**UNIVERSITAS
INDONESIA**

**UNIVERSITÉ
LILLE 1**

IMPLEMENTATION OF INTELLIGENT AUTONOMOUS VEHICLE IN PUBLIC TRANSPORT: STUDY CASE CORRIDOR I TRANSJAKARTA OF JAKARTA - INDONESIA

TESIS

FAJRI RIYADI M. NUR
1006788012

**FAKULTAS TEKNIK
PROGRAM STUDI TEKNIK SIPIL
DEPOK
JULI 2012**

**UNIVERSITAS
INDONESIA**

**UNIVERSITÉ
LILLE 1**

IMPLEMENTATION OF INTELLIGENT AUTONOMOUS VEHICLE IN PUBLIC TRANSPORT: STUDY CASE CORRIDOR I TRANSJAKARTA OF JAKARTA - INDONESIA

TESIS
Diajukan sebagai salah satu syarat untuk memperoleh gelar Magister Teknik

FAJRI RIYADI M. NUR
1006788012

FAKULTAS TEKNIK
PROGRAM STUDI TEKNIK SIPIL
KEKHUSUSAN TRANSPORTASI
DEPOK
JULI 2012

HALAMAN PERNYATAAN ORISINALITAS

Tesis ini adalah hasil karya saya sendiri,

dan semua sumber baik yang dikutip maupun dirujuk

telah saya nyatakan dengan benar.

Nama : **Fajri Riyadi M. Nur**

NPM : **1006788012**

Tanda Tangan :

Tanggal : **5 Juli 2012**

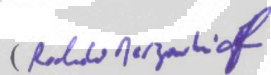# GAZETTE OF ENDORSEMENT

The proposal of this Thesis proposed by :
Name   : Fajri Riyadi Muhammad Nur
NPM   : 1006788012
Study Program   : Civil Engineering
Title the Thesis   : Implementation Of Intelligent Autonomous Vehicle In Public Transport: Study Case Corridor I Transjakarta Of Jakarta - Indonesia

Has been oficially approved, supervised and finally examined by the Thesis examiners in the Universitè Lille 1 on July 5th, 2012.

EXAMINERS

Supervisor : 1. Rochdi MERZOUKI   (Rochdi Merzouki)

Examiner : 1. Isam SHAHROUR   ( )

    2. Hassan NAJI   ( )

    3. Sibai MALEK   ( )

Legalized by
The Director of Civil Engineering Department, Faculty of Engineering, University of Indonesia

Prof. Dr. Ir. Irwan Katili, DEA.

KATA PENGANTAR

Puji syukur kepada Allah SWT, karena atas berkat dan rahmat-Nya, sehingga tesis dengan judul **"Implementasi Kendaraan Otomatis Pada Transportasi Publik, Studi Kasus Koridor I TransJakarta di Jakarta – Indonesia"** ini dapat terselesaikan dengan baik. Penulisan tesis ini dilakukan dalam rangka memenuhi salah satu syarat untuk memperoleh gelar Magister Teknik, Program Studi Teknik Sipil Fakultas Teknik Universitas Indonesia. Penulis menyadari bahwa tanpa bantuan dan bimbingan dari berbagai pihak, dari masa perkuliahan sampai pada penyusunan tesis ini, sangatlah sulit bagi saya untuk menyelesaikan tesis ini. Oleh karena itu, saya mengucapkan terima kasih kepada:

(1) Professeur Rochdi Merzouki sebagai pembimbing yang dengan sabar mendidik dan bersedia meluangkan waktu, tenaga, dan pikiran dalam membimbing penulis melewati tahapan demi tahapan sehingga tesis ini dapat selesai;

(2) Seluruh Dosen Engineering Urban and Habitat yang telah mendidik penulis selama satu tahun dalam program double degree Indonesia Perancis (DDIP).

(3) Pihak PT. TransJakarta Tbk yang telah banyak membantu dalam usaha memperoleh data yang saya perlukan;

(4) Orang tua dan keluarga tercinta serta Dini Pratiwi Rustam, istri tersayang yang telah memberikan bantuan dukungan material dan moral;

(5) Sahabat dan semua pihak yang telah banyak membantu saya dalam menyelesaikan tesis ini.

Akhir kata, saya berharap Tuhan Yang Maha Esa kiranya membalas segala kebaikan semua pihak yang telah membantu. Semoga tesis ini membawa manfaat bagi pengembangan ilmu.

<div align="right">

Depok, 19 Juli 2012
Penulis

</div>

HALAMAN PERNYATAAN PERSETUJUAN PUBLIKASI

TUGAS AKHIR UNTUK KEPENTINGAN AKADEMIS

Sebagai sivitas akademik Universitas Indonesia, saya yang bertanda tangan di bawah ini :

Nama : Fajri Riyadi M. Nur
NPM : 1006788012
Program Studi : Transportasi
Departemen : Terknik Sipil
Fakultas : Teknik
Jenis Karya : Tesis

Demi pengembangan ilmu pengetahuan, menyetujui untuk memberikan kepada Universitas Indonesia **Hak Bebas Royalti Noneksklusif** *(Non-exclusive Royalty-Free Right)* atas karya ilmiah saya berjudul :

Implementasi Kendaraan Otomatis Pada Transportasi Publik, Studi Kasus Koridor I TransJakarta di Jakarta – Indonesia

beserta perangkat yang ada (jika diperlukan). Dengan hak bebas Royalti Noneksklusif ini Universitas Indonesia berhak menyimpan, mengalihmedia/format-kan, mengelola dalam bentuk pangkalan data (database), merawat, dan mempublikasikan tugas akhir saya selama tetap mencantumkan nama saya sebagai penulis/pencipta dan sebagai pemilik Hak Cipta.

Demikian pernyataan ini saya buat dengan sebenarnya.

Dibuat di : Depok
Pada Tanggal : 19 Juli 2012

Yang menyatakan

Fajri Riyadi M. Nur

ABSTRAK

Nama   : Fajri Riyadi M. Nur
Program Studi   : Teknik Sipil
Judul Tesis   : Implementasi Kendaraan Otomatis Pada Transportasi Publik, Studi Kasus Koridor I TransJakarta di Jakarta – Indonesia

Penelitian ini dimaksudkan untuk mengkaji faktor yang mempengaruhi jarak waktu kedatangan *(headway)* dan kecepatan *(speed)* bus TransJakarta di setiap halte bus. Observasi dilakukan untuk melihat pengaruh faktor-faktor yang mempengaruhi *headway* dan *speed* yang mengakibatkan waktu tunggu para penumpang menjadi lebih besar. Metode yang dilakukan dengan melakukan simulasi dengan menggunakan data pengamatan secara langsung waktu keberangkatan bus dan waktu tiba bus di setiap halte serta kecapatan yang digunakan. Kemudian hasil simulasi dianalisa menggunakan permodelan *macroscopic* dan dibandingkan dengan menggunakan bus otomatis yang dikembangkan di labolatorium LAGIS. Kendaraan Otomatis sejak otomatisasi tugas-tugas mengemudi membawa sejumlah besar manfaat, seperti optimalisasi penggunaan infrastruktur transportasi, peningkatan mobilitas, minimalisasi risiko, waktu perjalanan, dan konsumsi energi.

Kata Kunci : Macroscopic, Waktu Perjalanan, Kecepatan, *Headway*, Transportasi Publik, Kendaraan Otomatis.

ABSTRACT

Name : Fajri Riyadi M. Nur
Study Program : Teknik Sipil
Title : Implementation of Intelligent Autonomous Vehicle in Public Transport: Study Case Corridor I Transjakarta Of Jakarta - Indonesia

This study aimed to examine the factors that cause time income (headway) and speed of the bus TransJakarta in each bus station. Observations carried out to see the influence of headway and speed that cause of waiting time of passangers more longer. The method carried out with make simulation with using observation data directly of departure and arriving in each station and speed that using of the buses. Then simulation result analyzed by using macroscopic modelling and compared with using the intelligent autonomous vehicle which is developed in LAGIS Laboratory. The automation of driving tasks carries a large number of benefits, such as the optimization of the use of transport infrastructures, the improvement of mobility, the minimization of risks, travel time, and energy consumption.

Key words : Macroscopic, Travel Time, Travel Speed, Headway, Public Transport, Intelligent Autonomous Vehicles.

AKNOWLEDGEMENTS

First, we would like to thanks to Mr. Rochdi MERZOUKI, Associate Professor of Laboratory of Automatics, Computer Engineering and Signal Processing (LAGIS) University of Lille 1, for all support, suggestion and direction he has provided over the life of this internship. He has provided his instruction and the perfect balance of motivation to finish this project. A huge thanks to Professor Isam SHAHROUR, head Program of Master International of Urban Engineering and Habitat, University of Lille 1. We would also like to thanks for the team of InTraDe project for giving us assistance during our internship. Also, special thanks us giving to Mr. Olivier SCRIVE, for his supporting in computer facility. We are also thankful for friends and family for the moral support they have provided through everything.
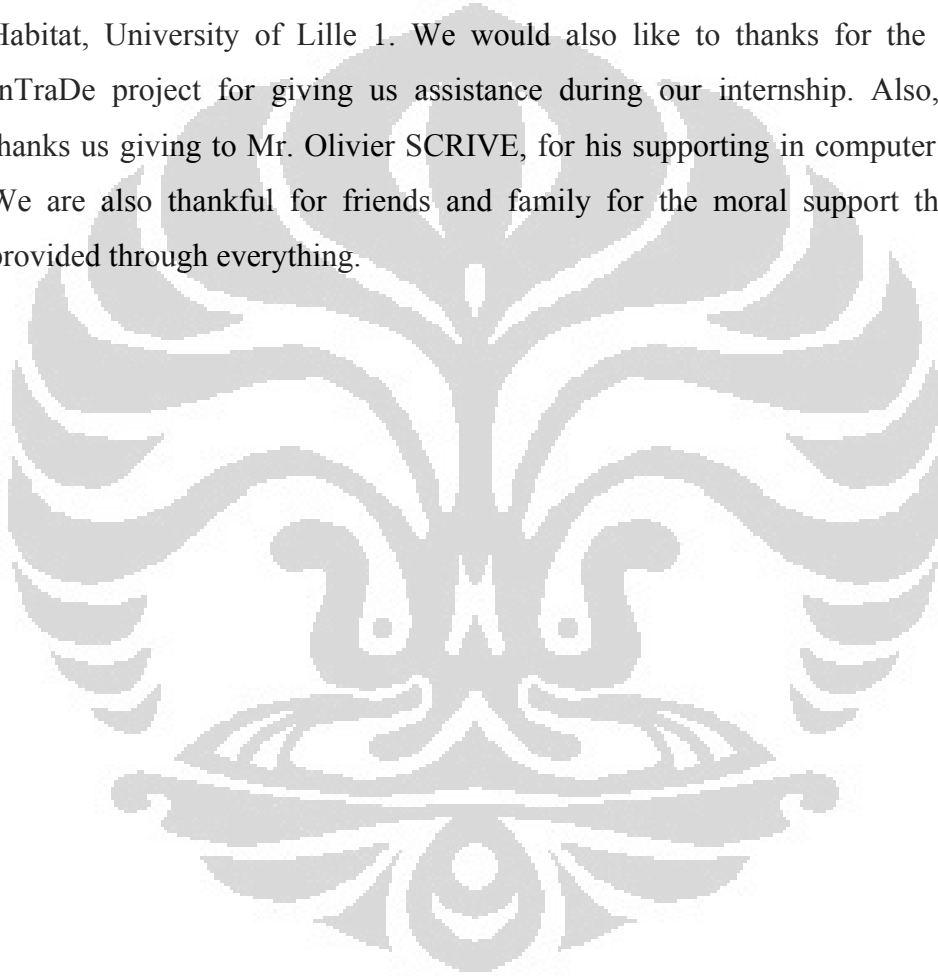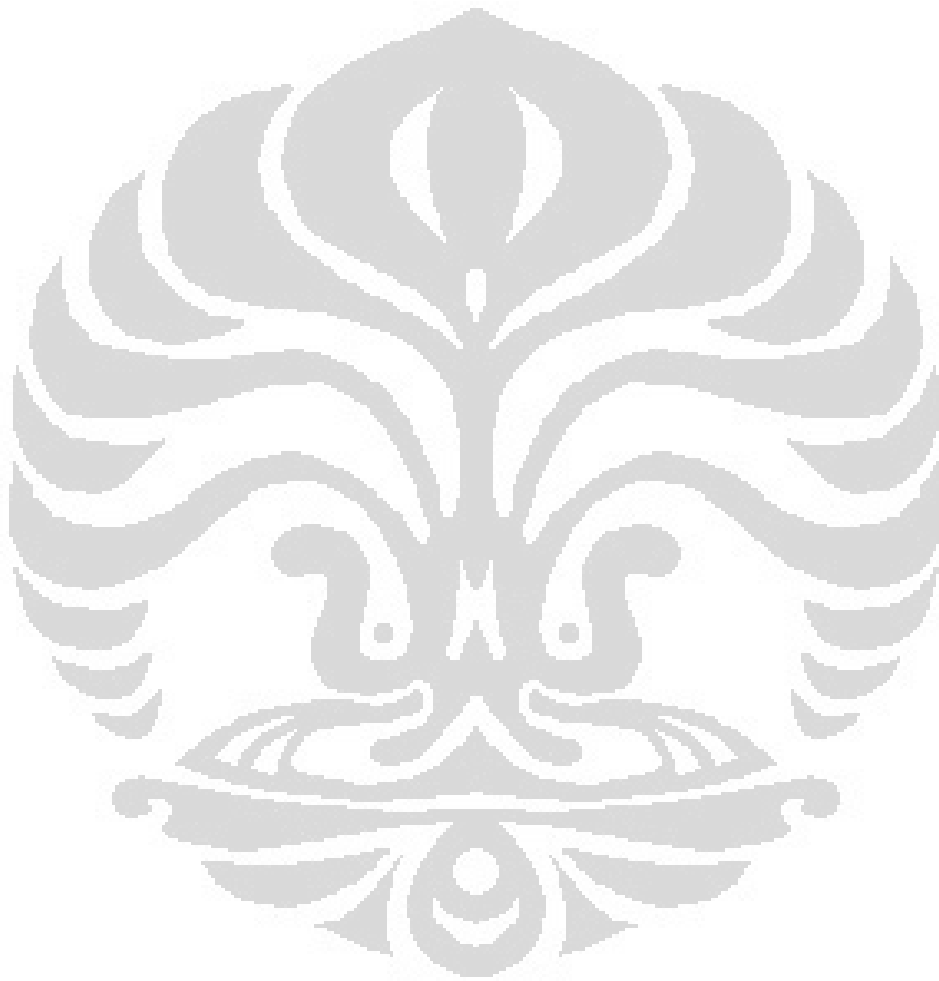
TABLE OF CONTENTS

x

LIST OF TABLES

xiii

LIST OF FIGURE

NOMENCLATURE

q	=	flow (veh/h)
U	=	Speed (km/h)
v	=	velocity at any time
v_f	=	free-flow speed
k	=	density (veh/km)
k_j	=	maximum density
TMS	=	Time Mean Speed (fps or mph)
SMS	=	Space Mean Speed (fps or mph)
d	=	Distance traversed (ft or mi)
n	=	number of travel times observed
ti	=	Travel time for the ith vehicle (sec or hr)
U	=	speed (km/h)
U_m	=	speed at maximum flow (km/h)
K	=	density (veh/m)
K_j	=	jam density (veh/m)
U_f	=	free flow speed (km/h)
K_m	=	maximum density (veh/m)
Q	=	(P,T,Pre, Post, M0)
P	=	place
T	=	transition
ρ	=	density
q	=	traffic flow (veh/h)
t	=	time (s)
T	=	total travel time (s)
T_r	=	running time (s)
T_m	=	average minimum trip time per unit distance (s)
b	=	dimensionless travel time factor (platoon dispersion model)
a	=	dimensionless platoon dispersion factor (platoon dispersion model)
F	=	smoothing factor

T_a = mean roadway travel time, measured in units of time steps (s)

v = space mean speed

l = number of lane in segment

T = sampling time (new mixed flow model) (s)

L_m = length of segment

I = traffic intensity (per unit area)

