Prediction and Analysis on Micro-Cars' Influence to Traffic Flow, Traffic Safety, and Environment

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Abstract

Transformational change is coming to the automobile. We are entering a new era when the automobile is unable to fulfill, in a sustainable manner, its function as the primary provider of personal powered mobility. There are many issues threatening the car's autonomy, such as peak oil concerns and rising fuel prices, legislation to reduce carbon emissions and other factors concerning climate change, congestion and parking limitations. Alternative vehicles have been developed and produced by niche manufacturers for decades, and these will enjoy mainstream popularity in years to come. Micro-cars are perhaps the most likely type of alternative vehicle to be seriously produced by the major Original Equipment Manufacturers (OEMs), given they are closest to the traditional car, no matter the shape, speed, or the weather protecting advantage when compared to motorcycle or the other types of alternative automobile.

Micro-car, usually two-seat, two-door, less than three meters in length, low weight, the smallest applied to standard small cars (being smaller than the city car), evolved out of necessity in a post-World War II Europe short of raw materials and money, have a rebirth and play an important role in the changing mobility landscape. Micro-cars are convenient for short and medium distance trips. They can provide convenient personal urban mobility at a cost below that of conventional cars; they will take up less of the city space currently needed for parking; they will significantly improve the throughput of streets and roads.

This research aims to analysis the effect of micro-cars after their introduction to the traffic flow in three aspects, their influence to traffic flow straightly, whether their join will cause safety hazard, as well as whether they have positive effects to the environmental if they are mixed to traffic flow. There are three levels for the analysis, road segment level, downtown small network level, and metropolitan network level. As to do realistic experiments is unavailable for many uncontrolled factors, TCA and VISSIM are chosen to complete simulations.

In road segment level analysis, VISSIM and TCA's performance is compared for research objective of investigating micro-cars' influence in all traffic flow conditions, which is reflected by a density spectrum ranging from 0 veh/km to more than 100

veh/km in which it is a highest density on road for only-conventional-car traffic. Although VISSIM has the advantage that possesses more parameters than TCA to discribe detailed driving behaviors, the simulated results from VISSIM show some unstable points, and have deficiency of points in some density spectrums, especially on road segment with traffic signal. TCA has simpler rules and parameters, however, just so it can provide clear curves in different micro-car rate assumptions, not scattered points output from VISSIM, for the analysis in this research. So finally TCA was used to execute the segment level simulations after the comparison for the reasons mentioned above and its excellent ability in simulating realistic traffic in condition of the precise detailed driving behaviors are not necessary to catch, and its efficiency and fast performance when used in computer simulations.

In downtown small network level analysis, VISSIM is used to do simulations in the chosen network, as TCA models cannot easily handle dynamic traffic assignment for macroscopic simulation and driver behavior for microscopic simulation in network. And amount of required simulation results for the target analysis are computed.

For metropolitan network level analysis, TCA results are used to calculate the traffic flow and environmental effects on Nagoya metropolitan network in 2020, with the previous predicted traffic demand results. The predicted average traffic speed of every link is the original input for calculation. And all links have the same value for every micro-car rate assumption. This network and assumption are used because it will cost much time if use VISSIM to simulate large network and TCA model can simulate very fast.

In the congestion perspective analysis, micro-cars will relieve traffic congestion to some extent, and their introduction will bring about higher traffic volume in higher density traffic. It is confirmed that introduction of micro-car will relieve traffic congestion to some extent by the results from both TCA and VISSIM in segment level. The results also suggest that VISSIM provides more accurate results for expressway in some density region, while TCA seems more reasonable for arterial road with traffic signal. Many parameters for network performance evaluation are figured out during the network level simulations. The average speed, total travel time and total delay time are mainly used for the traffic point of view. The results suggest that more micro-cars gives positive effect on travel network when desired speed of micro-cars being the same with or a little lower than that of conventional cars, and more micro-cars cause negative effect when desired speed of micro-cars being close to the average speed of base model, even it is a little higher than the latter one. To balance between the effect from environmental analysis and effect from network performance analysis, micro-cars' desired speed being 40-45km/h is recommended to be more applicable in downtown small network traffic. The results calculated on Nagoya metropolitan network suggest that travel speed in network have tiny change after micro-cars' introduction, i.e. micro-cars' effect on traffic flow is negligible.

For the safety influence analysis, mixed flows of conventional cars and micro-cars result in a negative effect on safety as measured by all the three assess indicators, number of lane changes, number of deceleration and coefficient of variation of speed on expressway in free flow, while in very congested flow, it will be safer after micro-cars' introduction both on expressways and arterial roads. However, micro-cars have a positive effect or no negative one on safety on arterial road for all the assess indicator except in free flow and very congested flow considering number of lane changing. Those are the results of road segment level. For network level, the results suggest that micro-cars will not produce negative effect for safety for number of lane changing point of view, and the same effect for number of deceleration point of view except they have much lower desired speed than conventional vehicles, and have positive effect for coefficient of speed variation consideration.

In the environmental effect analysis, introduction of micro-cars on road segment have evident positive influence on environment when consider HC, CO, NO_x emissions as a measurement, on arterial roads, but have negative effect on expressway in free flow. So driving micro-cars on expressway is not recommended, while on arterial road is recommended. The needed power for the total travel demand is computed for the emission prediction in the VISSIM small network simulation. More micro-cars in traffic will reduce the emission, and so does the lower micro-cars' desired speed. More micro-cars driven on road give a positive influence to the atmosphere as they give less emission when driving in the 2020 Nagoya metropolitan network.

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CHAPTER 1

INTRODUCTION

1.1 Background

Achieving efficient, safe, and convenient urban automotive transportation has been the primary concern of transportation planners, traffic engineers, and operators of road networks. (Kitamura and Kuwahara, 2005)

As transportation and traffic is inevitable for human's daily life in our era. Many problems emerge following individuals' requirements for move to commute, to receive education, to participate entertainment activities, and so on. Traffic congestion, traffic safety problem, emission from transportation and traffic equipment, as well as the increasing parking demand recent years is the main issues generated from transportation and traffic, especially from the increasing automobile.

Since automobile's generation, human relies heavily on it for social as well as economic functionality. It encourages labor force mobilization, accessibility to essential goods as well as services and the urban development and lifestyle choices we have grown accustomed to, and it is regarded by many individuals as a means of creating personal space, maintaining autonomy and serving quality capabilities. It is well publicized, however, that we are reaching a tipping point for sustainable automobile use, with many issues mentioned above threatening the cars' autonomy. Congestion problem is the main one, and may cause the other issues.

During the early period of traffic congestion, the main solution is to construct more roads to cater to the increasing automobile. Nevertheless, the construction cannot always satisfy the demand from continuous grown of automobile for space shortage and finiteness. After that, traffic control strategies, demand management schemes are generated to solve the problems so far. Lighter and green concept for personal automobile is welcomed recent years, and it may become on solution when facing all these congestion, parking problem, etc. Some Original Equipment Manufacturers (OEMs) have produced such vehicles, say, alternative vehicles (such as Segway produced by Segway Inc., and COMS produced by Toyota), and traffic engineers are starting to argue about it. Micro-cars, a category of alternative vehicles, are considered by some academics that they can alleviate the pressure from congestion, climate concern, parking problem, fuel price rises, vehicle storage, and household financial constraints, and will be a trend of personal mobility(Richardson and Rose, 2010)(Mitchell et al, 2010).

1.1.1 Issues caused by traditional automobile

1.1.1.1 The four factors

Nowadays, traffic congestion is a widespread problem. It is an external effect by traffic and transportation. Traffic during peak hours in major Australian cities, such as Melbourne, Sydney, Brisbane and Perth, is usually very congested and can cause considerable delay for motorists. In USA, according to the 2011 Urban Mobility Report (Schrank et al, 2011), congestion is a significant problem in the 439 urban areas. Congestion caused urban Americans to travel 4.8 billion hours more and to purchase an extra 1.9 billion gallons of fuel for a congestion cost of $101 billion compared to $21 in 1982. Traffic congestion is increasing in major cities and delays are becoming more frequent in smaller cities and rural areas.

The large number of serious injuries and fatalities resulting from traffic accidents is recognized as a major health problem around the world today. Traffic safety problem is another external effect brought by traffic and transportation. In Japan, there were 4914 fatalities from the annual 736688 accidents during 2009 (White Paper on Traffic Safety in Japan 2010). The fatality rate per 100 million vehicle miles of travel (VMT) is 0.88

(Japan Statistical Yearbook 2013). Motor vehicle travel is the primary means of transportation in the United States, providing an unprecedented degree of mobility. Yet for all its advantages, motor vehicle crashes are the leading cause of death for age 4 and every age 11 through 27 (based on 2009 data). In 2011, 32,367 people were killed in the estimated 5,338,000 police-reported motor vehicle traffic crashes. An average of 89 people died each day in motor vehicle crashes in 2011—one every 16 minutes. In 2011, the fatality rate per 100 million vehicle miles of travel (VMT) was 1.10, and it was a fallen down value, the 2002 rate was 1.51 per 100 million VMT (Traffic Safety Facts 2011 Data). Although many measures and policies has been implemented to reduce the number of deaths and injuries in many countries, and there are progresses. Governments, traffic engineers, as well as academics keep finding the solutions to avoid collisions between vehicles, including improving the road traffic environment, disseminating and reinforcing messages on traffic safety, ensuring safe driving practices, advancing vehicle safety, preserving order on roads, and enhancing rescue and emergency medical systems. The fatality and accident rate are still very high. And traffic safety issue will be a long period problem perplexing traffic engineers as well as operators of road networks.

Transportation has accounted for about 40% of the growth in carbon dioxide (CO2) emissions from all energy-using sectors since 1990 (U.S. Environmental Protection Agency, 2006). The emissions include carbon monoxide (CO), carbon dioxide (CO2), volatile organic compounds (VOCs) or hydrocarbons (HCs), nitrogen oxides (NO_x), particulate matter (PM), and other pollutants associated with vehicles. Impacts due to vehicle emissions have been receiving increasing attention, and recent epidemiological studies show elevated risks of non-allergic respiratory morbidity, cardiovascular morbidity, cancer, allergic illnesses, adverse pregnancy and birth outcomes, and diminished male fertility for drivers, commuters and individuals living near roadways (WHO, 2005).

A remarkable problem in all major cities is downtown parking. The increasing total automobile amount produce more demand for parking, then result in deficiency for parking space.

1.1.1.2 Relationships of the four

The four transportation and traffic issues mentioned above have some causal relationships. See Figure 1-1, the increasing automobile bring about congestion, at the same time, it cause parking problem and more emission. The parking problem will also result in congestion in the marginal effect way. Many vehicles have to search for parking space around the destinations in our motorized era. And the behavior represents a major source of congestion in urban areas. A significant fraction of the trip time in a congested urban area may be spent searching for a parking space (Anderson and Palma, 2004). Arnott and Rowse (1999) report the claim that for cities like Boston and major European cities with serious parking problems, over one-half the cars driving downtown during rush hour are cruising to find a parking space. Cruising for parking is both time-consuming and frustrating, and the behavior causes traffic congestion significantly by increasing traffic volume and slowing traffic down. A smaller number is cited by Allen (1993), who reports an estimate that inefficient parking traffic accounts for up to 30% of total traffic in city centers.

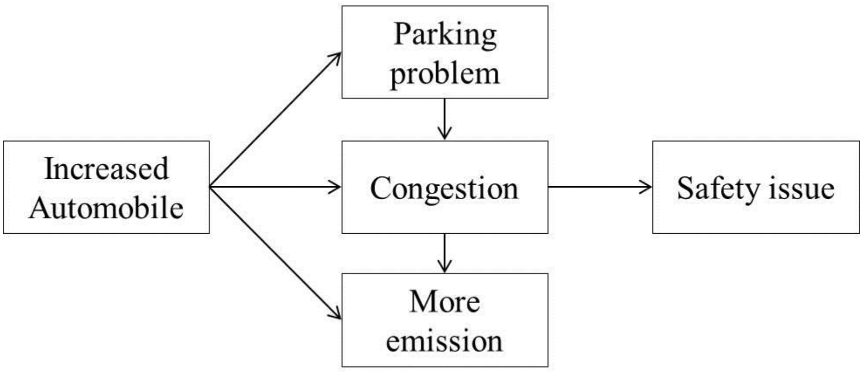

Figure 1-1 Relationship between the four transportation and traffic issues

The congestion will cause more emission and safety issue. As the increased traffic in transportation networks in recent years has led to widespread traffic congestion, which is now nearly ubiquitous in many areas (Schrank and Lomax, 2007). Since 1980, for example, urban vehicle miles traveled (VMT) in the U.S. grew 40% faster than urban capacity (BTS, 2006). Such growth in traffic, and the congestion that it causes, not only affects the mobility of travelers, but also may increase vehicle emissions. Emissions may increase as vehicles spend more time in congestion, idling or crawling, and undergoing numerous acceleration and deceleration events. And congestion has the potential to significantly worsen ambient air quality, particularly near major roadways, attributed to emissions under congested Vehicles being the dominant source of many air pollutant emissions in urban areas (TRB, 2002).

The past investigations have provided evidence that congestion will cause more safety issue. McCartt et al, (2004) found that traffic congestion was noted in 90% of police reports for rear-end crashes on ramps after examined a sample of 1,150 crashes that occurred on heavily traveled urban interstate ramps in Northern Virginia. The predominant crash type on access roads was rear-end (about 72%), and congestion was a factor in all these crashes, based on the narrative portion of these crash reports. The primary factor in rear-end crashes was traffic congestion. Kim et al, (2007) claimed that chain-reaction accidents are more likely to occur during congestions.

After analysis on the relationships of the four issues, the point is to relieve congestion and solve parking problem. Micro-cars provide a small spatial footprint which ease congestion possibly and relaxes parking concerns. And they also have greater fuel efficiency, weather protection and some luggage capacity. So micro-cars are the most likely alternative vehicle of conventional cars (Rose and Richardson, 2010).

1.1.2 Development of micro-car

Micro-cars were generated in Europe immediately after World War I, which were often motorcycle-based and were called cycle-cars, and usually three-wheeled. Many micro-car designs flourished in post-World War II Europe, evolved out of demand for cheap personal motorized transport emerged and fuel prices being high, particularly in Germany, where prominent micro-car makers were former military aircraft manufacturers. So some micro-cars even had aircraft-style bubble canopies, giving rise to the term bubble car to refer to all these post-war micro-cars, and the main stream were still three-wheeled. In 1959, Automobile and motorcycle manufacturer BMW introduced Austin Mini, and the Mini provided four adult seats and more practical long distance transport often at a lower cost, which often credited with bringing about the demise of the bubble car. After that, four-wheeled micro-cars dominated the consumer market gradually. There was another tide of micro-car in 1980s, because of its advantages in fuel saving, maneuverability, and local trip-making primarily, and consequently there came a series of discussion about micro-cars' safety issue in the following several years. After that, micro-cars exist as a portion of personal automobile consumption market for twenty to thirty years, but not so popular. Then there comes transformational change to the automobile recent years (Mitchell et al., 2010). Micro-car concept is put forward again to cater to the new challenge from private automobile.

Global mainstream Original Equipment Manufacturers (OEMs) have provided market momentum – over 30 micro-car models were introduced in the recently concluded 2010 Paris Motor Show and the 2011 Geneva Motor Show. All the European OEMs or 7 out of the top 10 global OEMs will launch micro-cars models in Europe by 2013. According to Frost & Sullivan research (2011), micro-cars are expected to grow to nearly 280,000 units in Europe alone by 2017, with a Compound Average Growth Rate (CAGR) 41% from 2010 to 2017.

1.2 Definition of micro-cars

Micro-car is the smallest automobile classification, usually applied to very small cars (smaller than city cars). Such small cars were generally referred to as cycle-cars until the 1940s. The definition of a micro-car has varied considerably in different countries. Since there are usually tax and licensing advantages to the classification, multiple restrictions are often imposed, starting with engine size. The Register of Unusual Micro-cars in the UK says: "economy vehicles with either three or four wheels, powered by petrol engines of no more than 700cc or battery electric propulsion, and manufactured since 1945". The Bruce Weiner Micro-car Museum (the world's largest collection of Micro-cars) says "Engine sizes of 700cc and less and 2 doors or less" and the US-based Vintage Micro-car Club simply defines it as 1000cc or less. In Japan, there are K cars, which have a definition of have a length less than 3.4 m, a width less than 1.48 m, and have a displacement less than 660 cc. In short, definition of micro-car is not an exact science.

The micro-car defined in this research is less than three meters in length, low weight, usually two-seats, and two-doors. Smaller than K car in Japan now, and have much smaller size than the small cars defined in USA.

1.3 Motivation and objective

It is clear that we are entering into a new era when the ability of the automobile cannot sustainably fulfill its function as a primary provider of personal powered mobility, given that many issues threatening the car’s autonomy, such as peak oil concerns and rising fuel prices, legislation to reduce carbon emissions and other factors concerning climate change, increasing congestion and parking limitations. Alternative vehicles have been developed and produced by niche manufacturers for decades. For a culture accustomed to the conveniences of mobility, it will be difficult to find a direct replacement that possesses the functions traditional automobile have, such as speed, carrying capacity, comfort, weather protection and personal safety, etc.(Richardson and Rose 2010). Micro-car is the only one of them that can provide all those performance in a relative comprehensive way.

As micro-car has some similar characteristics with conventional car, and also has some with motorcycle, we can say it is a kind of vehicle between the compared two, where the compared aspects are size, speed, and some other characteristics. As micro-car has lower maximum speed and smaller size than conventional car, it will be more convenient to use micro-car for daily short to medium distance trip. For these trips, individuals do not need high speed. If there is not micro-car, they mostly choose motorcycle, which have lower speed but more mobility, but the latter one cannot protect people from bad weather, as the micro-car can meet all three requirements mentioned before for short to medium distance trip, it is the most appropriate vehicle for such kind of trip.

Although one conventional car can carry at most 5 people while one micro-car carrying 2, however, the average occupancy is usually less than 2. In the US, car occupancy has fallen from 1.95 in 1960 to 1.38 p-km/v-km in 2009. In Japan, it is even lower than in the US, having fallen from 1.45 in 1990 to 1.39 p-km/v-km in 2009. Thus the carrying capacity of micro-cars is enough for single or couple personal trips, and it can satisfy most travel requirement, especially in high motorized countries. For instance, in a family have two automobile, one can be conventional vehicle to cater to the demand for whole family trips, and another can be micro-car for normal commute or education et al purposes. And one micro-car can fulfill all travel requirements in a less than two member family.

Micro-car may be one way to remit the congestion because of their smaller size and flexibility, although they were originally produced for personal financial consideration after World War I. They seem to be convenience to individuals' daily travel, and may alleviate congestion, but evidences are needed to certify it before micro-cars flush in automobile market. And they surely have less emission due to lower weight, traffic speed and acceleration if just investigate the micro-cars, there is misgiving that whether emissions of the whole traffic will be reduced, however: introduction of micro-cars may cause more emissions discharged by the other conventional vehicles, attributed to driving behavior alteration of them caused by micro-cars. And their effects on traffic safety are also significantly needed to be investigated to provide the testimony whether micro-cars can be driven on expressway or urban street if micro-cars will occupy certain percentage of the automobile market.

So this research aims to analyze impact of micro-cars' presence in congestion, traffic safety, as well as environmental points of view in road segment, downtown small network, and metropolitan network level respectively using proper simulators, TCA (traffic cellular automata) or VISSIM. For road segment level, propose a two-lane TCA model considering the characteristics of micro-cars for road segment simulation. And develop a car-following model in VISSIM as similar as possible to the proposed TCA model, to compare and validate each other. For downtown small network level, propose a multi-class traffic assignment model considering micro-car as a travel mode, develop a dynamic traffic assignment model in a small network using VISSIM. Then accomplish the traffic flow, safety, and environmental effect analysis of micro-cars in downtown small network dimension. Use the predicted traffic demand of 2020 Nagoya metropolitan traffic network, and analyze the traffic flow and environmental influence of micro-cars by applying the previous developed TCA model for calculation in metropolitan traffic network dimension.

1.4 Outline of this thesis

The analysis for effects of micro-car is divided into three main step, the road segment level, downtown small network level, and metropolitan network level, see Figure 1-2. As to do realistic experiments is unavailable for many uncontrolled factors, TCA and VISSIM are chosen to complete simulations. TCA was used to complete the segment level simulations due to its excellent ability in simulating realistic traffic in condition of the precise detailed driving behaviors are not necessary to catch, and it also has efficient and fast performance when used in computer simulations. VISSIM is also applied for simulations on road segment to complete the comparison and validation with TCA, attributed to TCA's comparative rough rules to describe drivers' behavior. VISSIM is used to do the simulations in downtown small network level, as it is difficult to accomplish the task that apply TCA model to simulate dynamic traffic assignment and driver behavior in network. And amount of required simulation results for aimed analysis are computed. In metropolitan network level, TCA results are used to calculate the traffic flow and environmental effects on Nagoya metropolitan network in 2020, with the predicted traffic demand with only conventional car in a previous another research, in which effects of EV were investigated. Table 1-1 shows reasons of using a certain simulator for each level.

The thesis is organized as follows. Chapter 1 introduces the background, the objectives and the scope of this research. As micro-cars can save space both for traffic and parking ascribed to their smaller size, and can save energy and decrease emission if just consider their lighter weight. At the same time they may cause safety problem, also due to their smaller size and lighter weight: passengers in them may get more grevious injury than those in conventional vehicles if these two type run into each other. Micro-cars have different driver behaviors, and the difference also affect other vehicles' behavior, which will query micro-cars' ability to reduce the total emission of the traffic network as well as their possibility to cause safety hazard. All these hypotheses are necessary to get evidence as reference for related policy formulation, because micro-cars are more and more welcome recent years for their convenience emerging into people's mind.

Chapter 2 presents a comprehensive review on discussions on micro-cars, smaller vehicles' safety issues, emission calculation models, the past developed TCA models, researches about VISSIM, as well as multi-class simulation.

The following Chapter 3 demonstrates the developed simulation models, proposes a two-lane Cellular Automata model, also a two-lane car following model in VISSIM, as well as a dynamic traffic assignment simulation model for downtown small network in VISSIM.

Chapter 4 shows the results of traffic flow influence analysis, and analysis the traffic flow mixed with micro-cars on road segment, then compares the results from TCA and VISSIM. In downtown small network and metropolitan network level, results calculated on 2020 Nagoya metropolitan network and Kichijoji area are described.

Chapter 5 analyzes the safety influence of micro-cars, based on the calculated number of lane changing, number of deceleration, and coefficient of speed variation, both in road segment and downtown small network level.

In Chapter 6, environmental effect of conventional car and micro-car traffic flow in road segment level, downtown small network level, as well as metropolitan network level is analyzed. The needed power or the predicted emissions are computed using different models.

The thesis ends with conclusions and perspectives in Chapter 7.

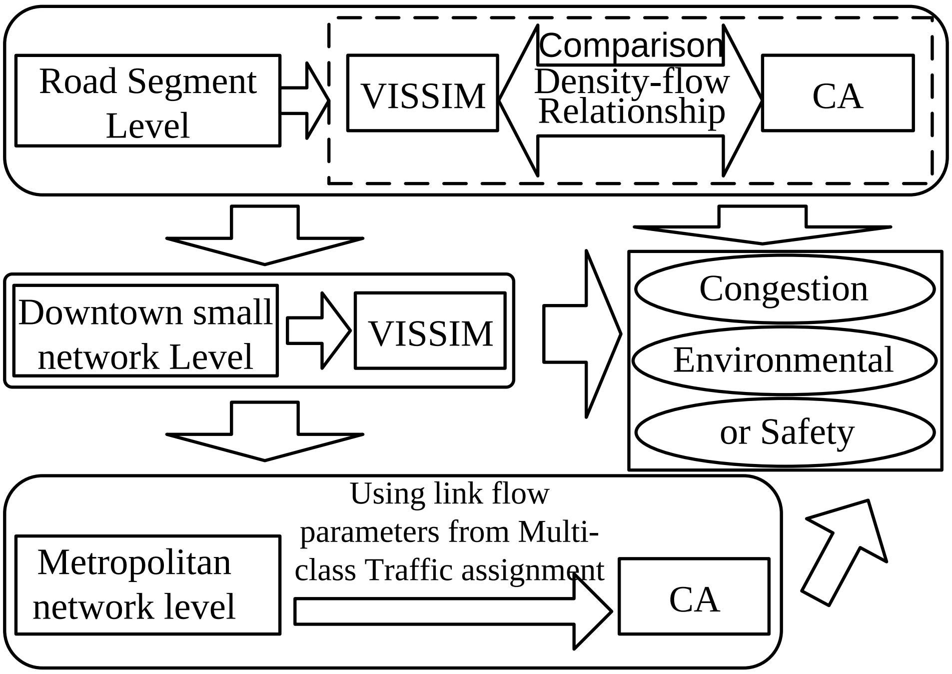

Figure 1-2 Work flowchart of this thesis

Table 1-1 Selection of simulators for each level

Network level	Applied simulator	Advantage
Road segment	TCA	Fast and simple, can handle many cases in short time and reproduce many traffic phenomena. But doubted for simplified driver behavior. Still win after comparison with VISSIM, because plots get from VISSIM is too unstable.
Downtown Small network	VISSIM	VISSIM can handle it easier, and more realistic. Difficult to simulate with TCA, traffic assignment and more complicated driver behavior than road segment. Parameters for whole network performance are used as indicators, so unstable plots mentioned above from VISSIM for road segment can be ignored.
Metropolitan network	User equilibrium assignment and TCA	Predicted traffic demand already know, use TCA developed for road segment level can have more deterministic results, and calculate faster.

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CHAPTER 2

LITERATURE REVIEW

This chapter reviews related and useful literatures for the simulation, calculation, or analysis of the thesis. First, discussions on micro-cars are demonstrated, many academics have paid attention on this kind of small vehicle after some automobile manufacturers produced them. Second, smaller cars such as mini-compact car in USA and K-car in Japan have been famous and have clear definition, the safety related research on these kind of vehicles are reviewed, and it is useful for analysis on micro-cars as they have the many similar characteristics. Third, the calculation models for vehicle emissions are reviewed. Fourth and fifth, researches on TCA and VISSIM are briefly reviewed for the later development of simulation models. Sixth, researches on multi-class traffic simulations are reviewed for the simulations in this study are also multi-class ones.

