Thesis for Degree of Master of Engineering

Development of a Methodology to Evaluate an Environmental Impact for Future Advanced Safety Vehicle

by

Ji Eun Choi

Department of Geoinformatic Engineering

The Graduate School

Pukyong National University

February 2011

Development of a Methodology to Evaluate an Environmental Impact for Future Advanced Safety Vehicle

(미래 첨단차량의 환경적 효과 평가를 위한 방법론 개발)

Advisor: Prof. Sang Hoon Bae

by
Ji Eun Choi

A thesis submitted in partial fulfillment of the requirements
for the degree of

Master of Engineering

in Department of Geoinformatic Engineering,
The Graduate School, Pukyong National University

February 2011

Development of a Methodology to Evaluate an Environmental Impact for Future Advanced Safety Vehicle

A dissertation
by
Ji Eun Choi

Approved by:

ywLee

(Chairman) Yang Won Lee

(Member) Yong Cheol Suh

(Member) Sang Hoon Bae

February 25, 2011

Contents

List of Figures

List of Tables

미래 첨단차량의 환경적 효과 평가를 위한 방법론 개발

최지은

부경대학교 대학원 위성정보과학과

요 약

교통수요의 증가로 인해 지체가 발생하고 온실가스 배출량을 증대시킨다. 이러한 문제점을 해결하고자 안전성을 확보하고 이동성을 향상시키는 첨단차량 및 도로시스템이 도입되었다. 첨단차량 및 도로시스템 분야는 주로 차량제어 관련 연구가 진행되고 있으며 온실가스 감축 관련 연구는 미비하다. 따라서 본 연구에서는 첨단차량이 추종거동, 차로변경 시 CO_2 배출량을 정량적으로 산정하고자 방법론을 개발하였다. 일반차량은 Pipes model에 의해 추종거동하며 첨단차량은 FVADM (Full Velocity Acceleration Difference Model)에 의해 추종거동 한다. 일반차량과 첨단차량이 추종거동 시 차두거리, 용량을 산정하고 교통량 대 용량 비에 의해 서비스 수준별 통행시간을 산정하였다. 거리와 시간 관계식을 통해 산정된 속도를 CO_2 배출계수 식에 적용하여 CO_2 배출량을 산정하였다. 첨단차량이 추종거동 시 환경적 효과를 평가하고자 시뮬레이션을 수행하였다. 시뮬레이션 결과 교통량이 850대/시일 때 CO_2 배출량이 59,330g, 1050대/시일 때는 550,200g, 1300대/시일 때 1,497,990g 감소하는 것으로 도출되었다. 따라서 첨단차량은 최소 차간간격으로 추종거동 함으로써 용량이 증대되어 혼잡한 교통상황을 완화시킴으로써 일반차량에 비해 CO_2 배출량이 감소하는 것으로 나타났다. 첨단차량이 고속에서 저속으로 차로변경, 저속에서 고속으로 차로변경 시 환경적 효과 평가를 위한 방법론을 개발하였다. 대상차량과 선행차량 간의 차간거리, 대상차량과 후행차량 간의 차간거리가 안전거리 이상이면 차로변경을 수행한다. 첨단차량이 차로변경 시 환경적 효과를 평가하고자 시뮬레이션을 수행하였다. 시뮬레이션 결과 첨단차량이 고속에서 저속으로 차로변경 할 경우, CO_2 배출량이 7,196,457g 감소하였으며, 저속에서 고속으로 차로변경 할 경우, CO_2 배출량이 1,014,732g 감소하였다. 따라서 첨단차량은 혼잡한 지체 없이 안전거리를 확보하여 차로변경을 수행하므로 CO_2 배출량이 일반차량에 비해 감소하는 것으로 나타났다. 따라서 첨단차량이 추종거동, 차로변경 시 안전성을 확보하고 도로이용의 효율성을 향상시킴으로써 CO_2 배출량이 감축되는 것을 입증할 수 있다.

1. Introduction

1.1. Background

The volume of traffic has been increasing. Traffic congestion is caused by increasing volume approaching roads' capacity. Congestion adversely affects mobility, safety, and air quality. The CO_2 emissions account for 88.6% of the total emissions of greenhouse gases. The ministry of land, transport and maritime affairs in Korea said that CO_2 emissions in transportation sector account for 20% of the total greenhouse gases emission and CO_2 emissions emitted on roads account for approximately 80% of transportation emissions. To solve these problems, many studies have suggested how efficiency of highway could be improved and how greenhouse gas emissions could be reduced by intelligent transportation systems (ITS). An advanced vehicle and highway system (AVHS) within ITS can be expected to bring benefits in terms of safety, efficiency, and environment. IVHS incorporates information processing, communications, control, and electronics. If advanced safety vehicle (ASV) drives on the automated highway, ASV and highway infrastructure will exchange information. ASV also communicates with other vehicles continuously. ASV can recognize maneuver of the other vehicle such as speed, acceleration, and position through a communication technologies based on vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). ASV can automatically follow leading vehicle at the same lane while keeping safe distance between vehicles by adaptive cruise control(ACC). To execute lane changing, ASV considers whether gap between vehicles is longer than safe distance or not. If gap between vehicles is shorter than safe distance, ASV can control automatically to create a sufficient gap. ACC and lane changing technologies within advanced vehicle control systems (AVCS) is executed to avoid collision and improve efficiency of road. However, it is not obvious how greenhouse gas emissions of ASV could be reduced.

This paper presents a methodology to evaluate an environmental impact for ASV. An environmental impact of ACC and lane changing technologies is evaluated.

1.2. Goal and Objectives

The goal of this study is to develop a methodology to evaluate an environmental impact for future advanced safety vehicle. When ASV executes car following, an environmental impact was evaluated. ACC car following model was compared with a human driven car following model. The headway, capacity and CO_2 emissions were estimated in manual traffic where a human driven car following is represented as a Pipes model. Those were estimated in ACC traffic where ACC car following is represented as full velocity and acceleration difference model. The CO_2 emissions in ACC traffic are compared with the CO_2 emissions in manual traffic. When ASV executes lane changing from or to a faster lane, an environmental impact was evaluated. The CO_2 emissions for automated driving are compared with CO_2 emissions for manual driving.

1.3. Scope

Smart highway project has been progressing. Smart highway is a next generation road that significantly improves the traffic flow, convenience, and safety by ITS technologies. This project was launched in 2007 and it is expected to be completed by 2017. In 2020, ASV can drive on the automated highway in Korea. So, this paper assumes ASV drives on the automated highway. ASV communicates with other vehicles and highway infrastructure. ASV exchanges information such as speed, acceleration, and position. ASV and smart highway incorporate processing information, warning, and control. ASV is equipped with AVCS which incorporates ACC, lane departure, and lane changing technologies.

In this paper, when a vehicle executes car following and lane changing, a maneuver for automated driving is compared with a maneuver for manual driving. We evaluate an environmental impact for car following and lane changing.

1.4. Flow of Study

We understanded the recent trend on study and reviewed the relevant literature on baseline methodology, emission factor, traffic flow, ACC, and lane changing. In this paper, we developed a methodology to evaluate an environmental impact for ASV. We evaluated maneuver of manual vehicle and ASV which executes car following and lane changing automatically.

When ASV executes car following and lane changing, CO_2 emissions for automated driving condition are compared with CO_2 emissions for manual driving condition.

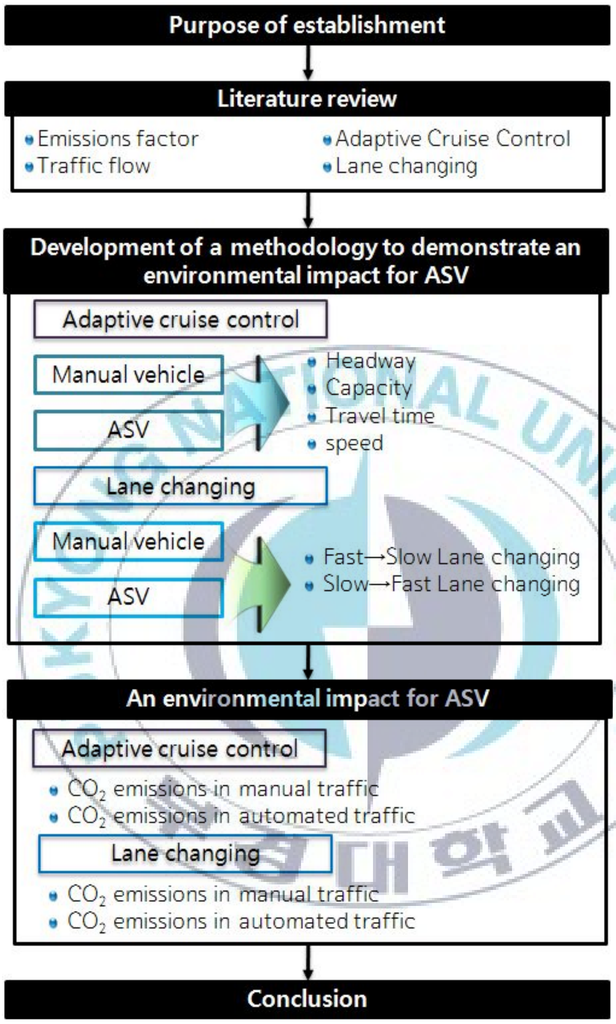

Figure 1.1. Flow chart of study

2. Literature Review

2.1. Baseline Methodology and Emission Factor

To develop a methodology to evaluate an environmental impact for ASV, we reviewed baseline methodology approved by UNFCCC (United Nations Framework Convention on Climate Change). To an environmental impact for ASV, we reviewed studies on emission factor.

UNFCCC (2006) provides a baseline methodology for BRT (Bus Rapid Transit) projects. BRT system has an effect on reduction of greenhouse gas emissions. The fuel efficiency is improved by the availability of a more efficient and attractive public transport system. Baseline emissions determine emissions per passenger transported per vehicle category. The baseline emissions factor focuses on potential changes in trip distance and type of fuel used by passenger. Leakage emissions address upstream emissions because of construction, reduced life-span, life-cycle effect of reduced fuel usage, change of load factor of the baseline transport system, reduced congestion in remaining road, and rebound effect.

UNFCCC (2009) provides baseline methodology for MRT (Mass Rapid Transit) projects. Baseline emissions include the emissions that happen due to the transportation of the passengers. Baseline emissions are calculated per passenger surveyed. Leakage emissions address emissions due to changes of the load factor of taxis and buses of the baseline transport system, reduced congestion on affected roads, and a rebound effect.

