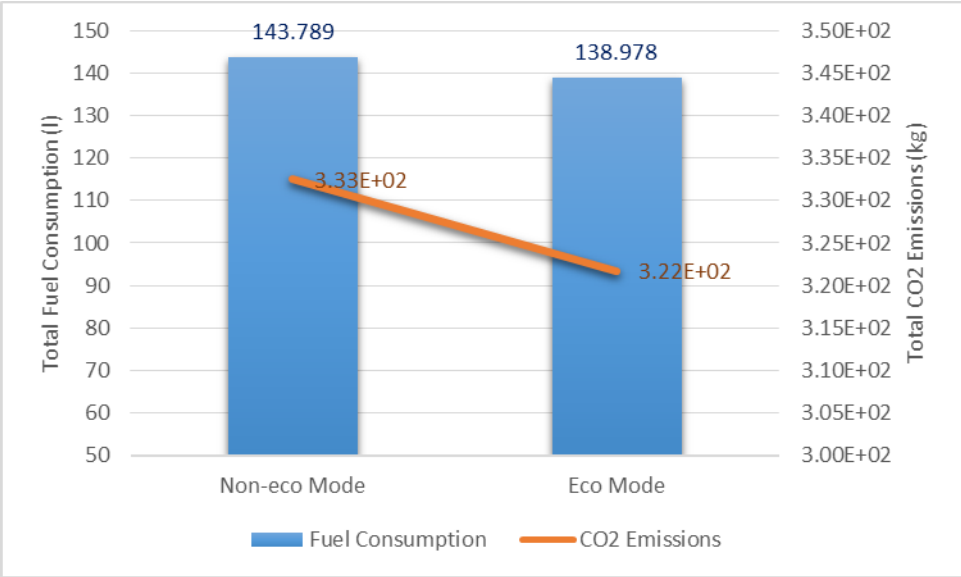
(b) When the Intersection has Different Volumes of Traffic by Directions

(The one direction has 1000 vehicles and the other direction has 600 vehicles for an hour)

Figure 4.6 Non-stop Pass Rate

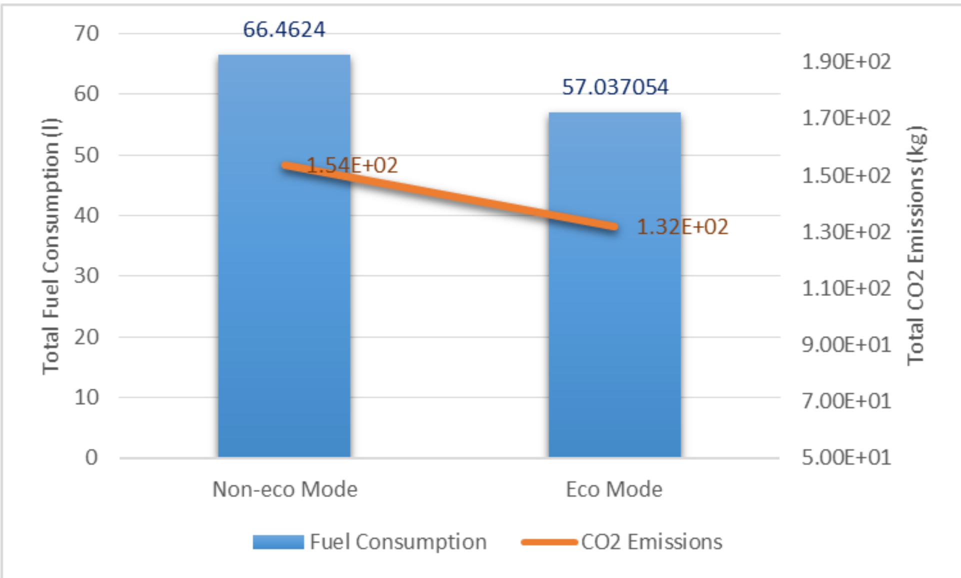
4.4.2.3 Fuel consumption and CO_2 emissions

Figure 4.7 shows the relationship between the proposed system and the existing system in terms of fuel consumption and CO2 emissions. The proposed system has less fuel consumption and CO2 emissions than the existing system. Fuel consumption and CO2 emissions, in common with other items (average travel time and non-stop pass rate), have better performance when the intersection has different volumes of traffic by direction.



(a) When the Intersection has Same Volumes of Traffic by Directions

(All directions have 1000 vehicles for an hour)



(b) When the Intersection has Different Volumes of Traffic by Directions

(The one direction has 1000 vehicles and the other direction has 600 vehicles for an hour)

Figure 4.7 Fuel Consumption and CO_2 Emissions

As per the simulation results, we can get better performance from the proposed system in terms of eco-driving such as average travel time, non-stop pass rate, and fuel consumption and CO_2 emissions than the existing system. Also, we can confirm that our system is more effective at intersections that have different volumes of traffic by direction. Table 4.1 shows detailed figures. Eco-driving mode can reduce about 14% of fuel consumption and CO2 emissions in comparison with non-eco-driving mode from each simulation result.