2.1 Micro-car's prospect

Richardson and Rose (2010) gathered the information of alternative personal mobility, concluded that an increasingly diverse range of alternatives are becoming available. They proposed that we are entering a new era when the automobile is unable to fulfill, in a sustainable manner, its function as the primary provider of personal powered mobility. There are many issues threatening the car's autonomy, such as peak oil concerns and rising fuel prices, legislation to reduce carbon emissions and other factors concerning climate change, congestion and parking limitations. They predicted that Micro-cars perhaps the most likely type of alternative vehicle to be seriously produced by the major Original Equipment Manufacturers (OEMs), given they are closest to the traditional car package.

Mitchell et al. (2010) indicated that conventional cars are well suited to conveying multiple passengers over long distances at high speeds, but inefficient as providers of personal mobility within cities —where most of the world's people now live. They re-imagined the automobile, describing vehicles of the near future that are green, smart, connected and fun to drive.

In Japan, the Ministry of Land, Infrastructure, Transport and Tourism reported a guideline under the condition of introducing micro-car to daily life traffic in June, 2012, which analyzed the merits according to Japan’s own situation, and concluded the experiments of using micro-cars in planned several circumstances. As micro-cars have smaller foot print, and are more flexible for daily trips of urban residents because of their short distance and lower required speed. On the other hand, many micro-cars are designed easier to be manipulated, so they provide more chance for the aged inhabitants to have trips outside. A conventional car parking space can accommodate two micro-cars, as those small vehicles usually have a length around 2.5 m, almost half of the conventional ones.

2.2 Relationship between car size and accidents

2.2.1 Physical difference and crash experiments between two

As micro-cars are smaller and lighter than conventional cars in physical characteristics, it is anticipated whether the smaller size and lighter mass cause severer injuries or even fatality if accidents occur. And then there were series of discussion about relationship between car size and traffic safety. The relationship between car size and accidents was discussed in the literatures by building equations or experimenting actual collisions between two vehicles, both based on mechanics and physical theory. Wood (Wood, 1997) examined the influence of car size and mass on the relative safety of cars using Newtonian mechanics to derive a generalized equation for the relative safety of cars of different sizes when involved in frontal collisions. The theory showed that the size (length of the car) determined Relative Injury Risk in collisions between cars of similar size and in single vehicle accidents, whereas mass and the structural energy absorption properties of the cars is the determinant for risk in collisions between dissimilar sized cars. Occupants of small cars have a greater risk of injury than those in larger cars. The safety disadvantage of small cars relative to large cars can be reduced by changing the design of the front structures of small cars in a number of ways. Niederer et al, (Niederer et al., 1995) investigated the low mass vehicles' safety characteristics in terms of structural compatibility. They performed two crash experiments along with a theoretical model analysis to evaluate the compatibility properties of low mass rigid-belt vehicles. The results indicated that due to its low mass a low mass vehicle (LMV) did not represent an excessive compatibility problem for other car occupants in spite of the stiff rigid-belt body (RBB) characteristics. So the possible changes in driver protection with car mass may generate decreases in driver risk, and partially offset the expected increase in fatalities. These studies suggest that small cars will suffer more safety issue. However, these studies just experimented on the collisions between two vehicles which were regarded as physical substance. They ignored the driver behaviors, which is an important factor affecting traffic safety.

2.2.2 Statistical analysis

On the other hand, different conclusions were found in statistical analyses of actual accident data, though micro-cars are not explicitly considered but small cars in general. Evans (1984) examined a function between accidents per unit distance of travel and car mass using police reported crashes for North Carolina, New York, and Michigan. Accident involvement rate was found to increase with car mass when cars were driven by drivers of similar age, due to driver behavior changes related to how drivers perceive protection to vary with car size. The trend is in the opposite direction if without the disaggregation by driver age, which support the headline "Large Cars Have Lower Crash

Rates" (Expressway Safety Research Center, 1981), based on similar north Carolina data (Stewart and Carroll, 1980) for all ages. And the national traffic fatalities increase radically as car mass decrease. Evans (1984) also presented a new approach yields relationships between driver fatality likelihood and car mass, essentially independent of driver behavior. And illustrated that a driver of a 900 kg car is 2.6 times as likely to be killed as is a driver from a 1800 kg car. However, the multiple would decrease to 1.68 if the driver behavior were considered to be associated with driver fatality. There is evidence in the literature suggesting that drivers of small cars exhibit greater caution, possibly in response to a perception of greater danger. Further driver behavior changes might results which could negate, or even reverse, any safety disadvantage of the small car. Sparrow (Sparrow, 1985) found that while small cars (called "kei" or "K" cars, defined be cylinder displacement-550 cc or less at that time) are involved in more accidents per vehicle or per vehicle kilometer traveled than larger cars, there was a lower likelihood of a fatality if an accident occurred after an investigation on the related 1980, 1981, and 1982 data. It was totally different from the similar statistics of U.S., and it was tentatively attributed to the direct and indirect impact of the lower speed limits (80 versus 100 km/h) for small cars in Japan, as well as the greater caution drivers of such vehicles exhibit. The United States General Accounting Office (1991) concluded that heavier cars are not invariably safer than lighter ones in its testimony "Automobile Weight and Safety". The highest fatality rates are from cars in the middle of the weight distribution. They also estimated that if the proportion of small cars on the road were to grow substantially, the total fatality rate in two-car accidents would decline slightly due to the decreased likelihood of comparatively deadly collisions between large and small cars. In brief, for statistic and mechanics analysis, small cars will suffer more safety issue if only consider their weight or size. However, precisely because of this, the drivers in such vehicles will try to reduce the risk by increasing their perception of danger, and will be more cautious.

2.2.3 Policy analysis

Sparrow and Whitford (Sparrow and Whitford, 1984) gave a short history of small vehicles regulations in the U.S., the worldwide markets for such vehicles, and closed with a discussion of mini/micro-cars' safety issues in urban traffic and on expressway. It was summarized that mini/micros should not be dismissed as posing too great a safety risk just because of size. The effects of introducing micro-cars into traffic flow for congestion perspective have been studied in previous research (Mu and Yamamoto, 2012), it was proved that micro-cars will relieve traffic congestion to some extent, and that the volume will be greater in higher density traffic due to the smaller size of micro-car. Mu and Yamamoto (2012) also calculated the lane changing number, deceleration number as well as coefficient of speed variation (C_v) of traffic with different rate of micro-cars driven on a hypothesized expressway segment and an arterial road segment with traffic signal by a cellular automata model, and made an analysis on safety effects of micro-cars with the results. The results suggested that micro-cars have a positive effect on safety when the number of decelerations and speed variations are considered for both kinds of road when traffic density is over 75 veh/km/two lane, in other words, micro-cars bring affirmative effect on safety in high density traffic.

2.3 Emission calculation models

There existing three broad categories for approaches to modeling air pollution from road traffic, macroscopic, mesoscopic, and microscopic.

Numerous variables influence vehicle energy and emission rates. These variables can be classified into six broad categories, as follows: travel-related, weather-related, vehicle-related, roadway-related, traffic-related, and driver-related factors. The travel-related factors account for the distance and number of trips traveled within an analysis period, while the weather-related factors account for temperature, humidity, and wind effects. Vehicle-related factors account for numerous variables including the engine size, the condition of the engine, whether the vehicle is equipped with a catalytic converter, whether the vehicle's air conditioning is functioning, and the soak time of the engine. The roadway-related factors account for the roadway grade and surface roughness, while the traffic-related factors account for vehicle-to-vehicle and vehicle-to-control interaction. Finally, the driver-related factors account for differences in driver behavior and aggressiveness.

The state-of-the-art emission models such as MOBILE6 developed by the US Environmental Protection Agency (EPA) and EMFAC7F developed by the California Air Resources Board (CARB) attempt to account for travel-related, weather-related, and vehicle-related factors on vehicle emissions. These models use average speed and vehicle miles traveled to estimate vehicle emissions. And generally fail to capture roadway, traffic, and driver related factors on vehicle emissions. While state-of-the-art emission models in microscopic level focus the critical changes in traffic behavior between a before and after scenario.

2.3.1 Macroscopic models of air pollution from road traffic

In a macroscopic model, traffic is regarded as a compressible fluid, and movement of a single vehicle is ignored. Emissions are usually demonstrated as functions of total traffic volumes and average speed of traffic flow. Thus, macroscopic models cannot represent the influence of speed fluctuations in general.

The UK TRRL model developed by Hickman and Colwill (1982) is amongst the most straightforward of the macroscopic models and forms the basis for UK guidelines on air pollution modeling in Design Manual for Roads and Bridges. The model defines

CO emission as a direct function of average traffic speed and flow and then calculates the emissions of other pollutants (i.e., HC, NO_x) as a function of CO emission. The empirical relationship between speed, flow and CO emissions is given by

$$E(CO) = 1.031 \cdot q \cdot v^{-0.175} \cdot 10^{-4} \tag{2-1}$$

Where, E(CO) is the emission of CO in g/m, q is traffic flow (veh/h), v is average traffic speed (km/h).

The US Environmental Protection Agency's (EPA) expressway vehicle emission factor model, MOBILE, is a model that provides average in-use fleet emission factors for each of eight predefined categories of vehicles, for any calendar year between 1970 and 2020, and under various conditions affecting in-use emission levels (e.g. ambient temperatures, average traffic speeds, petrol volatility) as specified by the model user (EPA 1997). Three criteria pollutants (volatile organic compounds (VOC), a precursor of ground level ozone; carbon monoxide (CO); and nitrogen oxides (NOx)) can be calculated. The output from the model is in the form of emission factors expressed as grams of pollutant per vehicle mile travelled (g/mile). The value input for speed (which refers to the average speed of vehicles during trips calculated thorough dividing the total trip time and trip distance) has a significant impact on the resulting emission factors for exhausts. All trips in the MOBILE model assume a fixed and predetermined mix of idle, accelerations, decelerations and cruises. The average speed of the FTP drive cycle (19.6 mph) provides the basic MOBILE emissions factors.

Both the UK TRRL/DRMB and US MOBILE provide quick and relatively straightforward means of assessing the air pollution impacts of transport policy measures, However they both lack the ability to represent the impacts of these measures on the fluctuation of traffic speeds as well as acceleration and deceleration, and hence are unable to properly account for the influence of speed, acceleration, and deceleration fluctuations on emissions.

2.3.2 Mesoscopic models of air pollution from road traffic

The objective of mesoscopic models is to attempt to accommodate the influence of speed fluctuations into the general macroscopic modeling approach. This is done by characterizing driving behavior in terms of a number of distinct modes such as cruising, acceleration, deceleration and idling, each of which generate different levels of emissions.

A typical example of the mesoscopic approach is the model developed by Matzoros and Van Vliet (1992), which is based on the SATURN traffic assignment model. This model can estimate emissions from four different modes: cruise, acceleration, deceleration and idling near a junction area.

$$E_o(P) = \sum_{i=1} \sum_{j=1} \Delta x_j(o) \cdot e_{ipo}(v) \tag{2-2}$$

$$E_o(P) = \sum_{i=1} \sum_{j=1} w_j \cdot e_{ip} \tag{2-3}$$

where, j is single vehicle of type i, o is cruising, acceleration, and deceleration phases, P is pollutants (CO, HC, NO_x, and Pb), $\Delta x_j(o)$ is distance travelled by vehicle j in operating mode o, $e_{ipo}(v)$ is specific emission of pollutant P (g/m) by vehicle type I in operating mode o at speed v (km/h), w_j is idling time (s) of vehicle j, e_{ip} is specific emission of pollutant P (g/s) by vehicle type I in idling phase.

The advantage of the mesoscopic model is that it can represent different traffic flow conditions along a section of road, particularly changes in flow conditions in the proximity of junctions with a simple macroscopic representation of traffic flow. Moreover, mesoscopic models use the same input data of macroscopic models, and only need the specific emission rates for each driving mode.

However, traffic is still represented as moving at a single constant average speed in cruise mode over the entire network. In addition, a single acceleration rate and deceleration rate are applied to acceleration and deceleration modes for all traffic flows in the network. Thus, the effects of the two most important factors influencing emission, speed and speed variation, are not properly described. One consequence of this is that in applying the mesoscopic approach, researchers must make somewhat arbitrary assumptions regarding these common acceleration and deceleration rates.

A mesoscopic model uses a simple representation of traffic flow requiring low computing times and input data, and therefore it can be applied to a large network. However, it lacks the ability to describe detail variation of speeds. Thus, it is not frequently used in the transport area now.

2.3.3 Microscopic models of air pollution from road traffic

In microscopic models, emissions are described at the level of single vehicle movement and are therefore related to parameters of vehicle movement such as instantaneous speed, acceleration rate and vehicle types. Emissions are expressed as a function of instantaneous speed and acceleration of each vehicle second by second, and then aggregated to calculate total emissions from traffic flow.

An early example of a microscopic emission model was the Automobile Exhaust Emission Modal Analysis Model developed for the US Environmental Protection Agency (Kunselman 1974). Emission rates of carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx) were deduced from surveillance tests performed on a test fleet of 170 automobiles in six US cities. Emissions were calculated for any given second in a driving sequence within a speed range of 0 and 60 mph. The input information for the model included both traffic conditions and emissions data. The traffic information was represented by second speed profiles of the vehicles, the number of vehicles, their age distribution by model year, and the relative altitude at which they were operated. The emission parameters included emission-rate coefficients that were specific to speed profiles.

Taylor and Young (1996) developed a more vehicle specific microscopic model called an instantaneous model. The variables in the model are instantaneous speed v(t) and acceleration a(t) at time t. The instantaneous model gives the rate of emission/consumption (E/C) of vehicle X, including components for:

1) The fuel used or emissions generated in maintaining engine operation, estimated by the idle rate (α)

2) The work done by the vehicle engine to move the vehicle

3) The product of energy and acceleration during periods of positive acceleration.

The energy consumed in moving the vehicle is further divided into drag, inertial and grade components. Part 3) allows for inefficient fuel consumption during periods of hard acceleration.

Taylor and Young (1996) also developed a more simplified model called the ‘Elemental Model’. Emissions are expressed as a function of speed at four different modes, cruising, deceleration, idling and acceleration. The speed profile is divided into small segments where each segment can be represented as one of the four different modes.

At cruise modes, carbon dioxide emissions from the model are expressed as follows:

$$E(CO_2)_c = 0.799 + 0.0625v + 0.00012v^2 \tag{2-4}$$

However, the relationship between emission rates and cruise speeds for carbon monoxide emissions is not as clear as that for carbon dioxide. Thus, the following two equations are applied to calculate carbon monoxide at different speed ranges:

$$E(CO)_c = 0.007 + 0.0007v + 0.0009v^2 - 0.00009v^3 \quad (0 \le v \le 11.2 m/s) \tag{2-5}$$

and

$$E(CO)_c = 0.0022 - 0.0002v + 0.000005v^2 \quad (v > 11.2 m/s) \tag{2-6}$$

At acceleration modes, carbon dioxide is expressed by the following equation:

$$E(CO_2)_a = Av_f + Bv_f^2 \tag{2-7}$$

where $E(CO2)_a$ is the acceleration emissions in grams, and v_f is the final speed of the acceleration phase in m/s. A and B is coefficient, different A and B are applied to various acceleration rates.

For carbon monoxide, the following exponential equation is applied for acceleration mode.

$$E(CO)_a = Ae^{Bv_f} \tag{2-8}$$

These results are based on a chassis dynamometer test of one vehicle. Thus, it is difficult to estimate emission from actual traffic flow, which has a mix of various vehicle types.

Ahn et al. (2002) developed several hybrid regression models that predict hot stabilized vehicle fuel consumption and emission rates for light-duty vehicles and light-duty trucks, which were found to be highly accurate as compared to the realistic data. Key input variables to these models are instantaneous vehicle speed and acceleration measurements. They used data collected at the Oak Ridge National Laboratory (ORNL) that included fuel consumption and emission rate measurements

(CO, HC, and NO_x) for five light-duty vehicles and three light-duty trucks to predict the parameters in the models. The emissions are calculated by the following equations:

$$MOE_e = \sum_{i=0}^{3}\sum_{j=0}^{3}(K_{i,j}^{e} \times s^i \times a^j) \tag{2-9}$$

$$\ln(MOE_e) = \sum_{i=0}^{3}\sum_{j=0}^{3}(K_{i,j}^{e} \times s^i \times a^j) \tag{2-10}$$

$$\ln(MOE_e) = \begin{cases} \sum_{i=0}^{3}\sum_{j=0}^{3}(L_{i,j}^{e} \times s^i \times a^j) & for\ a \geq 0 \\ \sum_{i=0}^{3}\sum_{j=0}^{3}(M_{i,j}^{e} \times s^i \times a^j) & for\ a < 0 \end{cases} \tag{2-11}$$

Jimenez (1999) presented a new parameter termed “vehicle specific power” (VSP). VSP is the ratio of instantaneous vehicle power to vehicle mass. He claimed that the VSP is very useful in the analysis of remote sensing data, chassis dynamometer data, and in emissions modeling for three main reasons: it can be calculated from roadside measurements, it captures most of the dependence of light-duty vehicle emissions on driving conditions, and it is directly specified in emissions certification cycles. The VSP was used as a core parameter of the Multi-scale Motor Vehicle and Equipment Emission System (MOVES) of EPA. The dependence of CO, HC, and NO_x emissions on VSP is better than on several other commonly used parameters, such as speed, acceleration, absolute power, or fuel rate. And using VSP as the basic metric allows meaningful comparisons to be made between data from different remote sensing sites, dynamometer driving cycles, and emission models.

2.4 Brief review on TCA models

In 1992, Nagel and Schreckenberg proposed the well-known Nagel-Schreckenberg (NaSch) model (Nagel and Schreckenberg, 1992). Although it is very simple, the NaSch model can reproduce some real-traffic phenomena, such as the occurrence of phantom traffic jams and the realistic flow-density relation (fundamental diagram). The NaSch model is a minimal model in sense that any further simplification of the model leads to unrealistic behaviour. Following NaSch, several extensions of the model are put forward, such as Fukui-Ishibashi (FI) model (Fukui and Ishibashi, 1996), TT model (Schadschneider and Schreckenberg, 1997), VDR model (Barlovic et al, 1998), VE model (Li et al, 2001), etc.

Those are single-lane models. They are not able to simulate realistic traffic, because the road is always multilane in real traffic, and there are different types of vehicles with different desired velocity. When a vehicle could not reach its desired velocity, it will change lane for better driving condition. Lane-changing behavior really affects traffic flow, but single-lane model cannot reproduce this phenomena. In order to simulate real-traffic, two-lane models have been proposed. Rickert et al. (1996) examined a simple two-lane cellular automata model based on the single-lane TCA proposed by Nagel and Schreckenberg. Wagner et al. (1997) proposed a set of lane changing rules for cellular automata simulating multi-lane traffic, and asymmetric lane changing rules were introduced. It was reproduced qualitatively that the passing lane becomes more crowded than the one for slower cars if the flux is high enough, which is true for motorways in countries like Germany where passing should be done on a specified lane as a rule. Chowdhury et al. (1997) developed particle-hopping of two-lane traffic models with two different types of vehicles (characterized by two different values of the maximum allowed speed Vmax), proposed a symmetric and an asymmetric two-lane model, and investigate effects of lane changing rules. Nagel et al. (1998) summarized different approaches to lane changing and their results and proposed a general scheme, according to which realistic lane changing rules can be developed, and they also reported density inversion. Knospe et al. (1999) discussed the effect of slow cars in two-lane systems, and it is shown that anticipation of drivers reduces the influence of slow cars drastically. After that, Knospe et al. (2000) proposed an inproved discrete model incorporating anticipation effects, reduced acceleration capabilities and an enhanced interaction horizon for braking. Knospe et al. (2002) analysed the reproduction of the lane usage inversion and the density dependence of the number of lane changes. It was proved that the single-lane dynamics can be extended to the two-lane case without changing the basic properties of the model. Jia et al. (2005) considered the velocity effect of the preceding car, the traffic behaviours in both homogeneous system and inhomogeneous system where honk effect exists is investigated. In the following year, Jia et al. (2005) investigate honk effect in two-lane traffic, and argued that the honk behaviour is not encouraged in the asymmetric two-lane traffic. Li et al. (2006) proposed a realistic two-lane TCA model condidering aggressive lane changing behaviour of fast vehicles. Gao et al. (2007) proposed a TCA model for traffic flow in the framework of Kerner's three-phase traffic theory, where the velocity-difference effect on the randomization of vehicles were mainly considered. Chen et al. (2008) presented a new cellular automata model, in which randomization effect is enhanced with the decrease of time headway. Tonguz et al. (2009) introduced a new automata cellular approach to construct an urban traffic mobility model. Das (2011) proposed a TCA based traffic model that allows the cars to move with a small velocity during congestion. Rosenblueth and Gershenson (2011) studied the model properties by simulating a single intersection using rules 184, 252, and 136.

2.5 Brief review on VISSIM and its application

VISSIM has been used for many traffic and transportation related researches. Fellendorf and Vortisch (2001) presented the possibilities of validating the microscopic traffic flow simulation model in VISSIM, both on a microscopic and macroscopic level in homogeneous flows. Matsuhashi et al. (2005) assessed the traffic situation in Hochiminh city in Vietnam, using image processing technique and VISSIM. It was found that the high number of motorcycles in the network interfere with other vehicles which reduces average speed of traffic stream drastically. Further, VISSIM was applied for deriving the benefits of increasing the share of public transport. Zhang et al. (2008) conducted a study using VISSIM to evaluate a proposed feedback-based tolling algorithm to dynamically optimize High Occupancy Toll (HOT) lane operations and performance. Velmurgan et al. (2010) studied free speed profiles and plotted speed-flow equations for different vehicle types for varying types of multi-lane expressways using VISSIM and subsequently estimated roadway capacity for four-lane, six-lane and eight-lane roads under heterogeneous traffic conditions with reasonable degree of authenticity. Bains et al. (2012) used VISSIM to model traffic flow on Indian Expressways by evaluating Passenger Car Equivalents (PCE) of different vehicle categories at different volume levels in a level terrain.

2.6 Multi-class simulation

There has been no research about multi-class traffic including micro-cars, but in many ways the micro-car and conventional car pairing is parallel to the conventional car and truck pairing, with two very different sizes of vehicle, etc. Hence, studies of mixed traffic with conventional cars and trucks are reviewed here as a reference for this study.

In the area of microscopic multi-class simulation, Mason and Woods (1997) proposed a multispecies car-following model for traffic flow analysis and gave a first understanding of multispecies traffic in a car-following model. A following study by Treiber et al. (2000) simulated congested truck-and-car traffic states with a continuous microscopic single-lane model using realistic data, which formulated the theoretical phase diagram for bottlenecks in a more general way. Kesting et al. (2007) proposed a general lane-changing model and applied it to traffic simulations of cars and trucks with the Intelligent Driver Model (IDM) as the underlying car-following model, by which it was verified.

In the TCA model field, Moussa and Daoudia (2003) presented computer simulations of traffic flow utilizing the TCA model on a two-lane roadway with two different types of vehicles, cars and trucks. The importance of braking noise and the proportion of trucks to the flow of traffic on a two-lane roadway was investigated. Chen et al. (2004) placed different kinds of vehicles (cars and trucks) with different driving behavior on a expressway to investigate traffic flow on a three-lane expressway using the TCA method.

The multi-class concept was first employed in macroscopic traffic flow simulations by Hoogendoorn and Bovy (2000). This was followed by a number of reformulations and extensions of the concept (Wong and Wong 2002, Zhang et al. 2006, Zhang et al. 2008). Wong and Wong (2002) developed a multi-class traffic flow model as an extension of the Lighthill, Whitham and Richards (LWR) model with heterogeneous drivers. Zhang et al. (2006), in attempting to solve hyperbolic conservation laws with spatially varying fluxes, applied the weighted essentially non-oscillatory method to solve a multi-class traffic flow model for a heterogeneous expressway. Zhang et al. (2008) extended the d-mapping algorithm to solve a multi-class traffic flow model on a heterogeneous expressway, which is characterized by spatially varying fluxes and very complex waves.

There have also been some other studies related to multi-class traffic including passenger cars and trucks. Ye and Zhang (2009) elucidated the existence of a qualitative difference in vehicle-type-specific headway and distribution in mixed truck-and-car traffic, and this knowledge can be used in improving microscopic traffic simulation models. Abdelgawad et al. (2011) simulated multi-class traffic with trucks in order to assess the impact of exclusive truck facilities, including truck-only expressway and a truck lane conversion on expressway.

The multi-class studies mentioned above mainly took a traffic operational point of view, while the safety and environmental effects of mixed flow have not yet been analyzed well.

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CHAPTER 3

SIMULATION MODELS

This chapter demonstrates the simulation models used in the research. The reasons to use simulation in the field of traffic are the same as in all simulation; the problems in analytical solving of the question at hand, the need to test, evaluate and demonstrate a proposed course of action before implementation, to make research (to learn) and to train people. The simulations are divided into road segment, downtown small and metropolitan network levels to cater requirement for this three level analysis. TCA and VISSIM are applied as simulators. Section 1 introduces the basic simulation models in traffic and transportation. Section 2 makes brief introduction of CA model and presents the TCA models developed in this research. Section 3 shows the models in VISSIM, both for road segment level and downtown small network level.

3.1 Traffic simulation models

In order to achieve the aim, there are two ways, one is to carry out the experiment, put assumed percent micro-car in real traffic, and obtain the desired data to analyze; another is to do the simulation. Simulation is an alternative tool for complex and prospect hypotheses. And it is an important pathway to solve the problems and answer the questions in traffic engineering because it can study models too complicated for analytical or numerical treatment, can be used for experimental studies, can study detailed relations that might be lost in analytical or numerical treatment and can produce attractive visual demonstrations of present and future scenarios.