The national institute of environmental research (2009) studied on CO_2 emission factor using real data which is consider characteristics of greenhouse gas emissions for vehicle such as vehicle type, fuel, and speed. The CO_2 emission factor equation was developed and reduction effects of greenhouse gases were evaluated.

Arnb Bose et al (2000) investigated the environmental performance of the Intelligent Cruise Control (ICC) system. The environmental evaluation of ICC vehicles shows that they have potential to reduce air pollution and fuel consumption in order to accelerate smoothly.

Matthew Barth (2000) studied emissions and fuel consumption between AHS (Automated Highway System) and non-automated highway system. AHS emissions and fuel consumption are compared to non-automated traffic at different levels of congestion and idealized traffic flow. An AHS operating at 60mph has lower emissions than non-automated traffic at the same average speed because of its smoother traffic flow. And AHS platoon has fuel savings and emission reduction.

2.2. Traffic Flow Theory

The manual traffic is different than the automated traffic. We reviewed studies on traffic flow to understand travel time, speed, volume, and capacity relation for automated driving.

YUN, Seongsoon et al (2004) developed a truck trip assignment methodology for use in the urban travel demand forecasting process. This paper presented the development of speed-flow relationships with truck impact based on CORSIM simulation results for freeways and urban arterial. The congested speed was calculated by free flow speed, volume, and capacity on the basis of BPR function. And parameters determined by a multiple linear regression analysis are applied to BPR function.

Jun Ma (2000) presented the relationships between traffic flow, travel speed and density in the scenario of automated highway system. The traffic volume was calculated by time headway. The capacity was analyzed by average time headway-traffic flow relationship and speed-density relationship.

Jason Carbaugh et al (1998) clarified comparison safety between automated highway and manual highway. The capacity was calculated by the speed, vehicle length, and separation as a function of the speed. The capacity is 2500 vphpl in the automated highway where vehicle drives at 30m/s. But, the capacity is less than 1600vphpl in the manual vehicle where vehicle drives near the same speed.

2.3. Adaptive Cruise Control Model

To understand maneuver of ACC technology and evaluate an environmental impact, we reviewed studies on ACC.

Masko Bando et al (1998) analyzed the optimal velocity model (OVM) with explicit delay. The properties of congestion and the delay time of car motion were investigated by analytical and numerical methods. It was show that the small explicit delay time has almost no effects. In the case of the large explicit delay time, a new phase of congestion pattern of OVM seems to appear.

X. Zhao et al (2005) developed a full velocity and acceleration difference model (FVADM). The main improvement upon the previous models is that the FVADM can exactly describe the driver's behavior under an urgent case, where no collision occurs and no unrealistic deceleration appears. The model was investigated by numerical methods. the simulation results indicated that the acceleration difference has an important impact on the traffic dynamics, especially under urgent conditions.

Zhao Xiaomei et al (2007) analyzed the stable conditions of the full velocity and acceleration difference model (FVADM), which is proposed by introducing the acceleration difference term based on the optimal velocity model (OVM) and the full velocity difference model (FVDM). By numerical simulations, it is found that when the traffic flow is unstable, the traffic jam in the FVADM is weaker than that in the FVDM. Also it is observed that the spreading speed of the jam is slower in the FVADM than that in the FVDM and the fluctuations of vehicles in the FVADM are smaller than those in the FVDM.

2.4. Lane Changing Model

To understand maneuver of lane changing technology and evaluate an environmental impact, we reviewed studies on lane changing.

Peter Hidas (2002) presented the lane changing and merging algorithms developed for the Simulation of Intelligent TRAnsport Systems (SITRAS) model. This model incorporates procedures for “forced” and “cooperative” lane changing, which are both essential for changing lanes in congested traffic conditions. The paper described the algorithms and presents simulation examples to demonstrate the effects of the implemented models. The results indicated that only the forced and cooperative lane changing models can produce realistic flow-speed relationships during congested traffic conditions.

Peter Hidas (2005) proposed free, forced and cooperative lane changing based on his collected data. A new lane changing model was developed, that incorporates explicit modeling of vehicle interactions using intelligent agent concepts. The model was simulated and several hypothetical test studies were conducted to demonstrate the capabilities of the new model. The results show that the model can reproduce the observed behavior of individual vehicles in terms of speed, gap acceptance, and conflict-resolution in all three types of lane changing.

3. Methodology: Car Following Condition

3.1. Evaluation Methodology

A vehicle equipped with adaptive cruise control(ACC) can automatically follow a leading vehicle at the same lane while keeping a safe spacing between vehicles. An environmental impact methodology for ACC was developed in this paper. To evaluate the environmental impact, an ACC car following model is compared with a human driven car following model. We consider how the efficiency of highway is enhanced by ACC vehicle. To evaluate the efficiency of highways, the capacity is calculated at the LOS E (Level of Service E). the LOS E is traffic condition which volume reaches capacity. Under LOS E, behavior of vehicles is a platoon which group of vehicles drives while keeping close spacing between vehicles. The capacity is related to headway and speed. The speed in manual traffic and automated traffic is estimated respectively. The headway is estimated in the human driven car following model and the ACC car following model at the LOS E. The capacity in manual traffic and automated traffic is calculated by the headway and speed at the LOS E. The travel time is estimated by V/C ratio. The speed is estimated per LOS into which highway congestion in categorized. The leading vehicle travels at an estimated speed and the speed of the following vehicles is estimated from the human driven car following model and the automated cruise controlled car following model. The CO_2 emissions are calculated in manual/automated traffic. The independent variable of the CO_2 emission factor equation is speed. The CO_2 emissions from the human driven car following model are compared with the CO_2 emissions from the ACC car following model. The CO_2 emission reduction rate was calculated.

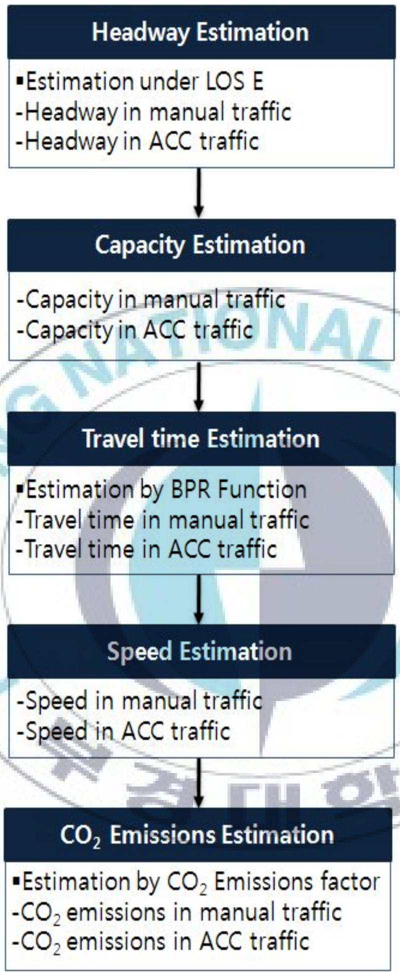

Figure 3.1. Flow chart of the environmental impact methodology

3.1.1 Car Following Model

For manual driving, following vehicle follows leading vehicle by pipes model. Pipes model is a simple car following model. The model responds to speed difference between the leading vehicle and following vehicles and driver reaction times. Pipes model represents the human driven car following condition in this paper. This model is as follows:

$$a_F = \frac{\lambda}{M}[LV(t-\tau) - FV(t-\tau)] \tag{1}$$

where

LV = Leading vehicle's speed(m/s),

FV = Following vehicle's speed(m/s),

a_F = Following vehicle's acceleration(m/s^2),

M = Mass of following vehicle, and

λ = Sensitivity factor.

For automated driving, following vehicle follows leading vehicle by FVADM(Full Velocity and Acceleration Difference Model). X. Zhao and Z. Gao (2005) proposed FVADM. The model incorporates an acceleration difference and a safe distance. Zhao Xiaomi and Gao Ziyou (2007) estimated parameters (K, a, b, c, d, and S$_c$) when FVADM was stable. This model represents the adaptive cruise controlled car following in this paper. This model is as follows:

$$a_F = K[FV(S_F(t)) - FV(t)] + \lambda \triangle FV(t) + kg(\triangle a_F(t-1), a_L(t)) \triangle a_F(t-1) \tag{2}$$

$$FV(S)=\begin{cases}0 & \text{if } 0 \leq S \leq S_M \\ U^0 \dfrac{(S-S_M)^3}{1+(S-S_M)^3} & \text{if } S > S_M\end{cases}$$

$$S_F(t)=X_L(t)-X_F(t)-l_L$$

$$\triangle a_F(t)=a_L(t)-a_F(t)$$

$$g(\triangle a_F(t-1),a_L(t))=\begin{cases}-1, a_F(t-1)>0 \text{ and } a_L \leq 0 \\ 1, \quad others\end{cases}$$

$$\lambda=\begin{cases}a, S \leq S_c \\ b, S > S_c\end{cases}$$

$$k=\begin{cases}c, S \leq S_c \\ d, S > S_c\end{cases}$$

Where

K = 0.85,

U^0 = Desired speed(m/s),

S_M = The minimum distance between leading vehicle and following vehicle (m),

X_L = Leading vehicle's travel distance(m),

X_F = Following vehicle's travel distance(m),

l_L = Leading vehicle's length(m),

$\triangle a_F$ = Acceleration difference between the leading vehicle and the following vehicle(m/s^2)

a_L = Leading vehicle's acceleration(m/s^2),

a_F = Following vehicle's acceleration(m/s^2),

U_F = Following vehicle's speed(m/s),

S_c = 100(m),

a = 0.8(s^{-1}),

b = 0,

c = 0.4(s^{-1}), and

d = 0.

The Minimum distance between the leading vehicle and following vehicles was fixed at 1m in conventional studies. It is an unrealistic distance without regard to speed transition. So, we consider the reaction time and speed and apply those to the minimum distance. The minimum distance is calculated by the following equation:

$$S_M(t) = \beta FV + \Upsilon FV^2 \qquad (3)$$

Where

β = Reaction time(s), and

γ = The maximum average deceleration of a following vehicle (=0.075s^2/m).