Table 4.1 Analysis of simulation results

	Non-eco driving	Eco driving	% Diff.
Fuel (*l*)	143.79	138.98	-3.35
CO_2 (k*g*)	332.51	321.74	-3.24
Average Travel Time (sec)	69.54	66.64	-4.18
Non-stop pass rate (%)	10.99	17.34	6.39

(a) When the Intersection has Same Volumes of Traffic by Directions.
(All directions have 1000 vehicles for an hour)

	Non-eco driving	Eco driving	% Diff.
Fuel (*l*)	66.46	57.04	-14.17
CO_2 (k*g*)	153.77	131.92	-14.21
Average Travel Time (sec)	37.29	31.89	-14.48
Non-stop pass rate (%)	44.23	70.80	26.57

(b) When the Intersection has Different Volumes of Traffic by Directions
(The one direction has 1000 vehicles and the other direction has 600 vehicles for an hour)

4.5 Summary

In this thesis, an intelligent transportation system was proposed and fuel consumption and CO2 emissions were reduced. The proposed system offered recommended speed and improved traffic light cycle for smooth traffic flow. As a result, because average travel time was reduced, fuel consumption and CO2 emissions were decreased, too.

This study used V2X communication to ascertain the state of an intersection and the information of each vehicle and traffic lights. The vehicle gathered around vehicles information and traffic light cycle, and then each vehicle calculated the recommended speed. The traffic light control system computed improved traffic light cycles through analysis of the volume of vehicles at each link. The proposed system offered improved performance by repeatedly calculating the recommended speed and improved traffic light cycle.

The proposed eco-driving system was simulated using VISSIM. We made two scenarios: general mode scenario and eco-driving mode scenario. We gathered data such as acceleration, speed, position, and travel time from two scenarios that were simulated by VISSIM. The acceleration and speed were used to calculate fuel consumption and CO2 emissions using the VT-Micro model. The results of the two scenarios were compared in order to show the superiority of the proposed system. The results of the simulation showed that the proposed intelligent intersection system was better than existing intersection systems in terms of eco-driving (i.e., the result of the proposed system had shorter travel time and less fuel consumption and CO2 emissions than the existing system).

Chapter 5. Conclusions

In this thesis, some intelligent transportation systems were shown using up-to-date smart devices such as smart sensors, DSRCs, high-powered computers, etc. This thesis dealt with three issues in transportation systems: route guidance, driving behavior, and eco-driving.

In the first part, we proposed route viability indices (i.e., dominancy index and beat the *average index) and demonstrated their usages through three selected origin and destination* pairs from Daegu City using actual route travel time distributions. This study compared the routes that have the shortest average travel time and the routes that have the second shortest average travel time to quantify the quality of routes. Drivers can have a chance to select various routes by getting information about alternative routes' quality from this system. Also, this system can improve traffic flow because the system is effective to disperse vehicles into other routes.

Secondly, we analyzed the issue of driving behavior. Four groups, including younger male and female drivers and late middle-aged female and male drivers, were used for this study. We quantified the aggressiveness of each group using inter-vehicular dynamics data. This study compared the result of the driving behavior questionnaire data and proposed a driver's aggressiveness index in order to improve reliability. The results of this study indicated that younger female drivers were most aggressive, followed by younger male drivers.

The final part of the study dealt with the issue of eco-driving. In this study, we used bi-level programming using vehicles speed control and traffic light cycle control at the intersection. This system uses V2X communication to realize intersection states such as average travel time, the volume of vehicles, traffic light cycle, etc. The system computed optimal vehicle speed and traffic light cycle using the information. This system made smoother traffic flows than existing traffic systems. This reduced travel time reduced fuel consumption and CO_2 emissions, too.

This thesis consisted of the three parts mentioned above. Each part was one of major issue in the transportation field. This thesis used the latest technology to resolve the problems. The real data that was gathered by smart sensors, V2X communication using DSRC, and data processing was used for this research. This thesis proposed an improved intelligent transportation system and collaboration between transportation systems and advanced technologies.