For this research, it is impossible to carry out the experiment, because the percent of micro-car cannot be controlled in real world, and the desired data are not easy to obtain. The remaining way is to do simulation.

3.1.1 Classification in level of detail dimension

Traffic flow modeling is usually classified into three categories, macroscopic, microscopic, as well as mesoscopic, if considering their nature and level of detail in handling road geometry and traffic elements.

3.1.1.1 Macroscopic model

Starting from first principles and then deriving macroscopic relationships is the preferred pattern in science. And macroscopic models are generated based on this conception. They represent traffic flow at a high level of aggregation in terms of measures such as density, space-mean-speed, and flow rate. Individual vehicles' detailed behaviors, such as lane-changing, are usually not specifically expressed in the model.

One of the important milestones of macroscopic traffic flow modeling dates back to the 1950s, when Lighthill and Whitham (1955) and Richards (1956) independently proposed a simple continuum model, now known as the LWR model, which represent the evolution of traffic stream over time and space by describing the relationship between three traffic state variables (density K, flow Q, and average speed V).

Another model that simulates the propagation of traffic flows is METACOR (Papageorgiou, M. et al., 1989) (Elloumi, N. et al., 1994). It is based on a continuum model, developed by Payne (Payne, H.J., 1971). The road is divided into cells, for which at discrete time intervals the flow, speed and density are calculated evaluating macroscopic differential equations. In each time interval, also interactions of consecutive cells in terms of speed and concentration are calculated. Step by step the temporal and spatial dynamics of the traffic system are approximated by these calculations. This way the interacting cells make up a road, and roads can be connected via intersections. Because of the explicit modeling of the interactions of the entities of the system (in this case the road cells and intersections), and the relative ease of modeling the (small) entities, the modeled area can be extended to include large road networks (Burghout, 2004). Daganzo (1994, 1995) developed Cell Transmission Model which is derived from LWR, and also discretize road network into cells. The model keeps track of the number of vehicles in each cell, and computes the amount of vehicles that cross the boundaries between adjacent cells in each simulation time step.

A macroscopic model describes entities and their activities and interactions at a low level of detail. The traffic stream may be represented in some aggregate manner such as a statistical histogram or by scalar values of flow rate, density and speed. The model may assert that the traffic stream is properly allocated to lanes or employ an approximation for that lane change maneuvers would not be represented at all.

3.1.1.2 Microscopic model

Microscopic models can conquer the low-detail defect of macroscopic ones. They focus on describing the behavior of the entities making up the traffic stream (the vehicles) as well as their interactions in detail, and also the individual road elements (e.g. traffic lights, intersections) to reproduce the variable and dynamic individual drivers' behaviors. In a microscopic model the car-following law can be invoked by lane-change maneuver for the subject vehicle depending on its current leader, then relating to its putative leader and its putative follower in the target lane, which is detailed.

One of the oldest and most well-known cases of the application of simulation in theoretical research is the car-following analysis based on the General Motors (GM) models. In these models a differential equation governs the movement of each vehicle in the platoon under analysis (Gerlough and Huber 1975). Car-following, like the intersection analysis, is one of the basic questions of traffic flow theory and simulation, and still under active analysis after almost 40 years from the first trials (McDonald et al. 1998). And the gap has been bridged smaller and smaller ascribed to the advances in traffic theory, in computer hardware technology and in programming tools, as well as the development of the general information infrastructure, and the society's demand for more detailed analysis of the consequences of traffic measures and plans. (Pursula, 1999)

Another well-known microscopic model is traffic cellular automata model (TCA). The modeled flushed after they are developed for traffic simulation by Nagel and Schreckenberg (1992), based on the cellular automata programming paradigm from statistic physics. These so-called TCA models are dynamical systems that are discrete in nature, in the sense that time advances with discrete steps and space is coarse-grained (e.g., the road is discretized into cells of 7.5m wide, each cell being empty or containing a vehicle). This coarse-graininess is fundamentally different from the usual microscopic models, which adopt a semi-continuous space. They are aimed at obtaining a correct macroscopic behavior through their crude microscopic description. Such an approach would involve more human-oriented aspects such as those found in socio-economic, behavioral, and psychological sciences (Maerivoet and Moor, 2005). TCA models are very flexible and powerful, in that they are also able to capture all basic phenomena that occur in traffic flows (Barlovic et al, 1998, Chowdhury et al, 2000).

3.1.1.3 Mesoscopic model

A mesoscopic model generally represents most entities at a high level of detail but describes their activities and interactions at a much lower level of detail than a microscopic model would, and they hold an intermediate level of detail between macroscopic ones and microscopic ones. Usually they consider the individual vehicles, but not describing their interactions, and are discrete in time and space. For example, the lane-change maneuver could be represented for individual vehicles as an instantaneous event with the decision based, say, on relative lane densities, rather than detailed vehicle interactions.

One form is vehicles grouped into packets (Leonard et al., 1989). The packet of vehicles acts as one entity and its speed on each link is derived from a speed-density function, and the link density. The density on a link is defined as the number of vehicles per km per lane. A speed-density function relates the speed of vehicles on the link to the density.

Another is that of individual vehicles that are grouped into cells which control their behavior. The cells traverse the link and vehicles can enter and leave cells when needed, but not overtake. The speed of the vehicles is determined by the cell, not the individual drivers' decisions (DYNAMIT (Ben-Akiva et al., 2002)). In addition, mesoscopic model (DYNASMART) is based on the queue-server method (Jayakrishnan et al., 1994). DYNASMART is a discrete time mesoscopic simulation model for ATMIS applications. It is designed to model traffic pattern and evaluate overall network performance under real-time information systems.

The Mesoscopic models have the ability to simulate large expressway networks. However, they have the same disadvantage with that of macroscopic model: do not consider the interactions between individual vehicles. The main application of mesoscopic models is where the detail of microscopic simulation might be desirable but infeasible due to a large network, or limited resources available to be spent on the coding and debugging of the network.

3.1.2 Classification in other dimensions

Traffic simulation models can also be classified as static, where average steady-state traffic situations are assumed, or dynamic, where the traffic situations change over time.

Stochastic or Deterministic is another dimension for assortment of traffic simulation. Deterministic models used to assume a consistency of behavior, and they have no random variables; all entity interactions are defined by exact relationships (mathematical, statistical or logical). Stochastic models have processes which include probability functions. They capture variation in e.g. reaction time, arrival processes, and route choice. But every simulation run results in different outcome, so usually replicating simulation runs is necessary.

For time continuity dimension, time-stepped or event-based is defined. The former one computes the activities which change the states of selected system elements for finite steps (e.g. 1 second). It is analogous to representing an initial-value differential equation in the form of a finite difference expression with the independent variable, Δt. And the latter one calculates changes in the system when something 'happens' (events). For instance, the state of a traffic signal indication (say, green) remains constant for many seconds until its state changes instantaneously to yellow. This abrupt change in state is called an event. Since it is possible to accurately describe the operation of the signal by recording its changes in state as a succession of timed events, considerable savings in computer time can be realized by only executing these events rather than computing the state of the signal second by second. For systems of limited size or those representing entities whose states change infrequently, discrete event simulations are more appropriate than are discrete time simulation models, and are far more economical in execution time. However, for systems where most entities experience a continuous change in state (e.g., a traffic environment) and where the model objectives require very detailed descriptions, the discrete time model is likely to be the better choice.

3.1.3 Argument to use TCA and VISSIM

Microscopic models that have high fidelity, and their resulting software, are costly to develop, execute and to maintain, when compared to the lower fidelity ones. At the same time these detailed models possess the potential to be more accurate than the other less detailed models, such as the macroscopic and mesoscopic models.

Most traffic system simulation applications today are based on the simulation of vehicle-vehicle interactions and are microscopic in nature. However, involving human behavior comprehensively in sciences is not so easy to achieve: the gap between first principles and human brain activity is very huge. So microscopic models' more accurate potential may not always be realized due to the complexity of their logic and the larger number of parameters that need to be calibrated. Microscopic traffic simulation have always been regarded as some time consuming, complex process involving detailed models that describe the behavior of individual vehicles.

To search heuristically for microscopically minimal "plausible" models that generate observed behavior on the macroscopic level is an approach to evade the contradiction between the precise necessity for simulation and not so accurate model. It is another way to handle the gap. And that is the starting point of TCA.

The main advantage of TCA models is an efficient and fast performance when used in computer simulations, due to their rather low accuracy on a microscopic scale, which makes prediction feasible. If one is hardly ever interested in the way individual cars move, but rather in the macroscopic properties of the whole system, when describing traffic, which means the ones that are expressed as probability distributions or averages taken over many vehicles, TCA model is capable to obtain the required data. Therefore it is obviously inefficient to use very detailed models of individual driver behavior if only the flow-density relation or lane-changing distributions, for example, are needed. And TCA models are not so rude because they are discrete both in time and space, the unit time and unit length of a cell as well as the rules for speed updating and lane changing can be defined depending on particular requirements. Also traffic phenomena such as the transition from free to congestion flow, lane inversion, platoon formation, metastable states, and hysteresis phenomena can be accurately reproduced using the TCA models.

VISSIM is a simulation package based on microscopic level, and it implements a psycho-physical car-following model and thus provides a very realistic driving behavior. The complex model offers many model parameters that can be calibrated using measurement data from driving experiments. Although TCA is deemed to be competent to obtain results approximate to reality, however, its comparative rough settings gives rise to doubt on its accuracy, so VISSIM is applied to do simulation on road segment for validation and comparison with TCA model. As plenty of time is needed if use TCA to develop a network simulator, and much less time is required if use VISSIM to do a small network simulation, also VISSIM has more detailed settings on driver behavior and it can do dynamic traffic assignment. So VISSIM is used again to complete a simulation in a downtown small network.

3.2 Two-lane TCA model on road segment

The cellular automata approach has been proved to be quite useful, not only in the field of modeling traffic flow, but also in other fields such as pedestrian behavior, escape and panic dynamics, the spreading of forest fires, population growth and migrations, cloud formation, material properties (corrosion, cracks, creases, peeling, etc.), ant colonies and pheromone trails, etc. (Helbing and Vicsek, 1999, Karafyllidis and Thanailakis, 1997, Nagel and Raschke, 1992, Gobron and Chiba, 2001, Nishinari and Chowdhury, 2003). It is now available to simulate large systems containing many ‘intelligent particles’, such that is it possible to observe their interactions, collective behavior, self-organization, etc. (Helbing and Nagel, 2004, Nagel, 2002, Chowdhury et al, 2004).

3.2.1 Historic origins of cellular automata

The mathematical concepts of cellular automata (CA) models can be traced back as far as 1948, when Johann Louis von Neumann introduced them to do research on (living) biological systems (Neumann, 1948). The notion of self-reproduction and theoretical machines (called kinematics) that could accomplish this was the essential of von Neumann's work. As his work progressed, von Neumann started to cooperate with Stanislaw Marcin Ulam, who introduced him to the concept of cellular spaces. Then there came the description of physical structure of a cellular automaton, i.e., a grid of cells which can be either 'on' or 'off' (Wolfram, 1983, Delorme, 1998). Intriguingly, Alan Mathison Turing proposed a model that illustrated reaction–diffusion in the context of morphogenesis in 1952 (e.g., to explain the patterns of spots on giraffes, of stripes on zebras, etc.). His model can be regarded as a type of continuous CA, in which the cells have a direct similarity with a simplified biological organism (Turing, 1990).

In the 1970s, CA models found their way to one of the most popular applications called 'simulation games', of which John Horton Conway's "Game of Life" (Gardner, 1970) is probably the most famous. The game found its widespread fame due to Martin Gardner who, at that time, devoted a Scientific American column, called "Mathematical Games", to it. Life, as it is called for short, is traditionally 'played' on an infinitely large grid of cells. Each cell can either be 'alive' or 'dead'. The game evolves by considering a cell's all surrounding neighbors, deciding whether or not the cell should live or die, leading to phenomenon called 'birth', 'survival', and 'overcrowding' (or 'loneliness'). An example of a Life game board can be seen in Figure 3-1. Typical of Life, is the spawning of a whole plethora of patterns or shapes, having illustrious names such as gliders, guns, space ships, puffers, beehives, oscillators, etc. The Game of Life is now all about how these shapes evolve, and whether or not they die out or live indefinitely (either by remaining stationary or moving around).

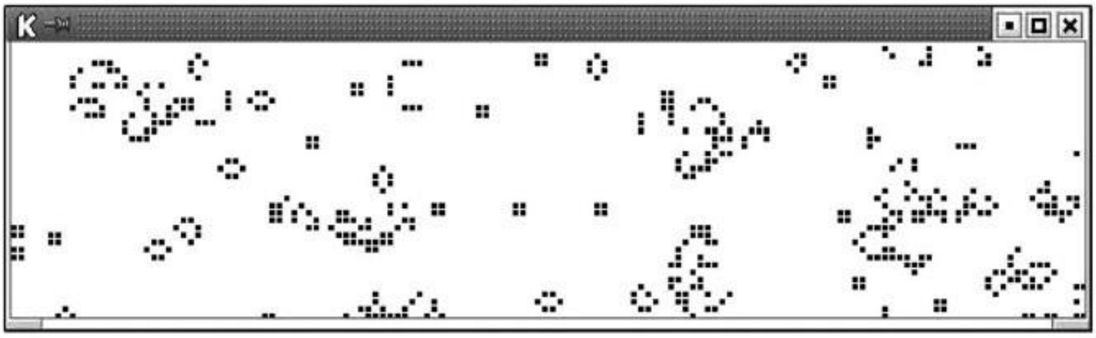


Figure 3-1 An example of the Game of Life
With a rectangular grid of cells. Live cells are colored black, whereas dead cells remain white. The image shows a snapshot during the game's course, illustrating many different shapes to either die out, or live indefinitely by remaining stationary or moving around (image adapted from Georget, 2002).

The widespread popularization of CA models was achieved in the 1980s through the work of Stephen Wolfram. Based on empirical experiments using computers, he gave an extensive classification of CA models as mathematical models for self-organizing statistical systems (Wolfram, 1983, 2002).Wolfram's work culminated in his mammoth monograph, called A New Kind of Science. In this book, Wolfram related cellular automata to all disciplines of science (e.g., sociology, biology, physics, mathematics, etc.). Despite the broad range of science areas touched upon, Wolfram's book has received its share of criticism. As an example of this, we mention the comments of Gray, who points out that Wolfram's results suffer from a rigorous mathematical test. As a consequence, the physical examples in his book are deemed either not checkable or unconvincing. Gray's final critique is that "he (Wolfram) has helped to popularize a relatively little-known mathematical area (CA theory), and he has unwittingly provided several highly instructive examples of the pitfalls of trying to dispense with mathematical rigor" (Gray, 2003). However, with respect to their computational power, CA models can emulate universal Turing machines within the theories of computation and complexity. Recently, Chua took Wolfram's empirical observations one step further, proving that some of the CA models are capable of Turing universal computations. He furthermore introduced the paradigm of cellular neural networks (CNN), which provide a very efficient method for performing massive parallel computations, and are a generalization of cellular automata (Chua, 2005).

Finally, there is an important step in certification of Wolfram's CA theory, is Bill Gosper's proof that the Game of Life is computationally universal, i.e., it can mimic arbitrary algorithms (Gosper, 1974). Notably, one of the most profound testimonies related to this concept, is the work of Konrad Zuse and Edward Fredkin at the end of the 1960s. Their Zuse-Fredkin thesis states that "The Universe is a cellular automaton", and is based on the assumption that the Universe's physical laws are discrete in nature (Zuse, 1967, Fredkin, 1990). This latter statement was also conveyed by Wolfram in his famous CA compendium (Wolfram, 2002).

3.2.2 General description of TCA model

3.2.2.1 Four elements of CA

The CA models conclude four elements, the physical environment, cell's status, cell's neighborhoods, as well as a local transition rule.

The physical environment defines the universe on which the CA is computed. There is many underlying structure for the distribution of array of the discrete lattice of cells, like a rectangular, hexagonal, or other topology (see Figure 3-2 for some examples). Typically, these cells have the unique size; the lattice itself can be finite or infinite in size, and its dimensionality can be 1 (a linear string of cells called an elementary cellular automaton or ECA), 2 (a grid), or even higher dimensional. In most cases, a common but which is often neglected assumption, is that the CAs lattice is embedded in a Euclidean space.

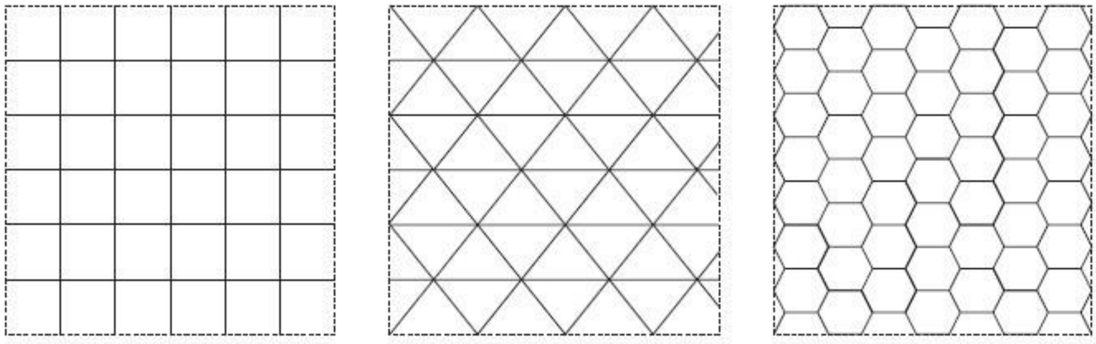


Figure 3-2 Some examples of different Euclidean lattice topologies for a cellular automaton in two dimensions

Left: rectangular. Middle: triangular/isometric. Right: hexagonal (image adapted from Maerivoet and Moor, 2005).

For the cell’s status, each cell can be in a certain state, where typically an integer represents the number of distinct states a cell can be in, e.g., a binary state. Note that a cell’s state is not restricted to such an integer domain, as a continuous range of values is also possible, in which case we are dealing with coupled map lattices (CML) (Crutchfield and Kaneko, 1987, Kaneko, 1990). We call the states of all cells collectively a CAs global configuration. This convention asserts that states are local and refer to cells, while a configuration is global and refers to the whole lattice.

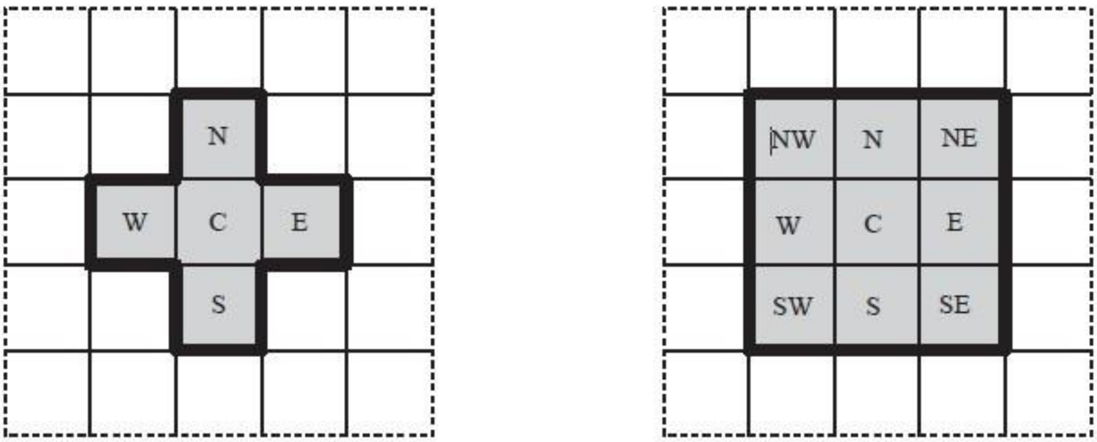


Figure 3-3 Two commonly used two-dimensional CA neighborhoods

With a radius of 1: the von Neumann neighborhood (left) consisting of the central cell itself plus 4 adjacent cells, and the Moore neighborhood (right) where there are 8 adjacent cells. Note that for one-dimensional CA’s, both types of neighborhoods are the same (image adapted from Maerivoet and Moor, 2005).

For each cell, a neighborhood that locally determines the evolution of the cell is defined. The size of neighborhood is the same for each cell in the lattice. In the simplest case, i.e., a one-dimensional lattice, the neighborhood consists of the cell itself plus its adjacent cells. In a two-dimensional rectangular lattice, there are several possibilities, e.g., with a radius of 1 there are, besides the cell itself, the four north, east, south, and west adjacent cells (von Neumann neighborhood), or the previous five cells as well as the four north-east, south-east, south-west, and north-west diagonal cells (Moore neighborhood); see Figure 3-3 for an example of both types of neighborhoods. Note that as the dimensionality of the lattice increases, the number of direct neighbors of a cell increases exponentially.

The local transition rule (also called function) works upon a cell and its direct neighborhood, which trigger the cell's state changes from one discrete time step to another (i.e., the system's iterations). The CA evolves in time and space as the rule is subsequently applied to all the cells in parallel. Typically, the same rule is used for all the cells (if the converse is true, then the term hybrid CA is used). We call a model deterministic CA when there are no stochastic components present in the rule, as contrary to a stochastic (also called probabilistic) CA.

As the local transition rule is applied to all the cells in the CAs lattice, the global configuration of the CA changes. This is also called the CAs global map, which transforms one global configuration into another. This corresponds to the notion of computing a function in automata theory. Sometimes, the CAs evolution can be reversed by computing past states out of future states. By evolving the CA backwards in time in this manner, the CAs inverse global map is computed. If this is possible, the CA is called reversible, but if there are states for which no pioneering state exists, these states are called Garden of Eden (GoE) states and the CA is said to be irreversible. Finally, when the local transition rule is applied to all cells, its global map is computed. In the context of the theory of dynamical systems, this phenomenon of local simple interactions that lead to a global complex behavior (i.e., the spontaneous development of order in a system due to internal interactions), is termed self-organization or emergence.

3.2.2.2 Transfer CA to TCA

When applying the cellular automaton analogy to vehicular road traffic flows, they also have the four elements in it. The physical environment of the system represents the road on which the vehicles are driving. In a classic single-lane assumption for traffic cellular automata (TCA), the layout consists of a one-dimensional lattice that is composed of individual cells (the description here thus focuses on unidirectional, single-lane traffic). Each cell can either be empty, or is occupied by exactly one vehicle; the term single-cell models are used to describe these systems. It is also feasible to allow a vehicle to occupy several consecutive cells, in which we call those multi-cell models. Because vehicles move from one cell to another, TCA models are also called particle-hopping models (Nagel, 1992). Special necessary to mention is that vehicles will drive away from the assumed road. If no vehicles drive into the system, there will be no vehicle on road finally. Different drive in rules can be assumed, and it is defined as boundary setting in TCA, commonly there are two types, periodical and open boundary. For the former one, the road is end to end and vehicles driving to the end then continue to drive from the front, i.e. if we assume x_{lead} and v_{lead} be the location and speed of frontest vehicle on road, x_{last} and v_{last} the location of lastest vehicle, and L_{road} the length of assumed road. If $x_{lead} > L_{road}$, then the frontest vehicle will drive to the other end of the road(the end where vehicle drive in), and become the lastest vehicle, and $x_{last} = x_{lead} - L_{road}$, $v_{last} = v_{lead}$. It is like a circle, and the traffic density will be constant. Periodical boundary is the most frequently applied one. In open boundary condition, vehicles just drive away, and there are different settings to put new vehicles on road according to design of researchers.

If define the status of cells, they have two attributes for their status, whether there is vehicle (and which type of vehicle for multi-class traffic), and speed of the cell (actually speed of the vehicle, 0 to V_{max}, usually set to be a value lower than 0 when there is no vehicle in it).

In the TCA models, vehicles have two neighborhoods in single-lane traffic, and five neighborhoods in two-lane traffic. If there are more than two lanes, the amount of vehicles' neighborhood depends on their position, i.e. which lane they are driven on.

There are rules for speed updating, and also rules for lane changing, in condition of multi-lane systems in TCA models, which are the local transition rule if transfer the definition to CA. Vehicles accelerate or decelerate or keep their present speed according to a series of updating steps, which are defined as speed updating rules for vehicles. And there are conditions for lane changing, in which vehicles can change lane if the conditions are all satisfied, in multi-lane systems. These are the rules for lane changing.

So in TCA models, space, time and velocity are discrete. For example, in a single-lane system, it consists of a one-dimensional grid of L lattice with a set boundary condition (periodical or open). A lattice can either be empty, or occupied by a vehicle with a speed from 0 to V_{max}. The speed is equivalent to the number of lattice that a vehicle advances in one update, provided that there are no obstacles ahead. Vehicles move only in one direction. Vehicles' evolution mode is shown in Figure 3-4.

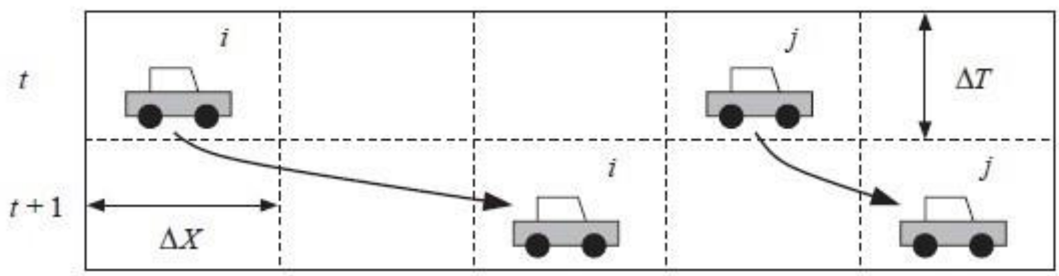


Figure 3-4 Schematic diagram of the operation of a single-lane traffic cellular automaton (TCA)

The time axis is oriented downwards, the space axis extends to the right. The TCA's configuration is shown for two consecutive time steps t and t+1, during which two vehicles i and j propagate through the lattice (image adapted from Maerivoet and Moor, 2005).

3.2.3 A multi-cell model

In this study, there are 100 cells counting as 400-meters in length on a highway and an arterial road both with two parallel lanes, the length of a cell is 4 meters. According to the attributes of vehicles in reality as shown in Table 3-1, Table 3-2 is the assumed ones in simulation.