R = road density
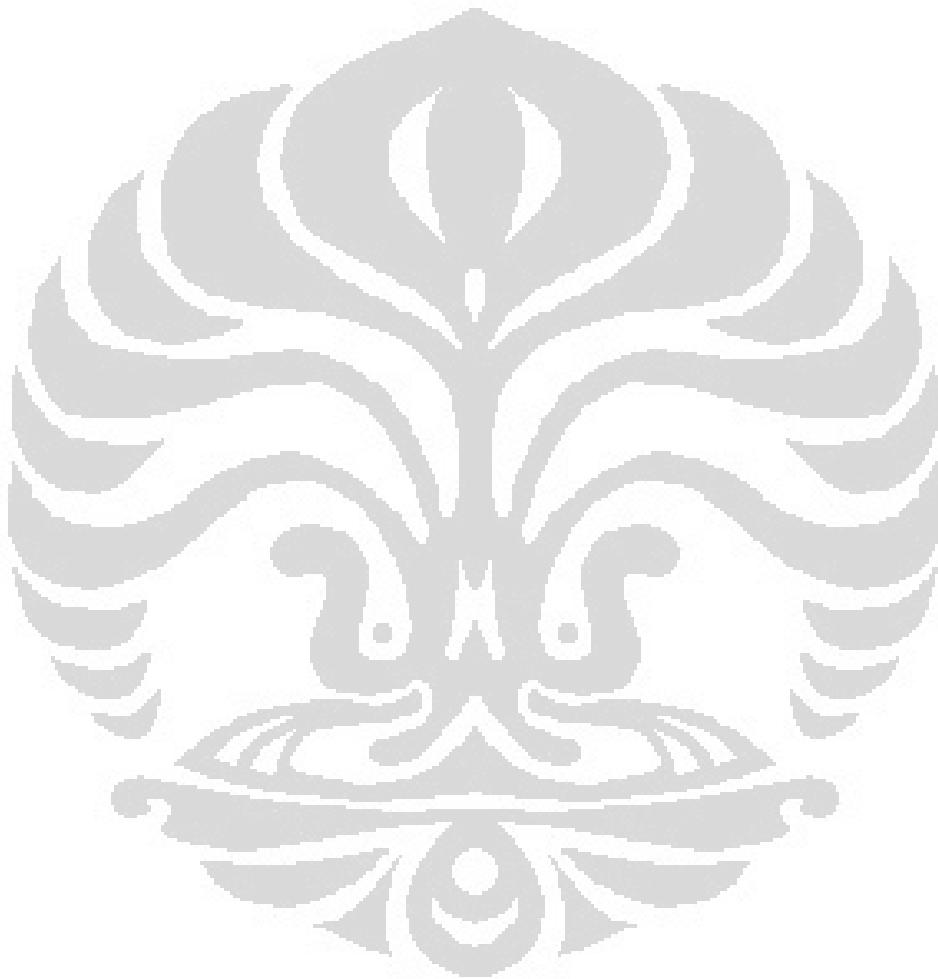
CHAPTER 1
INTROUDUCTION

1.1. Background

Jakarta is the most populous urban center in Indonesia. Home to approximately 3.9 million people in 1970, Jakarta's population had increased to 7.6 million in 1990, and is projected to grow to 17.2 million by the year 2015, making it one of the most populous cities in the world [13]. A dramatic rise in urban migration over the past twenty years is the primary cause of Jakarta's rapidly growing population. The number of population was expected to grow continuously due to natural growth as well as migration for better expectation of economy and employment in the city. The significant increase in mobility of person and goods government, number of motorized vehicles, and traffic volume would evolve in a way of such spatial distribution of population.

By National Economic Census 2004, Jakarta's overall share of the gross domestic product (GDP) represented 9 per cent of the national total, though this varied among sectors: 14 per cent of transportation and communication, 15 per cent of manufacturing, 25 per cent of trade and services and 65 percent of banking and financial services. The major manufactured goods that Jakarta produces include textiles, processed foodstuffs, published materials, chemicals and electronic devices. However, its share of the national GDP declined from 49 percent to 24 percent during 1969-1983 partly due to the development of port facilities elsewhere in the country, and GDP in 2004 grew at 5.13% as shown in Figure. 1.1. Shortage of land for industrial estates, pressures on industries to reduce pollution levels, and a low skill level of the labor force of the city have all contributed to the slow development of Jakarta's manufacturing sector. Reflected from the investment as shown in Figure. 1.2, a downswing in investment was obvious for both domestic and foreign investment. In terms of number of projects and investment value,

the Figure trended down. In fact, attracting new investment is crucial for the country if it is to enjoy economic growth of between 6% and 7%/year, and provide enough jobs for the millions of unemployed *Source: [13]*

.

Source : [13]
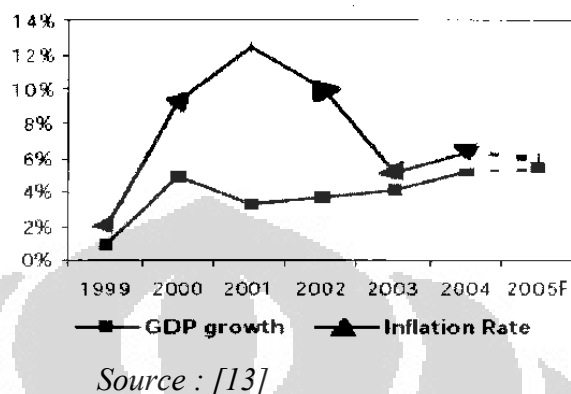
Figure 1.1. GDP and Inflation Rate, 1999 – 2005

Source : [13]
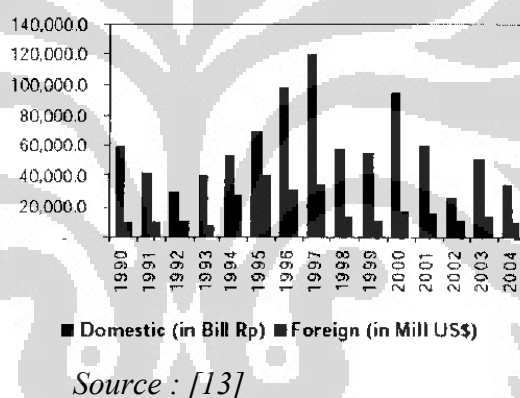
Figure 1.2. Investment Approval, 1990 - 2004

Transportation in urban areas is becoming more important nowadays, Jakarta as a capital of Indonesia has an important role to create sustainability in urban transportation system. Transportation is the key of the future; it is a driver of economic and social developments of developed countries. Transportation impacts on sustainability include [5]:

a. Economic:

Traffic congestion, mobility barriers, accident damages, transportation facility cost, consumer transportation cost, depletion of non-renewable resources.

b. Social:

Inequity of impacts, mobility disadvantaged, human health impacts, community cohesion and livability, aesthetic.

c. Environment

Air and weather pollution, climate change noise impact, hydrology impacts.

1.2. Transjakarta

TransJakarta is a bus rapid transit (BRT) system in Jakarta, Indonesia. It was the first BRT system in Southern and Southeast Asia. TransJakarta started on January 25, 2004. As of December 28, 2011 there were 11 corridors (or lanes) in operation, with 4 more to be built. TransJakarta was designed to provide Jakarta citizens with a fast public transportation system to help reduce rush hour traffic. The buses run in special lanes, and the regional government subsidizes the ticket prices. In 2011, TransJakarta carried 114,783,774 passengers or about 310,000 passengers per day, increased by 32 percent from 86,937,287 passengers last year. Subsidy per passenger-ticket was Rp.2,901 ($0.29) and for 2012 subsidy is Rp.2,114 ($0.21) per passenger-ticket Currently, TransJakarta has the world's longest BRT routes with 172 km system length and has more than 520 buses in operation.

The first TransJakarta line opened to the public on January 15, 2004. Following two weeks in which it was free to use, commercial operations started on February 1, 2004. It now carries an average of approximately 250,000 passengers a day [31].

TransJakarta was built to provide a fast, comfortable, and affordable mass transportation system. To accomplish those objectives, the buses were given lanes restricted to other traffic and separated by concrete blocks on the streets that became part of the busway routes.

Source : [24]

Figure 1.3. The Bus of TransJakarta in dedicated lane

There were some initial teething problems, such as when the roof of one of the buses rammed into a railway tunnel. In addition, many buses had technical issues such as broken doors and stop buttons.

In order to promote gender equity, TransJakarta is increasing the number of female driver recruits. The projected proportion is 30% of the total. The buses run along the following routes [37]:

a. January 15, 2004: Corridor 1, Blok M-Kota (soft launch)

b. February 1, 2004: Corridor 1, Blok M-Kota (commercial service)

c. January 15, 2006: Corridor 2, Pulo Gadung-Harmoni and 3, Kalideres-Pasar Baru opened

d. January 27, 2007: Corridor 4, Pulo Gadung-Dukuh Atas 2, Corridor 5, Kp. Melayu-Ancol, Corridor 6, Halimun-Ragunan, and Corridor 7 Kp. Rambutan-Kp. Melayu opened

e. February 21, 2009: Corridor 8, Lebak Bulus-Harmoni opened

f. December 31, 2010: Corridor 9, Pluit-Pinang Ranti, and Corridor 10, PGC Cililitan-Tanjung Priok opened.

g. March 18, 2011 Corridor-9 was the solely corridor served until 11.00 pm. Followed by Corridor-1, with intersection with Corridor-9 at Semanggi shelter, but not all of shelters serve in this program.

h. May 20, 2011 Corridor-2 and Corridor-3 initialized to serve until 11.00pm, but only open 9 shelters out of 22 on Corridor-2 and 9

out of 13 shelters on Corridor-3 remain open during the extended hours.

i. July 1, 2011 Corridors-4 to 7 have already began with the late night service, so all corridors now has already deployed late night service, except Corridor-8.

j. September 28, 2011 the feeders have been launched with Route 1 from West Jakarta Municipal Office to Daan Mogot, Route 2 from Tanah Abang to Medan Merdeka Selatan and Route 3 from SCBD to Senayan. The fare will be Rp.6,500 ($0.72), which cover tickets for both the feeder service and TransJakarta buses.

k. December 28, 2011: Corridor 11, Kp. Melayu-Pulo Gebang opened
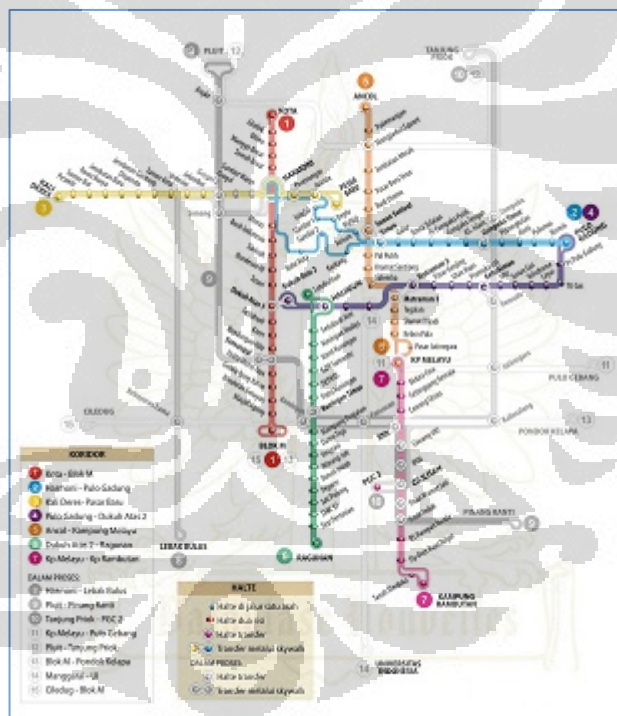
Source : [29]

Figure 1.4. Route map of TransJakarta

1.3. Problem Definition

The problems of urban city transportation especially for the public transport in Jakarta area are very complex. The problem of existing public transportation is the delay between buses, and also emission produced by the buses every day. The public buses using natural gas fuel and for refuel the gas, buses have to go to station which located far from the corridor where they operated, the impact operating buses while the other do some refueling will reduced and the delay for the passenger will be increased. From a passenger's perspective, whether buses are running regularly is more important than whether they are actually running on schedule under the conditions of short frequency [23]. With all problems above, we want to analyze feasibility of introducing the Intelligent Autonomous Vehicle (IAV) for one of corridor public transportation in Jakarta. This study encloses modeling of traffic and simulation by using the real traffic measurement. One of the advantages of using the IAV in urban environment is that infrastructure should not get modified, due to the new technologies capabilities.

1.4. Goal and Hypotheses

The goal of this project is to optimize the travel time and to reduce the waiting time of public in each station of the public transportation in Jakarta by using Intelligent Autonomous Vehicles (IAV) into the bus lane and describing traffic flow in macroscopic level. Other goal is to reduce the pollutant gas emission that the buses produce including the acoustic pollution.

1.5. The Scope of Work

This project is focused in Corridor 1 of public bus lane (Busway Transjakarta) after considering the following assumptions:

- Macroscopic traffic flow in confined area
- Bus line independently and did not consider the transfer points between bus lines
- Using simulation software to apply the appropriate model

- No external perturbation (weather, accident, pedestrian crossing)
- Considering macroscopic parameter only (flow, speed, density)
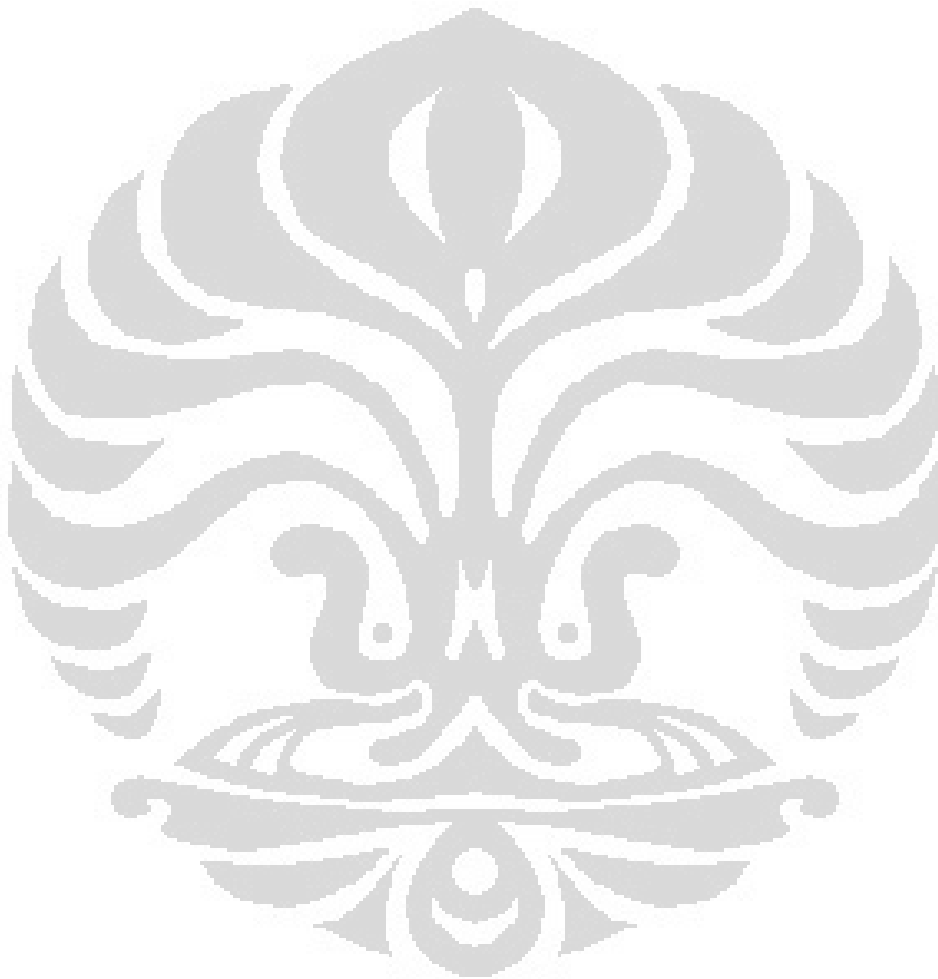
CHAPTER 2
LAGIS LABORATORY

2.1. Lagis Laboratory

This internship takes place at Laboratoire d'Automatique, Genie Informatique et Signal (LAGIS) University of Lille 1. The Laboratory of Automatics, Computer and negineering and Signal Processing (LAGIS) is a joint research unit of the University of Lille 1, the Ecole Centrale de Lille (high school of Engineering independent of the University) and the National Scientific Research Centre (CNRS).