3.1.2. Estimation of Headway in Manual/Automated Traffic

All vehicles drive as a platoon at LOS E. Speed and headway at LOS E are related to the capacity estimate. To estimate the speed at LOS E, travel time is estimated by a BPR function. Parameters(α,β) of the BPR function were validated using real data based on the KTDB (Korea Transport Database) by Yong-Tae Lim et al (2008). The BPR function is described by the following equation:

$$t = t_0(1 + \alpha(V/C)^{\beta}) \tag{4}$$

Where

t = Travel time(hour),

t_0 = Free flow time (hour),

V = Volume(veh/h),

C = Capacity of a single lane(veh/h),

α = 3.931, and

β = 5.316.

The speed at LOS E is related to travel distance and estimated time. The speed is estimated by the following equation:

$$U = \frac{L}{t} \tag{5}$$

Where

U = Speed (km/h),

L = Travel distance (km), and

t = Travel time(hour).

The headway between vehicles is estimated at LOS E. The headway in Pipes model was estimated by the following equation:

$$h = U \times t + l \tag{6}$$

Where

h = Headway under LOS E(m),

U = Speed under LOS E (m/s),

t = Reaction time (s), and

l = Vehicle's length.

To estimate headway in FVADM, the minimum distance was estimated by the following equation:

$$S_M = U \times t \times r \tag{7}$$

Where

S_M = The minimum distance between leading vehicle and following vehicle(m),

U = Speed under LOS E (m/s),and

r = Safe rate(=7).

3.1.3. Estimation of Capacity in Manual/Automated Traffic

Capacity is related to speed and headway at LOS E. The capacity is estimated in manual/automated traffic. The capacity is described by the following equation:

$$C = 1000 \times \frac{U}{h} \tag{8}$$

Where

C = Capacity of a single lane(veh/h),

U = Speed(km/h),and

h = Headway(m).

3.1.4. Estimation of Leading Vehicle's Speed in Manual/Automated Traffic

Travel time is calculated by a BPR function applied to the estimated capacity. Travel time per LOS can be estimated as a variable V/C ratio. Speed can be calculated by a distance-time relation. Speed per LOS is estimated by equation (5). The leading vehicle in Pipes model and FVADM travels on the basis of an estimated speed.

3.1.5. Estimation of CO_2 Emissions

The CO_2 emissions of ASV are compared with the CO_2 emissions of manual vehicles. The CO_2 emissions are estimated by a CO_2 emission factor equation. Table 1 shows the CO_2 emission factor equations developed at the National Institute of Environmental Research in Korea. The CO_2 emission factor equation was developed by real data considering the characteristics of greenhouse gas emissions for vehicles such as vehicle type, fuel and speed.

Table 3.1 CO_2 Emission factor equation

Vehicle Type		Fuel	Speed	CO_2 Emission Factor Equation
Passenger vehicle	Small size	Gasoline	U<65.4km/h	$Y = 1313.7U^{-0.6}$
			U≥65.4km/h	$Y = 0.5447U + 78.746$
		Diesel	U<65.4km/h	$Y = 1133.1U^{-0.587}$
			U≥65.4km/h	$Y = 0.6175U + 62.478$
	Medium size	Gasoline	U<65.4km/h	$Y = 1555.5U^{-0.578}$
			U≥65.4km/h	$Y = 0.0797U + 144.19$
		Diesel	U<65.4km/h	$Y = 1818.1U^{-0.6643}$
			U≥65.4km/h	$Y = 0.3184U + 95.66$
		LPG	U<65.4km/h	$Y = 1539.4U^{-0.5748}$
			U≥65.4km/h	$Y = 0.5056U + 117.39$
	Large size	Diesel	U<65.4km/h	$Y = 1970.1U^{-0.6187}$
			U≥65.4km/h	$Y = 0.1791U + 145.07$
		LPG	U<65.4km/h	$Y = 1849.8U^{-0.6164}$
			U≥65.4km/h	$Y = -0.1348U + 159.9$

3.2. Results

3.2.1. Simulation Condition

The environmental impact of automated traffic in comparison with manual traffic is evaluated. We apply the Pipes model to simulate the manual vehicle behaviors and the FVADM to simulate the ASV behaviors.

The simulation condition assumes that all vehicles equipped with ACC systems drive on automated highways. For all vehicles it is assumed that the vehicle type is small and it uses gasoline. A platoon including 10 vehicles drives at constant speed along a 5km section. 9 vehicles follow a leading vehicle in a single lane without overtaking. The response time of Pipes model is 2.5s and FVADM is 0.05s. To estimate the capacity, the free flow speed is assumed to be 100km/h (27.8m/s).

3.2.2. Simulation Results

The results of the simulation were as follows: The headway in manual traffic and automated traffic was calculated under LOS E for which the speed was 20km/h. In manual traffic, the headway between following vehicle and leading vehicle was 19m and the capacity was 1,053veh/h. In automated traffic, the headway was 9m and the capacity was 2,564veh/h. Travel times were calculated by a BPR function based on each capacity. The volume ranged from 0veh/h to 1300veh/h at increments of 50veh/h.

Table 3.2. Simulation results

	Manually driven vehicles cases			ACC driven vehicles cases		
Volume (veh/h)	LOS	Travel time (h)	Speed (km/h)	LOS	Travel time (h)	Speed (km/h)
700	D	0.07	69	B	0.05	99
750	D	0.08	61	B	0.05	99
800	D	0.10	52	B	0.05	98
850	D	0.11	44	B	0.05	98
900	E	0.14	37	B	0.05	98
950	E	0.16	31	B	0.05	97
1,000	E	0.20	25	B	0.05	96
1,050	E	0.24	21	B	0.05	95
1,100	F	0.30	17	B	0.05	93
1,150	F	0.36	14	B	0.06	91
1,200	F	0.44	11	C	0.06	89
1,250	F	0.54	9	C	0.06	84
1,300	F	0.65	8	C	0.06	81

The CO_2 emissions were estimated about 10 vehicles per LOS. When the volume was 850veh/h, the LOS in manual traffic was shown as D and the speed in manual traffic was 44km/h. LOS in automated traffic was shown as B and the speed in automated traffic was 98km/h. In manual traffic, the total CO_2 emission was 563,125g when the leading vehicle traveled at 44km/h. In automated traffic, the total CO_2 emission was 503,795g when the leading vehicle traveled at 98km/h.

When the volume was 1,050veh/h, the LOS in manual traffic was shown as E and the speed in manual traffic was 21km/h. The LOS in automated traffic was shown as B and the speed in automated traffic was 95km/h. In manual traffic, the total CO_2 emission was 1,227,345g when the leading vehicle drove at 21km/h. In automated traffic, the total CO_2 emission was 677,145g when the leading vehicle drove at 95km/h.

When the volume was 1,300veh/h, the LOS in manual traffic was shown as F and the speed in manual traffic was 8km/h. The LOS in automated traffic was shown as C and the speed in automated traffic was 81km/h. In manual traffic, the total CO_2 emission was 2,292,940g when the leading vehicle traveled at 8km/h. In automated traffic, the total CO_2 emission was 794,950g.

The CO_2 reduction rate is given in Table 3. When the volume was 850 veh/h, the CO_2 emissions of vehicles equipped with ACC could be reduced by approximately 11%. When the volume was 1,050veh/h, the CO_2 emissions in automated traffic could be reduced by approximately 45%. When the volume was 1,300veh/h, the CO_2 emissions in automated traffic could be reduced by approximately 65%.

Table 3.3. CO_2 Reduction rate between automated traffic and manual traffic

	Manual traffic	Automated traffic	CO_2 reduction rate
850 veh/h	563,125g	503,795g	11%
1,050 veh/h	1,227,345g	677,145g	45%
1,300 veh/h	2,292,940g	794,950g	65%

4. Methodology: Lane Changing Condition

4.1. Evaluation Methodology

Lane changing is classified as either mandatory or discretionary. A driver performs mandatory lane changing when he/she must leave the current lane because of events such as accidents and road construction. A driver executes a discretionary lane change when he/she wants to drive at a desired speed. In this paper, mandatory lane changing assumes that host vehicle executes a lane change from the fast lane to the slow lane. Discretionary lane changing assumes that the driver of the host vehicle executes a lane change from the slow lane to the fast lane.

The driver of a host vehicle who wants to change lanes recognizes relative speed and gaps. A lane changing is considered feasible if there is a sufficient gap between the host vehicle and adjacent vehicle, so that host vehicle can move into the target lane safely. In this paper, a lane changing maneuver is proposed for manual driving conditions and automated driving conditions. The vehicles that follow are in the current lane and the target lane and are following the lead vehicle. When the host vehicle executes lane changes, the environmental impact was evaluated for manual driving conditions and automated driving conditions. To evaluate the environmental impact, CO_2 emissions were estimated by CO_2 emission factor equations.

4.1.1. Lane Changing for the Manual Driving

Figure 4.1 shows that a driver can change from or to a faster lane. The host vehicle determines whether the initial gap between adjacent vehicles is enough or not. If the gap is enough, the vehicle can execute lane changing. If the gap is shorter than a safe distance, the following vehicle in the target lane decelerates to create a sufficient gap. When the gap is longer than a safe distance, the vehicle can enter the target lane. The following vehicles in the current lane and the target lane follow the leading vehicle according to the Pipes model, a simple car following model. The CO_2 emissions of the host vehicle, leading vehicle, and following vehicles in the current and target lanes are estimated by the CO_2 emission factor equation.

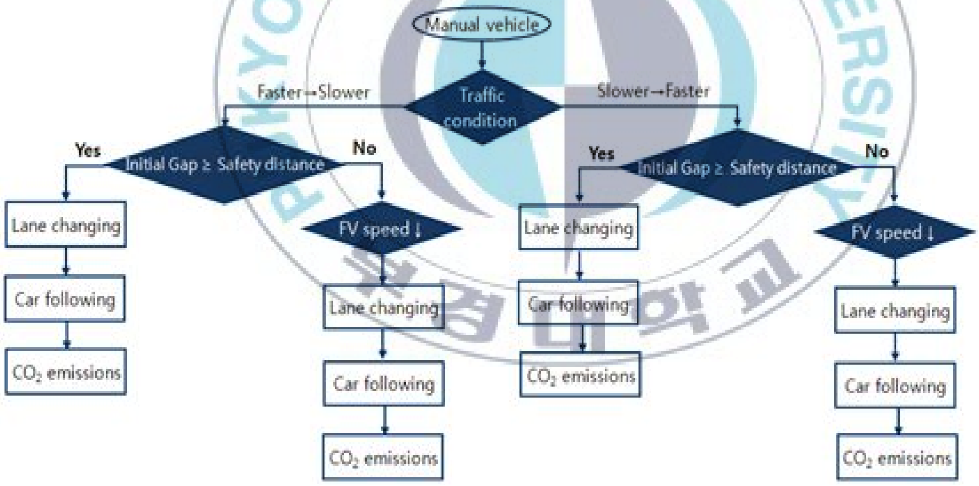

Figure 4.1. Flow chart of a methodology to evaluate an environmental impact for manual driving.