Table 3-1 Vehicle attributes in reality

Attribute	Conventional car	Micro-car
Length(m)	4.0~5	2~3
Maximum speed(km/h)	200~260	60
Maximum speed on road(km/h)	80	60
Acceleration (m/s^2)	-6~6	-6~3

Vehicles run with periodic boundary on the road, and the original positions of vehicles are distributed on the road probabilistically. A signal cycle which results in intersection delay with a 60 seconds cycle and 30 seconds green time is arranged in the middle of arterial road. The total time steps is 10000, while results calculated from the last 600 s for some outcome or 3600 s for the other outcome are print out as output as shown in Table 3-3.

Table 3-2 Vehicle attributes in simulation (cell length = 4 m)

Attribute	Conventional car	Micro-car
Length(unit length, one unit length=4m)	2	1
Maximum speed on road(unit length/s)	6	4
Maximum speed on road(km/h)	86.4	57.6
Acceleration and deceleration(unit length/s^2)	1	1

There are usually more than one lane in reality, so in multi-lane models the update step is usually divided into two sub-steps: In the first sub-step, the system updates according to independent single-lane speed updating rules, like NaSch model (Nagel and Schreckenberg, 1992) and in the second sub-step vehicles may change lanes in parallel according to lane-changing rules. The speed updating rules in this paper are the same with the NaSch model. The lane-changing rules can be symmetric or asymmetric with respect to the lanes and vehicles, and we used the former one in this paper.

Table 3-3 Set variables in simulation

Variable	Value
Unit time	1s
Time steps(s)	10000
Count time(s)	600
Total length(unit length)	100
Total length(m)	400
Signal cycle(s)	60
Green time(s)	30

3.2.3.1 Rules of speed updating

There are four consecutive steps which are performed in parallel for all vehicles to change speed, and the details are shown as follows.

Step 1. Acceleration

$$v_n \to \min(v_n + 1, v_{\max}) \tag{3-1}$$

Step 2. Deceleration

$$v_n \to \min(v_n, d_n) \tag{3-2}$$

Step 3. Randomization (with probability p)

$$v_n \to \max(v_n - 1, 0) \tag{3-3}$$

Step 4. Car motion

$$x_n \rightarrow x_n + v_n \tag{3-4}$$

Where,

v_n : speed of vehicle n

$v_{\max}$: maximum speed of vehicle n

d_n : space headway of vehicle n and its front vehicle

P: randomization probability

x_n : location of vehicle n

The first three steps is a decision procedure. Vehicles move in the fourth step according to the decided speed from the decision procedure. It is assumed that drivers intend to accelerate first come in mind, so Step 1 represents a linear acceleration until the vehicle has reached its maximum speed. Step 2 ensures that vehicles having predecessors in their way slow down in order not to run into them. In step 3 a random generator is used for vehicle to decelerate with a certain probability to model erratic driver behavior. It takes into account nature speed fluctuations due to human behavior or varying external conditions. Step 3 is essential in simulating realistic traffic as it makes the dynamics stochastic. Without the randomness, every initial configuration of vehicles and corresponding speed reaches very quickly a stationary pattern.

3.2.3.2 Rules of lane-changing

Rickert et al. (1996) have assumed a symmetric rule set where vehicles change lanes if the following criteria are fulfilled:

A. $d_n < \min(v_n + 1, v_{\max})$ (3-5)

B. $d_{n,other} > \min(v_n + 1, v_{\max})$ (3-6)

C. $d_{n,back} > 5$ (3-7)

D. $rand() < p_{n,change}$ (3-8)

Where,

d_n : space headway of vehicle n and its front vehicle

$d_{n,other}$: space headway of vehicle n and its front vehicle of the other lane

$d_{n,back}$: space headway of vehicle n and its back vehicle of the other lane

$rand()$: a random number between 0 and 1

$p_{n,change}$: lane-change probability

Condition A is a motivation standard, if the space headway between vehicle n and its front vehicle is not long enough for vehicle n to accelerate or keep its maximum speed, vehicle n may have the willing to change lane. Condition B is used to check whether the driving condition in the other lane is better. Condition C is used to check if the condition of the other lane permits vehicle n to change lane. Condition D is a random factor for lane changing, because not all vehicles decide to change lane even if the first three conditions are satisfied, also due to human behavior or varying external conditions. If the random generated number lower than the set lane-change probability, motion of lane changing will be triggered.

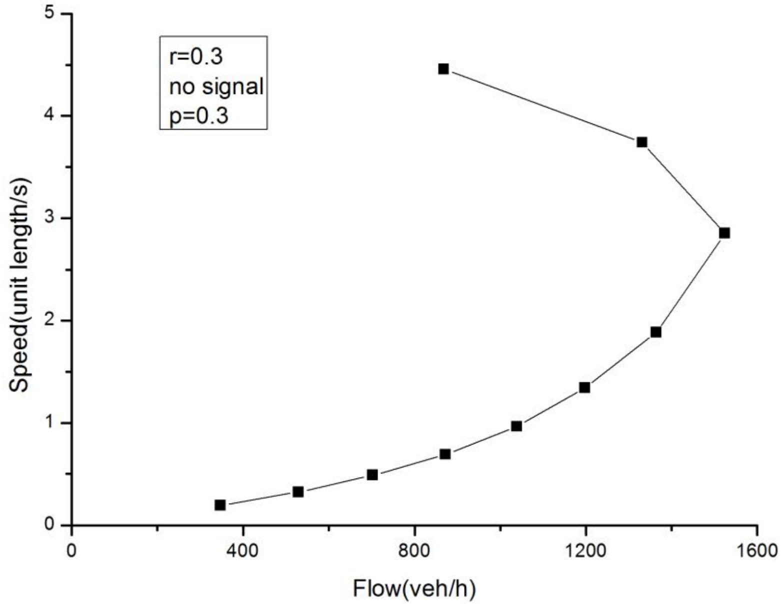


Figure 3-5 Speed and flow fundamental diagram when micro-car rate equals 0.3

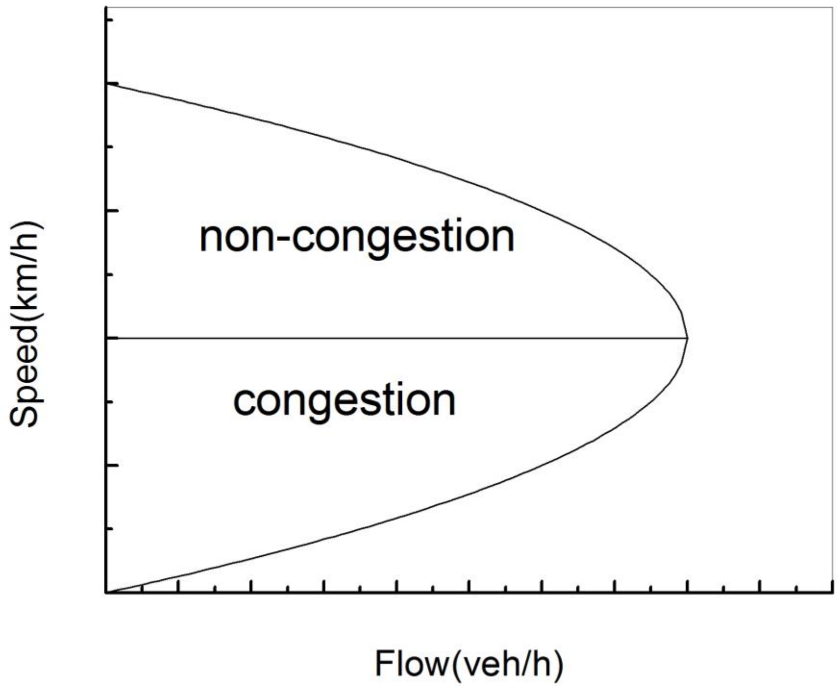
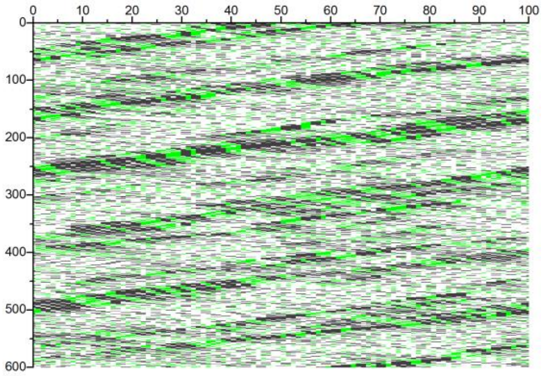
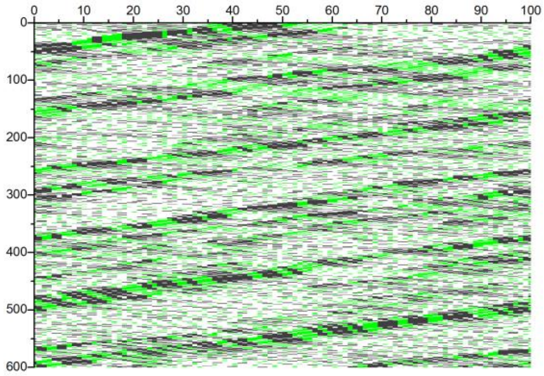


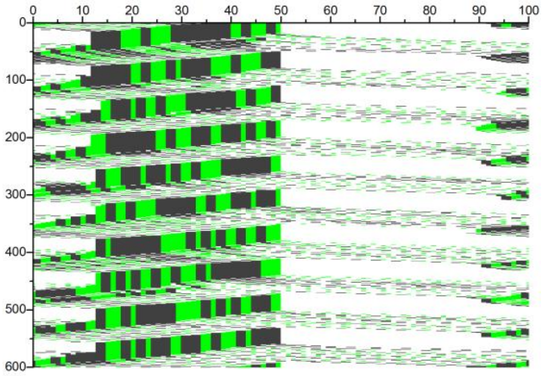
Figure 3-6 Greenshields speed-flow parabola



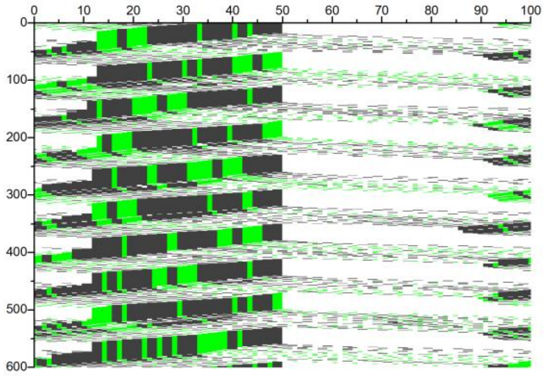
r=50%, number of vehicles=50, expressway, right lane



r=50%, number of vehicles=50, expressway, left lane



r=50%, number of vehicles=50, arterial road, right lane



r=50%, number of vehicles=50, arterial road, left lane

Figure 3-7 Time-space figure when micro-car rate is 50%, number of vehicles is 50

Micro-cars defined as green ones, while conventional cars designed as dark gray ones.

Referring to a comprehensive examination of naturalistic lane changes by Lee et al. (2005), drivers of fast vehicles are willing to change lane even when a vehicle is approaching from behind in the adjacent lane. So in this paper, the condition that the space headway of vehicle n and its back vehicle of the other lane is considered being more conformed with reality. Here if vehicle n meets the following three conditions, it can change lane.

A. $d_n < \min(v_n + 1, v_{\max})$ (3-9)

B. $d_{n,other} > \min(v_n + 1, v_{\max})$ (3-10)

C. $d_{n,back} > \min(v_{back} + 1, v_{\max,back})$ (3-11)

D. $rand() < p_{n,change}$ (3-12)

Here, v_{back} is speed of the back vehicle in the other lane of vehicle n, and $v_{\max,back}$ is maximum speed of the back vehicle in the other lane of vehicle n.

Figure 3-5 is a flow-velocity curve from one of the simulations, where micro-car rate is 30% on expressway. Figure 3-6 proves that the model here accord with realistic traffic except the flow coming down decreasing so violently. The time-space figure (Figure 3-7) demonstrates tracks of all the vehicles. When the number of vehicles equals 50, there are some blocks on expressway, and we can see intersection delays that exacerbate blocks on arterial road.

3.2.4 The developed multi-cell model

In the previous model, one micro-car occupies one cell which has the length of 4 meters, so vehicles can only accelerate or decelerate in a unit of 4 m/s^2, and the value is so huge, it is not so realistic. So a multi-cell model in which the length of one cell is 1 meter is developed. A expressway and an arterial road, both with two parallel lanes, are modeled, with the 700-meter length comprising 700 end-to-end cells.

According to the real attributes of vehicles as shown in Table 3-1, it is assumed in the simulation (as shown in Table 3-4) that one micro-car occupies 4 cells, while one conventional car occupies 7 cells, which are interpreted as average space headway in a jam (Length of the two vehicle types is abbreviated to LM for micro-car and LC for conventional car in following description). One time step lasts 1 second, which is of the order of the reaction time of humans. In the present paper, the velocity of conventional cars ranges from 0,…,$v_{max,c}$=28 cells/update on expressway and 17 cells/update on arterial road, as that of micro-cars is 0,…,$v_{max,m}$=17 cells/update, corresponding a maximum speed of 100.8 km/h for $v_{max,c}$=28 cells/update, and 61.2 km/h for $v_{max,m}$=17 cells/update. The maximum acceleration and deceleration unit are set as 2 m/s^2 mostly in this research in order to imitate the reality better, and the maximum acceleration is made to be 4 m/s^2 according to higher acceleration on the urban street segments near intersection during green light time.

Table 3-4 Vehicle attributes in simulation (unit length = 1 m)

1) 4 cells/update for vehicles near intersection (driven between the 301st and 400th cell) on arterial road.

Attributes	Conventional car	Micro-car
Minimum space headway (cell)	7	4
Maximum speed (cells/update) considering speed limit	28 at expressway, 17 at arterial road	17
Maximum Acceleration (cells/update)	2 or 4[1)]	2 or 4[1)]
Deceleration unit in stochastic deceleration step	2	2

Vehicles run with periodic boundary on the road and initial vehicle positions are distributed probabilistically. A signal cycle which results in an intersection delay with a 60-second cycle and 30-second green time is arranged at the mid-point of the arterial road. The total number of time steps is 10000, while results calculated from the last 3600 s are used as the output, as shown in Table 3-5.

Table 3-5 Simulation parameters

Variable	Situation
Boundary	Periodic
Unit time	1s
Time steps (s)	10000
Time steps used as output (s)	3600
Total length (cells)	700
Total length (m)	700

The rules for speed updating and lane-changing are the same with the previous model.

The input data for the simulation are the number of vehicles on the roads (ranging from 10 to 200 in steps of 10) with different micro-car ratios, *r* (ranging from 0% to 100% in steps of 20%) as shown in Table 3-6. To transfer number of vehicles to density, one can multiply 1.43, i.e., one vehicle on one lane means the density of 1.43 veh/km/lane. Simulations in which braking probability, *p*, equals 0.3 and lane changing probability equals 0.8 are carried out. As the simulation includes stochastic elements, each simulation was executed ten times to allow averaging of the results and avoid randomness to some extent.

Table 3-6 Simulation parameters

Attributes	Range	Step
Micro-car ratio (r)	0%–100%	20%
Number of vehicles	10–200	10
Braking probability (p)	0.3–0.3	0
Lane changing probability	0.8–0.8	0

The outputs from the simulation are the following:

1) The number of lane-changes in the ultimate 3600 time steps;

2) The number of decelerations in the ultimate 3600 time steps;

3) The speed variation in the ultimate 3600 time steps;

4) The vehicle-specific power (VSP) of every vehicle in the ultimate 3600 updating time.

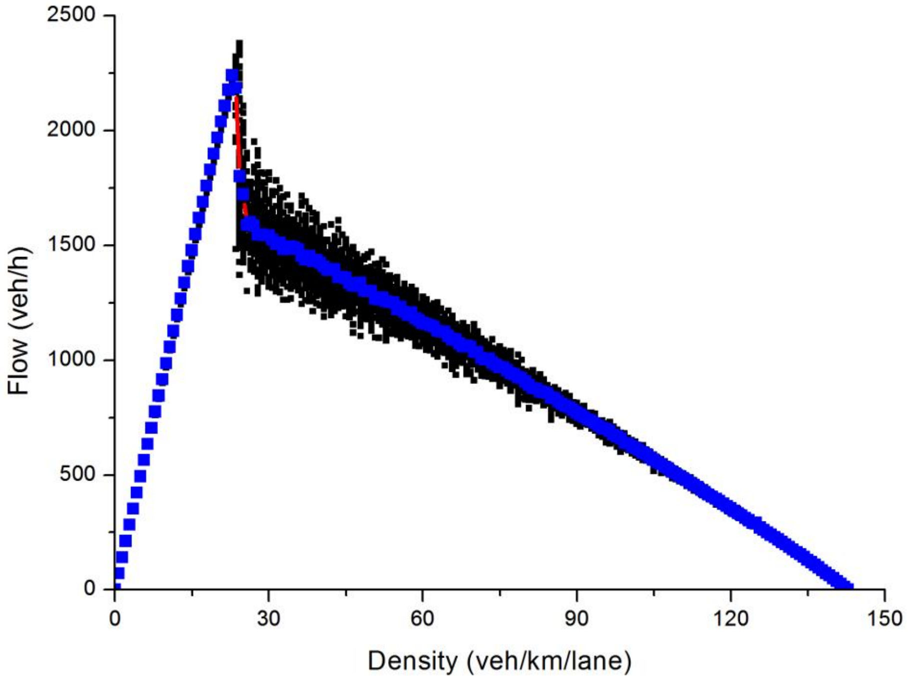


Figure 3-8 Flow-density fundamental diagrams with 0% micro-car ratio on expressway

Black scatters are short-time averages taken over 60 simulation steps and thus mimic the 1-min averages. Blue plots linked with red line ones are 1-hour average.

The flow increases more or less linearly for densities lower than 25 veh/km/lane, which is called the free-flow branch of the fundamental diagram (Figure 3-8). At the critical density 25 veh/km/lane, the flow reaches a maximum value at about 2300 veh/h/lane. In the congested region (for densities higher than the critical density), the flow degrades with increasing density, until jam density is reached and traffic stands still, resulting in a zero flow. The fundamental diagrams in Figure 3-8 depict reasonable trends of the correlations between traffic flow characteristics according to Maerivoet and De Moor (2005).

There are typical reversed λ shapes in Figure 3-8, which indicate a capacity drop, and the drop behavior due to a stabilization effect, which is akin to the observations in the STCA'S cruise-control limit, not finite size effects as an infinite system being adopted in this research. The upper branch in Figure 3-9 denotes 1-hour average flow when starting from homogeneous initial condition, while the lower one is based on a compact super jam as initial condition, which equates with removing vehicles from a jammed state and allowing the system to disentangle after the intervention. The curve trends are not so stable because vehicles are randomly located on the two lanes (half possibility for each lane) one by one with same intervals for each density, then vehicle quantity may different on each lane at the beginning of simulations. In this way a hysteresis loop can be traced (arrows in Figure 3-9), and metastable state is found here.

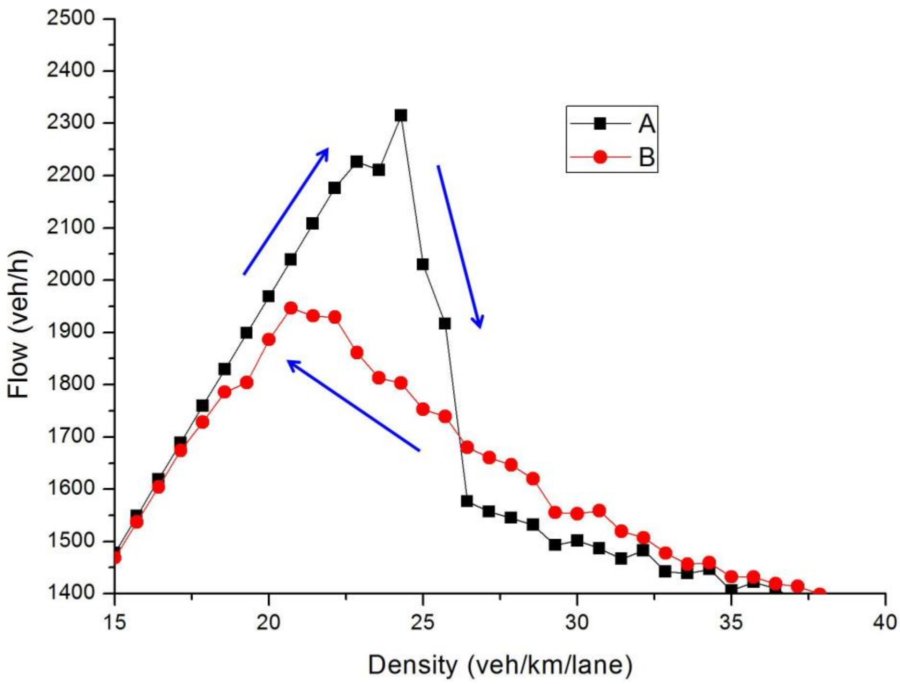


Figure 3-9 Branched fundamental diagram in the case of lane-changing being forbidden with 0% micro-car ratio on expressway.

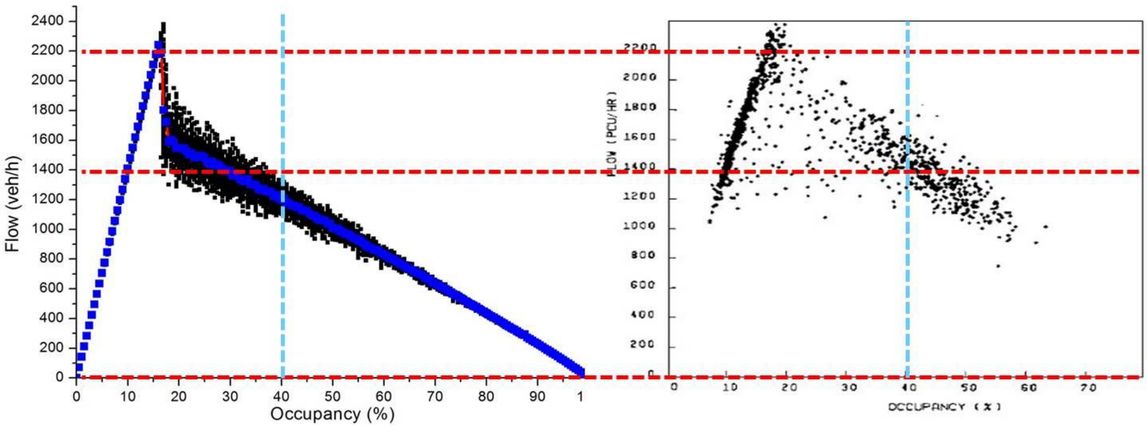


Figure 3-10 Validation with realistic data for the developed TCA (1)

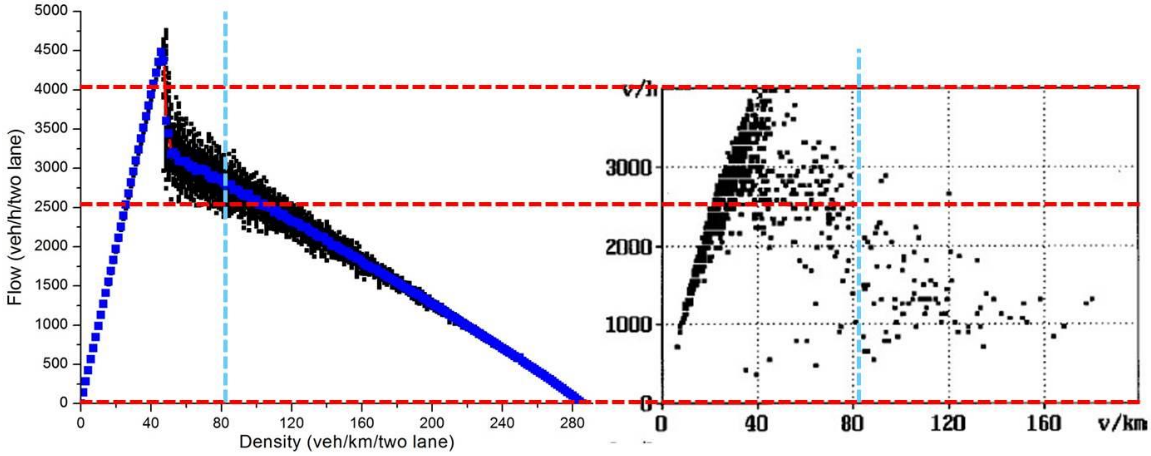
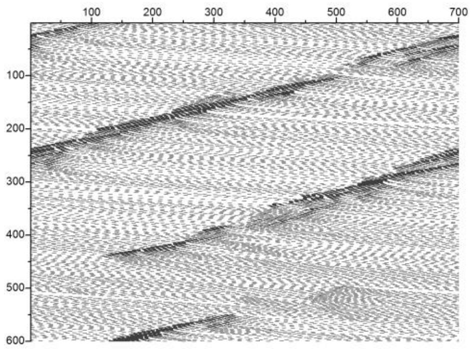
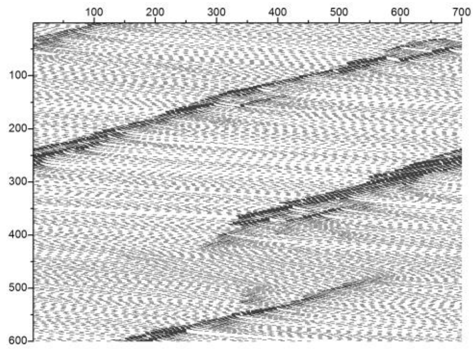


Figure 3-11 Validation with realistic data for the developed TCA (2)

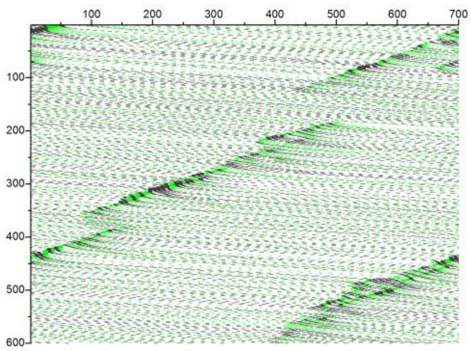
In Figure 3-10, the left hand figure is fundamental diagram from developed TCA here, same results with Figure 3-8, but with horizontal axes adjusted from density to road occupancy according to the left hand figure. The right hand figure is got from a realistic expressway, and it is empirical data collected by counting loops on a Canadian expressway in 1979-1980 (Hall et al., 1986), with speed limitation 100 km/h, which approximates to maximum speed of conventional vehicles here, 100.8 km/h, so the conditions of two roads are very similar, and each point corresponds to an average over a time interval of 5 min. To validate the TCA by comparing the two fundamental diagrams, first, the peak is similar, both about 2400 veh/h for about 18% occupancy; second, the red horizontal dotted lines demonstrate similar shape of the scatter, and plots scatter when occupancy ranging from 20% to 60%. A difference can be observed after compare the blue vertical dotted lines. It has lower flow in developed TCA for the same occupancy. However, in Figure 3-11, middle crosses of blue and red dotted lines show opposite difference with Figure 3-10 between the compared two (the left hand diagram is empirical data from Wiedemann (1995), with speed limitation 120 km/h. Each point corresponds to an average over a time interval of 1 min). The realistic data strongly depend on several external influences, e.g. weather condition, or the performance of junctions (Hall et al. 1986). Therefore, even certain experimental facts are not well established.