The LAGIS research objectives concern the development of fundamental, methodological research in the fields of automatic control, computer engineering and signal processing. The LAGIS research teams are active in [5].

    a. Integrated design of multi physical systems

    b. Nonlinear and time-delay systems

    c. Optimization of logistic systems

    d. Fault tolerant systems

    e. Signal and image processing

LAGIS Research in Intelligent Transportation Systems (ITS) includes:

    a. Control and supervision autonomous vehicles

    b. Virtual and dynamic simulations

Figure 2.1 represent that ITS system is able to connect and control the infrastructure of transportation with automobile. A center station could control this system. For example center can detect position of vehicle and get information to the vehicles in real-time conditions.
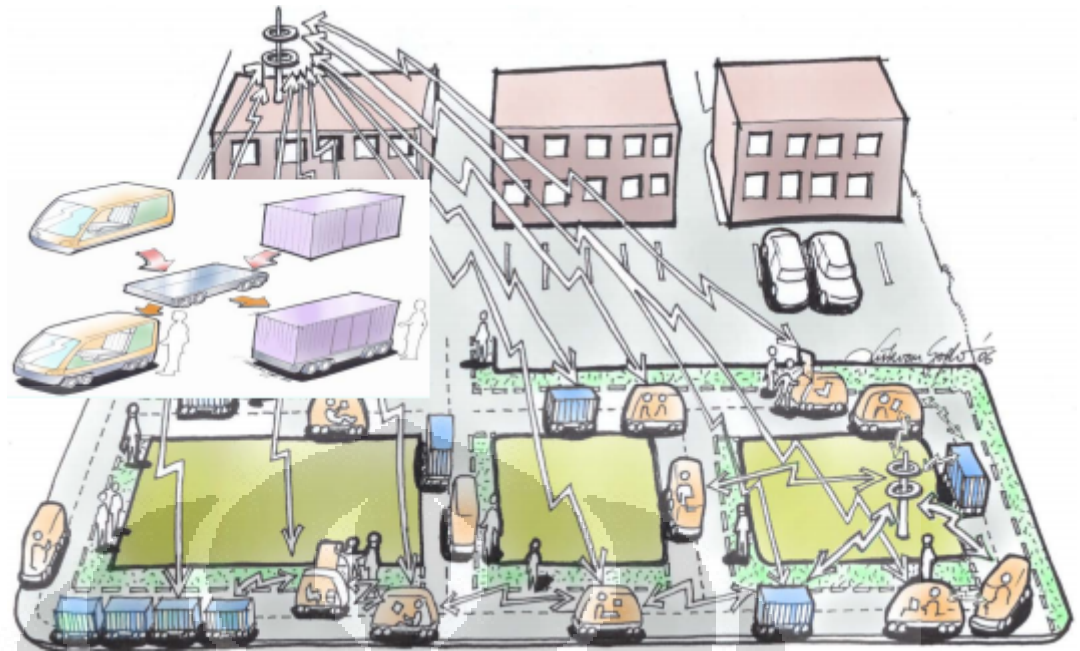
Source :[15]

Figure 2.1. Transportation Systems that adapt to the infrastructure

2.2. InTrade Project

Our internship theme is based on project research that has been doing at LAGIS laboratory (InTraDE Project). InTraDE (Intelligent Transportation for Dynamic Environment) is a multi disciplinary project with many benefits. The description of the project objectives and its partnership is given in [7], where the following text in taken:

a. Université Lille 1 – LAGIS (Project Leader)

LAGIS is the leader partner and thus, manages the project from an overall perspective. It collaborates with Port of Oostende, NITL (Dublin Institute of Technology (DIT) and CRITT for coordination and administrative tasks.

b. Institute National de Recherche et Informatique et Automatique (INRIA – Loria)

c. South East England Development Agency (SEEDA)

d. Centre régional d'Innovation et de Transfert de Technologie Transport et Logistique (CRITT TL)

e. AG Port of Oostende (AGHO)

f.   National Institute for Transport and Logistics, Dublin Institute of Technology (DIT)

g.   Liverpool John Moores University.

The main objectives of this project are:

a.   To study traffic flow within confined spaces of container terminals and develop an insight into the factors influencing the overall productivity of such facilities, and to investigate existing traffic control methods and develop new methods where necessary to improve efficiency whilst ensuring safety.

b.   To identify automatic navigation methods and develop new algorithms for robust supervision, and to investigate practical issues in implementing automatic navigation system in container terminals.

c.   To develop an automatic traffic time-domain simulators for autonomous and human driven-vehicles within the terminals and to carry out a design case study of terminal layout using the simulator.

d.   To design, test and validate intelligent transport vehicles prototype with dynamic environment inside confined spaces or combined urban-confined spaces.

InTraDE project contributes to improve the traffic management and space optimization inside confined space by developing a clean and safe, intelligent transportation system. This system would adapt to the specific environment requirement, and could be transferred to different sizes of ports and terminals. The transportation system operates in parallel with automated site [7], allowing a robust and real-time supervision of the goods handling operation. Hence, no infrastructures requirement and investment, while the project took a port as an area study, we take confined urban area in Jakarta, Indonesia with the same vehicle and simulator.

Intelligent autonomous vehicles (IAV) can run inside confined and private area or on existing roadway network if they follow accurately in safe condition a manned driven vehicle. Many advantages can be synthesized by using the intelligent autonomous vehicles in our daily life,

and can have real impacts for society, from social, economical and environmental point of views. They can be more reactive than human drivers, in case of dangerous driving situation, where human lives can be saved, and therefore decrease the number of road accidents originally caused by human. Intelligent autonomous vehicles can improve the traffic in term of congestion, when the number of vehicles is dense according to space motion.

Figures 2.2. show the heavy IAV of InTraDE. This IAV called Robutainer has specification:

- Weight without lad   : 3000 kg
- Payload   : 7000 kg
- Dimension   : 7 x 2.5 x 1.2 m (l x w x h)
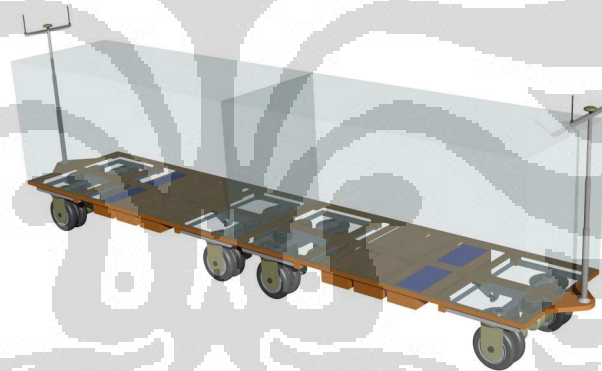
Source; [26]

Figure 2.2. Heavy Intelligent Autonomous Vehicles (IAV) of InTraDE

While Figure 2.3. shows the light vehicle type of IAV.

Source : [26]

Figure 2.3. Light Intelligent Autonomous Vehicles (IAV)
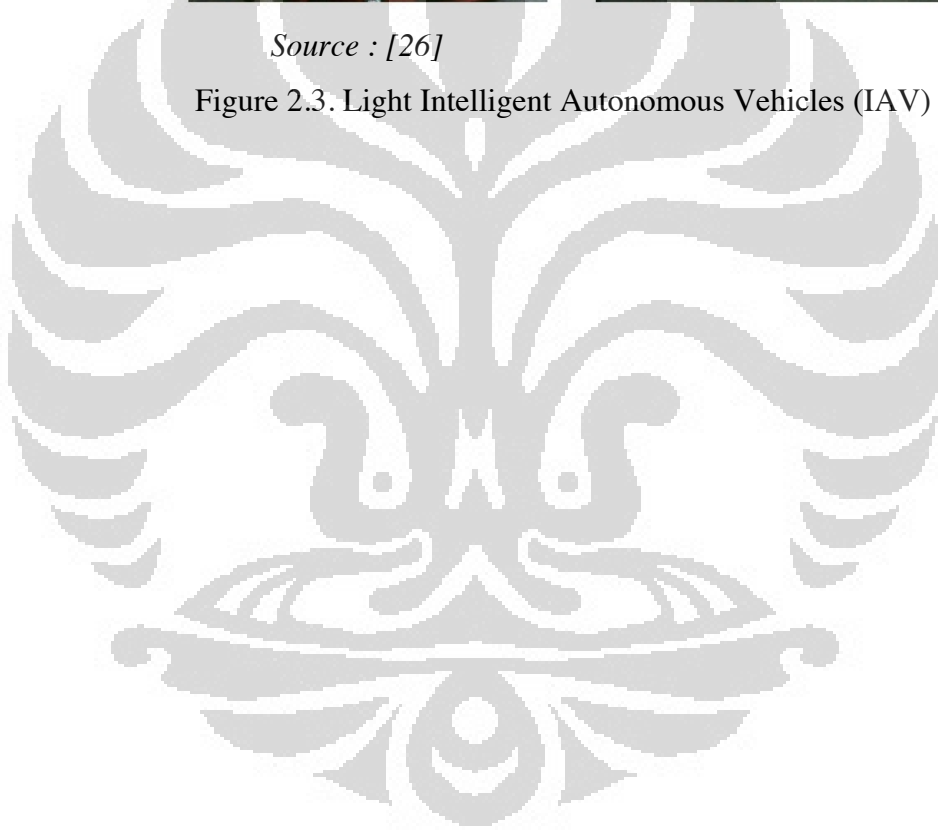
CHAPTER 3
STATE OF ART

3.1. Introduction

The aim this chapter is to do literature study of modeling of bus public transport in Jakarta and make comparison between different models according to the performances and the objectives in order to optimize the travel time of bus public transport.

3.2. Model Definition

The *Model* is a closest representation of the traffic behavior in static and dynamic aspects. It contains the essential information on the bus line and its surrounding environment. The representation may take two major forms:

1. Physical, as in bus models.
2. Symbolic, as in a natural language, computer program, or a set of mathematical equations.

3.3. Model Classification

Many simulations of transportation models have been developed and can be categorized as macroscopic, mesoscopic and microscopic models.

Macroscopic should be used when the available time-instant based model and resources are too limited for the development of microscopic model. Macroscopic models were the first to be derived by scientist studying traffic in the 1950's. Macroscopic model were chosen because traffic flow initially appeared to be similar to the flow of a fluid through a river or pipe system. These models attempt to classify the average behavior of a system instead of the behavior of a specific vehicle.

Alternative models come from a continuum or macroscopic approach that is an Eulerian, fluid-like approach. These models describe the average velocity and density of the traffic at a point. Unlike the car-following method the movement of all the vehicles is described by two

coupled partial differential equations, and is therefore less computationally expensive to solve.

Transportation includes infrastructure, administration, vehicles, and users and can be viewed from various aspects, including engineering, economics, and societal issues. A transportation system can be defined narrowly as a single driver /vehicle with its second-by-second interactions with the road and other vehicles. The system can also be defined broadly as a regional transportation infrastructure with its year-by-year interactions with the regional economy, the community of transportation users and owners, and its control components such as transportation administration and legislature. These two extremes exemplify the range of transportation systems, with various intermediate possible scenarios.

Transportation models are a formal description of the relationships between transportation system components and their operations. Knowledge of these relationships allows for estimating or predicting unknown quantities (outputs), from quantities that are known (inputs). Because our knowledge of the transportation relationships is limited, transportation models are subsequently imperfect and selective. Awareness of the models' limitations facilitates using the models according to the need, to the required accuracy, and to the budget.

Evaluation has two distinct meanings: ''calculate approximately'' and ''form an opinion about.'' Both meanings are reflected in the two basic steps of transportation systems evaluation:

1. Quantify by applying a model
2. Qualify by applying evaluation criteria

The first step requires a valid model, while the second step uses preferences of decision makers and transportation users. Modeling, in most cases, is a required part of transportation systems evaluation.

A transportation model is a simplification of transportation reality. It focuses only on what is essential at the level of detail appropriate for its application. If one wants to improve traffic at a specific location by redesigning signals, then optimal signal settings are the solution, which

has a negligible economic effect on the regional economy and this variable therefore should not be considered in the model. The situation changes if one wants to program transportation improvements in the region that must compete with large-scale highway projects for funding. Then the economic impact of the decision is important and detail signal settings are not considered; instead, the overall effect of the typical control is represented in the analysis. These two cases require two distinct models that differ in scope and detail. A specific job requires a specific model. Understanding the basics of modeling in transportation engineering is helpful in selecting an adequate model, using it properly, and interpreting the results correctly.

This chapter aims to help deciding whether a model is needed, how to select an adequate model, and how to use it effectively. The reader will find neither endorsements nor a complete overview of the existing modeling software packages, and specific references are mentioned for illustration of the points raised in the presentation without any intention either to compliment or criticize.

Although this chapter has been written with all the areas of transportation engineering in mind, examples are taken from surface transportation, which is the author's area of expertise. The author believes that this focus does not constrain the generality of the chapter.

3.3.1. Gap, Headway, and Occupancy

Flow, speed, and density are the macroscopic parameters characterizing the traffic stream as a whole. Headway, gap, and occupancy are microscopic measures for describing the space between individual vehicles. These parameters are discussed in the paragraphs below.

Headway: Headway is a measure of the temporal space between two vehicles, or, more specifically, the time that elapses between the arrival of the leading vehicle and the following vehicle at the designated test point along the lane. Starting a chronograph when the front bumper of the first vehicle crosses the selected point and

subsequently recording the time that the second vehicle's front bumper crosses over the designated point, that measure the headway between two vehicles. The headway is usually reported in units of seconds.

Gap: Gap is very similar to headway, except that it is a measure of the time that elapses between the departure of the first vehicle and the arrival of the second at the designated test point. Gap is a measure of the time between the rear bumper of the first vehicle and the front bumper of the second vehicle, where headway focuses on front-to-front times. Gap is also reported in units of seconds. If a bus is delayed by some fluctuation, the time headway (gap) between it and its predecessor becomes larger than the initial time headway because this bus has to pick up more passengers than the initial value. During the period of delay, more passengers will be waiting for the bus [19].

Occupancy: Occupancy denotes the proportion or percentage of time a point on the road is occupied by vehicles. It is measured, using loop detectors, as the fraction of time that vehicles are on the detector. Therefore, for a specific time interval T, occupancy is the sum of the time that vehicles cover the detector, divided by T. For each individual vehicle, the time spent on the detector is determined as function of the vehicle's speed, its headway, its length L, plus the length of the detector itself C. That is, the vehicle where the time from the front bumper crosses the start of the detection zone until the time of the rear bumper clears the end of the detection zone affects the detector [2].

3.3.2. Traffic Flow Theory

Knowledge of fundamental traffic flow characteristics (speed, volume, and density) and the related analytical techniques are essential requirements in planning, design, and operation of transportation systems. Fundamental traffic flow characteristics have been studied at the microscopic, mesoscopic, and

macroscopic, levels. Existing traffic flow models are based on time headway, flow, time-space trajectory, speed, distance headway, and density. These models lead to the development of a range of analytical techniques, such as demand-supply analysis, capacity and level of service analysis, traffic stream modeling, shock wave analysis, queuing analysis, and simulation modeling [2].

Fundamental diagrams could be of great use for the reconstruction of trajectories using traffic flow theory. Fundamental diagrams describe the fundamental relation between the flow, speed and density. The basic relation between flow, speed and density is given by

$$q = k \times v \qquad\qquad (3.1)$$

$$v = \frac{s}{t} \qquad\qquad (3.2)$$

Where:

k $\qquad$ = Density (veh/km)

q $\qquad$ = flow (veh/h)

v $\qquad$ = Speed (km/h)

s $\qquad$ = Length (km)

t $\qquad$ =Time (h)

With the fundamental diagram known, only one of these three values has to be known to calculate the other two.

Traffic simulation models are also classified as microscopic, macroscopic, and mesoscopic models. Microscopic simulation models are based on car-following principles and are typically computationally intensive but accurate in representing traffic evolution. Macroscopic models are based on the movement of traffic as a whole by employing flow rate variables and other general descriptors representing flow at a high level of aggregation without distinguishing its parts. This aggregation improves computational performance but reduces the detail of representation.

Mesoscopic models reproup between the other two approaches and balance accuracy of representation and computational performance. They represent average movement of a group of vehicles (packets) on a link. Microscopic analysis may be selected for moderate-size systems where there is a need to study the behavior of individual units in the system. It may be selected for higher-density, large-scale systems in which a study of behavior of groups of units is adequate. The Knowledge of traffic situations and the ability to select the more appropriate modeling technique is required for the specific problem. In addition, simulation models differ in the effort needed for the calibration process. Microscopic models are the most difficult to calibrate, followed by mesoscopic models. On the other side, they are easily calibrated.

3.3.3. Traffic Flow Models

Microscopic traffic flow modeling is concerned with individual time and space headway between vehicles, while macroscopic modeling is concerned with macroscopic flow characteristics. The latter are expressed as flow rates with attention given to temporal, spatial, and modal flows [2]. This section describes the best-known macroscopic, mesosopic, and microscopic traffic flow models.

Macro Models: In a macroscopic approach, the variables to be determined are:

1. The flow $q(x,t)$ (or volume) corresponding to the number of vehicles passing a specific location x in a time unit and at time period t;
2. The space mean speed $v(x,t)$ corresponding to the instantaneous average speed of vehicles in a length increment;
3. The traffic density $k(x,t)$ corresponding to the number of vehicles per length unit.