If an event such as an accident and construction happens, the host vehicle in the fast lane executes a lane change into the slower lane.

Figure 4.2. Manual vehicle of lane changing from the fast lane to the slow lane.

The vehicle makes a judgment as to whether the initial gap(DO) between the host vehicle and the leading vehicle in the target lane and the initial gap(D1) between the host vehicle and the following vehicle in the target lane are safe distance or not. The safe distance is calculated by the following equation (3). The vehicle decelerates and executes a lane changing when the sum of DO and D1 is longer than the safe distance. The host vehicle decides whether to execute a lane changing or not by the following equation (9);

$$(D0+LV\times t)-(HV\times t+\frac{1}{2}\times d\times t^2)=S0 \qquad (9)$$

$$(D1+(HV\times t+\frac{1}{2}\times d\times t^2))-(FV\times t)=S1$$

$$S0+S1\geq SD$$

Where

$D0$ = Inital gap between LV and HV(m),

$D1$ = Initial gap between HV and FV(m),

LV = Speed of LV(m/s),

HV = Speed of HV(m/s),

FV = Speed of FV(m/s),

d = Deceleration(m/s^2),

$S0$ = Gap between LV and HV when HV executes lane changing(m), and

$S1$ = Gap between HV and FV when HV executes lane changing(m).

If the gap between adjacent vehicles is smaller than a safe distance, the following vehicle decelerates to assure a safe distance. The host vehicle executes a lane change when the gap between adjacent vehicles is longer than a safe distance.

Figure 4.3. Manual vehicle of lane changing from the slow lane to the fast lane.

A driver who wants to drive at a desired speed changes into the faster lane. This lane changing is permitted when the sum of the initial gap (D0) between the host vehicle and the leading vehicle and the initial gap (D1) between the host vehicle and the following vehicle are longer than a safe distance. Changes are prohibited when D0 and D1 are shorter than a safe distance according to the following equation:

$$(D0+LV\times t)-(HV\times t+\frac{1}{2}\times a\times t^2)=S0 \tag{10}$$

$$(D1+(HV\times t+\frac{1}{2}\times a\times t^2))-(FV\times \mathrm{t})=S1$$

$$S0 + S1 \geq SD$$

If the gap between adjacent vehicles is shorter than a safe distance, the following vehicle decelerates to assure a safe distance. After the following vehicle decelerates and the gap between adjacent vehicles is longer than a safe distance, the host vehicle executes a lane change.

4.1.2. Lane Changing for the Automated Driving

If an ASV drives on an automated highway, the vehicle and the highway will exchange information. The automated highway will have a set of lanes on which vehicles with proper sensors and wireless communications systems can travel under automated control. The vehicle can continuously exchange information with other vehicles and the infrastructure about speed, acceleration, position, obstacles, road conditions, etc. The vehicle can recognize the maneuvers of other vehicles and traffic conditions and then determine whether to execute a lane change or not.

Figure 4.4 shows that a driver can change from or to faster lane. The host vehicle recognizes whether the initial gap between the adjacent vehicles is enough or not. If the gap is enough, the vehicle can execute a lane changing. If the gap is shorter than a safe distance, the following vehicle in the target lane decelerates to create a sufficient gap. When the gap is longer than a safe distance, the vehicle can enter the target lane. The following vehicles in the current lane and target lane follow the leading vehicle by FVADM. The CO_2 emissions of host vehicle, leading vehicle, and following vehicles at the current lane and the target lane are estimated by CO_2 emission factor equation.

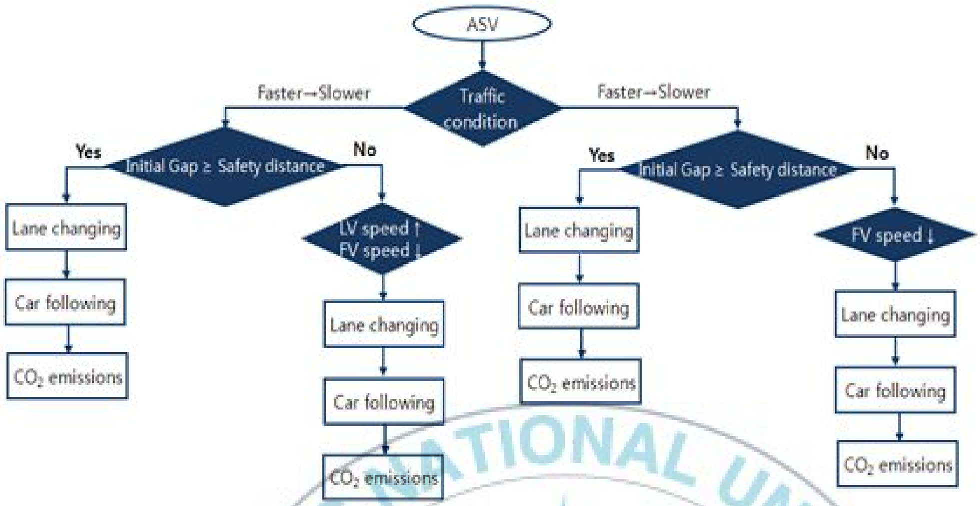

Figure 4.4. Flow chart of a methodology to evaluate an environmental impact for automated driving.

An ASV can be controlled automatically through communication systems based on V2V and V2I. The vehicle that wants to change into a slower lane sends a “courtesy” request to subsequent vehicles in the slow lane. The request is evaluated by each vehicle depending on the speed, position, and gap between adjacent vehicles. When the host vehicle sends a “courtesy” message to the leading and following vehicles in the target lane, the leading vehicle in the target lane accelerates and the following vehicle in the target lane decelerates to ensure that a sufficient gap is created during the next few seconds for the lane change.

Figure 4.5. ASV of lane changing from the fast lane to the slow lane.

The host vehicle decides whether to execute a lane change or not by the following equation:

$$((LV\times t+\frac{1}{2}\times a\times t^2)+D0)-(HV\times t+\frac{1}{2}\times d\times t^2)=S0 \tag{11}$$

$$(HV\times t+\frac{1}{2}\times d\times t^2)-(FV\times t+\frac{1}{2}\times d\times t^2)=S1$$

$$S0+S1\geq SD$$

If the gap between adjacent vehicles is shorter than a safe distance, the following vehicle in the slow lane will decelerate and give way and the leading vehicle in the slow lane will accelerate to allow the host vehicle to move to the slow lane. When the gap between adjacent vehicles is sufficient, the host vehicle changes to the slow lane.

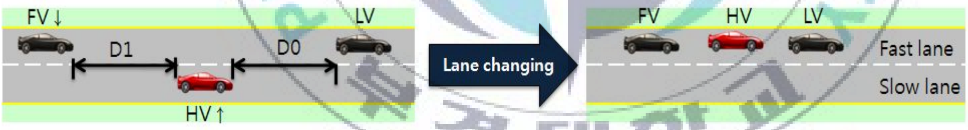

Figure 4.6. ASV of lane changing from the slow lane to the fast lane.

When the host vehicle that is driving in the slow lane is about to change to the fast lane, the following vehicle in the fast lane decelerates to allow the host vehicle to move into the fast lane. The host vehicle evaluates whether the gap between adjacent vehicles is longer than a safe distance or not by following equation:

$$(LV\times t+D0)-(HV\times t+\frac{1}{2}\times a\times t^2)=S0 \qquad (12)$$

$$((HV\times t+\frac{1}{2}\times a\times t^2)+D1)-(FV\times t+\frac{1}{2}\times d\times t^2)=S1$$

$$S0+S1\geq SD$$

In this case, the gap is shorter than a safe distance and the following vehicle in the fast lane is forced to slow down to created a safe distance

4.2. Results

4.2.1. Simulation Condition

The simulation condition assumes the following: All vehicle types are midsize and use gasoline. The host vehicle and five other vehicles drive in the current lane. The leading vehicle and five other vehicles drive in the target lane. The following vehicle follows the leading vehicle by the Pipes model for manual driving. For automated driving, the following vehicle follows according to FVADM. The minimum deceleration is $3m/s^2$ and the maximum acceleration is $2m/s^2$.This is a safe and suitable acceleration range for drivers comfort according to Heejin Jung et al (2005). Changing lanes from the fast lane to the slow lane and changing from the slow lane to the fast lane are simulated. CO_2 emissions were estimated by the CO_2 emissions factor equation.

Scenario 1 and Scenario 2 describes how the vehicle in fast lane wants to change to the slow lane. Vehicles in the current lane accelerate up to 15m/s. Vehicles in the target lane accelerate up to 10m/s. In 200 seconds, the host vehicle considers whether the gap between adjacent vehicles and the target vehicle is a safe distance or not. If the gap is wide enough, the host vehicle enters the target lane. All vehicles drive without acceleration after the host vehicle changing lanes.

In scenario 1, gap between leading vehicle at the target lane (LV) and host vehicle (HV) and gap between HV and following vehicle at the target lane (FV6) which drives on the target lane are 60m respectively. Gaps between following vehicles are 10m respectively.

In scenario 2, all gaps between vehicles are 10m.

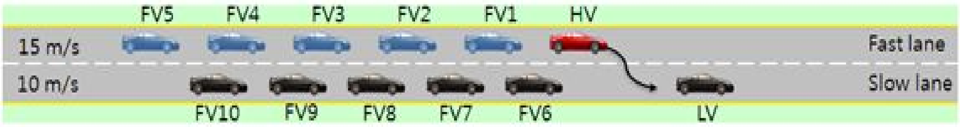

Figure 4.7. Lane changing of scenario 1 and scenario 2.

Scenario 3 and Scenario 4 describes how the host vehicle changes to a faster lane. Vehicles in the current lane accelerate up to 10m/s. Vehicles in the target lane accelerate up to 15m/s. In 200 seconds, the host vehicle decides whether or not to enter the gap between the leading vehicle and the following vehicle in the target lane. If the gap is enough, the HV executes lane changing.

In scenario 3, gap between LV and HV and gap between HV and FV6 are 60m respectively. Gaps between following vehicles are 10m respectively.

In scenario 4, all gaps between vehicles are 10m.