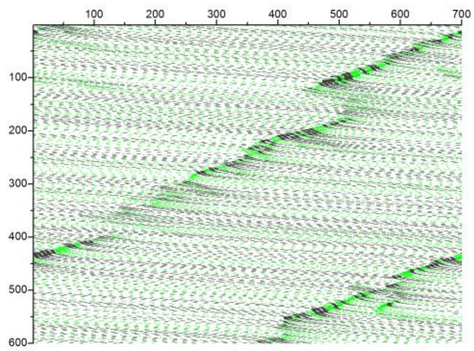
a) r=0%, number of vehicles=50, expressway, right lane



b) r=0%, number of vehicles=50, expressway, left lane



c) r=50%, number of vehicles=50, expressway, right lanes

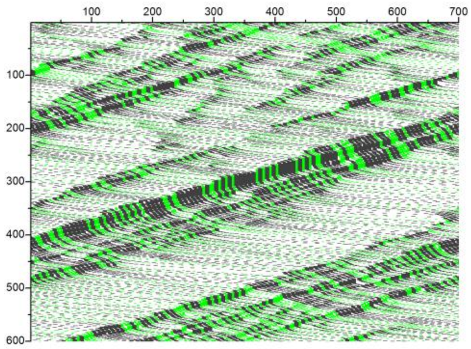


d) r=50%, number of vehicles=50, expressway, left lane

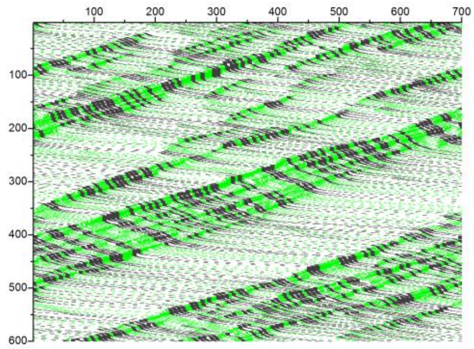
Figure 3-12 Time-space plots for 50 vehicles.

Sites occupied by a conventional car are represented by dark gray dots, while micro-cars are represented by green dots. The shown lattices each contain 700 cells, with period of the last simulated 600 time steps (second). Vehicles are driven from left to right, and vertical direction (down) is (increasing) time.

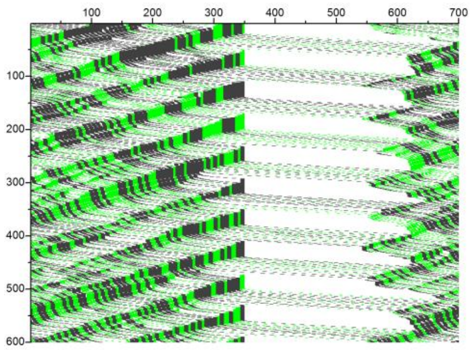
The time-space plots shown in Figure 3-12 and Figure 3-13 indicate the positions of all vehicles on the roadway. 50%-micro-car case shows more small fluctuations instead of fully developed jams. Locations of jams in the two lanes are a little staggered, which manifest the lane-changing behavior. With 100 vehicles on the roadway, there are some slowdowns on the expressway, and we can see intersection delays that exacerbate blockages on the arterial road.



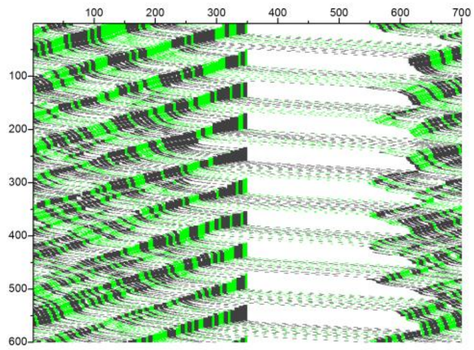
a) r=50%, number of vehicles=100, expressway, right lane



b) r=50%, number of vehicles=100, expressway, left lane



c) r=50%, number of vehicles=100, arterial road, right lanes



d) r=50%, number of vehicles=100, arterial road, left lane

Figure 3-13 Time-space plots for 100 vehicles with a 50% of micro-car ratio.

3.3 Model in VISSIM

3.3.1 General description of VISSIM

The quality in modeling the behavior of vehicles, is an essential factor for the accuracy of a traffic simulation model, i.e., the methodology of moving vehicles through the network is the core of traffic simulation modeling. In contrast to less complex models using constant speed and deterministic car following models, VISSIM uses the psycho-physical car-following driver behavior model for longitudinal vehicle movements and a rule-based algorithm for lateral movements based on the continuous work of Wiedemann (1974, and 1991). The model is based on a driver's perception and reaction to changes in distance and speed differences with surrounding vehicles.

The model in VISSIM describes vehicle movements in traffic flow on urban and interurban networks. Its essentials is formed by two models representing basic vehicle movements: the longitudinal and lateral movement, like that of Multi-lane TCA models. The first, which is often called the car-following model, deals with movement within one lane. The latter focuses on vehicles' movement behavior between lanes and is named the lane-changing model. Both models of vehicle movement are based on extensive investigations and measurements of human driving behavior. Changes in driver behavior and vehicle improvements in reality are reacted by the adjustment of model parameters after periodic field measurements, and these keep model in VISSIM creditable and practical.

VISSIM simulates each vehicle to generate the complete traffic stream; traffic characteristics such as acceleration and driver's behavior can be recorded and investigated. As discussed in Chapter two, traffic characteristics and driver's behavior are important factors of air pollutions from road traffic. If these results of VISSIM are linked with appropriate emission factors, such as those provided by the MODEM database, it can produce a detailed description of the air pollution from vehicles, which conventional macroscopic models cannot describe.

3.3.2 The VISSIM car-following and lane-changing model

The traffic flow model in VISSIM is a discrete, stochastic, time step based microscopic model, with driver-vehicle-units as single entities. The model contains a psycho-physical car following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements. The car-following model is based on the continued work of Wiedemann.

3.3.2.1 Car-following model

The longitudinal movements of vehicles are mainly influenced by the vehicle directly in front of it. Two different approaches have been developed to represent this influence:

- Continuous follow-the-leader models
- Models consisting of different descriptions for vehicle movement

In the first approach, vehicle movement is represented by only one equation defining parameters of the movement to be functions of actual speed, speed difference and distance from the front vehicle (Gazis et al 1961).

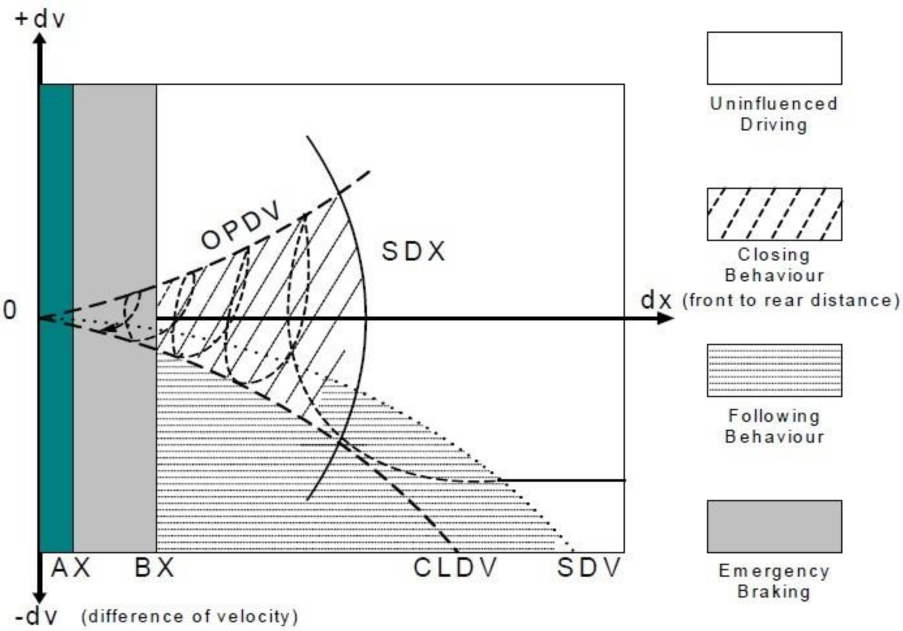


Figure 3-14 Phase plan and thresholds of the car-following model in VISSIM

In the second approach, different situations are defined, each of them describing a different state of interaction relative to the leading vehicle. Michaels and Cozan (1965) and Hoefs (1972) aimed at finding the limits of human perception called perception thresholds, in the car following processes. Perception thresholds represent a form of non-linear response in which a driver only perceives (and therefore potentially responds to) a change in distance or speed difference when it exceeds certain minimum values, i.e.

the thresholds. The driver of a faster moving vehicle starts to decelerate as he reaches his individual perception threshold of a slower moving vehicle. Since he cannot exactly determine the speed of that vehicle, his speed will fall below that vehicle's speed until he starts to slightly accelerate again after reaching another perception threshold. This results in an iterative process of acceleration and deceleration. These investigations form the basis of the car-following model developed by Wiedemann (1974).

Human driving behavior is naturally distributed: different drivers have different driving abilities, different abilities of perception and estimation, different needs for safety, different desired speeds and different maximum values of accepted acceleration/deceleration characterizing their aggressiveness. The same holds for some parameters characterizing vehicle capabilities like maximum speed and maximum acceleration/deceleration. The variation in this natural phenomenon across the population can be represented by assuming that these parameters follow a suitable distribution, such as the normal distribution. Hence, different random parameters are used within the model for calculation of threshold values and for the driving functions. The thresholds, characteristic distances and associated driving procedures are shown in Figure 3-14. The vertical axis represents the speed difference with positive values characterizing a closing process, and the horizontal axis represents the distance to the front vehicle.

The following threshold is defined:

AX: Desired distance for standing vehicles (front-to front distance). It consists of the length of the front vehicle L and the desired front-to-rear distance depending on the driver of vehicle I. The desired front-to-rear distance is normally distributed depending on the safety need of the driver. This is represented by a normally distributed parameter

RND1(I) = N(0.5, 0.15), having values between 0 and 1,with 0.5 as mean and a standard deviation of 0.15. Hence, AX is defined as

$$AX = L + AXadd + RND1(I) \times AXmult$$

AXadd and Axmult are both calibration parameters that are additive and multiplicative factors respectively for range definition of desired minimum front-to-rear distance.

BX: Desired minimum following distance at low speed differences. Measurements showed that distances in real traffic were not proportional to the speed (Todosiev 1963, Hoefs 1972). Drivers tend to underestimate safe distances at higher speeds, and drive in a more risky fashion at higher speeds than at lower speeds. This should be represented as a parabolic relation between BX and actual speed. This minimum value is normally distributed, depending on the safety needs of drivers represented by the parameter RND1(I). This results in

$$BX := (BXadd + BXmult \times RND1(I)) \times \sqrt{V}$$

BXadd and BXmult again are calibration parameters defining the range of variation.

SDV: Perception threshold of speed difference at long distances. This threshold marks the point at which the driver consciously realises that he is closing in on a slower vehicle. If lane change is impossible, the driver will react by reducing his own speed to the speed of the front vehicle trying to keep a distance greater than ABX (AX + BX). This approaching process at longer distances has been investigated by Michaels (1965) and Hoefs (1972). The measurements showed that the faster the vehicle is approaching, the greater the perception distance. It ranges between 25*SQRT(difference of speed) and 75*SQRT (difference of speed). For different drivers, the natural distribution again is modeled by normally distributed parameters, RND1(I) as mentioned above, RND2(I) has the same range, mean and standard deviation as RND1: N(0.5, 0.15). SDV is modeled by

$$SDV := \left(\frac{DX - AX}{CX} \right)^2$$

$$CX := CXconst \times (CXadd + CXmult \times (RND1(I) + RND2(I)))$$

CXconst, CXadd and CXmult again define the range of the threshold. DX is the distance between the two vehicles. Following the mentioned measurements CX should represent the range between 25 and 75.

SDX: This threshold describes a driver who is consciously recognizing that he is leaving the vehicle in the front and the following process recognizes that the vehicle is falling too far behind. He will react by accelerating to attain ideal headway. Measurements by Todosiev (1963) and Hoefs (1972) resulted in SDX varying between 1.5 and 2.5 times the minimum following distance. The variation does not only depend on the driver, but additionally the value SDX varies for one driver, which is modeled by a driver independent random parameter NRND = N (0.5, 0.15). SDX is calculated by

$$SDX := AX + EX \times BX$$

$$EX := EXadd + EXmult * (NRND - RND2(I))$$

For drivers having good estimation abilities, RND2(I) is close to 1.0, the element EX will have a smaller mean value and hence SDX will be small. The driver recogniZes early that he is leaving the following process, which results in small distance oscillations.

OPDV: Perceptual threshold for recognizing small speed differences at short but increasing distances. The range of variation is even larger than the range of CLDV. Measurements of Todosiev (1963) and Hoefs (1972) resulted in OPDV being about 1 to 3 times higher than the CLDV.

OPDV = CLDV × (−OPDVadd −OPDVmult × NRND)

OPDVadd and OPDVmult again define the range. The driver independent parameter NRND represents variations of the modeling.

An upper limit of reaction describes the maximum distance for interaction between two vehicles. Investigations within the HCM (Expressway Capacity Manual) (1965) showed that there is no significant influence between two vehicles at distances higher than 150 meters.

The described thresholds distinguish four types of driving behavior, the uninfluenced driving, the closing process, the following process and the emergency braking. Each driving type is represented by procedures calculating the actual driving behavior, for example, the value of acceleration in the longitudinal direction. Figure 3-14 also shows these thresholds and ranges of four different driving behaviors.

3.3.2.2 The lane-changing model

Similar to the car-following model, the lane-changing model is also based on human decisions influenced by human perception of the surrounding vehicles. Since it has the same basis as the car-following model, the lane changing model has been defined in close relation to the car- following model.

A driver’s decision to change lanes is a result of a complex decision process. It is represented in the model by a hierarchical

1. Is there a desire to change the lane?

2. Is the present driving situation in the neighboring lane favorable?

3. Is the movement to a neighboring lane possible?

There are two types of lane-changing scenarios defined in this model: from slow to faster and from fast to slower. The desire to change to a faster lane results from obstructions in the actual lane caused by a slower vehicle in front. The level of obstruction is a function of the difference between the actual speed of the front vehicle and the driver's own desired speed. The desire to change to a slower lane results from the general rule to keep to a slower lane or from the actual need to move out of the way to allow a faster vehicle to pass. Changing to another lane is only acceptable if no dangerous situation results from the movement. The level of safety is determined by estimating distances and speed differences of front and rear vehicles on the adjacent lanes.

In the car-following model, the influence of a slower vehicle is defined by the distance SDX and the perceptual threshold for speed differences SDV. In modeling a driver's lane changing decisions, this kind of influence is called actual influence. While driving, the driver might consider potential future situations caused by his lane-changing decisions. This is represented in the model by defining an additional kind of influence called potential influence.

The potential influence represents all situations where the driver is not influenced by a front vehicle, for example, situations where he cannot estimate the relative speed differences at that moment, but thinks there might potentially be an influence in the near future. New thresholds SDXP and SDVP defining the area of potential influence are defined as multiples of thresholds SDX and SDV, which are described in the car-following model.

SDXP: Perception threshold of growing distance in short distances of potential influence.

$$SDXP = AX + FX \cdot BX$$

SDVP: Perception threshold of speed difference at long distances of potential influence.

$$SDVP = FV \cdot SDV$$

The multiplicative factors of FX and FV vary, according to which of the surrounding vehicle is considered. This variation considers a human estimation of distance and speed differences of vehicles that are in front and behind. There are different types of lane changing: four types include changes to faster lanes and two types include changes to slower lanes.

The first type of lane change to a faster lane is FREE lane change. The lane changing vehicle is only influenced by a front vehicle in the same lane. Neither the front nor rear vehicles in the faster lane influence the manoeuvre.

The second type of lane change is called a LEAD lane change. The front vehicle in the faster adjacent lane is closer to the lane changing vehicle than the front vehicle in its own lane, thus it influences to the lane-changing vehicle. The rear vehicle in the faster lane is not influenced by the manoeuvre.

LAG lane change is the third type of lane change. The following vehicle in the faster lane is affected by the manoeuvre of the lane-changing vehicle. The front vehicle in the faster lane does not affect to the lane-changing vehicle.

The last type of lane-changing is called a GAP lane change. The following vehicle in the faster lane is influenced by the manoeuvre of the lane-changing vehicle and the front vehicle in the faster lane influences the lane changing vehicle. Gap lane change is a combination of LEAD and LAG lane changing.

The two types of lane changes to slower lanes are called FREE lane change and ACCEL lane change. FREE lane change is a lane change that is not influenced by a follower in its own lane, but is done by the driver's own decision. ACCEL lane change is a change to slower lane caused by the following vehicle in its own lane.

3.3.3 Model for segment

Although TCA model can simulate many traffic flow phenomena, its ability to simulate traffic flow on road segment approximating to reality is doubted because of its comparative simpler rules for driver behavior. VISSIM, as a well known and well developed microscopic simulator, is applied to simulate traffic on assumed road segments to accomplish a validation and comparison with the developed TCA model.

The VISSIM simulates traffic flow by moving 'driver-vehicle units' through a network. Every driver with his specific behavior characteristics is assigned to a specific vehicle. As a consequence, the driver behavior corresponds to the technical capabilities of his vehicle. Attributes characterizing each driver-vehicle unit can be divided into three categories: technical specifications, behavior of driver-vehicle unit, and interdependence of driver-vehicle units. Technical specification of the vehicle includes length, maximum speed, and potential acceleration, actual position within the network and actual speed and acceleration. The behavior of each driver-vehicle unit consists of psychophysical sensitivity thresholds of the driver (ability to estimate, aggressiveness), network knowledge of the driver and acceleration based on the current speed and the driver's desired speed. Interdependence of driver-vehicle units includes references to leading and following vehicles in their own as well as adjacent travel lanes, reference to its current link, the next intersection, and the next signal.

Table 3-7 Size of vehicles in VISSIM

Attribute	Conventional car	Micro-car
Length(m)	4.74	2.65
Widths(m)	1.9	1.77
Height (mm)	1485	1565
Ground clearance (mm)	155	140
Weight (kg)	1490	750
Occupancy	1	1

The procedure begins with inputs of the network configuration and travel demand information into VISSIM, the microscopic traffic flow simulation model. Network configuration and travel demand information include network data such as roads, junctions, signal timings and travel demands data such as vehicle types, desired speed and traffic volumes. As a result, the VISSIM model generates instantaneous speed and acceleration together with the location of each vehicle at any simulated time.

Table 3-8 Attributes set in two simulators

(1) Being 57.6 on arterial road; (2) Being 43.2 on arterial road; (3) The same condition with (1); (4) The same condition with (2).

Attributes	CA				VISSIM			
	Conventional car		micro-car		Conventional car		micro-car	
Length(m)	2 (8 m)		1 (4 m)		4.74 m		2.65 m	
Max speed (Desired speed) (km/h)	86.4(1)	72(2)	57.6	43.2	86.4(3)	72(4)	57.6	43.2
Probability	0.8	0.2	0.8	0.2	0.8	0.2	0.8	0.2
Acceleration	4 m/s^2		4 m/s^2		4 m/s^2		4 m/s^2	
Rates of micro-car	0~100%				0~100%			
Micro-car rates Step	10%				10%			
Input data	Density(25~250veh/km)				Volume(50~2900veh/h)			
Number of lanes	2				2			

In the segment level, Smart For-two 2012 is chosen as a representative for micro-car, and Toyota Camry 2012 is set in simulation to stand for conventional passenger car. The sizes of them are shown in Table 3-7.

Desired speed of micro-car ranges from 43.2km/h to 57.6km/h, and the probability of being 43.2 km/h is 0.2, which is the same with the deceleration probability in TCA. It is set like this because there is not concept of deceleration probability in VISSIM, instead, desired speed is an important parameter which designs the speed in traffic, and has a significant influence on roadway capacity and achievable travel speeds. If not hindered by other vehicles, a driver will travel at his desired speed (with a small stochastic variation called oscillation) in VISSIM. On the other hand, the highest speed in TCA can be regarded as desired speed, and the deceleration probability makes 20% vehicles' desired speed being a unit lower than the highest. Also there are similar settings in probability of desired speed for conventional car. Maximum acceleration, desired acceleration, maximum deceleration, and desired acceleration are all designed as 4 m/s^2 for both micro-car and conventional car, which is the same with that in TCA. Table 3-8 shows the settings for computation in VISSIM in detail, which are aimed to accord with settings in TCA. Rate of micro-car is ranged from 0% to 100% with a interval of 10%.

3.3.4 Model for downtown small network

For continuous consideration of using the same simulator, TCA should be the first in mind because it is applied for road segment level analysis finally. However, it will be very complex if continue to use TCA to simulate traffic network, even for small one. Because drivers have route choice behaviors in network, which will consequently cause complicated driving behaviors, such as a lane changing behavior for turning in next intersection, not like on road segment, just update speed and change lane according to the situation around. But VISSIM can handle it easier, then VISSIM is applied as the simulator for downtown small network.

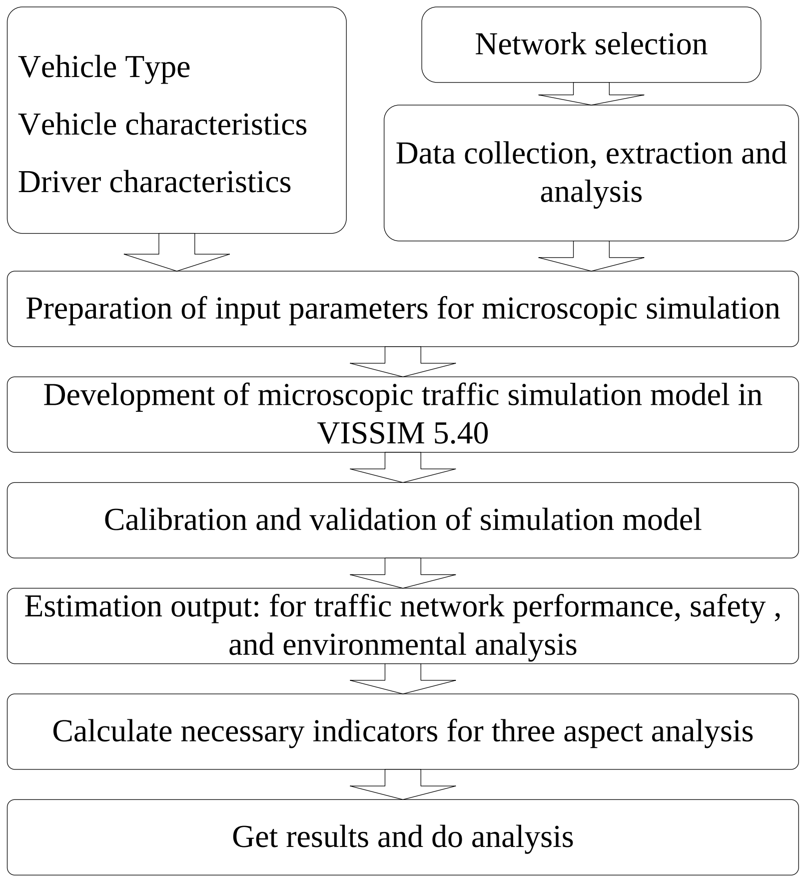
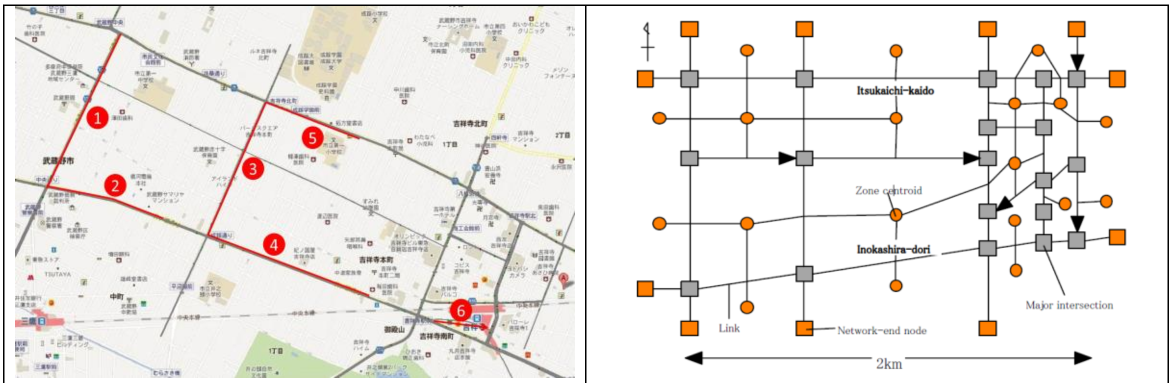


Figure 3-15 Methodology for estimating micro-cars' effect on travel network

In order to represent the traffic system that is studied in a suitable way, two aspects and their interaction need to be modeled. On the one hand there is the Supply side that consists of the traffic network (the roads and intersections) and its performance together with all the control and information systems (traffic lights, Variable Message Signs (VMS), speed limits, etc.). On the other hand there is the Demand side that consists of the travelers and their behavior. In other words, the drivers want to go from some place to another (Demand) and the traffic infrastructure provides the means to do that (Supply). These sides interact in the way that travelers react to the speed limit signs, the conditions on the roads and so forth, by making different choices (route choices, speed choices etc.), and control information systems adapt to the choices of drivers.