The static characteristics of the flow are completely defined by a fundamental diagram. The macroscopic approach considers traffic

stream parameters and develops algorithms that relate flow to density and space mean speed. Various speed-density models have been developed and are shown also to fit experimental data. These models are explained below.

Meso Models: fill the gap between the aggregate level approach of macroscopic models and the individual interactions of the microscopic ones. Mesoscopic models normally describe the traffic entities at a high level of detail, but their behaviour and interactions are described at a lower level of detail. These models can take varying forms. One form is vehicles grouped into packets, which are routed through the network [21]

Micro Models: A microscopic model of traffic flow attempts to analyze the flow of traffic by modeling driver-driver and driver-road interactions within a traffic stream, which respectively analyzes the interaction between a driver and another driver on road and of a single driver on the different features of a road. Many studies and researches were carried out on driver's behavior in different situations like a case when he meets a static obstacle or when he meets a dynamic obstacle. Several studies are made on modeling driver behavior in another following car and such studies are often referred to as car following theories of vehicular traffic [20].

3.3.3.1. Greenshield Model: The first steady-state speed density model was introduced by Greenshields, who proposed relationship between speed, density and flow as follows [20]:
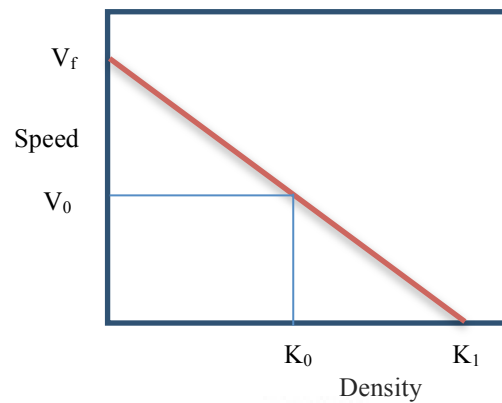
$$v = v_f - \left(\frac{Vf}{kj}\right) k \tag{3.3}$$

Where v = velocity at any time

v_f = free-flow speed

k = density at that instant

k_j = maximum density

To find density at maximum flow and q_{max} :

$$k_0 = \frac{kj}{2} \tag{3.4}$$

$$q_{max} = \frac{vf . kj}{4} \tag{3.5}$$

3.3.3.2. _Greenberg's Logarithmic Model:_ Greenberg assumed a logarithmic relation between speed and density, He proposed:

$$v = v_0 \ln \frac{k_j}{k} \tag{3.6}$$

This model can be derived analytically, but inability to predict the speed at lower densities [14]

Universitas Indonesia

3.3.3.3. Underwood model: Trying to overcome the limitation of Greenberg's model, Underwood put forward an exponential model as shown in equation (3.7):

$$u = u_f . e^{\frac{-k}{ko}}$$ (3.7)

In this model, speed becomes zero only when density reaches infinity which is the drawback of this model. Hence this cannot be used for predicting speeds at high densities [11].

3.3.3.4. Newell model: In his simplified theory of kinematic waves, Newell (1993) developed much more simple fundamental diagram: a triangular shaped – flow density diagram [8]

$$v(k) = \begin{cases} V_f & if \ k < k^* \\ \frac{Q_{cap}}{k^* - k_j} \left(1 - \frac{k_j}{k}\right) & if \ k \geq k^* \end{cases}$$ (3.8)

Where k^* is the optimal density

3.3.3.5. Van Aerde en Rakha model: Later, Van Aerde and Rakha (1995) described a continuous relation between flow, speed and density. In this method four parameters have to be estimated, by which this relation can be described. These parameters are free speed, V_{free}, speed at capacity, V_{cap}, jam density, k_{jam} and capacity flow, Q_{cap} [8]. The relation between flow and density is given by the following equation:

$$Q(k) = k(v) * v = v(k) * v$$ (3.9)

Universitas Indonesia

3.3.3.6. *Smulders model:* Smulders (1990) developed a fundamental diagram which is parabolic in the free flow of the fundamental diagram and linear in the congestion part of it [8].

$$v(k) = \begin{cases} V_f\left(1 - \dfrac{k}{kj}\right) & if\ k\ <\ k^* \\ V_f k^*\left(\dfrac{1}{k} - \dfrac{1}{kj}\right) & if\ k\ \geq\ k^* \end{cases} \tag{3.10}$$

Where k^* is the optimal density. This function looks like the fundamental diagram of Newell, but in the first part of this non linear diagram. It is more consistence with a real traffic condition, where the speed at capacity is not likely equal to the free flow speed

3.3.3.7. *Drew's Model:* Drew proposed a formulation, which modified Greesshield's model by introducing parameter called 'n' [14]

$$v = v_f\left[1 - \left(\frac{k}{kj}\right)^{n+\frac{1}{2}}\right] \tag{3.11}$$

Where,

n = coefficient

n = 1 ~ Linear model

n = 2 ~ Parabolic model

n = 1 ~ Exponential model

3.3.3.8. Piecewise Linear Models: The simulation group at King Fahd University of Petroleum and Minerals proposed a piecewise linear model to approximately depict the non-linear relationships between the traffic stream characteristics using simple equations [10]. The proposed model takes the form:

$$v = \begin{cases} 70 - k & (k \leq 10) \\ 60 - 0{,}5(k - 10) & (10 < k \leq 20) \\ 55 - 0{,}38(k - 20) & (20 < k \leq 33) \\ 50 - 0{,}59(k - 33) & (33 < k \leq 50) \\ 40 - 0{,}9(k - 50) & (50 < k) \end{cases}$$

Where v is speed and k is density

3.3.4. Traffic-Simulation Models

Computer simulation modeling has been a valuable tool for analyzing and designing complex transportation systems. Simulation models are designed to mimic the behavior of these systems and processes. These models predict system performance based on representations of the temporal and/or spatial interactions between system components (normally vehicles, events, control devices), often characterizing the stochastic nature of traffic flow. In general, the complex simultaneous interactions of large transportation system components cannot be adequately described in mathematical or logical forms. Properly designed models integrate these separate entity behaviors and interactions to produce a detailed, quantitative description of system performance.

In addition, simulation models are mathematical/ logical representations (or abstractions) of real-world systems, which take the form of software executed on a digital computer in an experimental fashion (Lieberman and Rathi 1998). The inherent value of computer simulation is that it allows experimentation to take place off-line without having to go out in the real world to test or develop a solution. Specifically, simulation offers the benefits of being able to control input conditions, treat variables independently even though they may be coupled in real life, and, most importantly, repeat the experiment many times to test multiple alternative performance (Middleton and Cooner 1999). The user of traffic simulation software specifies a ''scenario'' (e.g., highway network configuration, traffic demand) as model inputs. The

simulation model results describe system operations in two formats: (1) statistical and (2) graphical. The numerical results provide the analyst with detailed quantitative descriptions of what is likely to happen.

3.4. Bus Public Transport

There are many types of Rapid Transit Systems -- guided rail systems such as subways in Toronto and Montreal, Light Rail Transit (LRT) in Calgary and Edmonton, and elevated LRT like the SkyTrain in Vancouver. Others are more flexible, non-rail systems like the Transitway in Ottawa, and similar busway systems in Pittsburgh, Brisbane, Adelaide, and several cities in Japan, Europe, and South America [22].

Guided rail systems work well in high-density corridors where many people live and work within walking distance of the stations. However, in a low-density city like Winnipeg, a more flexible, cost-effective approach to Rapid Transit is needed. Bus Rapid Transit (BRT) systems are being embraced worldwide as an increasingly popular public transport development option. They apply rail-like infrastructure and operations to bus systems with offerings that can include high service levels, segregated right of way, station-like platforms, high quality amenities and intelligent transport systems [4]. Bus Rapid Transit (BRT) combines the attractive features of a rail system with the flexibility of a bus system to provide fast, convenient, comfortable transit service that minimizes the need to transfer. BRT features include [22]:

- Separate roadways called Busway -- exclusive to transit -- that permit high-speed operation (up to 80kph)
- Traffic signal priority for transit vehicles at intersections
- Full developed Rapid Transit stations on Busway
- Real-time route and schedule information at stations
- Next Stop displays and enunciators on vehicles
- Modern, state-of-the art rubber-tired vehicles that provide high-level comfort and passenger amenities
- High frequency, all day service

Basically, the static structure of a bus-network is composed of four elements: itinerary, line, bus stop and bus station [3]:
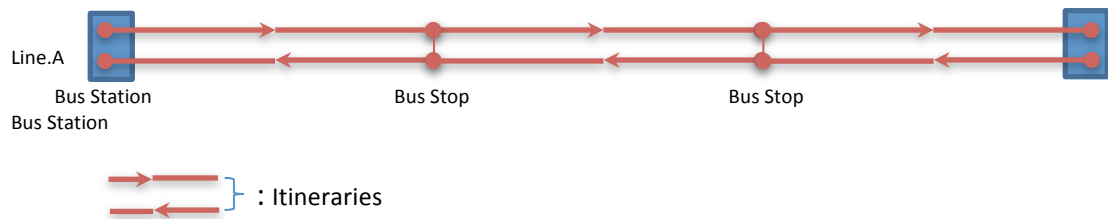

Figure 3.1. Structure of Bus- network

A section of corridor 1 transjakarta between Blok M and Jakarta Kota and the traffic circle around was chosen as the study area. The intended road section has following characteristic 4 lanes of traffic with 1 line as busway (bus line). With length 12,9 km and the center of Jakarta city reasonably heavy percentage of bus usage, land use consisting of governmental ministries and heavy commercial development including financial institutions, restaurant, hotels and stores.

The most basic approach is that of established standards for the spacing of bus stops. In urban areas this is 650 m, where the average walking distance is between 300 and 400 m [1]. Ammons (2004) states that stop spacing standards of 200–600m for bus systems are common. According to Demetsky and Lin (1982) standards for spacing in some urban areas can reach 800 m.

The bus stop is a kind of primary facility set along the roads and bus routes. In stops, buses dwell and provide services for passengers. The bus stops play an important role in bus operation [17].

The objectives was obtained data concerning the proportion of time a several buses stopped at each station along the line, and if the bus did in fact stop, what proportion of these stop to succeeding bus to avoid the accident and in fact preceding bus stop and stuck, what action can be took by succeeding bus to continue the trip in this corridor. The data was collected at any time during a working day using observer along the

corridor. This data collection procedure was accomplished for 48 bus runs in both directions (from and to Blok M – Kota).

3.5. Driver Performance

Studies have shown that there are marked health differences for urban bus driving compared to other occupations. Holme, Helgeland, Hjermann, Leren, and Lund-Larsen (1977) conducted a study of 14,677 Norwegian males aged between 40 and 49 drawn from a group of different occupations. Bus drivers were one of the professions with worst health, based on a range of health indicators (e.g., serum cholesterol levels, systolic blood pressure, body weight). More specifically, the literature indicates three salient categories of morbidity prominent in populations of bus drivers; cardiovascular disease, gastrointestinal disorders, and musculoskeletal problems (Backman, 1983; Winkleby et al., 1988a). These will now be expanded on in turn [6]:

- Cardiovascular disease (CHD)
- Gastrointestinal Problems
- Musculoskeletal disorders
- Fatigue
- Other physical health outcomes
- Psychological health

Driving performance was measured around three hazardous locations – a parallel bus stop, a layby bus stop (see Figure 1 for differences between bus stop types) and a cross road where the participant was requested to turn right. Dorn et al [9] found that these were the three locations where a high percentage of bus accidents take place. Approximately 100ft before the bus stops, the participants heard a bell ring to indicate that a passenger wished to alight the bus at the next bus stop. A number of performance parameters were chosen to investigate the drivers' behaviour in response to the hazards depicted. The simulator parameters were selected for measurement based on previous research by Dorn and Barker [9]. The parameters chosen were:

Universitas Indonesia
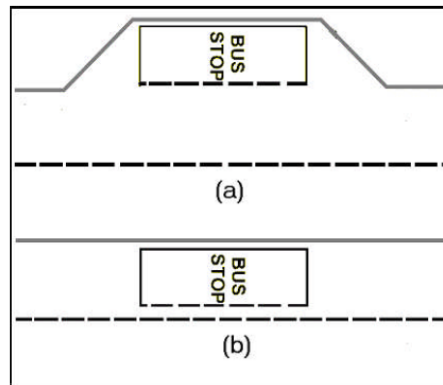
Figure 3.2 Diagram showing (a) Layby bus stop, and (b) parallel bus stop

- Lane position – The position of the simulated bus in the road, measured from the centre of the roadway, to the centre of the bus. The centre of the roadway is described as 0ft, the left hand kerb edge as −12ft and the right hand kerb edge as +12ft, for a single carriageway road. At a layby bus stop the right hand kerb edge is described as −24ft.

- Speed – The speed of the simulated vehicle (feet/second). The top speed of the simulated bus is 75 feet/second.

- Steering – Rate of change of the steering wheel angle (radians/second). This variable is always between 0 and 1.

- Acceleration – Longitudinal acceleration due to the throttle input (feet/second²). This variable is always positive.

- Braking – Longitudinal acceleration due to the brakes (feet/second²). This variable is always positive.

- Overall acceleration – The simulated bus is subjected to a number of different accelerations – those caused by the participant using the brake and the accelerator, the friction of the road, and the effect of the hill the vehicle has to climb/descend. Combined these form the overall acceleration parameter. This variable can be positive (acceleration) or negative (deceleration).

3.6. Emission of Public Bus

Emission standards are requirements that set specific limits to the amount of pollutants that can be released into the environment. Many emissions standards focus on regulating pollutants released by automobiles (motor cars) and other powered vehicles but they can also regulate emissions from industry, power plants, small equipment such as lawn mowers and diesel generators. Frequent policy alternatives to emissions standards are technology standards (which mandate Standards generally regulate the emissions of nitrogen oxides (NOx), sulfur oxides, particulate matter (PM) or soot, carbon monoxide (CO), or volatile hydrocarbons (see carbon dioxide equivalent) [12].

Bus of TransJakarta produce gas emission with lower then the other buses but still have impact to the environment. TransJakarta using two-type bus that is one type using natural gas fuel (compressed natural gas/CNG) and the other using diesel fuel. And the pollution that the buses of TransJakarta produce using natural gas are:

Table 3.1. Buses Pollution using Natural Gas Fuel

Pollutan	With CNG Buses (Tons/day)	With CNG Buses (Tons/year)
Nitrogen Oxides (NOx)	0,24	72
Particular Material (PM)	0,00	0,00
Carbon Monoxide (CO)	0,02	6

Source: [12]

Beside air pollution problem, the other problem in urban city already exists, that is acoustic pollution. Acoustic problem connected with land transportation, this pollution is very disturbing in developing country and the impact to the public healthy.

With all models above, we choose the macroscopic models with greenshield model because that model is linear and suitable for busway TransJakarta condition, where the condition of the bus not have an interference from other traffic. Besides the modeling of the bus, we

describe the air and acoustic pollution that is produced by conventional bus.
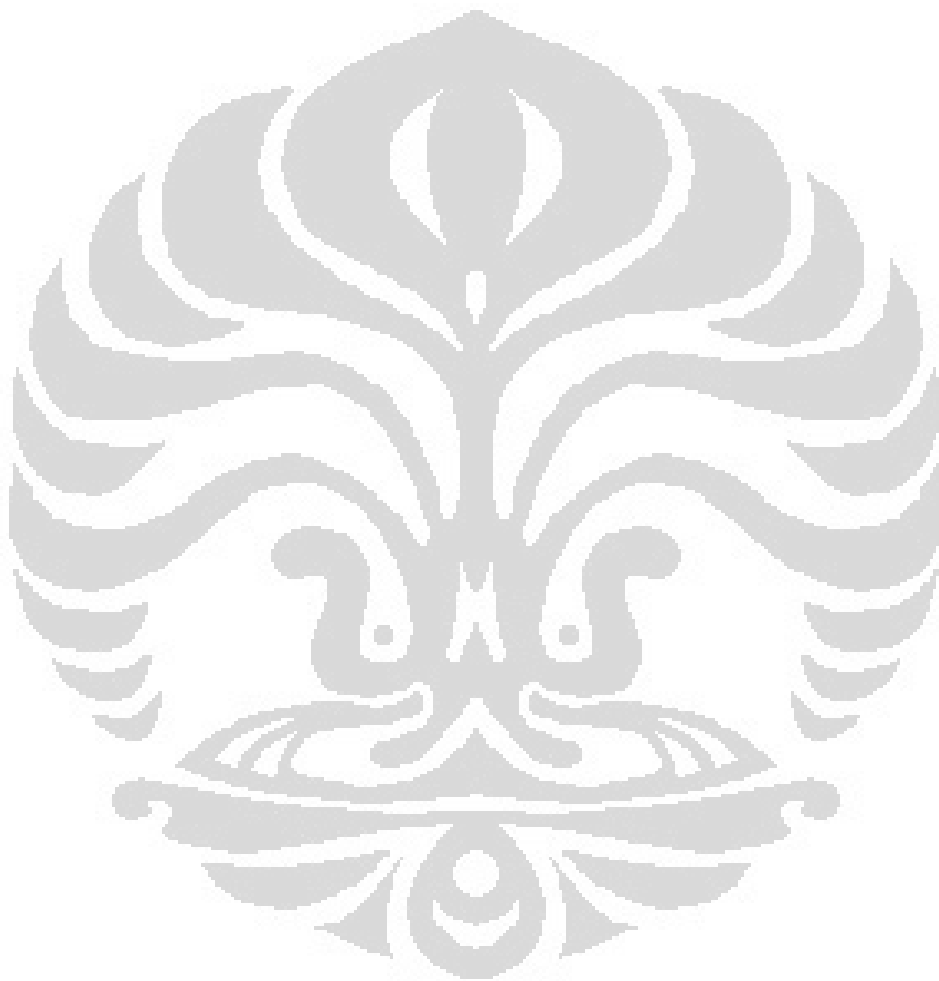
CHAPTER 4
APPLICATION IAV IN PUBLIC BUS LANE

4.1. Introduction

The aim of this chapter is to study the effect of using the IAV concept on the traffic quality of public transport in Urban Environment, compared to the conventional transport. To study the quality of traffic, we used the traffic simulation tool that reproduces the real-time traffic condition and allows the validation of the model studied in Chapter 2.