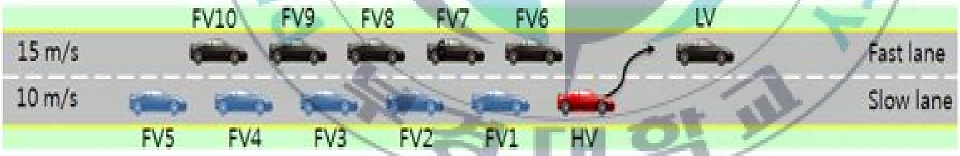

Figure 4.8. Lane changing of scenario 3 and scenario 4.

Table 4.1. Simulation scenario.

		scenario 1	scenario 2	scenario 3	scenario 4
Lane Changing time		In 200s	In 200s	In 200s	In 200s
Vehicles in the current lane	HV	15m/s	15m/s	10m/s	10m/s
	FV1,2,3,4,5	15m/s	15m/s	10m/s	10m/s
Vehicles in the target lane	LV	10m/s	10m/s	15m/s	15m/s
	FV6,7,8,9,10	10m/s	10m/s	15m/s	15m/s
Gap between vehicles	LV-HV	60m	10m	60m	10m
	HV-FV6	60m	10m	60m	10m
	HV-FV1	10m	10m	10m	10m
	FV1-FV2	10m	10m	10m	10m
	FV2-FV3	10m	10m	10m	10m
	FV3-FV4	10m	10m	10m	10m
	FV4-FV5	10m	10m	10m	10m
	FV6-FV7	10m	10m	10m	10m
	FV7-FV8	10m	10m	10m	10m
	FV8-FV9	10m	10m	10m	10m
	FV9-FV10	10m	10m	10m	10m

4.2.2. Simulation Results

Simulation results of scenario 1 for the manual driving are as follow: The sum of the gap between the LV and HV and the gap between the HV and FV6 is 120m. The safe distance is 55m. The HV executes lane changing because the sum of the gap between the LV and HV and the gap between the HV and FV6 is longer than a safe distance. Figure 4.9 shows that the LV drives at 10m/s without acceleration. Figure 4.10 shows that the HV drives at 15m/s and decelerates to change into the target lane. The HV decelerates up to 7.5m/s and executes lane changing. After the HV enters the target lane, the vehicle drives without acceleration. Figure 4.11 shows that FV1, FV2, FV3, FV4, and FV5 which are vehicles in the current lane drive at 15m/s without acceleration. Figure 4.12 shows that FV6 drives at 10m/s and FV7, FV8, FV9, and FV10 which are vehicles in the target lane follow FV6.

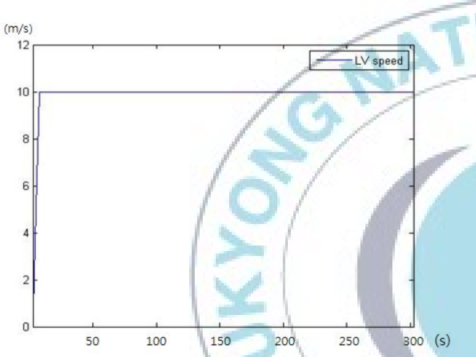

Figure 4.9. Speed of LV

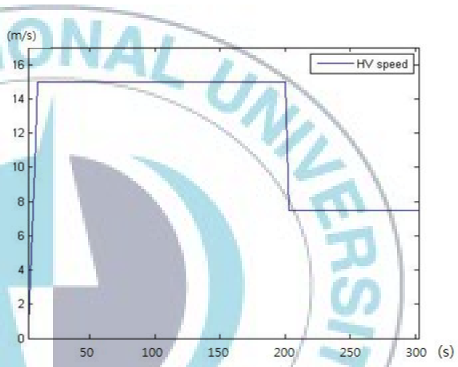

Figure 4.10. Speed of HV

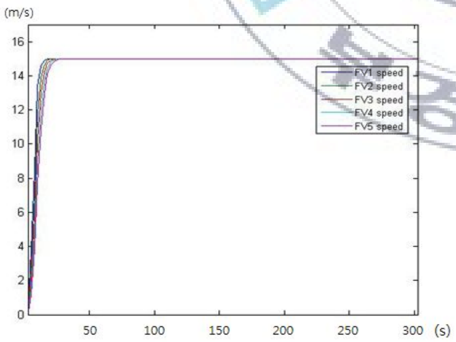

Figure 4.11. Speed of following vehicles in the current lane

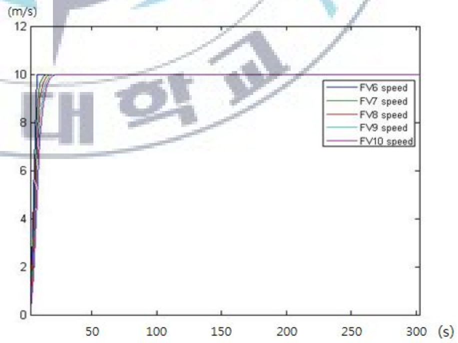

Figure 4.12. Speed of following vehicles in the target lane

Simulation results of scenario 1 for the automated driving are as follows: The sum of the gap between the LV and HV and the gap between the HV and FV6 is 120m. The safe distance is 25m. The gap allows the HV to move into the target lane. Figure 4.13 shows that LV drives at 10m/s and accelerates to create a sufficient gap between the LV and HV. When the HV executes lane changing, the speed of the LV is 10.1m/s. Figure 4.14 shows that HV drives at 15m/s and decelerates to change into the target lane. The HV decelerates up to 10.05m/s and executes lane changing. After the HV enters the target lane, the vehicle drives without acceleration. Figure 4.15 shows that FV1, FV2, FV3, FV4, and FV5 drive at 15m/s without acceleration. Figure 4.16 shows that FV6 drives at 10m/s and decelerates to create a sufficient gap between the HV and FV6. When the HV executes lane changing, the speed of the FV6 is 9.85m/s. FV7, FV8, FV9, and FV10 follow FV6.

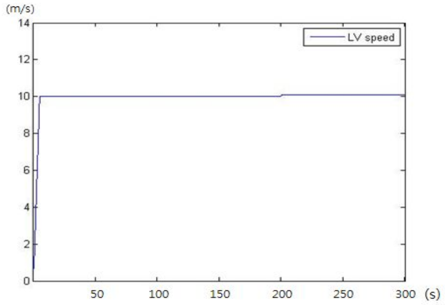

Figure 4.13. Speed of LV

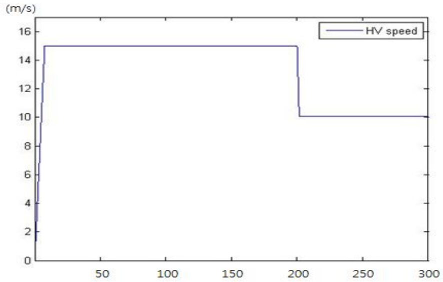

Figure 4.14. Speed of HV

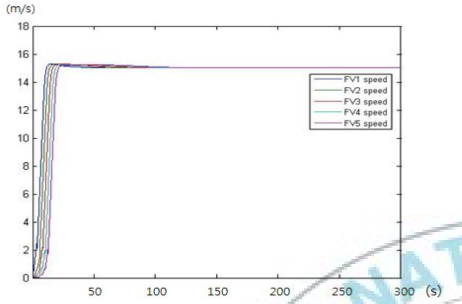

Figure 4.15. Speed of following vehicles in the current lane

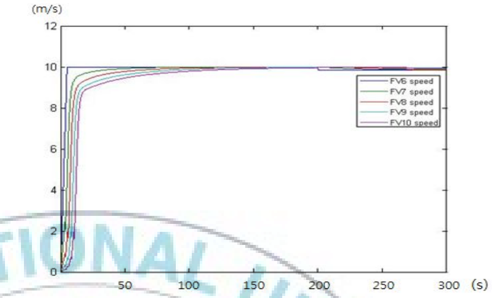

Figure 4.16. Speed of following vehicles in the target lane

There are not difference of CO_2 emissions between manual driving and automated driving. When the gap between adjacent vehicles is longer than a safe distance, the HV can execute lane changing without delay. So, the CO_2 emissions in manual driving are similar than the CO_2 emissions in automated driving because the speed of vehicles hardly changes.

Simulation results of scenario 2 for the manual driving are as follow: The sum of the gap between the LV and HV and the gap between the HV and FV6 is 20m. The safe distance is 55m. The HV can not execute lane changing because the sum of the gap between the LV and HV and the gap between the HV and FV6 is shorter than the safe distance. The FV6 decelerates for 19 seconds to create a safe distance. Figure 4.17 shows that LV drives at 10m/s without acceleration. Figure 4.18 shows that HV drives at 15m/s and decelerates to change into the target lane. The HV decelerates up to 7.5m/s and executes lane changing. After the HV enters the target lane, the vehicle drives without acceleration. Figure 4.19 shows that FV1, FV2, FV3, FV4, and FV5 which are vehicles in the current lane drive at 15m/s without acceleration. Figure 4.20 shows that FV6 drives at 10m/s and decelerates by 0m/s to ensure a safe distance. FV7, FV8, FV9, and FV10 decelerate and delay. After the HV executes lane changing, FV6 accelerates up to 10m/s and FV7, FV8, FV9, and FV10 drive at the speed of FV6.