The methodology applied for the microscopic simulation is shown in the form of flow chart in Figure 3-15. Vehicle type is decided first for simulation preparation. Toyota

Camry 2012 is set in simulation to stand for conventional passenger car, Smart For-two 2012 is chosen as a representative for micro-car. After that driver characteristics, and vehicle characteristics are investigated for preparation of input parameters for microscopic simulation.



Road network overlaid on Google Maps | O-D plots in the network

Figure 3-16 Kichijoji-Mitaka area in Tokyo

At the same time the network for downtown small network level analysis is chosen. It is a western part of central Tokyo, named Kichijoji-Mitaka area, which extends about 2 km from east to west and 1 km from north to south (Figure 3-16). The Kichijoji-Mitaka network consists of 138 links and 57 nodes, including four major north-south streets and two major east-west streets. Lower speed limitations are ruled for some links. These links are marked with red line in Figure 3-16. Links No. 1 to 5 have the same speed limitation of 40 km/h for each driving direction, and link No. 6 has a speed limitation of 20 km/h, with the arrowed direction (actually this link has only one driving direction). For links with no marked speed limitations, it is assumed that their speed limitation is 50 km/h, although it is 40 km/h in traffic regulation, because actual average link travel speed of some links observed in the survey was higher than 40 km/h (Horiguchi et al. 1998).

Horiguchi et al. (1998) carried out an intensive traffic survey on the selected network in morning peak period 7:00 am-10:00 am on 30 Oct. 1996, and made an open source data set. Link volume on 70 links were observed and totally 16,043 vehicle trajectories were identified and, after data extraction, link flows and OD demands for each 10-minute period for the time interval from 7:50 to 10:00 are derived. There are 26 origins and destinations identified in the network. Geometry of most intersections and all signal timings can be found in the Kichijoji-Mitaka open source data set additionally. This network is chosen not only because of the rather complete data set, but also because of alternative route options for several O-D pairs.

A model which accurately represents the realistic status is defined as the 'Base Model' in microscopic simulation. The base model is constructed by delineating the network area defined in model extent and using calculated OD demand or traffic volume from observed vehicle record. The former data source are employed in this research, and the 10-miniutes-interval mutative OD demands are put on the traffic network for dynamic traffic assignment simulations. After validation, one or more 'prospect base model' will be developed based on the base model, in which various scenarios and design options can be set and compared. The base model development can be summed up in the following four steps:

1) Developing base network

2) Defining model parameters

3) Calibrating the network

4) Validating the model

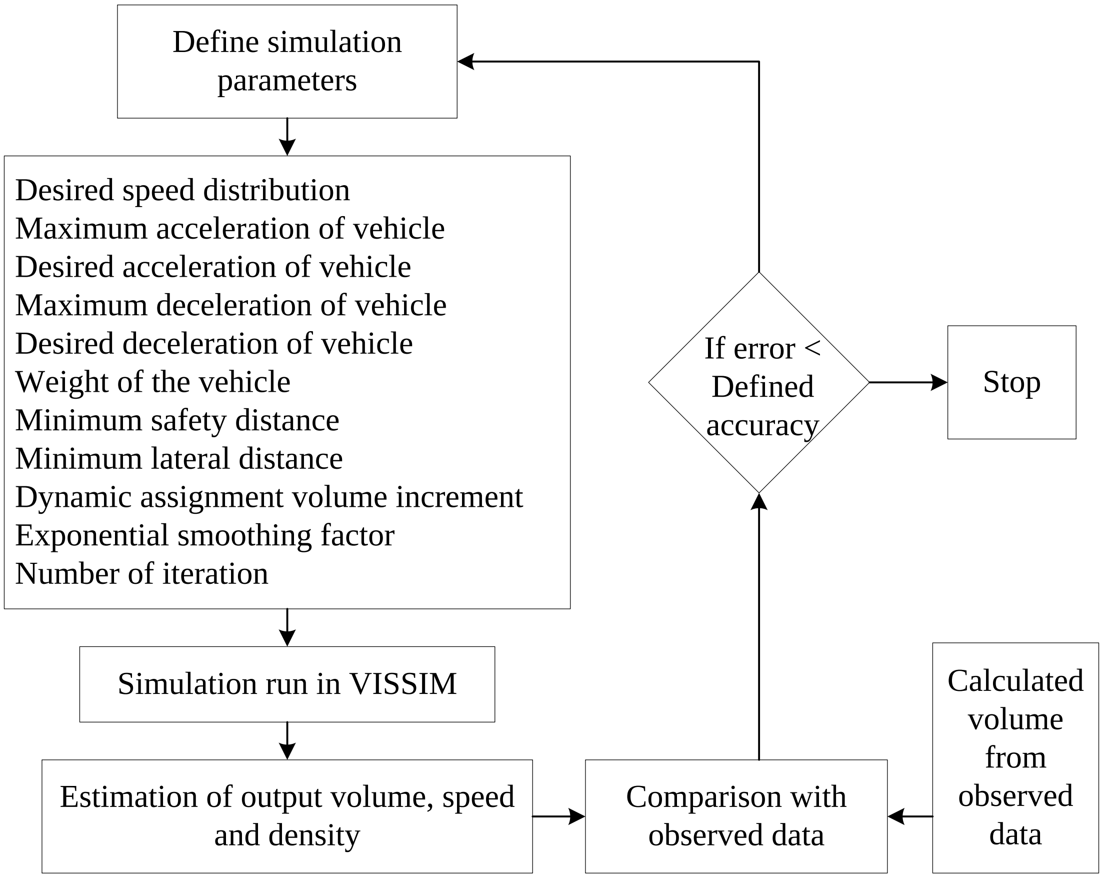


Figure 3-17 Calibration procedure for simulation model development

Calibration is a process of regulating the model parameters, network to represent and reflect observed data and/or observed site conditions to a competent level to satisfy the stated objectives. The process for calibration is shown in the form of flow chart in Figure 3-17. It involves adjusting simulation characteristics in user interface. By giving the parameters as an input to simulation model, simulation runs have to be carried out in order to estimate the output. In the present simulation model, the outputs obtained are the volume, speed, as well as density collected from 70 detectors set in the network. Since the observed data on these parameters are collected for validation of the developed simulation model. The comparison between estimated values and observed ones is carried out and error is estimated. This iterative process of simulation model calibration is implemented through the modification of various model parameters, and then simulation runs are performed till the error is within the satisfactory level.

Validation is the process of checking the developed simulation model and its simulation results in the light of comparing predicted traffic performance with field measurements of traffic flow characteristics such as traffic volumes, travel times, average speeds, and lane changes. Traffic volumes are used here. In the present study, the calibration and validation process is completed by trial and error method. After many trials, the simulated error in volume is reduced to satisfactory level. Figure 3-18 shows the validation results of traffic volumes from the 70 detecting plots for each 10-minutes period. The scatter plots indicate so high correlation as to prove the accuracy of the validated model. The linear fitting results are shown in Table 3-9, the correlation coefficient between observed data and simulated data is 0.895, much higher than the standard level, 0.7, and the RMSE (Root Mean Square Error) is 13.25 veh/10min. These results suggest that the simulator is able to reproduce real traffic conditions with a high accuracy.

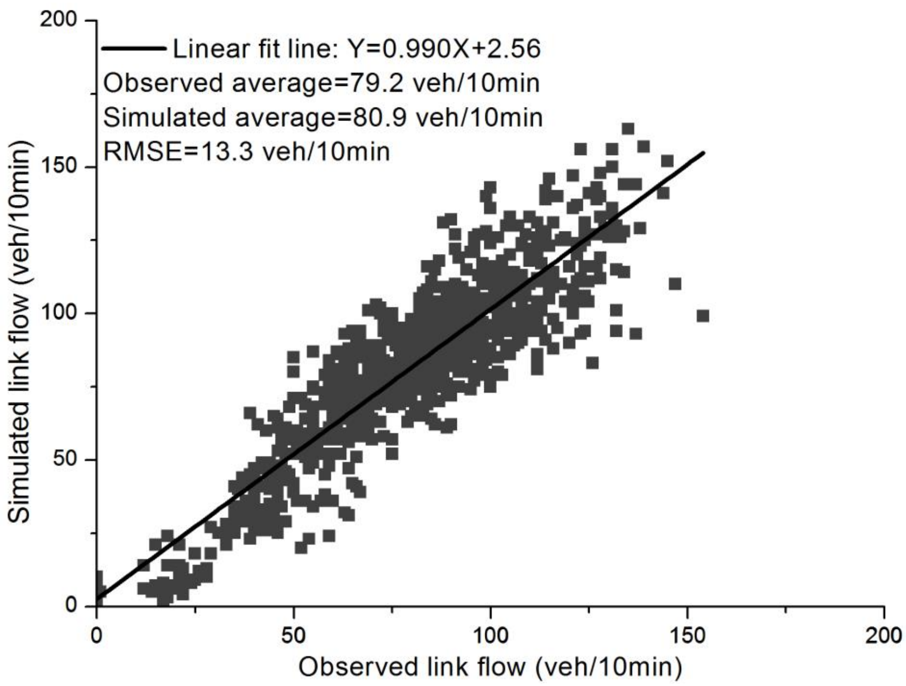


Figure 3-18 Correlation of throughput volumes

After calibration and validation, the parameters set in base model are confirmed. As there are so many parameters in the model, several significant ones are declared here.

The desired speed distribution is from 48km/h to 58km/h with constant high up acceleration. The maximum and desired acceleration and deceleration are chosen as the No.1 option. The Wiedemann 74 model, which is mainly suitable for urban traffic and merging/weaving areas, is used for drive behavior setting here. The average standstill distance and additive part of safety distance are both 2m, and the safety distance is 3m.

Table 3-9 Linear fitting parameters

Intercept		Slope		Statistics
Value	Standard error	Value	Standard error	Adj. R-Square
2.56	1.37	0.990	0.016	0.802

As most micro-cars have the maximum speed about 60km/h attributed to safety issue, and they usually have the desired speed lower than that value. Their lower speed may cause other vehicles to change lane more frequently, and also have effect on route choice behavior of drivers from the nearby vehicles. These may influence the travel efficiency of the whole network. So travel speed of micro-cars is a significant impact factor on traffic network performance, it is regarded as the foremost considered parameter in the simulations of this study. Three assumptions for desired speed of micro-cars are made here, and consequently three series of simulations are executed. See details in Table 3-10. Micro-cars need less power compared to conventional cars even if they have the same speed, because of their lighter weight. So they consume less fuel, and have higher fuel consumption efficiency. Less fuel means less cost for travel. And many micro-cars are designed to be electric powered, which means less cost for trips in another point of view. For these reasons, the travel cost of micro-cars is set lower than conventional cars, reflected by the parameter of travel distance in cost coefficients setting for vehicle types.

As introduced above, three series of simulations are carried out. In order to analyze effects of different micro-car rate, micro-car rate ranging from 0% to 100% with step of

10% are assumed for Assumption 1, and from 10% to 30% for assumption 2 and 3. In reality, the micro-car rate cannot be 100%, and even would not be over 40%. However, the maximum effect brought by micro-cars is necessary to be figured out in research to check the extreme situation. So the micro-car rate is set up to be full in Assumption 1. The convergence criteria for dynamic assignment is set as 15% for travel time on paths. The simulations run different iterations for different micro-car rate to fit the convergence conditions, from 20 to 53 iterations.

Table 3-10 Desired speed setting by assumptions

Assumption	Desired speed (km/h)	
	Conventional car	Micro-car
1	48-58	48-58
2	48-58	40-45
3	48-58	25-30

3.4 Summary of this chapter

This chapter provides a framework of classification on traffic simulation models, before argue to use TCA and VISSIM as simulators in this research. They are both microscopic simulator, and focus on individual drivers' behavior. As difference between driving behaviors of conventional vehicles and micro-cars, as well as difference of the two types of vehicles' physical or technical characteristics is the analysis target, consequently the aboved two simulators are applied.

Cellular Automata (CA) was original proposed in 1948 on (living) biological systems. It is applied in many fields up to now, traffic flow, pedestrian behavior, escape and panic dynamics, the spreading of forest fires, population growth and migrations, cloud formation, ant colonies and pheromone trails, etc. It has four elements, the physical environment, cell's status, cell's neighborhoods, as well as a local transition rule, also in

Traffic Cellular Automata (TCA). A multi-cell TCA is developed first, where one unit cell equals 4 meters, and one conventional vehicle occupies two cells, one micro-car occupies one cell, which means the smallest unit is 4 meters whatever for the speed or acceleration. To provide more precise results, another multi-cell TCA is developed following the first one, in which one unit cell equals 1 meter, so the smallest unit is deduced from 4 to 1. And hysteresis loop as well as metastable state can be found in that model. The validation results also testify accuracy of developed TCA to simulate traffic flow.

Psycho-physical car-following driver behavior model is used in VISSIM for longitudinal vehicle movements, and is well depicted in that simulator. A rule-based algorithm for lateral movements is also very detailed in VISSIM. These are also the reason to apply it for comparison and validation with previous developed TCA model on road segment. The results from simulation for road segment demonstrate that TCA is more appropriate for segment analysis, because it can keep density constant, and obtain curves which is more convenience to justify the advantage and disadvantage for all density region, provided that TCA is precise enough for simulating traffic flow which already proved after TCA's development. And only plots can get from VISSIM, furthermore, those plots is so scattered that even qualitative analysis is not easy to acheive. In simulating the small network, VISSIM performances well, after that much time has been spent to calibrate and validate the model. Different desired speed for micro-cars are set for three assumptions, and the simulation results will be analyzed in Chapter 4 to 6 for traffic flow, traffic safety, as well as environmental influence of micro-cars.

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CHAPTER 4

ANALYSIS OF INFLUENCE ON TRAFFIC FLOW

This chapter shows results on the basis of traffic flow analysis of mixed traffic of micro-cars and traditional vehicles. The road segment level analysis coming in section one, and then following the downtown small network level and metropolitan nektwork level.

4.1 Road segment level

Simulations are completed using the developed TCA model and VISSIM. Results from two continuous developed TCA models are shown first, then following the results from VISSIM. After that, there comes a comparison between the results of TCA and VISSIM.

4.1.1 Results from TCA

4.1.1.1 Results from the first multi-cell model

Micro-car rate is set to range from 0% to 100% with interval of 10% in this model. Figure 4-1 shows traffic flow by density and micro-car rates on expressway calculated from TCA. From the figure, we can see that the flow comes up as r increases especially when the density is from 75 to 250 veh/km. The curve in which r equals 0% is especially different from the other curves, the flow is higher than any other curves when density is from 25 to 50 veh/km, but is lower than all the other curves when that is from 75 to 250 veh/km. It is because the highest speed of normal car is higher than micro-car, and this superiority is obviously revealed when vehicle quantity is less, but as vehicle quantity becomes more and more, the superiority of micro-car is revealed. In conclusion, when density is more than 75, higher rate of micro-car gives higher flow.

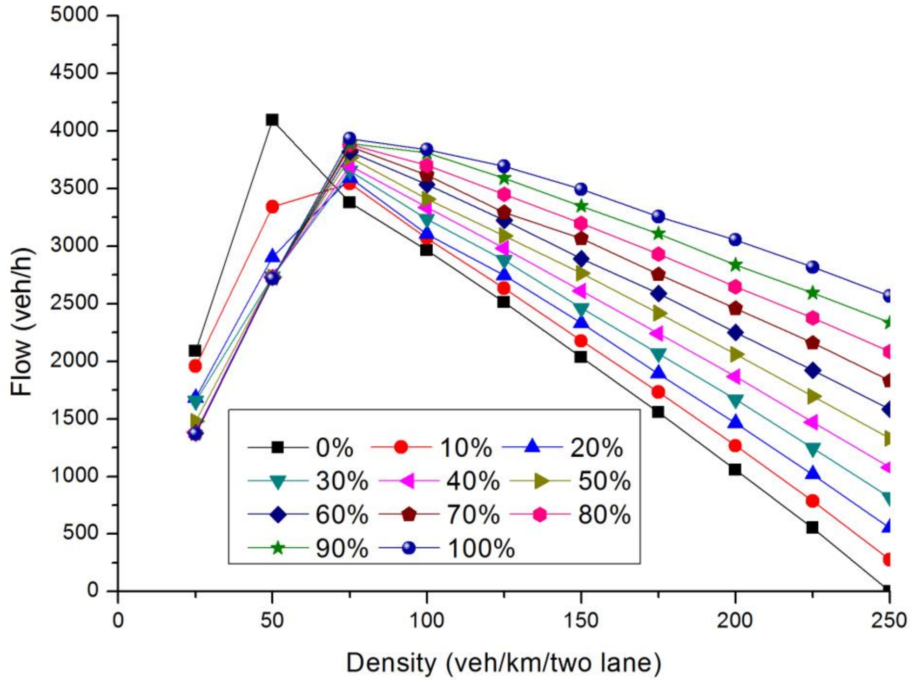


Figure 4-1 Flow-Density fundamental diagram under different micro-car rates on expressway for the first developed TCA model

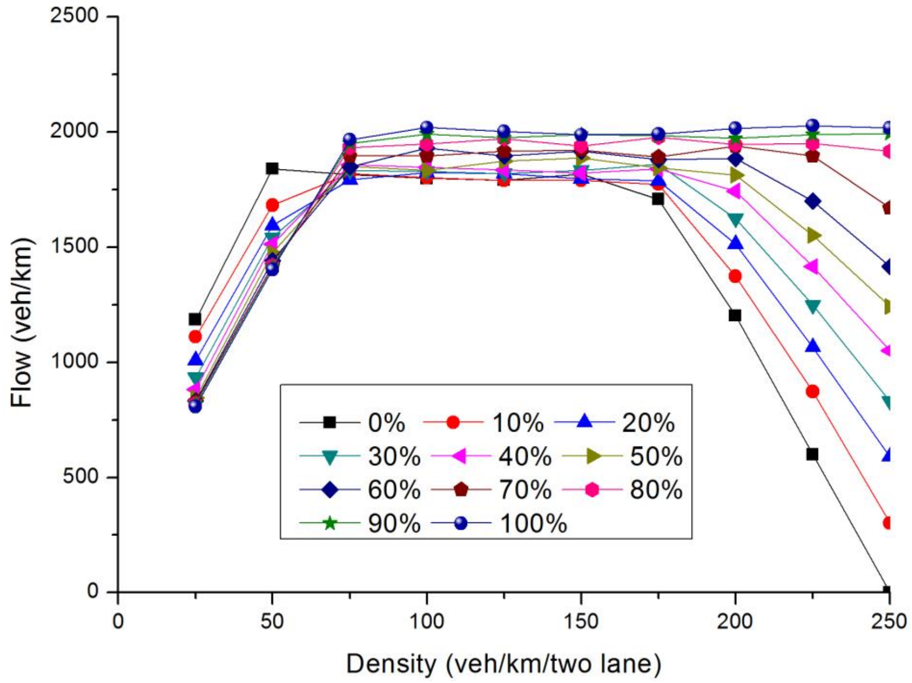


Figure 4-2 Flow-Density fundamental diagram under different micro-car rates on arterial road for the first developed TCA model

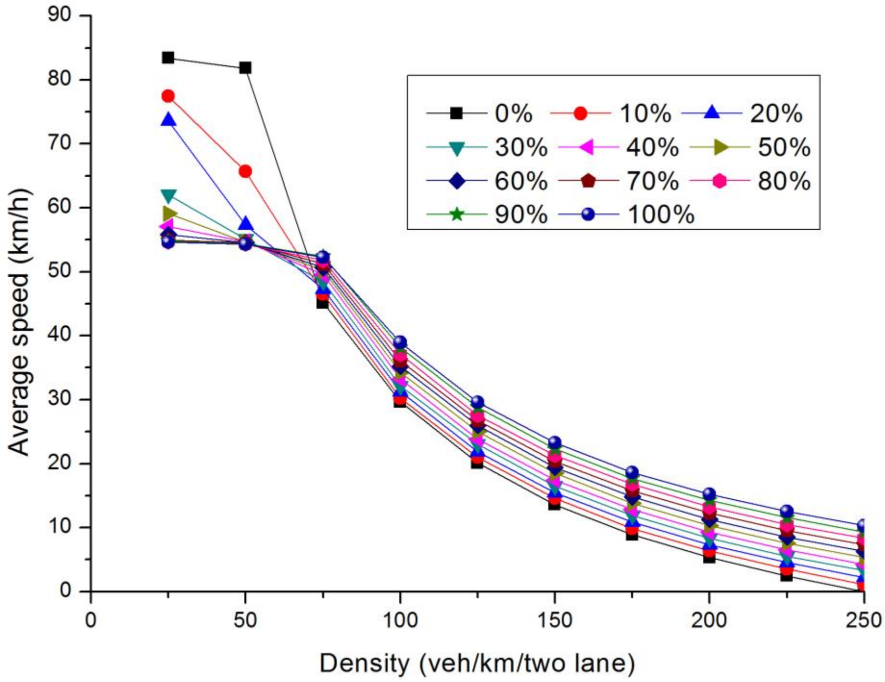


Figure 4-3 Average speed-Density fundamental diagram under different micro-car rates on expressway for the first developed TCA model

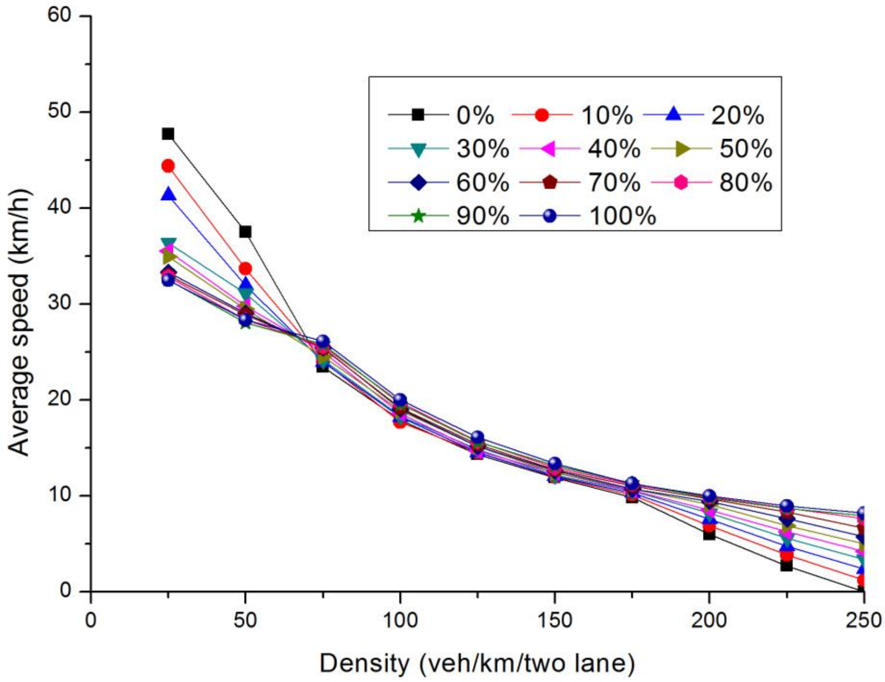


Figure 4-4 Average speed-Density fundamental diagram under different micro-car rates on arterial road for the first developed TCA model

Flow by density and micro-car rates on arterial road with a traffic signal from TCA is shown in Figure 4-2. This figure illustrates a similar trend to Figure 4-1, although the flow is about half of that in Fig.3 because of the signal. The flow comes up as r increases especially when density is from 75 to 250, but not so obvious for some points especially when the density is from 25 to 175. So in condition of arterial road with signal, introducing micro-car is better when there are more than 75 vehicles per km per two lanes.

From Figure 4-3, we can see that, the average speed in traffic flow goes down as number of vehicles comes up. When density is more than 75, the more micro-cars ratio gives the higher speed. The speed of all-normal-car flow is highest when vehicle quantity is less, but when density being more than 75 veh/km/two lane, the situation changes, the speed of all-normal-car flow becomes the lowest one.

On the arterial road (Figure 4-4), trends of curves mostly share the same characteristics with those of expressway. For details, speed of all-normal-car flow becomes the lowest one when density is more than 70, but the characteristic that the more micro-cars ratio gives the higher speed is not so obviously under condition of density being 75 to 250. The average speed of traffic flow mixed less micro-cars goes down faster than the ones with more micro-cars which causing the phenomena that higher rate of micro-car gives higher speed obviously when density is more than 175 veh/km/two lane on road.

For the traffic flow analysis, the observations can be summarized as follows:

1) In the relationship between traffic flow and number of vehicles, more micro-cars give more driving through vehicles especially when density is more than 75.

2) In the relationship between average speed and number of vehicles, more micro-cars give less driving through time in the same condition of (1).

4.1.1.2 Results from the second developed multi-cell model

Micro-car rate interval for simulation using this model is increased to 20%, as the difference between results of every adjacent 10% micro-car rate is not so distinct, and the curves may adhere to each other, which cause vague recognization and then influence the analysis.