4.2. Methodology of work
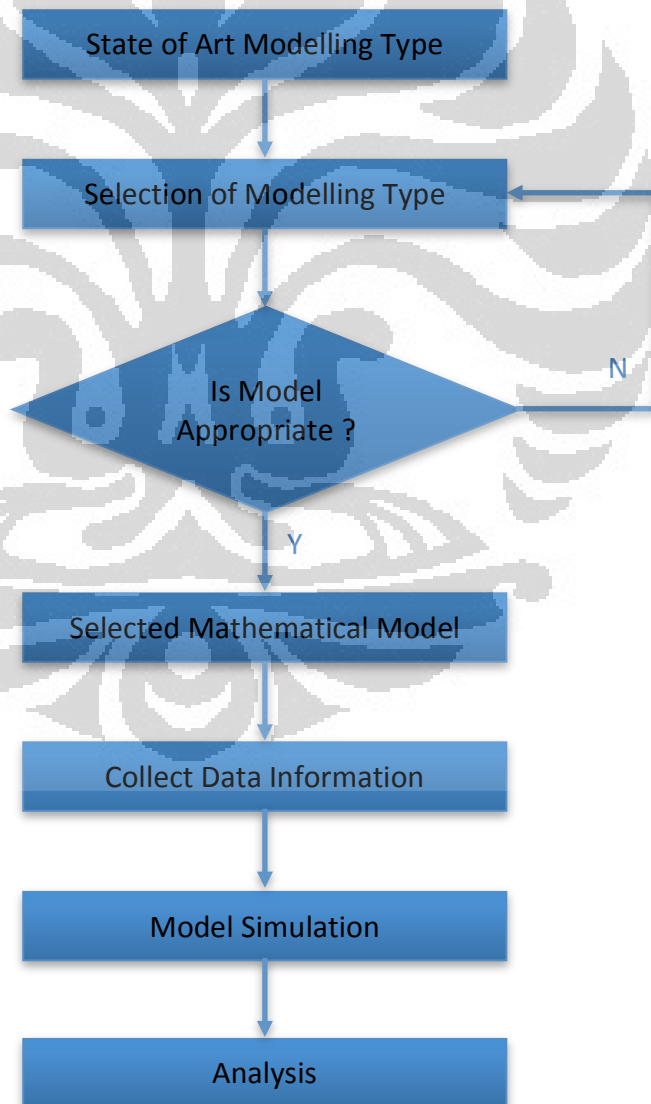
Figure. 4.1. Flowchart of Application IAV in Public transport

4.3. Study Area

The study area is corridor 1 public bus transportation in Jakarta, the capital of Indonesia. We took this corridor because this corridor has a highest demand and the most operated bus of all bus of TransJakarta. The route can be seen in Figure 4.2.

Source : [25]

Figure 4.2. Corridor 1 of TransJakarta

Corridor 1 with length 12,9 km and connected bus station in Blok M to the Jakarta Kota train station. This corridor has 20 bus station which located in busy point with range distance are approximately 650 m each station.

4.4. Comparison between Conventional Buses and IAV

After determined study area, we have to describe the exist problem and make comparison with when the IAV implicated in corridor I.

4.4.1. Refueling of conventional bus and recharge of IAV

First problem is refueling of the conventional buses with natural gas fuel, the location of gas station is the outside of the corridor I and need the time for reach the station, other problem when the buses make refueling is the queuing because the station of natural gas is very limited, even only 2 station for the bus of TransJakarta. For IAV with using the electric power, buses could recharge in each bus station inside the corridor I when the buses stop to loading and unloading the passenger.

4.4.2. Emission Produce of conventional bus

TransJakarta using conventional buses with natural gas fuel and the impact for environment is air pollution because the emission that produce and out from the exaust. The data for the emission produce shown in chapter 2, emission produce per day and in a year. For IAV with using the electric not produce the emission and make the environment of Jakarta more comfortable and healthy.

4.4.3. Time needed to back up when incident happened

Conventional buses with the specific lane and only one lane each direction will block the flow of other buses when incident or problem in engine or technical problem. Time needed to move the bus that is get the technical problem is very long because the bus need the other equipment, time needed approximately 30 minutes to one hour. For IAV with advanced technology already implemented into the vehicle which is each wheel have own engine and when one of the engine get the problem or fail, other engine will back up and the vehicle will move again and the time needed to back up about 5 – 10 second.

4.5. Traffic Simulation

After describe the problem and make comparison, we make comparison for the travel time, travel speed, and headway between the buses with using the conventional buses and IAV. Before the simulation, we make several assumption for the simulation so the simulation almost same with real condition. The assumption we specified is:

1. Traffic light in each intersection have cycle time during 123 sec, with:
   a. Red   : 95 Second
   b. Green   : 25 Second
   c. Yellow   : 3 Second
2. In corridor I have 13 intersections with 9 intersections have traffic light.

3. There is no interference form other traffic because the corridor I have specific lane.

With all assumption above, we make some simulation in SCANeR^TM studio with proposes 5 mains modes [27]:
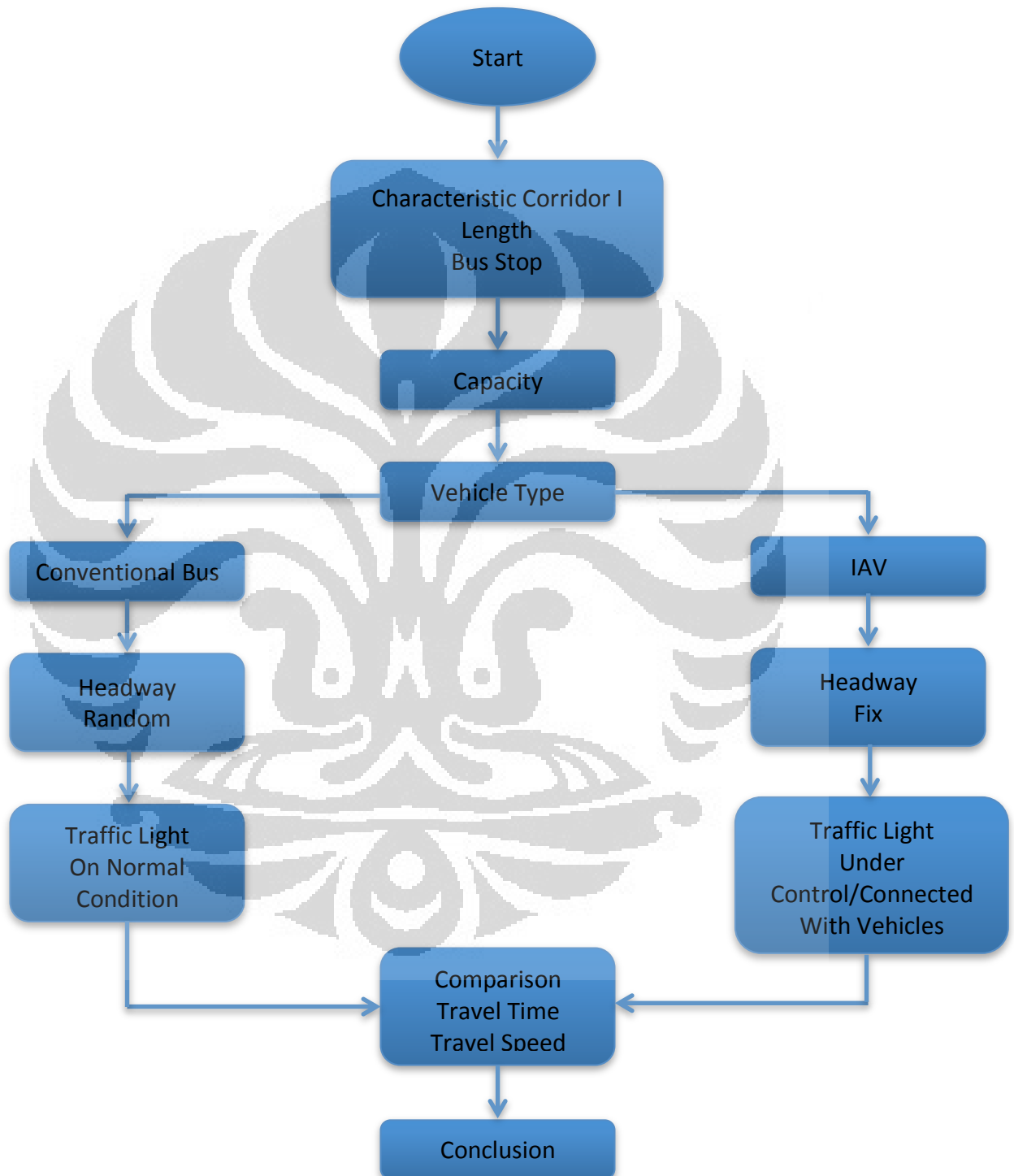
Figure 4.3. Flow Chart of Simulation

4.5.1. Studio terrain

Import the image of the background from Google map and draw the road, intersection, building, and environment considered the image. Then, input additional properties such as traffic signal, bus station, logical content, etc. As shown in Figure 4.4.
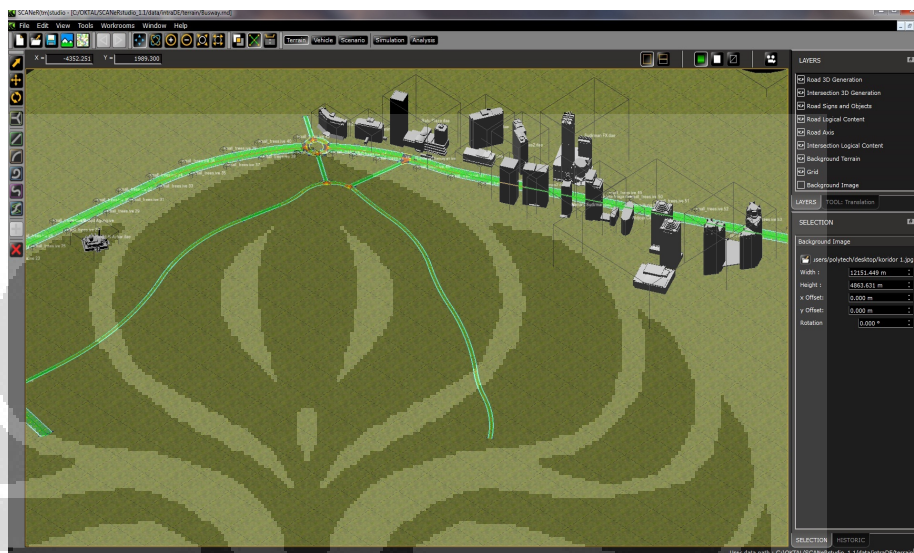
Figure 4.4. Image of the terrain

4.5.2. Studio Vehicles

For the vehicles, we can use default vehicles with all models including the bus, pedestrian, motorcycle. And for the IAV with specification referred to chapter 1 (one). Bus characteristic that we used can see in figure 4.5.
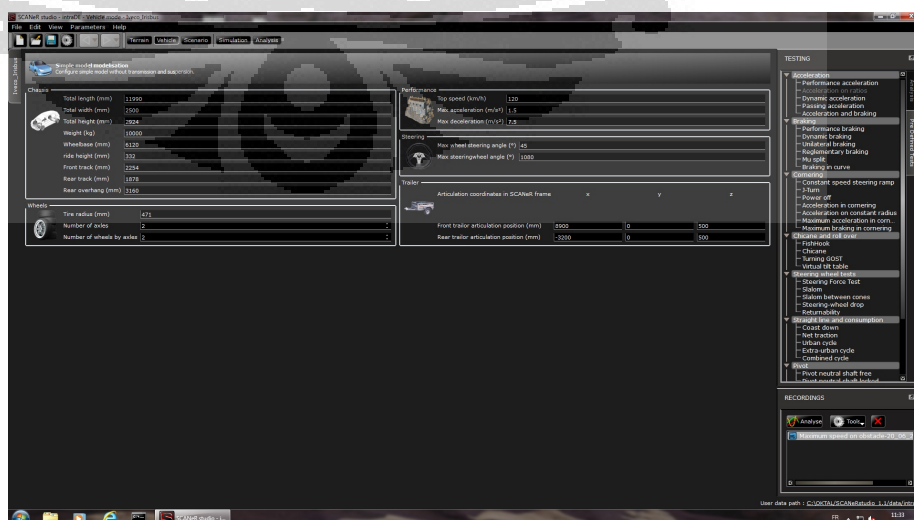
Figure 4.5. Characteristic of the Bus

Universitas Indonesia

4.5.3. Studio Scenario

Before begin using the scenario, we have to open the terrain that we already made and generated. First scenario is using conventional vehicles (buses and cars). Choose the vehicles from the window resources and put in the road where it will begin move. Input the number of bus based on the data in 2012.

For modify the properties of the buses by clicking it, we can change the maximum speed and for the buses we set the maximum speed are 50 km/h, change the literary considered the track, change the process in the buses parameters into traffic and process in driver selection into traffic.

We make randomize for the buses start considered the headway data from TransJakarta and the traffic light cycle as considered the real condition in Jakarta.