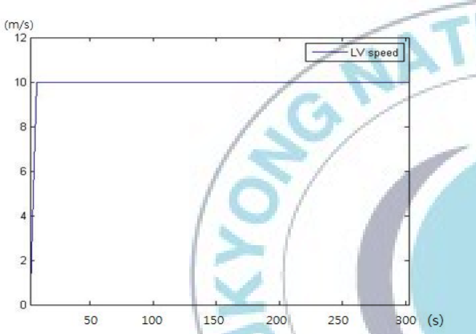

Figure 4.17. Speed of LV

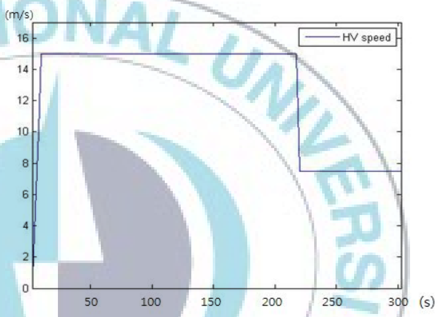

Figure 4.18. Speed of HV

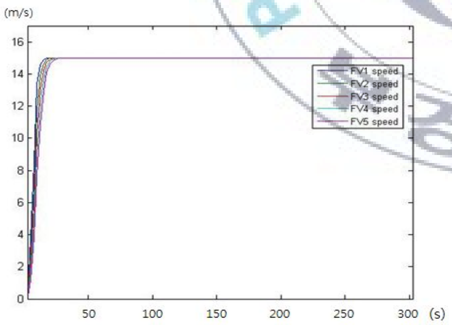

Figure 4.19. Speed of following vehicles in the current lane

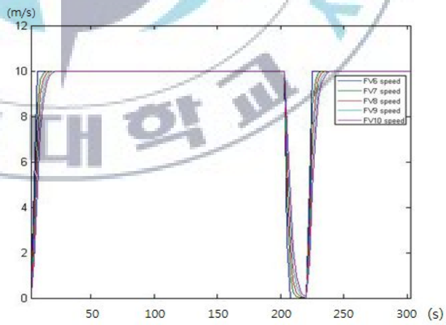

Figure 4.20. Speed of following vehicles in the target lane

Simulation results of scenario 2 for the automated driving are as follow: The sum of the gap between the LV and HV and the gap between the HV and FV6 is 20m. The safe distance is 25m. The HV is not able to execute lane changing because the gap is shorter than a safe distance. Figure 4.21 shows that LV drives at 10m/s and accelerates to create a sufficient gap between the LV and HV. When the HV executes lane changing, the speed of LV is 12m/s. Figure 4.22 shows that HV drives at 15m/s and decelerates up to 10.05m/s to execute lane changing. The HV decelerates up to 10.05m/s and executes lane changing. After the HV enters on the target lane, the vehicle drives without acceleration. To ensure a safe distance, the FV6 decelerates for 1 second. Figure 4.23 shows that FV1, FV2, FV3, FV4, and FV5 drive at 15m/s without acceleration. Figure 4.24 shows that FV6 drives at 10m/s and decelerates by 7m/s to create a safe distance. After FV6 accelerates up to 10m/s. FV7, FV8, FV9, and FV10 follow FV6.

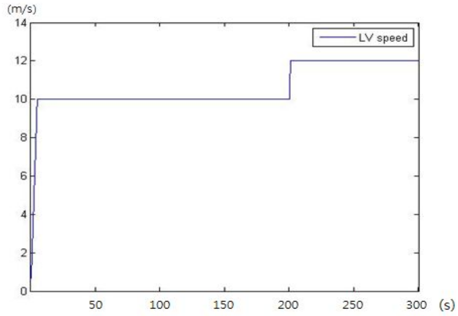

Figure 4.21. Speed of LV

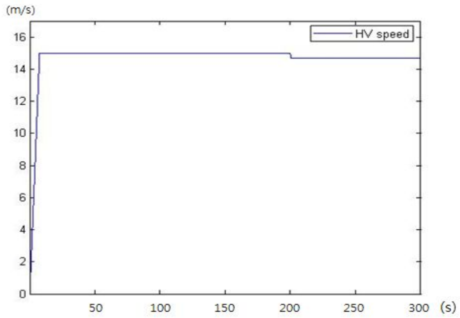

Figure 4.22. Speed of HV

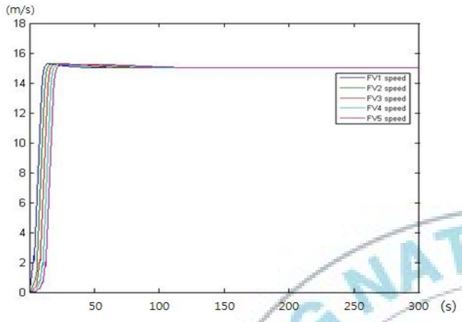

Figure 4.23. Speed of following vehicles in the current lane

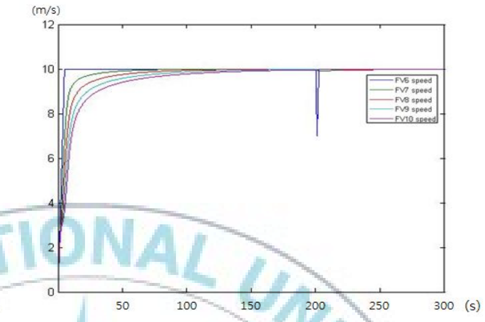

Figure 4.24. Speed of following vehicles in the target lane

In scenario 2, CO_2 emissions of manual driving and automated driving are as follows: The CO_2 emissions of LV for automated driving are reduced 6.6%. The CO_2 emissions of HV for automated driving are reduced 2.1%. The CO_2 emissions of FV1, FV2, FV3, FV4, and FV5 hardly differ between manual driving and automated driving. The CO_2 emissions of FV6 are increased 7.8%. Because FV6 for manual driving reaches 0m/s to create a safe distance and CO_2 emissions in idle condition emit few emissions. However, FV6 for automated driving can assure a safe distance although FV6 does not decelerate by 0m/s. So, CO_2 emissions of FV6 for automated driving are more than CO_2 emissions of FV6 for manual driving. For automated driving, CO_2 emissions of FV7 are reduced 85.3%. CO_2 emissions of FV8 are lowered 69.1%. CO_2 emissions of FV9 decline 54% and CO_2 emissions of FV10 decrease 42.2%.

Table 4.2. CO_2 emissions in scenario 2.

Vehicle	Manual vehicle	ASV	Reduction rate
LV	705,716 g/h	658,871 g/h	6.6% decrease
HV	714,170 g/h	562,649 g/h	2.1% decrease
FV1	558,276 g/h	558,276 g/h	0%
FV2	558,276 g/h	558,276 g/h	0%
FV3	558,276 g/h	558,275 g/h	0%
FV4	558,276 g/h	558,272 g/h	0%
FV5	558,276 g/h	558,261 g/h	0%
FV6	655,615 g/h	706,936 g/h	7.8% increase
FV7	4,831,500 g/h	706,530 g/h	85.3% decrease
FV8	228,3433 g/h	706,566 g/h	69.1% decrease
FV9	153,6957 g/h	706,771 g/h	54.0% decrease
FV10	122,4656 g/h	707,286 g/h	42.2% decrease

Simulation results of scenario 3 for the manual driving are as follow: The sum of the gap between the LV and HV and the gap between the HV and FV6 is 120m. The safe distance is 109m. The HV executes lane changing because the sum of the gap between the LV and HV and the gap between the HV and FV6 is longer than a safe distance. Figure 4.25 shows that LV drives at 15m/s without acceleration. Figure 4.26 shows that HV drives at

10m/s and accelerates to change into the target lane. Figure 4.27 shows that FV1, FV2, FV3, FV4, and FV5 drive at 10m/s without acceleration. Figure 4.28 shows that FV6 drives at 15m/s. FV7, FV8, FV9, and FV10 follow FV6.

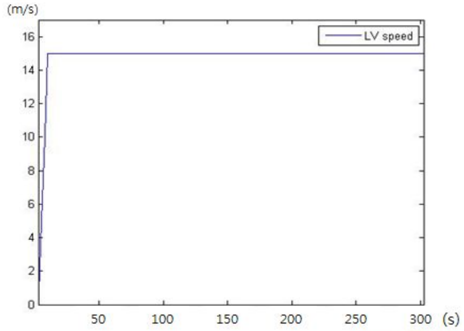

Figure 4.25. Speed of LV

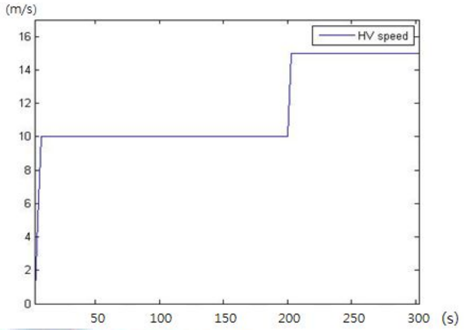

Figure 4.26. Speed of HV

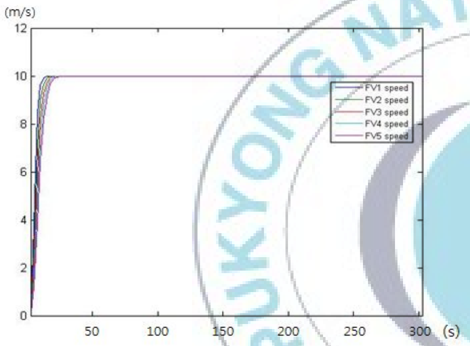

Figure 4.27. Speed of following vehicles in the current lane

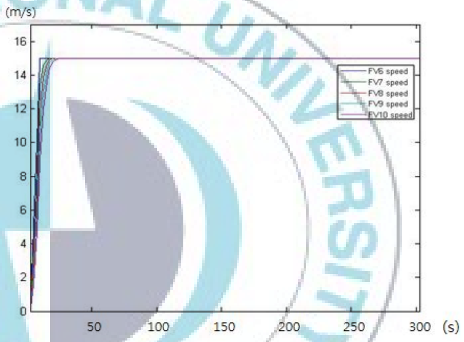

Figure 4.28. Speed of following vehicles in the target lane

Simulation results of scenario 3 for the automated driving are as follow: The sum of the gap between the LV and HV and the gap between the HV and FV6 is 121m. The safe distance is 25m. The gap allows the HV to move into the target lane. Figure 4.29 shows that LV drives at 15m/s. Figure 4.30 shows that HV drives at 10m/s and accelerates to change into the target lane. The HV accelerates up to 10.05m/s and executes lane changing. After the HV enters the target lane, the vehicle drives without acceleration. Figure 4.31 shows that FV1, FV2, FV3, FV4, and FV5 drive at 10m/s without acceleration. Figure 4.32 shows that FV6 drives at 15m/s and decelerates by 14.85m/s to create a sufficient gap. FV7, FV8, FV9, and FV10 follow FV6.