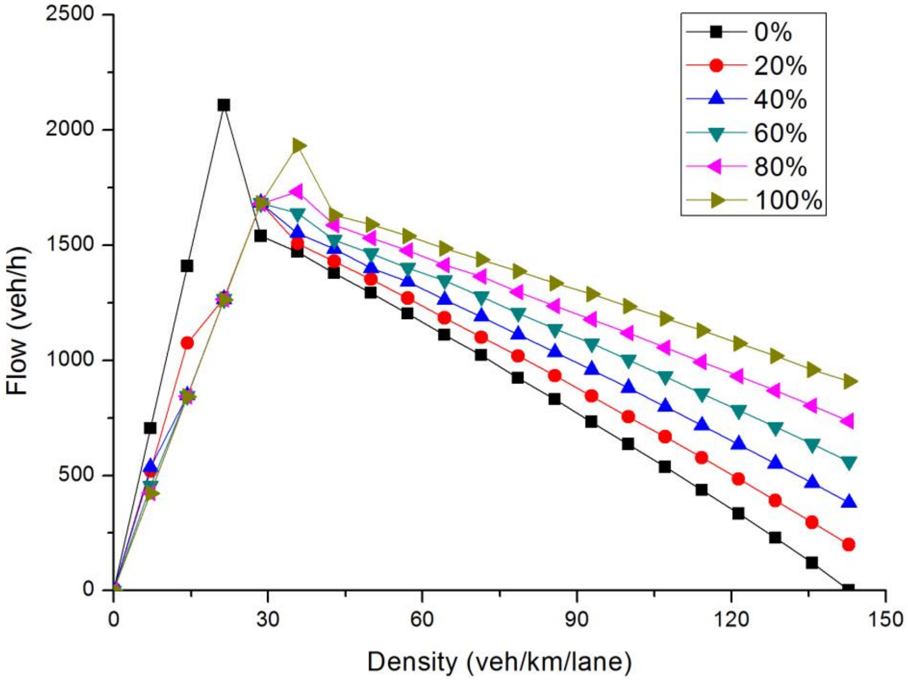


Figure 4-5 Flow-Density fundamental diagram under different micro-car rates on expressway for the second developed TCA model

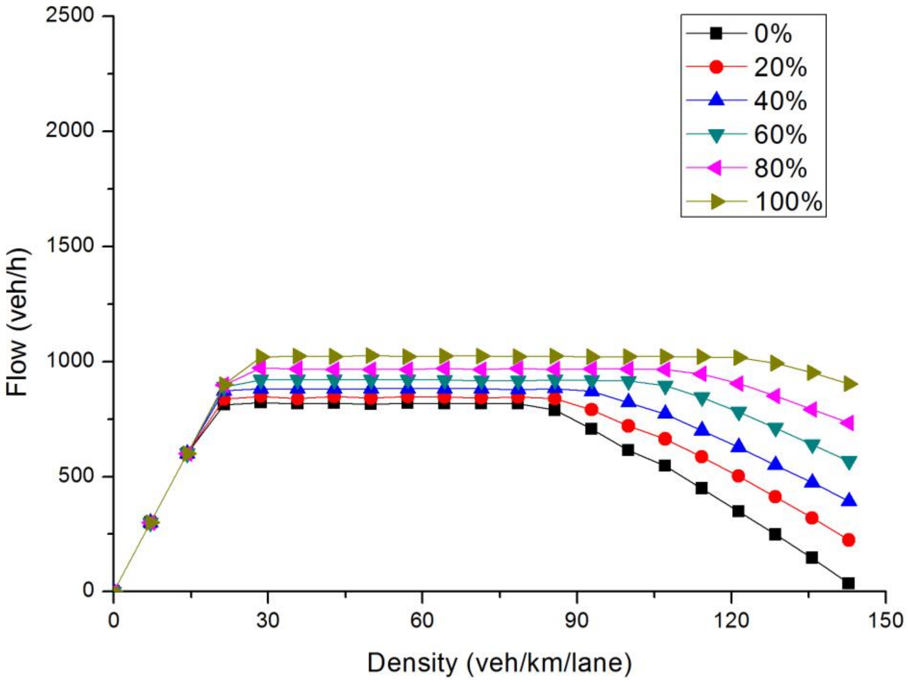


Figure 4-6 Flow-Density fundamental diagram under different micro-car rates on arterial road for the second developed TCA model

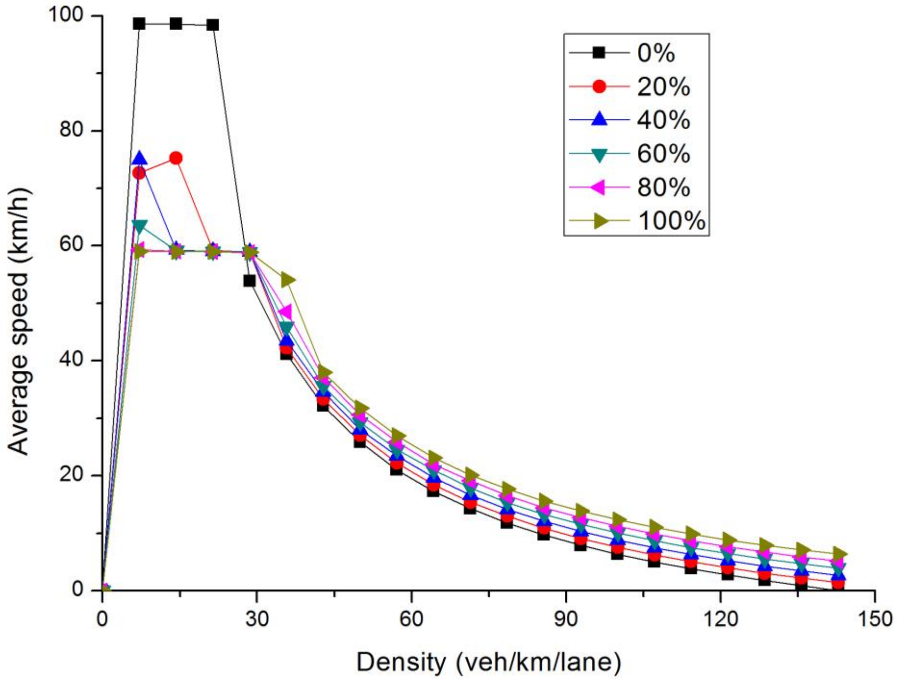


Figure 4-7 Average speed-Density fundamental diagram under different micro-car rates on expressway for the second developed TCA model

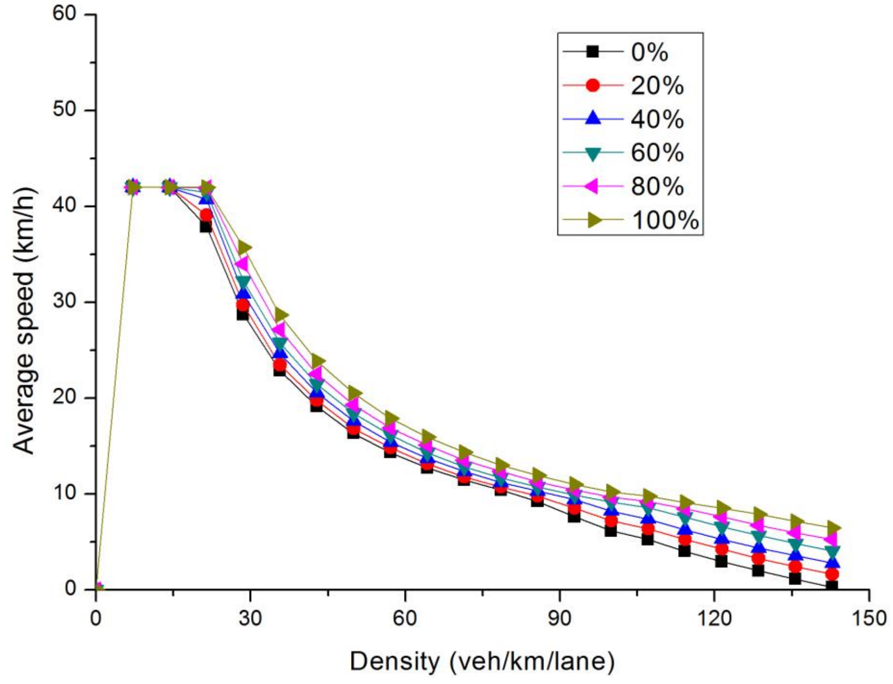


Figure 4-8 Average speed-Density fundamental diagram under different micro-car rates on arterial road for the second developed TCA model

On arterial road, there is a sharp decrease after traffic flow increase to its tip, especially for the no micro-car and no-conventional car case, the phenomena has already been analyzed in the TCA introduction developed in this research of Section 3. There is a hysteresis loop and metastable state.

Lower traffic flow for the same density can be found because of the higher lower probability 0.3 in the second model compare with the 0.2 in previous model. Maximum traffic flow calculated from the two models is both normal compared to realistic data for both expressway and arterial road. The curves' trends from two models are similar except that two sharp points. Micro-cars will performance its advantage on more than 30 veh/km density expressway and arterial road segments.

4.1.2 Results from VISSIM

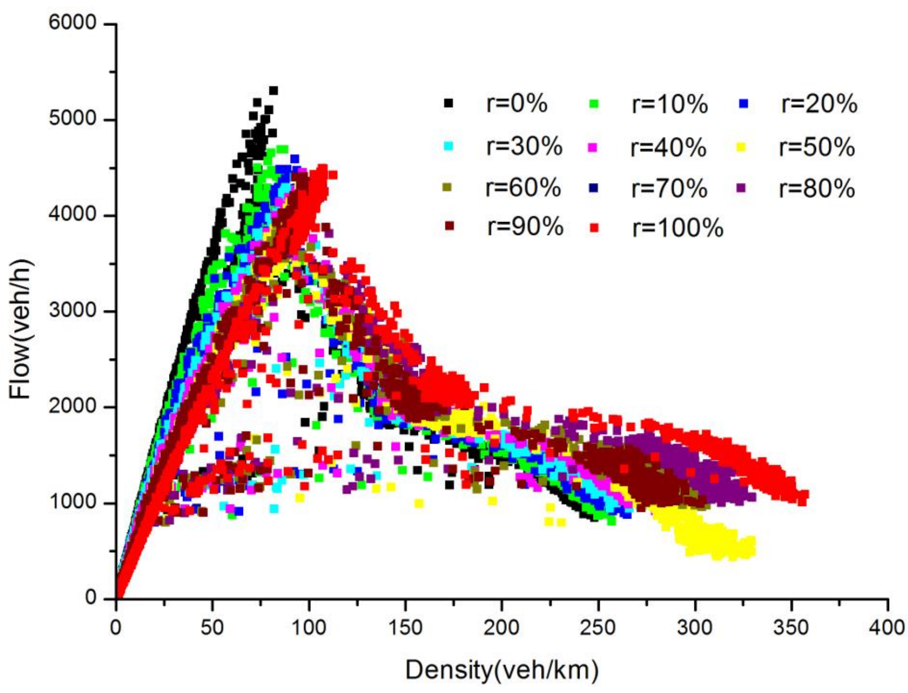


Figure 4-9 Traffic flow and density on expressway in VISSIM

There are some plots not according with traffic flow theory, which are scattering significantly lower than other plots. That means the flow is lower under the same density in some special conditions because of unexpected lower speed. In Figure 4-9, flow comes up as r increases especially when density is from 100 to 350 veh/km and r is from 0% to 80%. When r is 90%, there is a bit of skipping back, and then r equaling 100% gives the highest flow when density is from 100 to 350 veh/km. The plots of density from 0 to 100 veh/km are similar to that from TCA.

The plots in Figure 4-10 describe a peak when density is more than 100 veh/km, while ones in Figure 4-9 get a peak value at density being 75 to 100 veh/km for different micro-car rate. Traffic flow with more micro-cars get the peak value at higher density, and the density corresponding the peak value is higher on arterial road, which is ascribed to traffic light. The traffic light lower the highest volume of the flow, but at the same time allow more vehicles driven on unit length road before traffic volume reach at peak value. The plots obtained from arterial road in VISSIM are inclined to be more concentrated at several areas: they scattering somewhere, and disappearing somewhere. The results from VISSIM make analysis difficult, but it can be concluded from the general trends that introduction of micro-cars gives more obvious merit than that on expressway when the free-steam flow gets away.

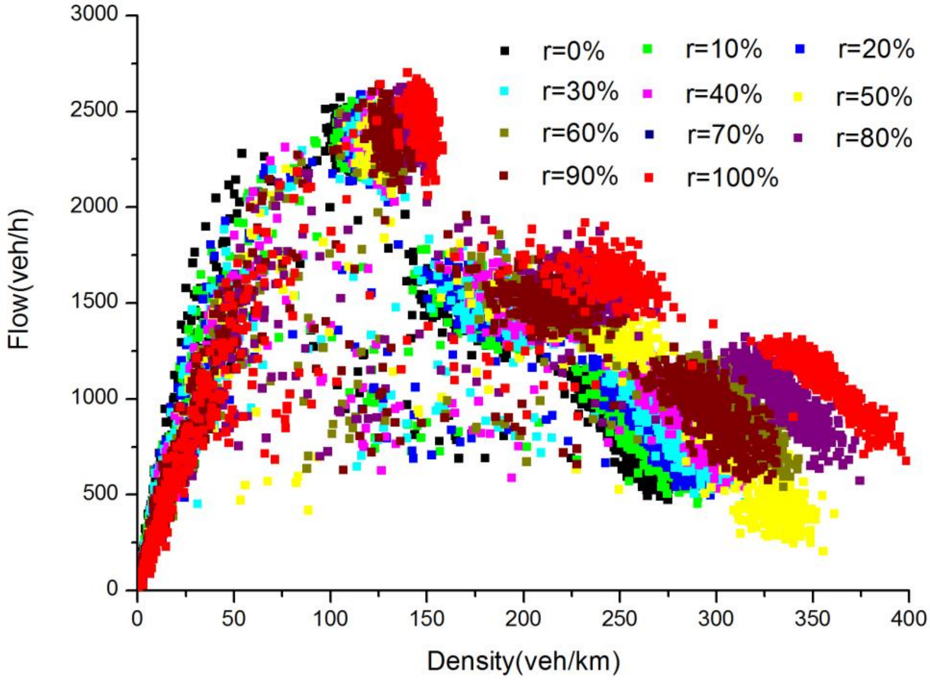


Figure 4-10 Traffic flow and density on arterial road in VISSIM

4.1.3 Comparison between the results of TCA and VISSIM

For road segment level, TCA is first applied for its calculation efficiency due to simple rules, and ability to simulate many traffic phenomena. However, TCA is doubted about its ability to simulate the realistic traffic, also because of its simple rules. So VISSIM is used for validation and comparison with the developed TCA model.

As there are 10 types of micro-car rates and two kinds of roads, the comparison of TCA and VISSIM will make 20 figures, and the tendencies are similar. So the fundamental diagrams of density and flow for r being 50% both on expressway and arterial road is shown here representatively.

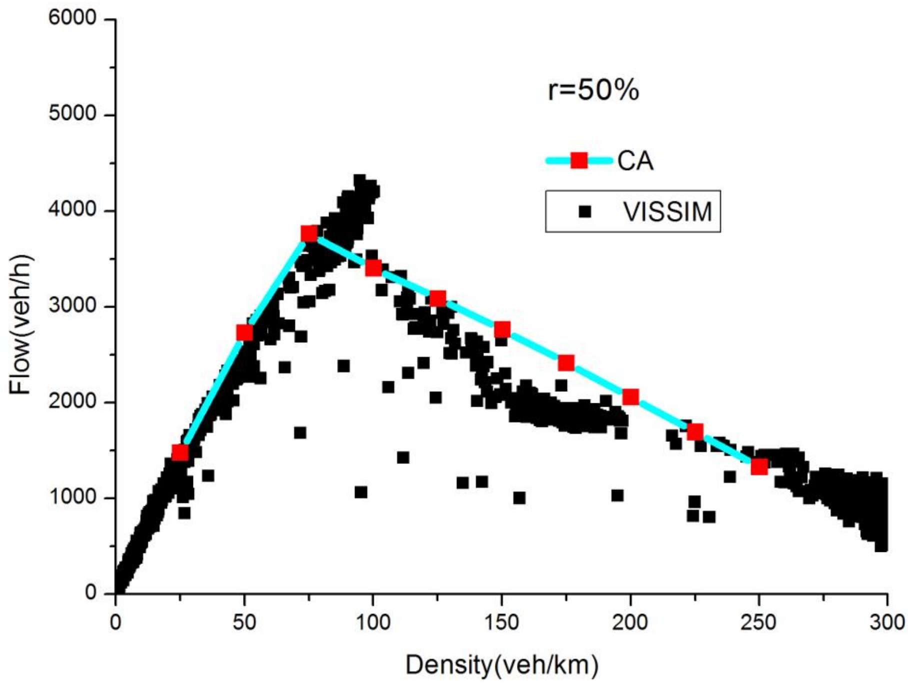


Figure 4-11 Traffic flow and density in TCA and VISSIM on expressway when r equals 50%

In Figure 4-11, tendencies from TCA and VISSIM are similar. There are two exceptions, one is that VISSIM has some higher flow plots which is more consistent with traffic theory, that may ascribe to too less plots obtained from TCA. Another exception is relationship between density and flow of VISSIM when density is more than 100 veh/km are not linear as that from TCA, the plots' trend is not stable, and they are both different from the traffic theory by Kerner. It is not easy for analysis if there are too many scattered plots, or unstable trend. So TCA have superiority for the analysis which focus on difference of traffic with different rate of micro-car, not on characteristics of traffic flow, i.e. the unstable points get from VISSIM.

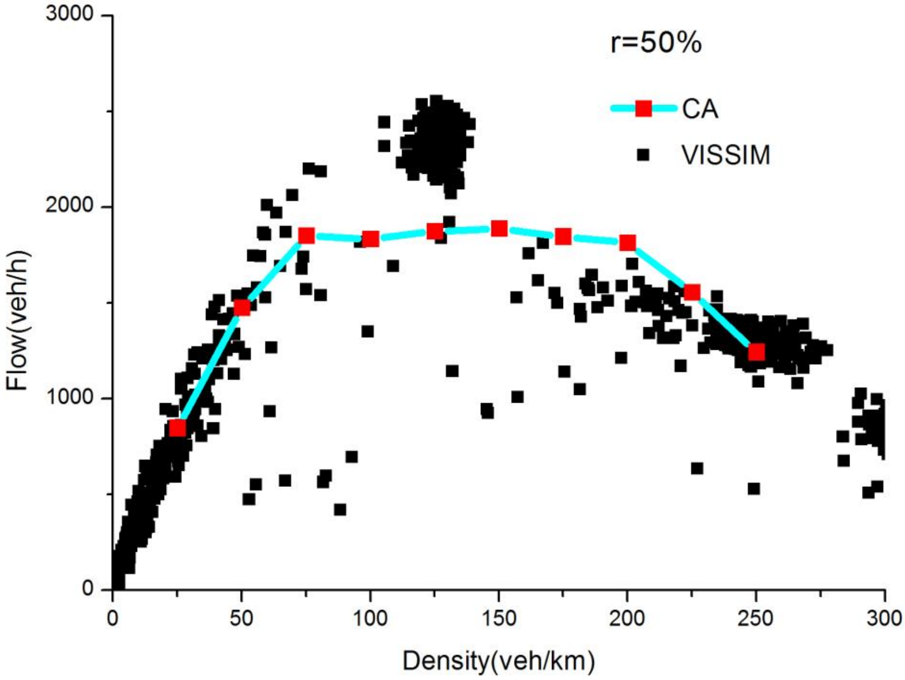


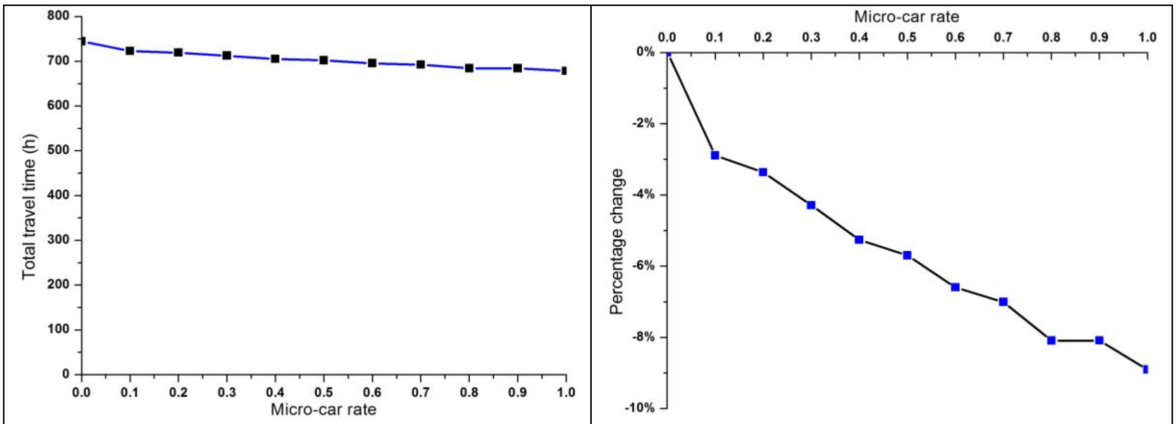
Figure 4-12 Traffic flow and density in TCA and VISSIM on arterial road when r equals 50%

In Figure 4-12, the results from two simulators are not so similar. In TCA, when density is from 75 to 200 veh/km, the flow just changes a little. But that in VISSIM experiences an up and down, where the flow get to the highest when density is around 125 veh/km, and there lack plots in some density range. The smooth curve from TCA is because of the signal, while the plots from VISSIM is not so reasonable on arterial road. So for the simulation on arterial road for mixed micro-car and conventional car, TCA is also more feasible for analyzing difference of traffic flow with different micro-car rate.

About the computation time, one run of TCA is about 90s, while that for VISSIM is about 300s, which is over 3 times more than that of TCA, under the same condition. It confirms that TCA model is computationally extremely efficient. In conclusion, TCA is more appropriate for the road segment level analysis in this research.

4.2 Downtown small network level

Average delay per vehicle, average number of stops per vehicle, average speed, average stopped delay per vehicle, total delay time, total distance traveled, latent delay time, latent demand, number of stops, number of vehicles in the network, number of vehicles that have left the network, total stopped delay, total travel time for all vehicle types, and average speed, total delay time, as well as total travel time for conventional cars and micro-cars respectively, are set as the output for network performance evaluation in the simulations.

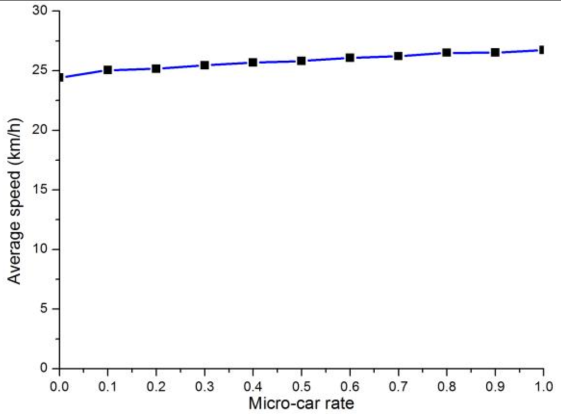


Total travel time change | Percentage change of total travel time

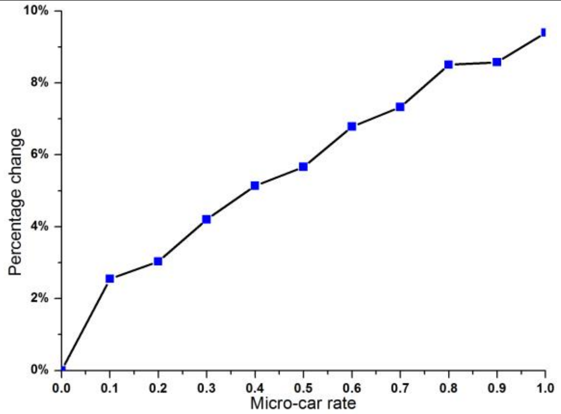
Figure 4-13 Network total travel time of different Micro-car rates for Assumption 1

Figure 4-13 demonstrates us positive effect of micro-cars to travel network, the total travel time decreases as micro-car rate increases for Assumption 1. The left part gives the actual value, while the right part shows the percentage change. The total travel time ranges from 678.283 to 744.558 hours. As the actual changed value is small, the percentage changes are calculated for more minute and accurate analysis. The value descends sharply when micro-car rate change from 0.0 to 0.1, then keep a stable decline speed until 0.8 micro-car rate, and alleviate decrease speed between 0.8 and 0.9, and decrease a little rapid again from 0.9 to 1.0. The network travel time deceases about 5.5% if there are 40% micro-cars in traffic, which is the expected micro-car share in United

Kingdom and Germany automobile market in 2017.



Average speed change



Percentage change of average speed

Figure 4-14 Network average speed of different Micro-car rates for Assumption 1

Both conventional cars' and micro-cars' average speed increase as micro-car rate rise. As the travel distance cost parameter for micro-car is lower than conventional car, micro-car may choose longer distance route, and consequently the travel time increase after introduction of micro-cars from this aspect. However, it means fewer vehicles choose the shorter route if the condition mentioned happen, then the vehicles in shorter route will have higher speed. And also the travel speed will increase because of more space for traffic, if the smaller foot print micro-cars are driven on road. So the three impact factors will achieve a balance point, and the point is proved to be always decreased travel time after introduction of micro-cars, and maybe sharply decreased, or gently decreased, as there are the different decrease rates when micro-cars' desired speed is set to be 48-58km/h, the same with conventional cars. If the total travel time decreases, of course the change of average speed will occur to be increasing, Figure 4-14 convinces it, and the average speed ranges from 24.427 km/h to 26.723 km/h. Its percentage change image (the right part) exactly gives inverse trend as micro-car rate rises comparing with that of total travel time, and the slopes are totally identical for every micro-car rate increase step.

Table 4-1 Average speed of conventional cars and micro-cars separately for the three assumptions

(1) micro-cars' desired speed being 48-58km/h; (2) micro-cars' desired speed being 40-45km/h; (3) micro-cars' desired speed being 25-30km/h. MC: micro-car rate; All: all vehicle types; C: conventional car; M: Micro-car. The unit for each value is km/h.