Next scenario is changing the buses with IAV and put in the same position and number with the first scenario. Change the maximum speed IAV into 50 km/h. all parameters are same with the first scenario, but for the traffic light we make assumption that the IAV make some interference and when the IAV approach the traffic light, the lamp will change into green and the other way or the opposite way will be red. For the headway, we make all same because the IAV will respect the time that we already arrange.
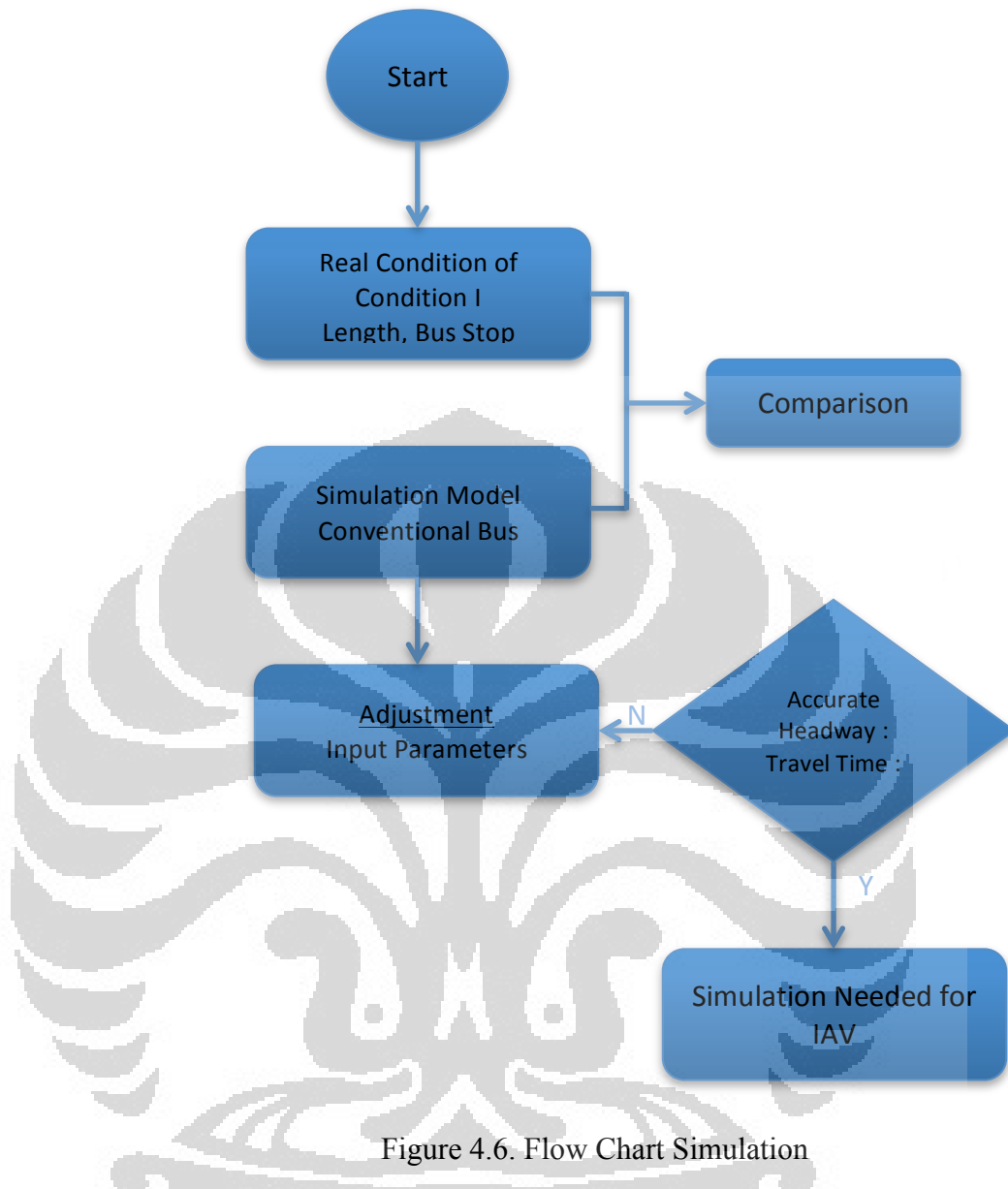
Figure 4.6. Flow Chart Simulation

4.5.4. Studio Simulation

After scenario already done with the complete terrain, click the simulation tab to simulate the scenario in the terrain. In simulator windows, click traffic, scenario, visual and record. Traffic display mean all the vehicles and buses will controlled with default program, scenario display means to simulate the traffic network using script, visual display means to show the simulation in 3D and we could change the view of simulation, weather condition and day lighting. After that, click play button to run the simulation for one trip in study area. Figure 4.7 shows the traffic network simulation.

Figure 4.7. Traffic Network Simulation

4.5.5. Studio Analysis

Final step is viewing the result of the simulation with clicking the analysis button. Clicks recorded and choose the last file simulation and then click analyze button until we got the simulation window. While playing the recording file save it to AVI file type to get the tabular and graphical data, click tools button and export to ascii file until we got a data convertor window as shown in Figure 4.8 here we got time and speed every vehicle.
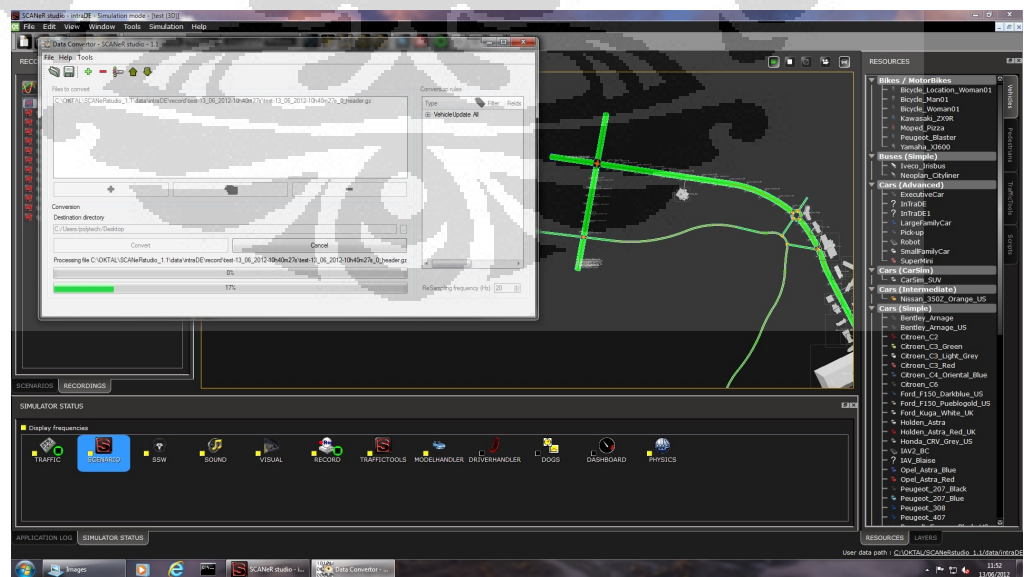
Figure 4.8. Export Data result to ASCII file

Universitas Indonesia

4.6. Data Analyzing of conventional buses

The traffic data can be seen on Annex 1, based on [16], we have got data:

- Travel time   = 2.045 sec
- Number of bus stop   = 18 (exclude 2 terminal)
- Length of Corridor   = 12,9 km

We also get data about traffic condition from PT.TransJakarta and for analysis of traffic in bus lines, we choose condition at 5:00 am - 6:00 am, which:

- Head way   = 150 sec
- Stop time at bus stop   = 30 sec
- Number of bus   = 36 (for two ways)

Based on data above, we can calculate travel speed for bus in real condition using equation 2.2 :

$$V = \frac{s}{t}$$

For comparison real travel speed with travel speed at simulation, we decrease travel time at real condition, because bus at simulation condition only stop 2 sec at each bus stop.

Travel time real (adapt) = 2.045 – (18 x (30-2)) = 1.541 sec = 0,428 hr

$$V = \frac{12,9}{0,428} = 30, 13 \text{ km/ hr}$$

In traffic analyze, we used data of bus at direction from terminal *Blok M* to terminal Jakarta Kota (one way). There is no congestion at bus way corridor, because bus using dedicated lane and obstacle only at traffic light. For simulation, we set headway of departure for conventional bus by random refer data from PT.TransJakarta. The headway graphic is shown in figure 3.9.
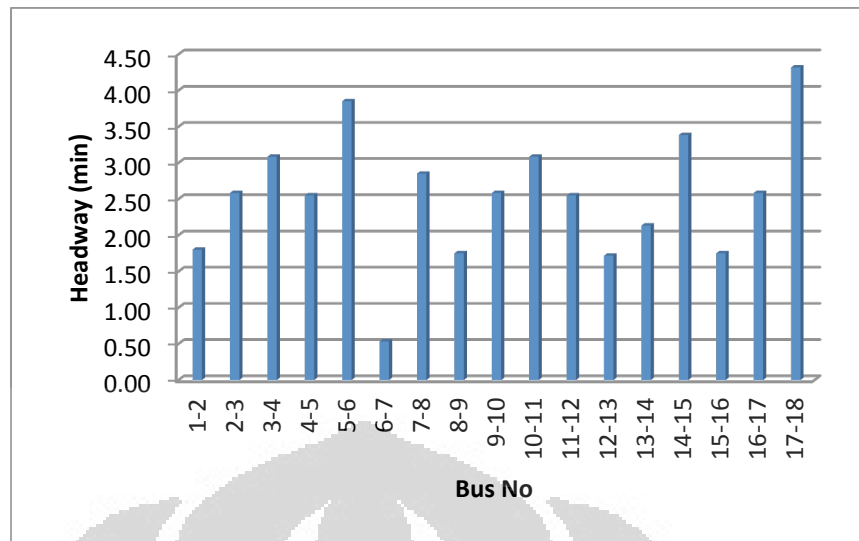
Figure 4.9. Headway of departure time of conventional bus

With SCANeR^{TM}, we get the travel time of conventional bus with average travel time is 36,97 . The travel time all bus can be seen in figure 4.10.
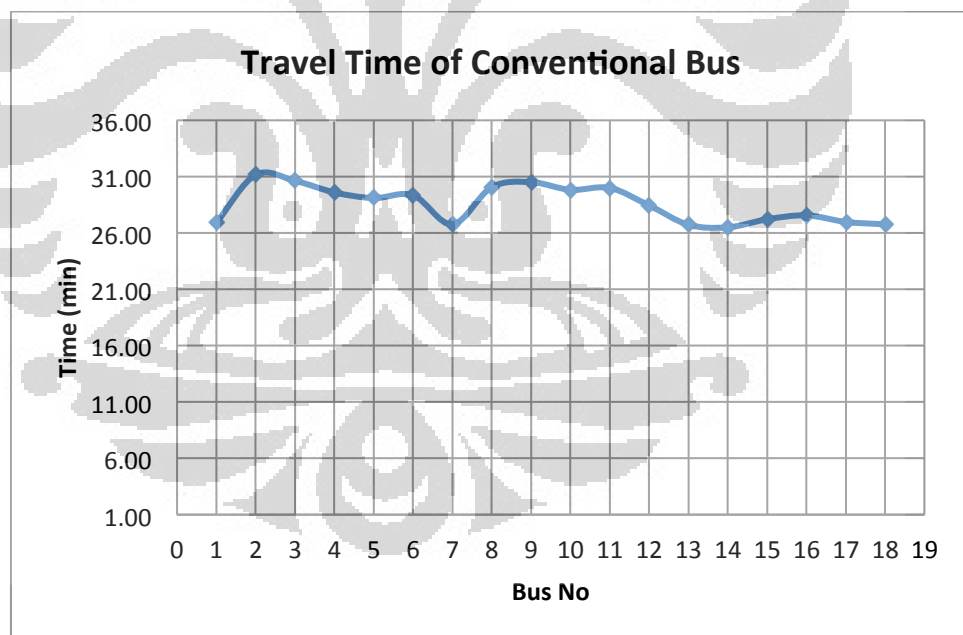
Figure 4.10. Travel Time of Conventional Buses

For the travel speed can be seen in figure 4.11 with maximum average speed is 30,62 km/h and the minimum is 26,16 km/h, with average speed 28,56 km/hr
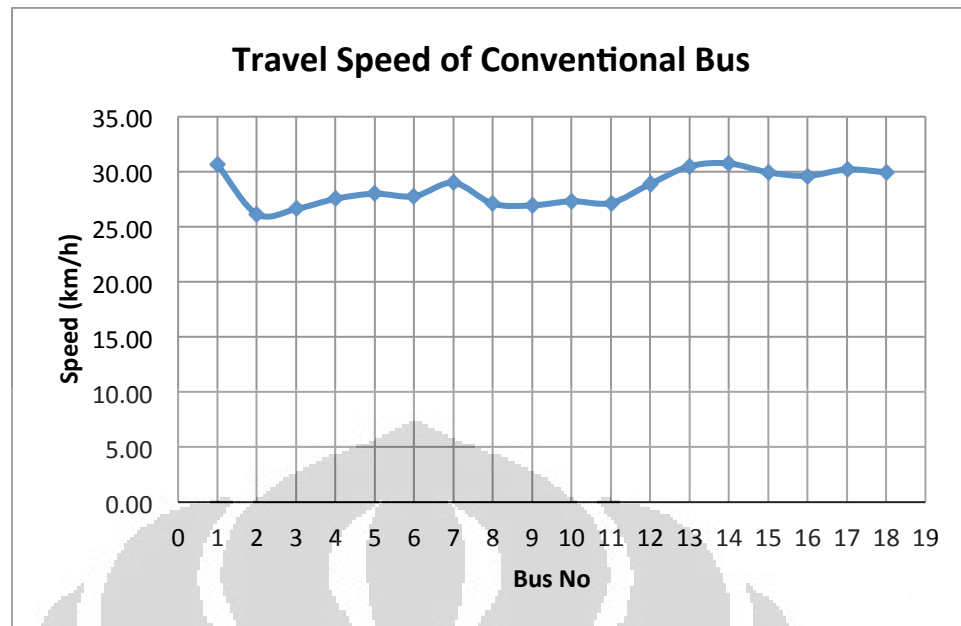
Figure 4.11. Travel Speed of Conventional Buses

After we get data simulation of conventional bus from SCANeR™, we make comparison with data at real condition in table 4.1 below.

Table 4.1 Comparison data conventional bus from simulation with data real

No	Category	Real Condition	Simulation
1.	Travel Time	34,1 min	36,97 min
2.	Travel Speed	30,13 km/hr	28,56 km/hr
3.	Headway	150 sec	151 sec

In table 4.1 above, we can see data of conventional bus at real condition almost same with data from simulation, and we conclude that our simulation is suitable.

For analyze density of traffic in this corridor, we can calculate using equation 2.1

q = k x v

k = q / v = 36 / 28,56

= 1,24 veh/ km

Density in this corridor is very low and this data show us, no congestion at that corridor.

$$v = v_f - \left(\frac{Vf}{kj} \right) k$$

$$28,56 = 50 - \left(\frac{50}{kj} \right) 1,24$$

k_j= 2,892 veh/ km

      Using Greenshield's models, we can make correlation between speed and density, show in figure 3.12 below
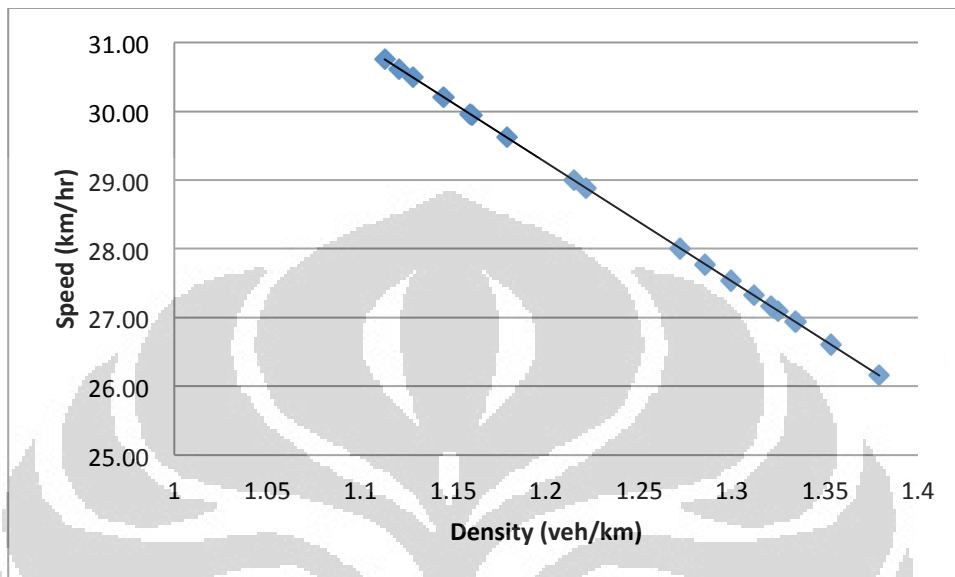
Figure 4.12. Correlation between Speed and Density

4.7. Data analyzing of intelligent autonomus vehicles (IAV)

      After simulated the conventional buses and get data almost same with the real condition, we make simulation with change all conventional buses with IAV and make assumption:

1. All IAV have same headway and the IAV always respect the headway to keep the distance between the vehicles.

2. The IAV can control/connected the traffic light, it means when the IAV approaching the traffic light, it change to green and other traffic light in the intersection change to red.