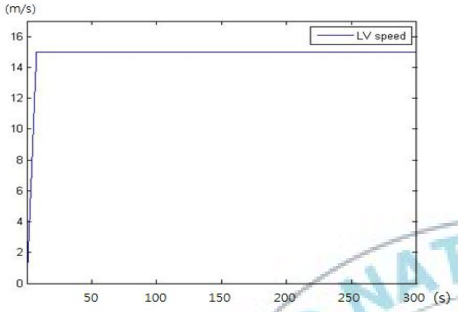

Figure 4.29. Speed of LV

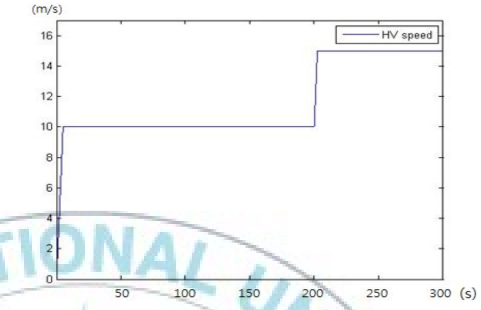

Figure 4.30. Speed of HV

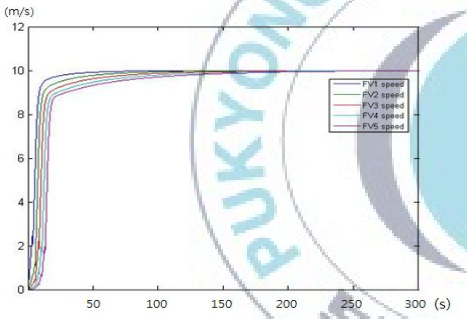

Figure 4.31. Speed of following vehicles in the current lane

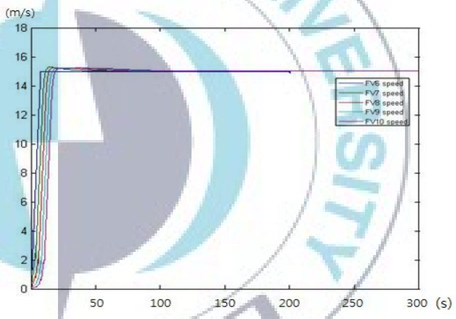

Figure 4.32. Speed of following vehicles in the target lane

There are not difference of CO_2 emissions between manual driving and automated driving. When the gap between adjacent vehicles is longer than a safe distance, the HV can execute lane changing without delay. So, the CO_2 emissions for manual driving are similar than the CO_2 emissions for automated driving because the speed of vehicles hardly changes.

Simulation results of scenario 4 for the manual driving are as follow: The sum of the gap between the LV and HV and the gap between the HV and FV6 is 20m. The safe distance is 109m. The HV can not execute lane changing because the sum of the gap between the LV and HV and the gap between the HV and FV6 is shorter than a safety distance. The FV6 decelerates for 8 seconds to create a safe distance. Figure 4.33 shows that LV drives at 15m/s without acceleration. Figure 4.34 shows that HV drives at 10m/s and accelerates to change into the target lane. When the HV executes lane changing, the speed of HV is 15m/s. After the HV enters the target lane, the vehicle drives without acceleration. Figure 4.35 shows that FV1, FV2, FV3, FV4, and FV5 drive at 10m/s without acceleration. Figure 4.36 shows that FV6 drives at 15m/s and decelerates by 0m/s to ensure a safe distance. FV7, FV8, FV9, and FV10 decelerate and delay. After the HV executes lane changing, FV6 accelerates up to 15m/s and FV7, FV8, FV9, and FV10 drive at the speed of FV6.

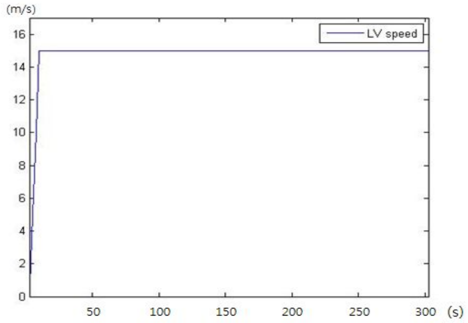

Figure 4.33. Speed of LV

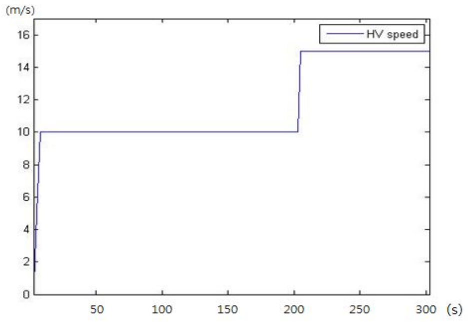

Figure 4.34. Speed of HV

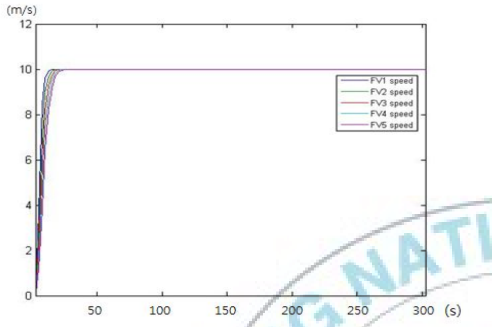

Figure 4.35. Speed of following vehicles in the current lane

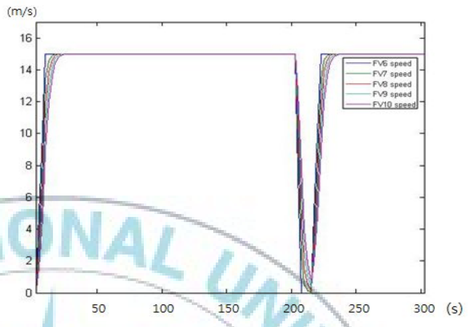

Figure 4.36. Speed of following vehicles in the target lane

Simulation results of scenario 4 for the automated driving are as follow: The sum of the gap between the LV and HV and the gap between the HV and FV6 is 21m. The safe distance is 25m. The HV is not able to execute lane changing because the gap is shorter than a safe distance. The FV6 has to decelerate to create a sufficient gap. To ensure a safe distance, FV6 decelerates for 2 seconds. Figure 4.37 shows that LV drives at 15m/s. Figure 4.38 shows that HV drives at 10m/s and accelerates to change into the target lane. When the HV executes lane changing, the speed of HV is 10.1m/s. After the HV enters the target lane, the vehicle drives without acceleration. Figure 4.39 shows that FV1, FV2, FV3, FV4, and FV5 drive at 11m/s which is the desired speed of FVADM. Figure 4.40 shows that FV6 drives at 15m/s and decelerates by 9m/s to create a sufficient gap. The FV6 accelerates up to 15m/s after HV executes lane changing. FV7, FV8, FV9, and FV10 follow FV6.

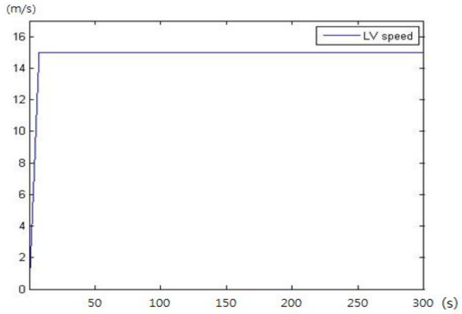

Figure 4.37. Speed of LV

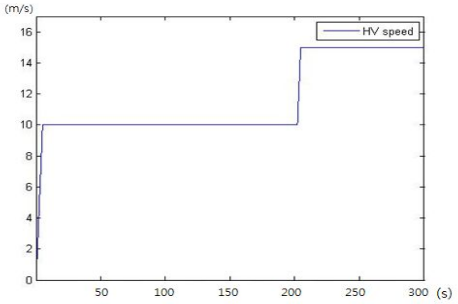

Figure 4.38. Speed of HV

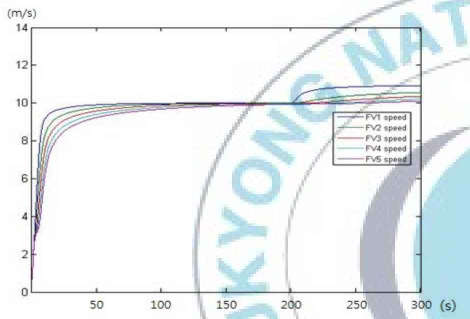

Figure 4.39. Speed of following vehicles in the current lane

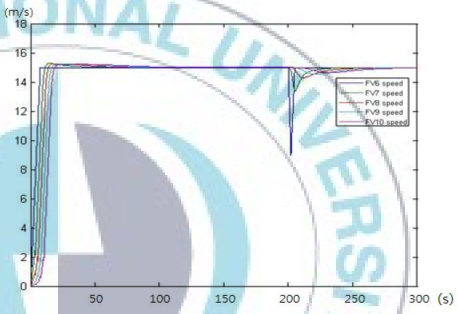

Figure 4.40. Speed of following vehicles in the target lane

In scenario 4, the CO_2 emissions of manual driving and automated driving are as follows: The CO_2 emissions of LV, HV, and following vehicles (FV1, FV2, FV3, FV4, and FV5) in the current lane for automated driving hardly differ between manual driving and automated driving. The CO_2 emissions of FV6 are increased 4.6%. Because the FV6 for manual driving reaches 0m/s to create a sufficient gap and CO_2 emissions in idle condition are lower. However, FV6 for automated driving can assure safety distance although FV6 does not decelerate by 0m/s. So, CO_2 emissions of FV6 for automated driving ensure a safe distance though FV6 does not decelerate by 0m/s. So, the CO_2 emissions of FV6 for automated driving emit more than CO_2 emissions of FV6 for manual driving. For automated driving, CO_2 emissions of FV7 fall 47.3%, CO_2 emissions of FV8 drop 30%. CO_2 emissions of FV9 decrease 21.4%, and CO_2 emissions of FV10 decline 17.1%.

Table 4.3. CO_2 emissions of scenario 4.