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요 약 문

지능형 교통 시스템: 길 찾기, 운전 행태, 친환경적 교통 시스템

과학기술의 발전은 현대인들의 생활에 많은 변화를 가져왔다. 교통에서도 이는 마찬가지이다. 이 논문에서는 지능화된 교통 시스템을 제안하였다. 교통 시스템 중 일반적으로 가장 많이 사용되는 자동차를 대상으로 한 시스템 이다. 스마트 센서, 고성능 컴퓨터, 그리고 발달된 통신 기술들을 교통 분야에 적용함으로써 지능형 교통 시스템을 구축하였다. 이러한 지능형 교통 시스템은 교통 분야 전반에 적용이 가능하다. 이 논문에서는 3 가지 분야에 이 시스템을 적용해 보았다. 첫 번째는 길 찾기에 적용하였다. 기존의 길 찾기 시스템은 거리가 짧은 경로나 목적지까지 도달하기까지 걸리는 시간이 짧은 경로에 초점을 맞추고 있다. 그러나 이것은 길을 찾아 주는데 있어서 가장 중요한 요소가 아니다. 따라서 이 연구는 여러 경로들의 가치를 수량화 해서 운전자가 가장 선호하는 경로를 쉽게 선택할 수 있도록 하는 것을 목표로 하였다. 두 번째로 우리는 운전자들의 운전 행태에 대해 연구하였다. 여기서 우리는 연령과 성별에 따라 4 개의 그룹을 만들고 각 그룹별로 실제 도로에서 차량을 운전한 데이터를 수집하였다. 또한 각 개인별 설문지를 통해 평소에 자신이 생각하는 운전 습관에 대해 답하도록 하였다. 이 두 가지 데이터의 분석을 통해서 성별과 연령이 운전 행태에 미치는 영향을 알아보았다. 마지막으로 우리는 친환경적인 교통 시스템을 개발 하였다. 이 시스템은 교차로에서 차량들이 경제적으로 주행 할 수 있도록 해주는 추천 속도를 각 차량에 제공하고 교통량에 따라 신호등의 주기를 가변적으로 변화 시킨다. 이 시스템은 교통흐름을 원활하게 하고 연료소비량과 CO_2 배출량을 감소시켰다.

Acknowledgement

대학원 생활 2 년동안 항상 즐거웠던 것 같다. 우리를 믿고 자유로운 랩 분위기를 만들어 주시고 학문적인 것부터 인생적인 부분까지 많은 것을 가르쳐 주신 손상혁 교수님과 박태준 교수님께 감사 드립니다. 믿어 주신만큼의 성과를 내지 못한 것 같아 죄송한 마음이…...(ㅠㅠ). 연구에 많은 도움을 주신 박병규 교수님과 손준우 박사님께도 항상 감사 드리고 있습니다.

그리고 항상 내 결정을 믿어주고 지지해 주는 나의 사랑하는 가족. 아버지, 어머니, 동생. 언제나 의지되고 든든해요. 항상 사랑하고 앞으로는 든든한 아들, 오빠가 되겠습니다.

내가 맨날 잘난 척 하고 놀려도 그래 넌 잘 될 거야 라며 날 응원해주는 친구들. 이름은 적지 않을게...ㅋㅋ. 지가 알겠지...(혹시 이름 빠뜨릴까 봐 꼼수 쓴 거임). 너희들이 알게 모르게 나에게 큰 힘이 되어 주었다. 항상 내가 젤 잘난 듯, 젤 강한 척 하기만 너희들이 없으면 잘나지도 강하지도 않은 그저 그런 사람이 나다. 너희들이 내 힘이자 자존심이다. 앞으로도 항상 함께 하면서 지금처럼 서로 응원하며 즐겁게 살자.

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랩실은 다르지만 항상 함께 즐거운 대학원 생활보단 즐거운 대구 생활을 하기 위해서 함께 노력했던 원홍이 형, 어린 티 팍팍 내면서 안 맞으면 정신 못 차리는 ICE baby 성민이. 미쳤지만 착한 종구, 이젠 삼성녀 앞으로 잘나갈 예정인 정예리 (너희 둘의 비밀은 꼭 밝혀 내고 말겠어), Global Yang-A-Chi 재섭이 형, 조용한 재욱이 형, 서울대로 전학 갈 경수형, AV1 이었던 창원 촌놈 김승욱, 재미없는 새 신부 홍인정, PP 게이 전강욱. 이상 DGIST ICE 동기들 모두들 즐겁고 재미있는 추억 만들어 줘서 고맙고 나의 장난에 마음이 상했었다면 언제든지 말해라. 한대 정도는 맞아 줄게….ㅋㅋ. 아, 외국인 친구들은 Just bye.

나머지 선배들, 후배들, 그리고 학과 사무실 선생님들은 너무 많으니 이름은 생략하고 내가 살갑게 대하진 못했지만 다들 좋은 사람들이고 항상 나한테 잘 해줘서 고맙다는 말 전하고 싶네요 (누군가 욕하는 소리가 들리는 듯 하지만).

지난 2 년동안 많은 일들이 있었고 그 속에서 아웅다웅 거리며 지냈지만 돌아보면 항상 웃을 일들만 있었던 것 같다. 이렇게 좋은 사람들을 만나서 이렇게 좋은 추억을 많이 만들고 떠나가게 되어서 정말 행복하고 DGIST 를 선택한 것이 내 인생의 best choice 였다고 자부한다. 내가 만나고 감사하는 모든 사람들의 앞날에 무한한 영광과 행복이 함께 하기를. 2014 년 다들 새해 복 많이 받으세요. Happy New Year~~~!!!