3. Maximum speed of IAV same with conventional bus 50 km/h

      With all assumption above, we make the scenario and running the simulation and get data result that can be seen on figure 4.13 for travel time and figure 4.14 for travel speed.
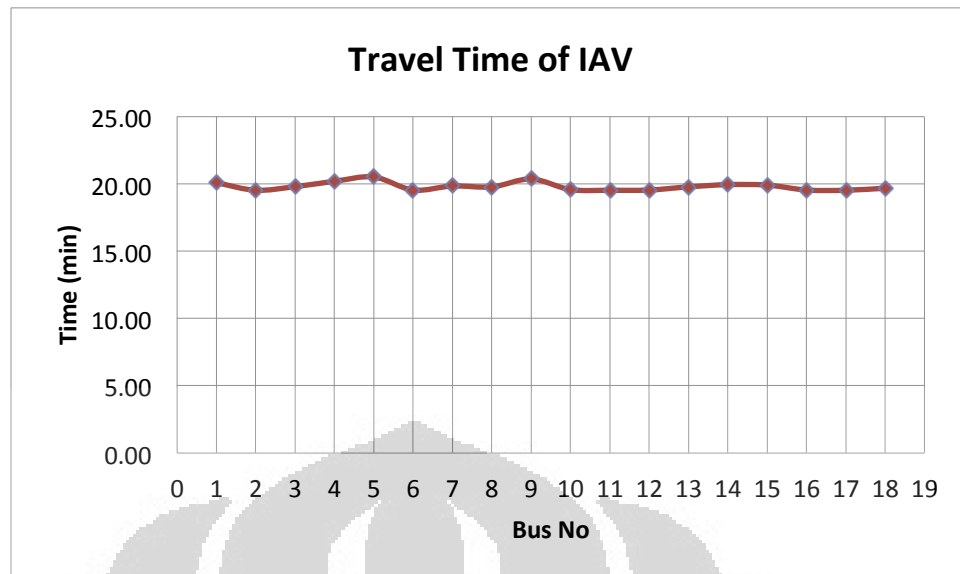
Figure 4.13. Travel Time of IAV

From data result of travel time IAV; we can see that the travel time constantly and there is no fluctuation between the buses. Also for the travel speed, all IAV almost have same mean speed that means IAV can reduce the accelerate and decelerate of it self.
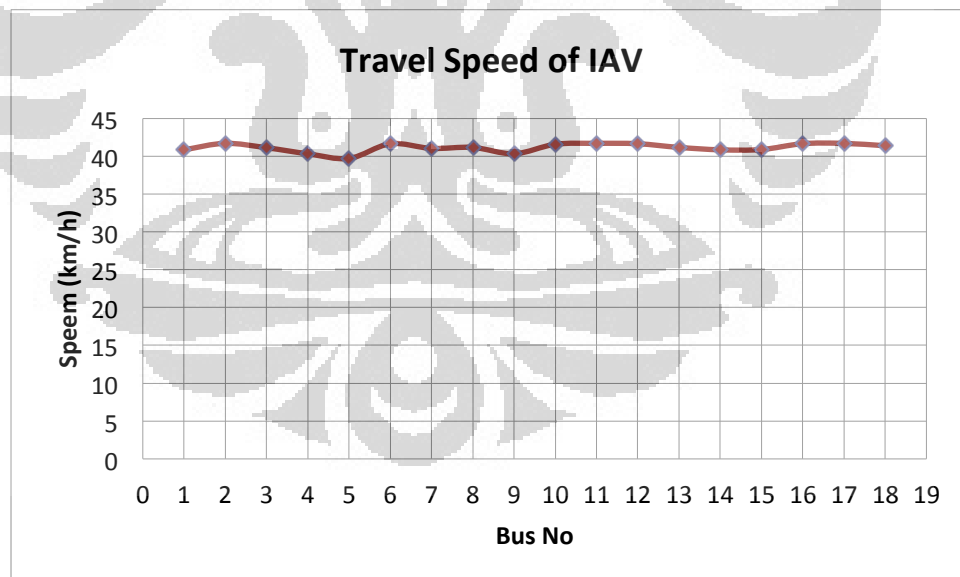
Figure 4.14. Travel Speed of IAV

With all data result, we make the comparison for both data and can be seen on figure 4.15 for travel time and 4.16 for travel speed
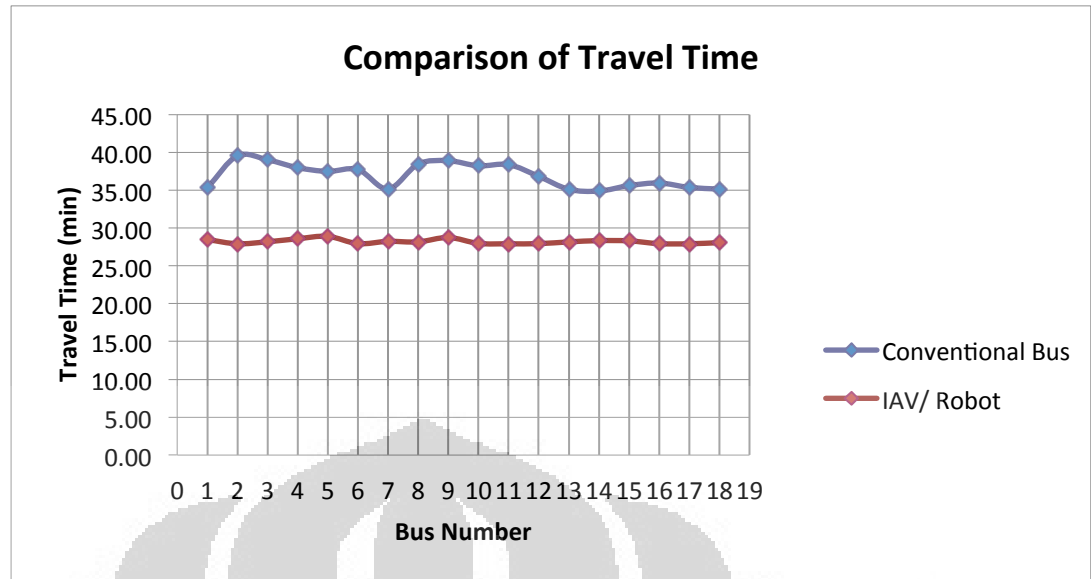
Figure 4.15. Comparison data travel time

With figure 4.15, we can see the comparison of travel time between the conventional bus and the IAV, for conventional bus there is the fluctuation between the buses and the IAV have more constantly and shorter travel time and that make the waiting time of passenger in each station can reduced. And for travel speed on figure 4.16, we can see the comparison of travel speed on conventional bus and IAV, that the IAV have faster and more constant of mean speed then the conventional buses.
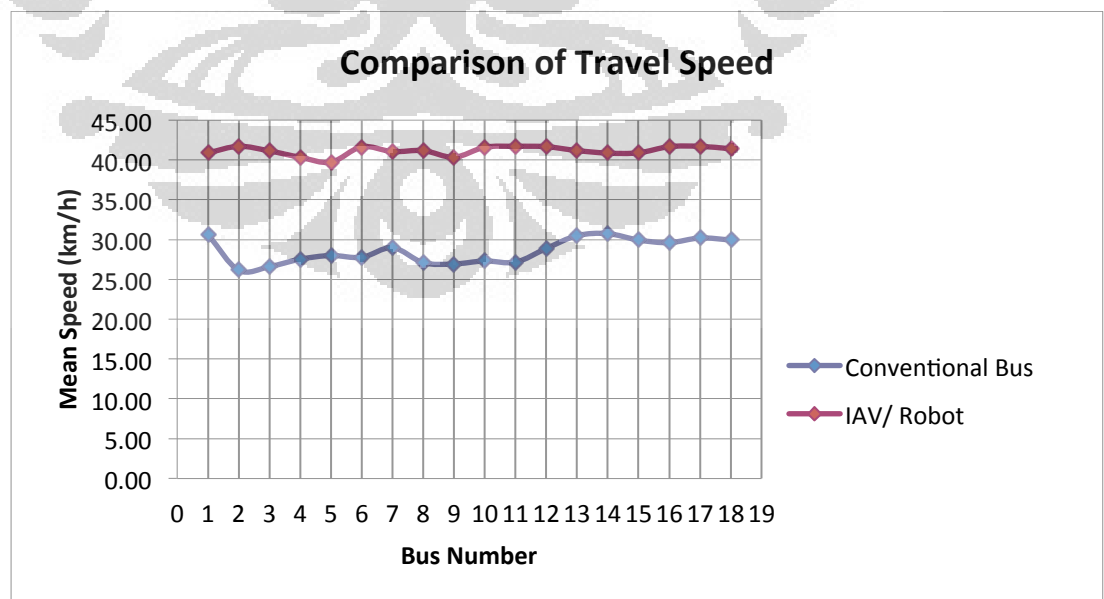
Figure 4.16. Comparison data travel speed

4.8. Conclusion

In this chapter, we got the result of the effect of using the IAV concept on the public bus traffic quality in urban environment; application of IAV in confined area contributes improvement of quality of public transport and the environment.
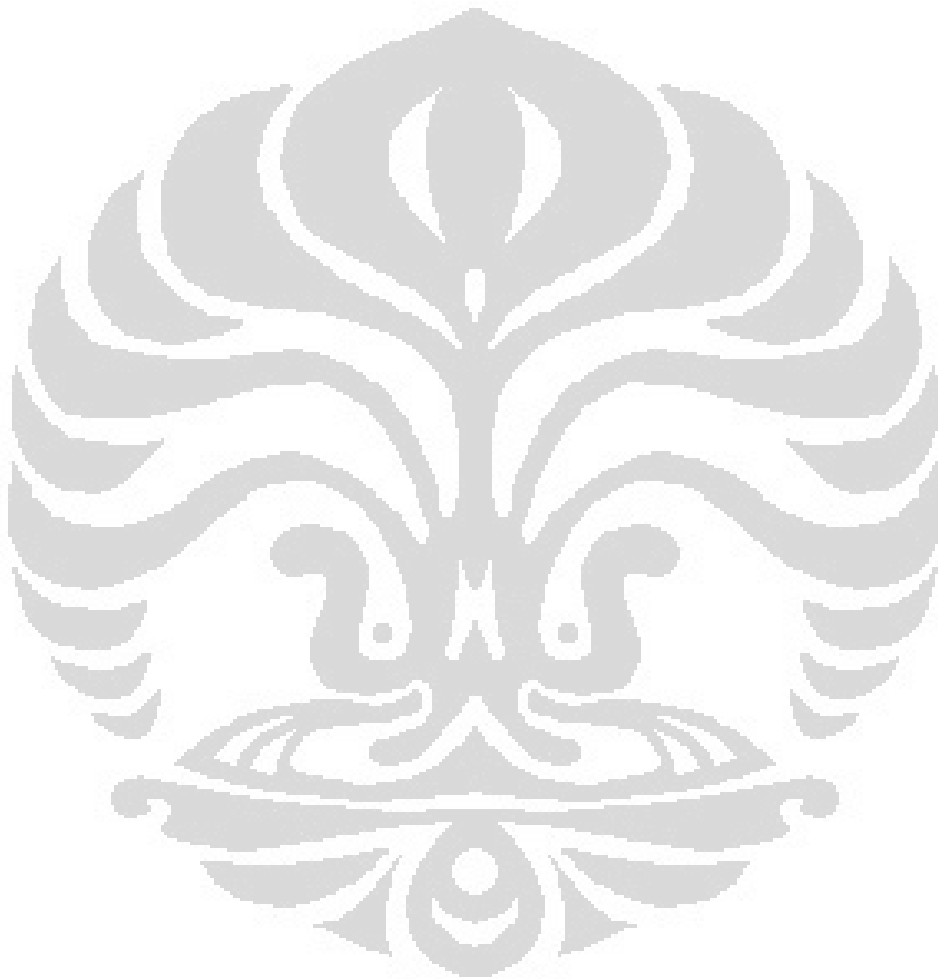
CHAPTER 5
CONCLUSION AND PERSPECTIVES

5.1. Conclusion

The use of macroscopic models such as the greenshields model can describe the characteristic in urban area, namely density, flow and mean speed. After we compare two different kinds of vehicles (conventional bus and IAV) with using SCANeR™ Studio Version 1.1 simulation, it can give us the result of bus flow in one corridor.

According to the work presented in this report, using IAV in corridor 1 of TransJakarta can improve traffic management since it has short time travel then using of conventional vehicle, travel speed be more constant and the headway between the bus more constantly. With the ability to reconfigure itself when there is an error or failed system. Other impact of application the IAV into corridor I is reducing the air pollution.

5.2. Perspectives

In the future, application of IAV into corridor I of TransJakarta is necessary to develop the public transport management in Jakarta and to make the environment more healthy and comfortable. There are two possibilities to using IAV in the busway, first we can change all the conventional bus with the IAV and second is we can collaborate the conventional bus as the lead and the IAV as the followers. The first possibility have the advantage is all vehicles run with automatically and there is no interference from human and the second possibility we still have human as a driver and the IAV as the additional vehicles that can increase the capacity of the bus without direct contact with it bus self.

REFERENCES

1. Mezyad M. Alterkawi, "computer simulation analysis for optimizing bus stops spacing: The case of Riyadh", Saudi Arabia.

2. Baher Abdulhai, Lina Kattan, Myer Kutz, "Handbook of transportation Engineering", McGraw-Hill, 2004

3. David Meignan, Olivier Simonin, Abderrafia Koukam, " Simulation and evaluation of urban bus-networks using a multiagent approach ", Elsevier, 25, February 2007

4. Graham Currie, Alexa Delbosc, " Understanding bus rapid transit route ridership drivers: An empirical study of Australian BRT systems", Transport Policy18_755–764, 2011

5. Hasriwan Putra, Yusmiati Kusuma, "Urban traffic management Using Intelligent Transportation System Case study Jakarta – Indonesia", in Final report of internship, Université Lille1, July 9, 2011

6. John L.M. Tse , Rhona Flin, Kathryn Mearns, " Bus driver well-being review: 50 years of research "

7. Kate Alexander, " Investigation of a New Macroscopic Model of Traffic Flow"

8. Lieuwe Krol, "The Reconstruction of Vehicle Trajectories with Dynamic Macroscopic Data", University of Twente, Deventer, The Netherlands, August 11, 2009

9. Lisa Dorn Jenny Stannard, "Simulator performance differences between experienced and novice bus drivers", Driving Research Group

10. Massimo Bertozzi , Alberto Broggi, Alessandra Fascioli, "Vision-based intelligent vehicles: State of the art and perspectives", Communicated by F.C.A. Groen, October 1999

11. M. E. Seliaman, S. O. Duffuaa, A. A. Andijani, "evaluating traffic stream models for Nafrah Using simulation", KFUPM, Dahran, December 2002

12. Muhammad Nasrullah, "Sistem bus rapid transit di Jakarta", in Final Project, University of Indonesia, 2010

Universitas Indonesia

13. Muhammad Zulkifli Mochtar and Yasua Hino, "Principal Issues to Improve the Urban Transport Problems in Jakarta, Osaka City University, September 29 2006.

14. Nanditha Koppula, "A comparative analysis of weaving areas in HCM, TRANSIMS, CORSIM, VISSIM and INTEGRATION", in thesis Virginia Polytechnic Institute and State University, April 2002

15. N. Christov, Laboratory of Automatics, Computer Engineering and Signal Processing (LAGIS) in ERRIC Kickoff Meeting, 2010

16. Sabungan H.Hutapea, Michael, Ngarap Im Manik, "Perancangan Program Simulasi Penjadwalan Busway-Transjakarta Dengan Metode Repetitive Scheduling" in Jurnal Mat Stat, Vol.11 No.1 January, 2011

17. SHI Hongwen, LUO Liangxin, BAO Tongzhen, " Research on the Way to Determine Types and Scales of Bus Stops ", Journal Of Transportation Systems Engineering And Information Technology, Volume 7, Issue 2, April 2007

18. Simon Mc Donnell, Moira Zellner, " Exploring the effectiveness of bus rapid transit a prototype agent-based model of commuting behavior", Transport Policy 18_825–835, 2011

19. Takashi Nagatani, Physica A, "Interaction between buses and passengers on a bus route", 296_ 320–330, 2001

20. Tom V. Mathew and K V Krishna Rao, "Introduction to Transportation Engineering", NPTEL, May 24, 2006

21. Wilco Burghout, "Mesoscopic Simulation Models for Short-Term Prediction", Institute of Technology Linkopings University, October 11th 2005

22. Winnipeg, "Rapid Transit Backgrounder", Winnipeg Rapid Transit System, January 2004

23. Xumei Chen, Lei Yu, Yushi Zhang, Jifu Guo, "Analyzing urban bus service reliability at the stop, route, and network levels", Elsevier, 2009

24. http://adekfi.wordpress.com

25. www.google.com

26. www.intrade-nwe.eu

27. www.oktal.fr

Universitas Indonesia

28. www.scanersimulation.fr

29. http://theprashanta.wordpress.com

30. www.transjakarta.co.id

31. www.wikipedia.com

Universitas Indonesia

ANNEXES 1

Data of Corridor I TransJakarta

Table Names of Station of TransJakarta in Corridor I

NO	Name of Bus Stop	Info
1	Blok M	
2	Mesjid Agung	
3	Bunderan Senayan	
4	Gelora Bung Karno	
5	Polda Metro Jaya	
6	Bendungan Hilir	
7	Karet	
8	Setiabudi	
9	Dukuh Atas 1	Halte Transit to Corridor 4 & 6
10	Tosari	
11	Bunderan HI	
12	sarinah	
13	Bank Indonesia	
14	Monumen Nasional	
15	Harmoni Central Busway (HCB)	Halte Transit to Corridor 2, 3, & 8
16	Sawah besar	
17	Mangga Besar	
18	Olimo	
19	Glodok	
20	Kota	