Emissions	Manual vehicle	ASV	Reduction rate
LV	558,276 g/h	558,276 g/h	0%
HV	607,423 g/h	608,496 g/h	0%
FV1	705,716 g/h	685,821 g/h	2.7% decrease
FV2	705,716 g/h	696,657 g/h	1.2% decrease
FV3	705,716 g/h	701,774 g/h	1% decrease
FV4	705,716 g/h	704,855 g/h	0%
FV5	705,716 g/h	707,083 g/h	0.%
FV6	536,505 g/h	561,045 g/h	4.6% increase
FV7	1,063,858 g/h	560,535 g/h	47.3% decrease
FV8	797,214 g/h	560,475 g/h	30.0% decrease
FV9	712,649 g/h	560,448 g/h	21.4% decrease
FV10	676,066 g/h	560,370 g/h	17.1% decrease

5. Conclusion

This paper presents a methodology to evaluate the environmental impact for an ASV. The environmental impact is evaluated when ASV executes ACC and lane changing. To evaluate the environmental impact of ACC, we estimated headway, capacity, and CO_2 emission in manual traffic where the manually driven vehicles case was represented by Pipes model. We also estimated headway, capacity and CO_2 emission in automated traffic where the ACC driven vehicles case was represented by FVADM. The CO_2 emission in automated traffic was compared with the CO_2 emission in manual traffic. Thus, vehicles equipped with ACC evaluated an environmental impact. Under LOS E, the headway and capacity were calculated in manual traffic and automated traffic. Capacity in the automated traffic could be increased because gap between vehicles equipped with ACC was closer than gap between manually driven vehicles. So, vehicles equipped with ACC can support a platoon in which vehicles travel in closely spaced groups. The study demonstrated that speed of vehicles equipped with ACC is higher than the speed of manually driven vehicles under congested traffic conditions because of the extended capacity and closer spacing. When the volume approaches capacity, the speed was close to 0km/h in manual traffic where vehicles almost stop. However, the speed was 17km/h in ACC traffic where vehicles move slowly. Thus, vehicles equipped with ACC can travel without stopping. This study demonstrated that CO_2 emissions of vehicles equipped with ACC can be reduced. When the volume was 850veh/h, 1,050veh/h, and 1,300veh/h, CO_2 emissions were reduced by 59,330g, 550,200g, and 1,497,990g respectively. The more traffic is crowded, the more reduced the CO_2 emissions of vehicles equipped with ACC become. Therefore, vehicles equipped with ACC can expect that the efficiency of roads is enhanced due to the close gap between vehicles. CO_2 emissions can also be decreased under congested traffic conditions.

We evaluated the environmental impact when the ASV executes lane changing. For manual driving conditions, the following vehicles in the current lane and the target lane follow leading vehicle through the Pipes model. An environmental impact is evaluated when the ASV changes from or to a faster lane. For automated driving, the following vehicles in the current lane and the target lane follow the leading vehicle through FVADM. The CO_2 emissions for manual driving are compared with the CO_2 emissions for automated driving. When the ASV in the fast lane enters a large gap between the leading vehicle and the following vehicle in the slow lane, there is not much difference in CO_2 emissions between the ASV and the manual vehicle. When the ASV in the fast lane enters a small gap between the leading vehicle and the following vehicle in the slow lane, the total CO_2 emissions of the ASV are reduced by 7,196,457g. When the ASV in the slow lane enters a large gap between the leading vehicle and the following vehicle in the fast lane, there are not difference of CO_2 emissions between the ASV and the manual vehicle. When the ASV in the slow lane enters small gap between the leading vehicle and the following vehicle in the fast lane, the total CO_2 emissions of the ASV are reduced by 1,014,732g. So, this study demonstrated that the CO_2 emissions of the ASV can be reduced. The ASV can be expected to improve efficiency, safety, and the environment.

References

Arnab Bose and Petros Ioannoul., 2001, Evaulation of the environmental effects of intelligent cruise control vehicle. Transportation Research Record 1774, Paper No. 01-2203, pp. 90-97.

Gabor Orosz, Bernd Krauskopf, and R. Eddie Wilson., 2005, Bifurcations and Multiple Traffic Jams in a Car-Following Model with Reaction Time Delay. Physica D:Nonlinear phenomena, Volume 211, Issues 3-4, pp.277-293.

Heejin Jung., 2006. Development of integrated simulation model for intelligent vehicle control under the ubiquitous computing environment. Department of satellite Information science, Gruduate school Pukong National University.

Hesham Rakh, Michel Van Aerde, K. Ahn, and Antonio A. Trani, 2000, Requirements for Evaluating Traffic Signal Control Impacts on Energy and Emissions Based on Instantaneous Speed and Acceleration Measurements. Transportation Research Record 1738, Paper No. 00-1133, pp.56-67

Huaxin Gong, Hongchao Liu. Bing-Hong Wang, 2008, An Asymmetric Full Velocity Difference Car-Following Model. Physica A: Statical Mechanics and its Applications, Volume 387, Issue 11,pp.2595-2602.

Nathan Gartner, Carroll J. Messer, and Ajay K. Rathi., 1997. Traffic flow theory, Transportation Research Board National Research Council Washington, D.C.

National institute of environmental research., 2009. Establishment of climate change responding system for transportation sector(Ⅱ), Development of bottom-up type GHGs emission factor for vehicles. p.64.

Mattew Barth., 2000, An emissions and energy comparison between a simulated automated highway system and current traffic conditions, 2000 IEEE Intelligent Transportation Systems Conference Proceedings, pp.358-363.

Matthew Barth, Kanok Boriboonsomsin. 2008, Real-World CO_2 Impacts of Traffic Congestion. Transportation Research Record, pp.1-18.

Pipes, Louis., 1953. An operational analysis of traffic dynamics. Journal of applied physics, vol.24, pp.271-281.

Peter., 2002. Modelling lane changing and merging in microscopic traffic simulation. Transportation Research Part C 10, pp.351-371.

Peter., 2005. Modelling vehicle interactions in microscopic simulation of merging and weaving. Transportation Research Part C 13, pp.37-62.

UNFCCC, 2006, Baseline Methodology for Bus Rapid Transit Projects, http://cdm.unfccc.int/EB/025/eb25_repan01.pdf

UNFCCC, 2009, Baseline Methodology for Mass Rapid Transit Projects, http://cdm.unfccc.int/methodologies/PAmethodologies/approved.html.

William R. Mcshane, Roger P. Roess, Elena S. Prassas. 1998. Traffic Engineering. Prentice hall, Inc.

X. Zho and Z. Gao., 2005. A new car-following: full velocity and acceleration difference model, The European physical journal B, vol.47, issue 1, pp.145-150.

Yong-Taek Lim, Min-Goo Kang, Sang-Min Lee, and Sang-Ho Choo, 2008, A Volume-Delay Function Parameter Estimation and Validation for Traffic Assignment. Journal of Korean Society of Transportation Vol.26, No3, pp.17-29.

Zhao Xiaoei, Gao Ziyou. 2007, The Stability Analysis of the Full Velocity and Acceleration Velocity Model. Physica A: Statistical Mechanics and its Applications, Volume 375, Issue 2, 2007, pp.679-686.

감사의 글

새로운 각오와 목표를 가지고 시작했던 대학원 생활은 힘들 때도 있었지만 돌이켜보면 아쉬움과 뿌듯함이 가득한 시간이었습니다. 지금 이 자리에 제가 서 있을 수 있도록 칭찬과 격려를 아끼지 않으셨던 많은 분들께 진심으로 감사의 마음을 전하고자 합니다.

지금의 제가 대학원 생활을 잘 마무리 할 수 있도록 그 누구보다도 저를 많이 아껴주시고 이끌어 주신 배상훈 교수님께 존경의 마음을 담아 감사를 드립니다. 많은 조언과 항상 할 수 있다는 자신감을 심어주시고 논문을 지도해주셔서 감사합니다.

학문적인 가르침과 지혜로운 삶에 대한 길을 열어주신 김영섭 교수님, 윤홍주 교수님, 최철웅 교수님, 서용철 교수님, 한경수 교수님, 이양원 교수님께 감사를 드립니다.

하나의 울타리 안에서 항상 부족했던 저를 잘 이끌어 주시고 격려해 준 병용선배 감사합니다. 선배 덕분에 제가 많이 성장할 수 있었습니다. 제 논문에 대해서 세심하게 신경 써 주신 희진선배 정말 감사합니다. 희진선배, 논문 쓰느라 많이 힘드시겠지만 조금만 더 힘내서 좋은 결과 있길 바래요. 제가 허둥지둥 하고 있을 때 올바른 길을 인도해주신 희종선배, 연구실 들어왔을 때 잘 챙겨주신 태동선배, 당찬 희제언니, 듬직한 탁영선배, 격려해주신 상원선배께 감사의 마음을 전합니다. 앞으로 연구실을 이끌어 갈 유쾌한 성범선배, 항상 긍정적인 마인드를 가진 패션리더 민성선배, 재간둥이 오지, 마음이 여린 선민이에게도 감사의 말을 전합니다. 힘들더라도 잘 이겨내고 좋은 결실 맺기를 기도할께요. 그리고 같이 석사과정을 하면서 제 마음을 잘 헤아려주고 도와준 유진이 언니한

테도 감사하다는 말 꼭 전하고 싶습니다.

학부 때부터 인연이 되어 석사과정을 함께한 인지랑 경진이, 세미나 시간 마치고 나면 항상 고민, 진로에 대한 이야기도 나누고 속상한 일이 있거나 힘이 들 때 항상 힘이 되어줘서 고맙다는 말 전합니다. 그리고 미국에서 석·박사 과정을 할 진형이, 항상 날 응원해줘서 고마워. 미국 가서 힘들더라도 포기하지 않고 잘 이겨내길 바랄께. 니 옆에 항상 내가 응원하고 있다는 거 잊지 않고 꼭 좋은 결실 맺어서 돌아와! 혼자서 씩씩하게 잘 헤쳐 나가고 있는 나리, 따끈따끈한 최신 곡, 영화도 제공해주고 잘 도와준 치영선배, 눈웃음이 예쁜 수재언니, 늘 밝은 웃음으로 챙겨주신 태우선배, 민서쌤, 미나쌤께도 감사의 마음을 전하고 싶습니다.

학부 때 영어학원에서 만난 티나 선생님, 앤 선생님, 피트, 보미, 은빈이, 조언도 해주시고 항상 날 응원해주시고 격려해주셔서 감사하다는 말 전합니다. 제가 힘들어하면 토닥토닥 보듬어주시고 기쁜 일이 있으면 함께 기뻐해주셔서 감사합니다. 앞으로는 좋은 소식만 전해 드릴께요. 답답하거나 힘들 때 힘이 되어준 해연, 인진, 승희, 설, 유나, 민지언니 정말 고맙다는 말 전합니다. 그리고 호주에서 학위까지 따면서 잘 지내고 있는 향미, 항상 응원해주고 격려해줘서 고마워! 타 대학원에서 열심히 공부하고 있는 나영이, 용기와 희망을 잃지 않도록 힘이 되어줘서 고마워!

내가 원하는 일에 언제나 열정적으로 응원해주시고 지지해주신 어머니, 아버지께도 진심으로 감사를 드립니다. 그리고 객관적으로 날 평가해주면서 내 편이 되어주는 나의 든든한 버팀목 같은 남동생 정민이에게도 고맙다는 말을 전합니다.

석사과정을 무사히 마칠 수 있도록 도와주신 모든 분들께 머리 숙여 감사드립니다.