Source: PT. TransJakarta Tbk

Universitas Indonesia

Table Travel time in real condition in Corridor I

No Bus Stop	Origin	Destination	Travel Time (Sec)
1	Blok M	Mesjid Agung	275
2	Mesjid Agung	Bunderan Senayan	165
3	Bunderan Senayan	Gelora Bung Karno	150
4	Gelora Bung Karno	Polda Metro Jaya	70
5	Polda Metro Jaya	Bendungan Hilir	125
6	Bendungan Hilir	Karet	55
7	Karet	Setiabudi	65
8	Setiabudi	Dukuh Atas 1	170
9	Dukuh Atas 1	Tosari	70
10	Tosari	Bunderan HI	125
11	Bunderan HI	sarinah	65
12	sarinah	Bank Indonesia	60
13	Bank Indonesia	Monumen Nasional	70
14	Monumen Nasional	Harmoni Central Busway (HCB)	120
15	Harmoni Central Busway (HCB)	Sawah besar	130
16	Sawah besar	Mangga Besar	110
17	Mangga Besar	Olimo	50
18	Olimo	Glodok	70
19	Glodok	Kota	100
	TOTAL		2045

Universitas Indonesia

OPERATIONAL SCHEDULE, HEADWAY, SPEED BUS
Number bus which operated in corridor I is 62 bus
Standard Maximum Speed is 50 Km/jam
Table Operational Schedule of Corridor I

KORIDOR 1 (BLOK M - KOTA)								
PERIODE (Hour)		SENIN s/d JUMAT			Saturday/Sunday/Vacance		CAR FREE DAY (CFD)	
		HEADWAY (minutes)	OPERATED	BUS SPLIT / RUTE LAIN	HEADWAY (minute)	Operating Bus	HEADWAY (minute)	Operated
5:00	6:00	02:30	36		03:45	24	03:45	24
6:00	7:00	01:58	46	10 = Blok M - HCB	01:52	48	02:30	36
7:00	8:00	01:43	52	6 = from Ragunan	01:30	60	01:52	48
8:00	9:00	01:27	49	3 = to Harm-Anc & 10 HCB - Blok M	01:30	60	01:30	60
9:00	10:00	01:27	49	3 = to Harm-Anc & 10 HCB - Blok M	01:30	60	01:30	60
10:00	11:00	01:27	49	3 = to Harm-Anc & 10 HCB - Blok M	01:30	60	01:30	60
11:00	12:00	01:27	49	3 = to Harm-Anc & 10 HCB - Blok M	01:30	60	01:30	60
12:00	13:00	01:27	49	3 = to Harm-Anc & 10 HCB - Blok M	01:30	60	01:30	60
13:00	14:00	01:27	49	3 = to Harm-Anc & 10 HCB - Blok M	01:30	60	01:30	60
14:00	15:00	01:27	49	3 = to Harm-Anc & 10 HCB - Blok M	01:30	60	01:30	60
15:00	16:00	01:27	49	3 = to Harm-Anc & 10 HCB - Blok M	01:30	60	01:30	60
16:00	17:00	01:43	52	3 = from HCB-Anc	01:30	60	01:30	60
17:00	18:00	01:27	52		01:36	60	01:30	60
18:00	19:00	01:36	56	6 = to Ragunan	01:30	60	01:57	60
19:00	20:00	01:36	56		01:57	46	03:28	46
20:00	21:00	01:58	46		03:28	26	03:28	26
21:00	22:00	03:30	26		05:37	16	05:37	16
22:00	23:00	10:00	6		15:00	6	15:00	6

Source: PT. TransJakarta Tbk

Universitas Indonesia

ANNEXES 2

Data Result

Table Headway of departure time of conventional bus

Bus No	Headway of Depart (min)
1-2	1,80
2-3	2,58
3-4	3,08
4-5	2,55
5-6	3,85
6-7	0,53
7-8	2,85
8-9	1,75
9-10	2,58
10-11	3,08
11-12	2,55
12-13	1,72
13-14	2,13
14-15	3,38
15-16	1,75
16-17	2,58
17-18	4,32

Universitas Indonesia

Table Travel Speed of Conventional Bus and IAV

Bus no	Travel Speed (km/hr)	
	Conventional Bus	IAV/ Robot
1	30,62	40,89
2	26,16	41,72
3	26,61	41,14
4	27,54	40,34
5	28,01	39,73
6	27,78	41,66
7	29,00	41,05
8	27,10	41,18
9	26,94	40,35
10	27,33	41,60
11	27,17	41,72
12	28,89	41,67
13	30,50	41,18
14	30,76	40,86
15	29,95	40,90
16	29,62	41,68
17	30,21	41,72
18	29,96	41,40
Av	28,56	41,16

Universitas Indonesia

Table Travel Time of Conventional Bus and IAV

| Bus no | Travel Time (min) | |
	Conventional Bus	IAV/ Robot
1	35,33	28,48
2	39,57	27,93
3	39,03	28,20
4	38,00	28,60
5	37,50	28,92
6	37,75	27,95
7	35,17	28,25
8	38,47	28,18
9	38,92	28,77
10	38,23	27,98
11	38,40	27,93
12	36,85	27,95
13	35,13	28,18
14	34,90	28,35
15	35,62	28,32
16	35,97	27,95
17	35,38	27,93
18	35,17	28,08
Av	**36,97**	**28,22**

Universitas Indonesia

Table Speed and Density of Conventional Bus

Veh No	Speed (km/hr)	Density (veh/km)
1	1,1209	30,621
2	1,3792	26,156
3	1,3528	26,611
4	1,2992	27,538
5	1,2720	28,008
6	1,2855	27,775
7	1,2149	28,996
8	1,3243	27,105
9	1,3338	26,939
10	1,3115	27,325
11	1,3206	27,168
12	1,2211	28,888
13	1,1281	30,496
14	1,1131	30,756
15	1,1598	29,948
16	1,1787	29,621
17	1,1447	30,209
18	1,1593	29,956

Universitas Indonesia

Headway of Conventional Bus at each bus stop

| No	Bus Stop	Headway (min)																
		Bus 1-2	Bus 2-3	Bus 3-4	Bus 4-5	Bus 5-6	Bus 6-7	Bus 7-8	Bus 8-9	Bus 9-10	Bus 10-11	Bus 11-12	Bus 12-13	Bus 13-14	Bus 14-15	Bus 15-16	Bus 16-17	Bus 17-18
1	Mesjid Agung	2,03	2,07	4,12	2,07	2,00	2,05	4,12	0,52	3,57	2,05	2,07	2,03	3,57	2,60	2,03	2,07	4,12
2	Bunderan Senayan	6,43	1,88	0,30	1,28	2,10	2,03	4,37	1,73	2,60	1,75	1,90	1,97	2,03	4,10	2,05	2,53	3,63
3	Gelora Bung Karno	6,43	1,88	0,32	1,28	2,07	2,03	4,38	1,73	2,58	1,75	1,92	1,95	2,05	4,10	2,03	2,53	3,67
4	Polda Metro Jaya	6,17	1,90	0,35	1,28	2,03	2,03	4,38	1,77	2,55	1,75	1,93	1,93	2,05	4,12	2,02	2,55	3,67
5	Bendungan Hilir	6,15	1,92	0,37	1,32	1,97	2,03	4,40	1,78	2,52	1,73	1,97	1,92	2,07	4,12	2,00	2,57	3,70
6	Karet	6,13	1,92	0,38	1,32	1,95	2,42	4,03	1,78	2,50	1,73	1,97	1,92	2,07	4,13	1,98	2,57	3,72
7	Setiabudi	6,12	1,93	0,40	1,33	1,90	2,42	4,03	1,82	2,47	1,73	2,00	1,88	2,08	4,13	1,97	2,58	3,73
8	Dukuh Atas 1	6,10	1,95	0,40	1,35	1,87	2,42	4,05	1,82	2,45	1,73	2,00	1,88	2,10	4,12	1,97	2,58	3,75
9	Tosari	6,07	1,97	0,43	1,37	1,80	2,42	4,07	1,85	2,40	1,73	2,03	1,85	2,12	4,13	1,93	2,62	3,77
10	Bunderan HI	6,25	1,85	0,30	1,77	2,03	2,05	4,27	1,88	2,52	1,58	2,05	2,05	2,05	4,10	2,05	2,05	4,10
11	sarinah	6,22	1,87	0,33	1,77	1,98	2,05	4,30	1,90	2,48	1,57	2,08	2,02	2,07	4,12	2,02	2,07	4,13
12	Bank Indonesia	6,15	2,17	0,23	1,90	1,90	2,12	4,12	1,98	4,12	2,08	0,23	1,70	2,05	4,10	2,10	2,12	3,98
13	Monumen Nasional	6,15	2,07	0,27	1,80	2,00	2,05	4,28	1,88	4,08	2,05	0,27	1,78	2,05	4,12	2,05	2,03	4,12
14	Harmoni Central Busway (HCB)	6,12	2,08	1,88	2,05	2,05	2,05	4,10	2,05	2,17	2,05	1,93	0,30	1,90	4,12	2,02	2,07	4,15
15	Sawah besar	6,08	2,12	1,90	2,07	2,00	2,05	4,12	2,07	2,13	2,05	1,95	0,67	1,52	4,13	1,98	2,08	4,18
16	Mangga Besar	6,13	2,07	2,08	2,07	1,98	2,05	4,12	2,08	2,00	2,05	2,07	0,28	1,77	4,10	2,03	2,07	4,13
17	Olimo	6,10	2,08	2,08	2,08	1,95	2,05	4,13	2,08	1,98	2,05	2,10	0,30	1,73	4,12	2,00	2,08	4,13
18	Glodok	6,10	2,08	2,10	2,08	1,93	2,05	4,13	2,10	1,97	2,05	2,10	0,32	1,72	4,12	2,00	2,08	4,15
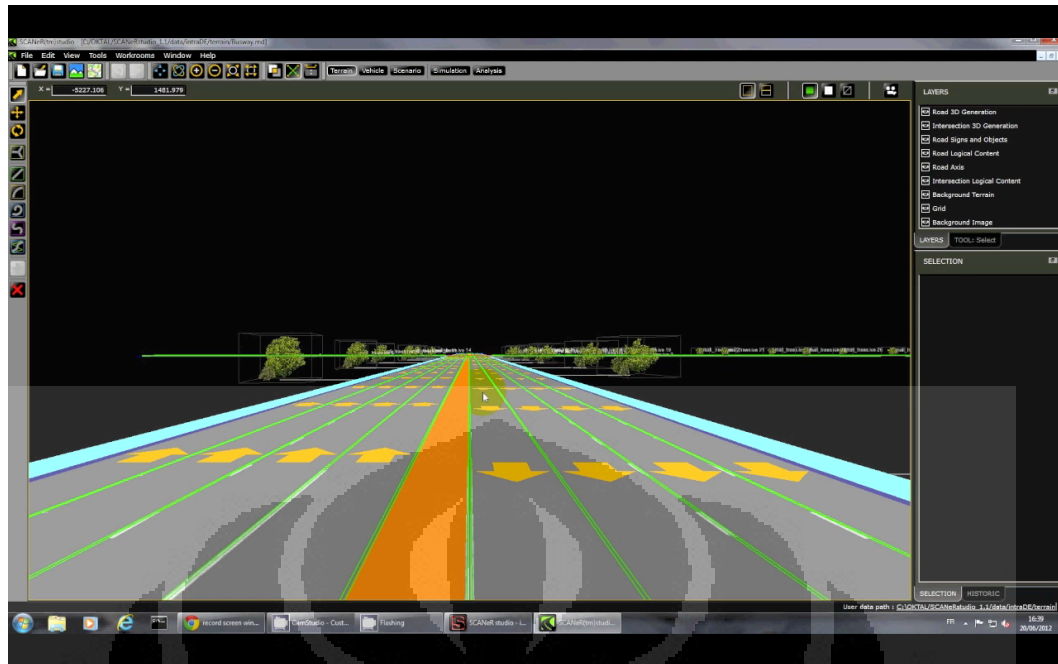
Figure Profile of Road Corridor I TransJakarta
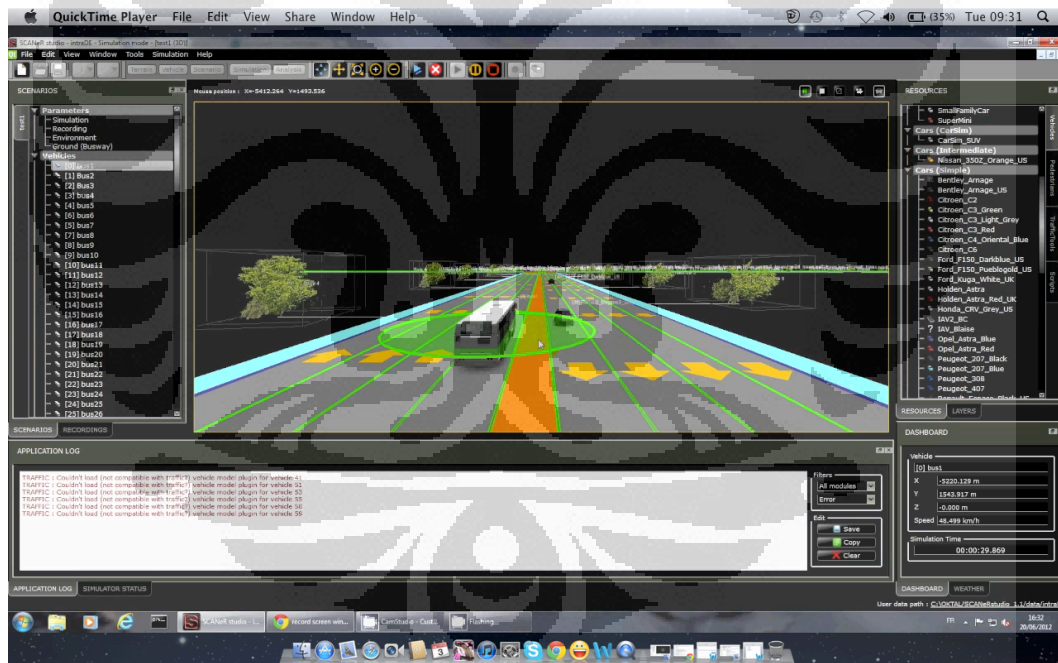
Figure Conventional Bus Running in Simulation

Figure Speed Analyze Result of Simulation
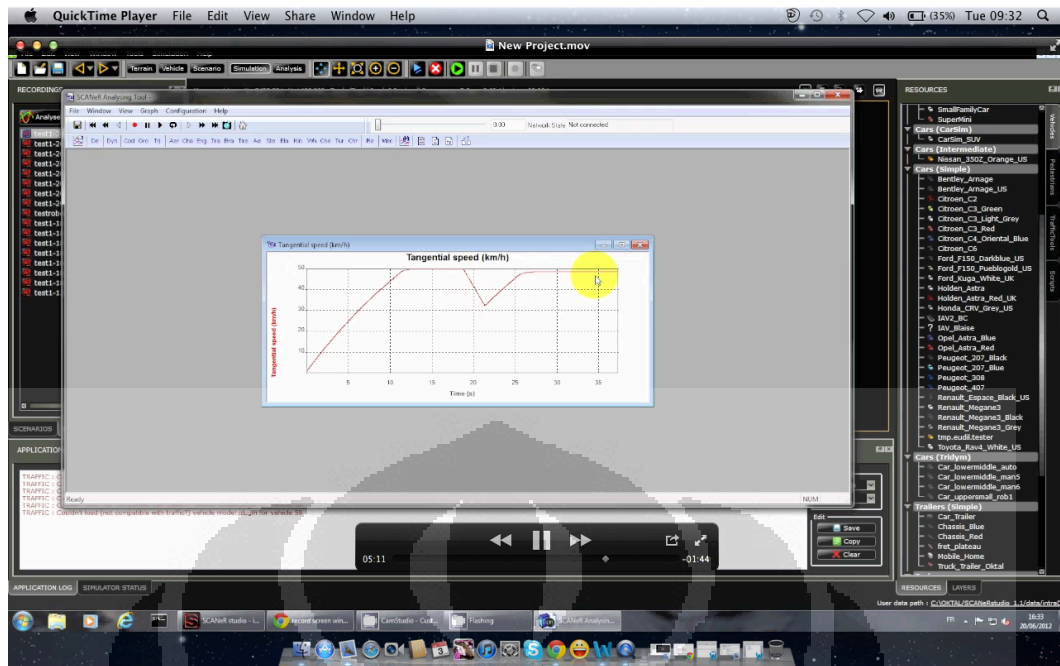

Figure IAV Running in Simulation

Universitas Indonesia

Figure IAV Running in Simulation