	Assumption 1			Assumption 2			Assumption 3		
MC	All	C	M	All	C	M	All	C	M
0	24.54	24.54	0	24.54	24.54	0	24.54	24.54	0
0.1	24.863	24.875	24.751	24.654	24.775	23.64	22.938	23.296	20.213
0.2	25.104	25.092	25.149	24.602	24.777	23.927	21.915	22.441	20.052
0.3	25.439	25.427	25.464	24.641	24.908	24.052	21.463	22.199	19.94

Figure 4-15 to 4-17 show the percentage change of different parameters for network performance evaluation, of different assumptions and micro-car rates. For Assumption 2, even micro-cars have lower desired speed than conventional cars, and they still provide positive effects for the investigated travel network. The reason is that the average speed in urban traffic is usually lower than 30km/h (for the base model of this research, also Assumption 1, the network average speed is 24.427km/h), because of the intersections and traffic lights. And the desired speed of micro-cars is much higher than the base model's average one in that assumption.

When turning to Assumption 3, the situation becomes negative, which is ascribed to a not so much higher desired speed of micro-cars when compared with the base model's network average speed. So it can be deduced that, if only the desired speed of micro-cars is a little lower than that conventional vehicles, and much higher than the base model's average speed, no negative effect will be brought for congestion point of view.

Different results are got for different micro-car rate for every same assumption. More micro-cars in traffic will cause less total travel time if micro-cars' desired speed is 48 to 58km/h or 40 to 45km/h. More ones in traffic will result in more total travel time under the condition of micro-cars' desired speed being 25 to 30km/h, inversely. Obviously, the lower desired speed of micro-cars make the average speed of total network lower, and then bring an increase to the total travel time in network. More such micro-cars, more interference to the other higher desired speed normal vehicles, accordingly longer travel time for trips.

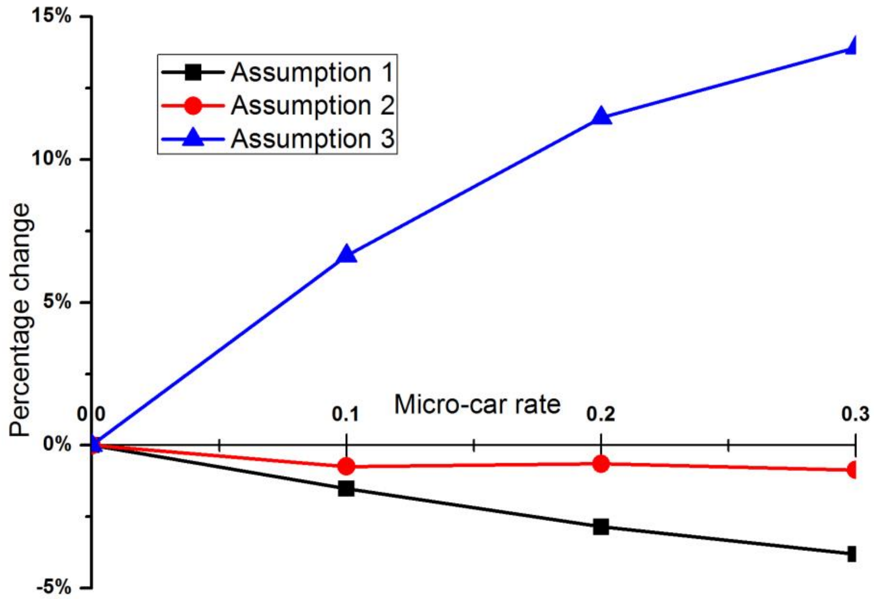


Figure 4-15 Percentage change of network total travel time of different Micro-car rates

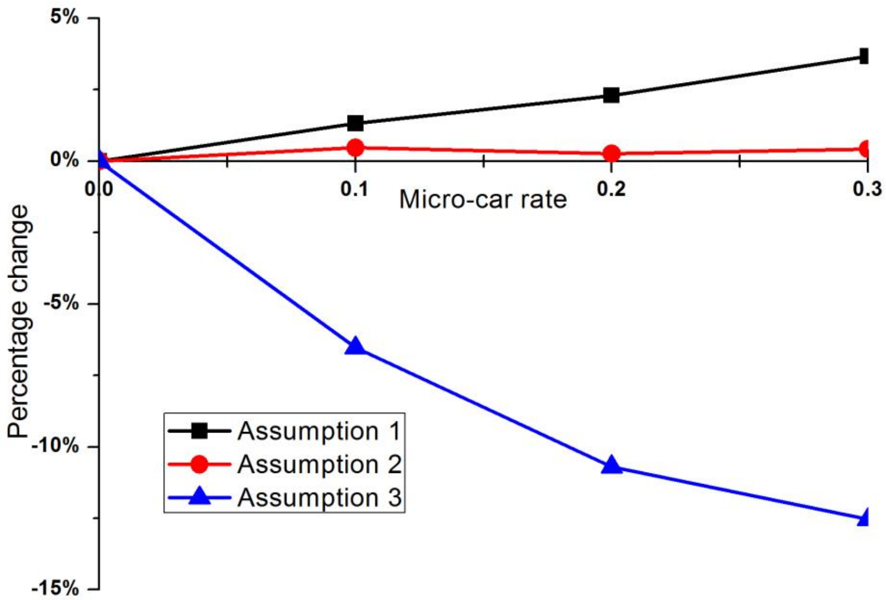


Figure 4-16 Percentage change of network average speed of different Micro-car rates

Table 4-1 shows the average speed difference of the two types of vehicle in different parameter settings. In Assumption 1, the two kinds of vehicle have similar average speed, and micro-cars' speed is even higher when their rate equals 0.2 or more. The average speed, for all the vehicle types, or conventional cars and micro-cars respectively, all rises after the introduction of micro-cars, and more micro-cars, more rises, which can be explained by the smaller size as well as positive effect from different route choice behavior of micro-cars as demonstrated above. In that case, the micro-cars promote the travel efficiency.

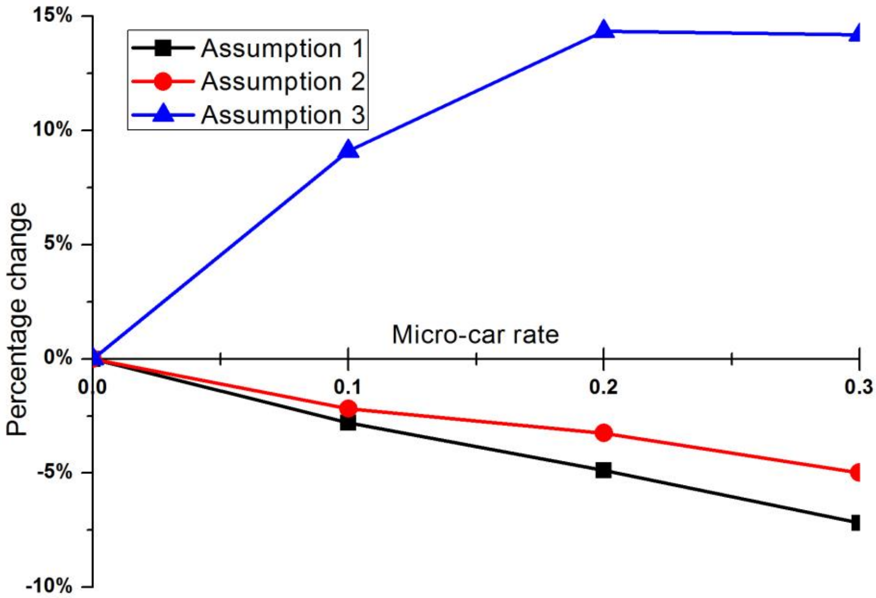


Figure 4-17 Percentage change of network total delay time of different Micro-car rates

For Assumption 2, the total average speed also becomes higher as micro-car rate increases, and similarly the average speed of conventional cars or micro-cars, which proves that the effect from smaller size of micro-cars and positive effect from different route choice behavior of micro-cars still notch above the negative effect from different route choice of micro-cars. Nevertheless, the average speed of micro-cars is always lower than conventional cars', not the same characteristic when compared to Assumption 1. Every value under same condition with Assumption 1 in Assumption 2 is lower than that of the former assumption in with-micro-car traffic, because of the lower desired speed set for micro-cars. For Assumption 3, all the values drop as micro-car rate increases, distinctly due to the much lower desired speed of micro-cars.

4.3 Metropolitan network level

The results of traffic assignment on 2020 Nagoya metropolitan network in preceding study (Kanamori, et al. 2011) are used in this study as traffic demand on each link, which was calculated for the investigation of the impact of introducing electric vehicles on road network. The travel speed of every link without micro-cars can be obtained from predicted traffic assignment data of 2020 in Nagoya metropolitan area. And traffic density of every link can be calculated using travel speed and speed-density function calculated from the TCA results by doing curve fitting. Then traffic density is used as input together with micro-car rate, as well as density-speed or density-needed power function (also calculated from TCA results by doing curve fitting) to figure out travel speed or needed power per vehicle per km of every link. Here the micro-car rate is assumed to range from 0% to 25% (step being 5%), but with the same micro-car ratio in all links for each assumption. See technical route in Figure 4-18.

The simulation results from the developed two-lane cellular automata model on road segment with micro-cars are used here. Relationship between average speed and density, density and average speed, as well as density and power needed per km per vehicle for 0% to 25% micro-car rate traffic flow with interval of 5% is made into function to calculate the average speed or total travel time of network, for network performance analysis, and needed power of the total traffic network as an indicator of emission for environmental analysis, when it is assumed that there are some percentage micro-cars in traffic. The average speed and total travel time of network are analyzed in this section to quantify micro-cars' traffic congestion consideration impacts on every link.

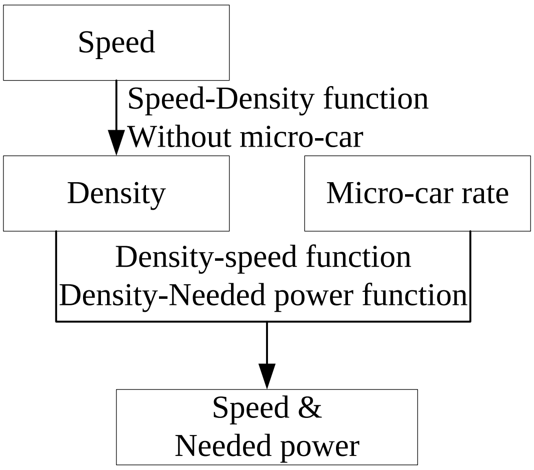


Figure 4-18 Flowchart of micro-cars' effect calculation for 2020 Nagoya metropolitan network

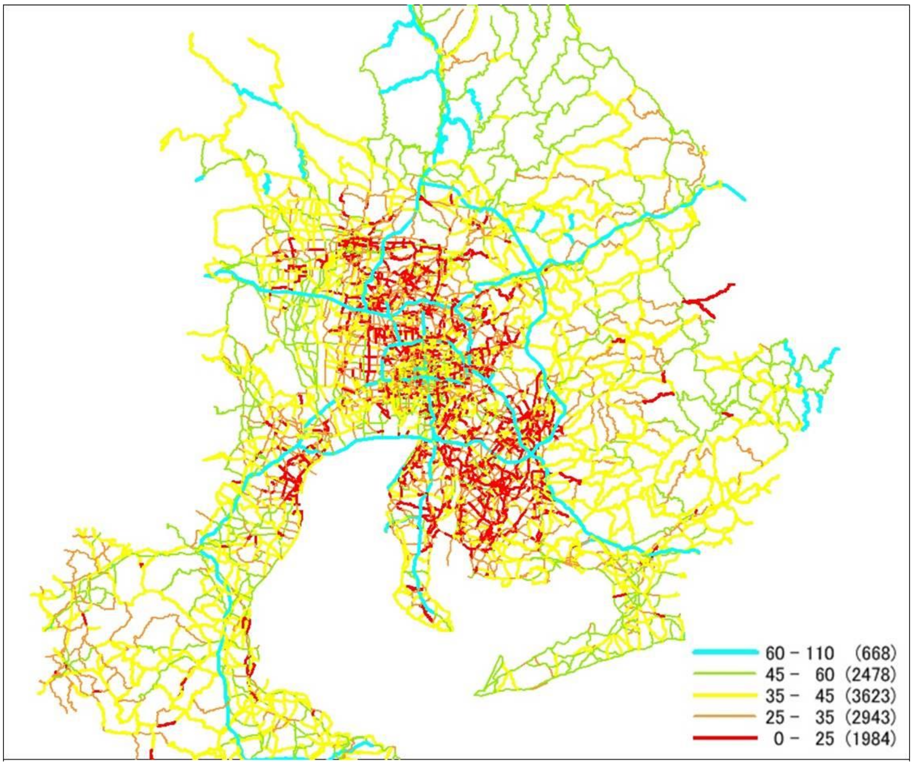


Figure 4-19 Nagoya metropolitan road network on 2020

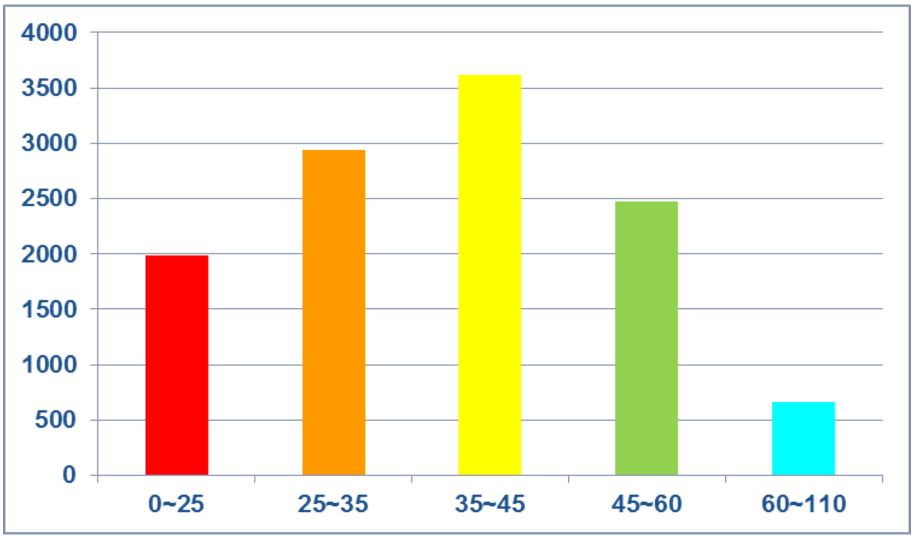


Figure 4-20 Speed distribution of Nagoya metropolitan network on 2020

There are 100 cells counting as 400-meters in length on a expressway with two parallel lanes, the length of a cell is 4 meters, which is interpreted as the length of a micro-car plus distance between vehicles in a jam. It was assumed in the simulation that one micro-car occupies one cell, while one conventional car occupies two cells. Thus 8 meters is the headway space of a conventional car in a jam. One time step lasts 1 second, which is of the order of the reaction time of humans.

Table 4-2 Distribution of speed limit in Nagoya metropolitan network

Speed limit	100	80	70	60	50	45	40	35	30	25	20
Number of links	543	2	89	1685	3548	5	4761	120	912	839	42

Because it is not as simple as that on road segment, vehicles just need to abide by one speed limitation, there are different speed limitations for different road category in the network. The links in this study are categorized in four types. Check the distribution of speed limitation in network in Table 4-2. Different maximum speed is set in the simulation according to road classification in this research (Table 4-3). The links have speed limitation of 70 to 100 km/h belong to category 1, conventional vehicles have the maximum speed of 100.8 km/h, while micro-cars are forbidden to higher their speed over 57.6 km/h; 50 to 60 km/h links are category 2, 35 to 45 km/h links are category 3, and 20 to 30 km/h ones belong to category 4, and the two types of vehicles have the same speed limitation for these three categories.

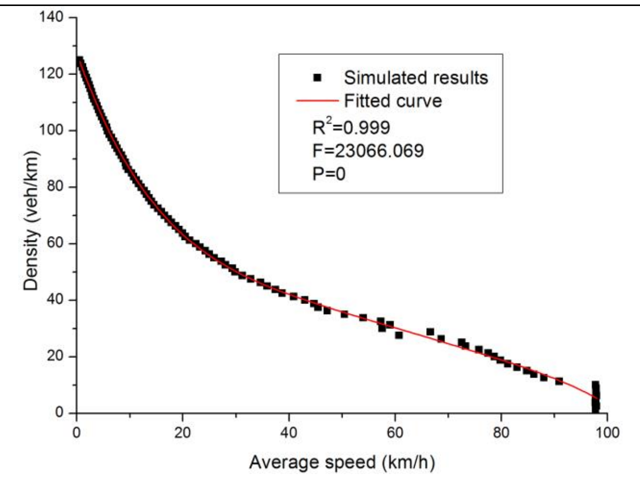
Table 4-3 Road category for speed limitation

	Realistic speed limitation (km/h)	Maximum speed in simulation (unit cell/s)	
		Conventional car	Micro-car
Category 1	70,80,100	7 (100.8 km/h)	4 (57.6 km/h)
Category 2	50,60	4 (57.6 km/h)	4 (57.6 km/h)
Category 3	35,40,45	3 (43.2 km/h)	3 (43.2 km/h)
Category 4	20,25,30	2 (28.8 km/h)	2 (28.8 km/h)

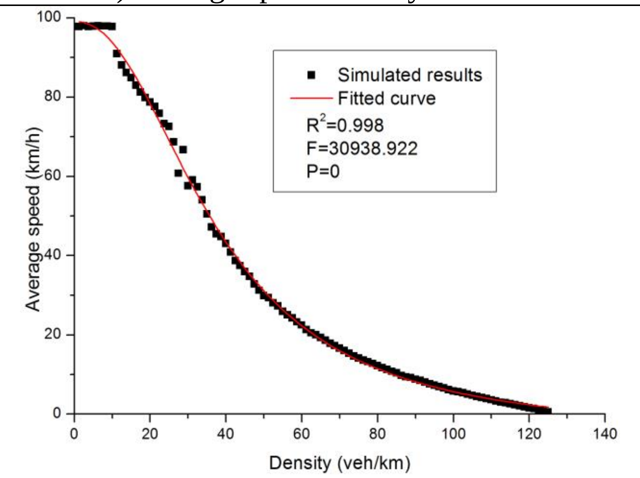
The input data of the simulation are the number of vehicles on the road ranging from 20 to 200 with step 20 with different rates of micro-cars (mentioned as r in following expression) whose range is from 0% to 25% with interval 5%. Simulations in which brake probability (mentioned as p in following expression) equals 0.2 and lane changing probability equals 0.8 are used. As the simulation includes stochastic elements, each simulation was ran ten times to calculate the average values of the results to avoid randomness to some extent.

The output results are as follows: Average speed of all vehicles in the last counted 600 time steps; needed power per vehicle per km.

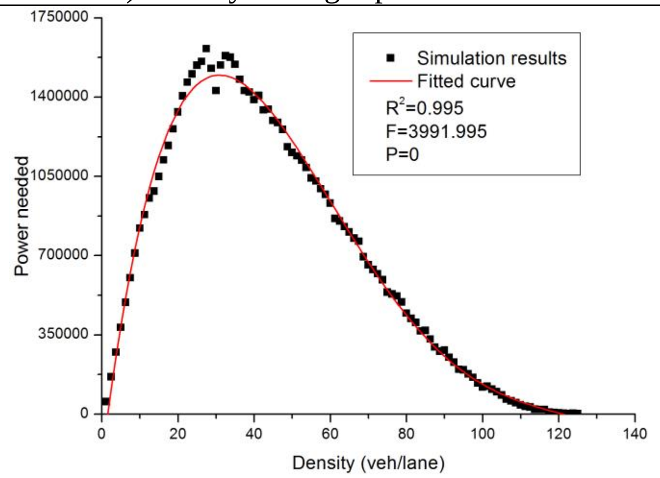
The relationships between average speed and density, density and average speed, as well as density and power needed are calculated by curve fitting using the simulation results from TCA described above for different micro-car rate. And curve fitting results require validations. In each category, there are so totally 13 functions, between which 1 (0% micro-car) for speed-density function, separately 6 (0% to 25% with interval 5%) for density-speed and density-needed power function, consequently 13 multiply 4 categories equal 52 functions for the whole caculation. After many trials, polynomial curbve fitting is applied, and the polynomial order is 5. All the cureve fitting get R^2 over 0.98, and P=0, as it is not necessary to show all the figures, see Figure 4-21 for one micro-car rate in category 1.



a) Average speed-density function



b) Density-average speed function



c) Density-power needed function

Figure 4-21 Curve fitting results of micro-car rate 0.05 for category 1

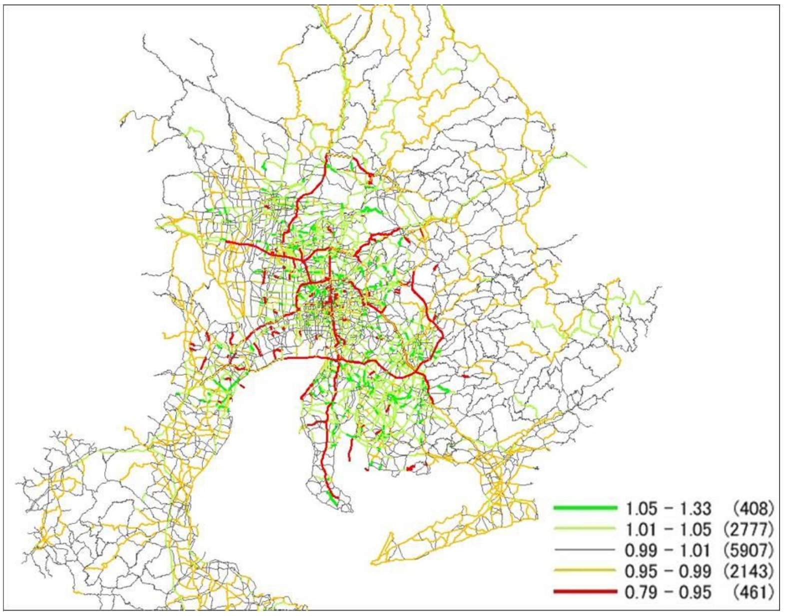


Figure 4-22 Percentage change of travel speed for 5% micro-car demand by 0% micro-car demand of every link

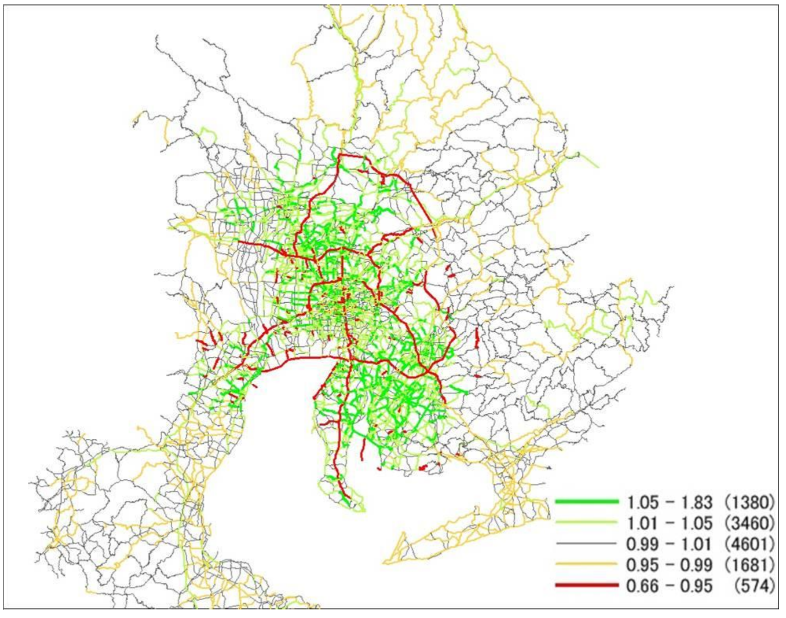


Figure 4-23 Percentage change of travel speed for 15% micro-car demand by 0% micro-car demand of every link

Figure 4-22 to 4-24 demonstrate that when there is more micro-cars travel demand, there are more green links, which have higher speed than no-micro-car traffic. So these diagrams illustrate micro-cars assigned in network relieving congestion.

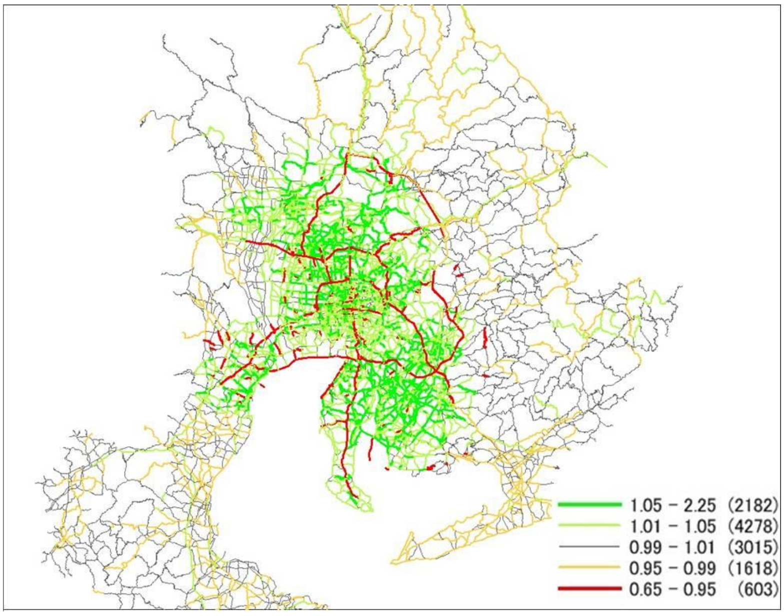


Figure 4-24 Percentage change of travel speed for 25% micro-car demand by 0% micro-car demand of every link

However, in Figure 4-25, the total average link travel speed actually have small change after introduction of micro-car, which attributed to a balance between micro-cars' influence on category 1 and category 2,3,4. For category 1, mostly they are expressway, and micro-cars have no supriority as concluded from the segment level results. For category 2, 3 and 4, the condition is complemently adverse, micro-cars can find their positive effect on traffic flow, i.e. they can relieve congestion, which identify with the analysis in road segment level. And most links belong to these three categories (11912 links for them, while only 634 links for category 1), which can explain why positive effect of micro-cars on those roads can neutralize the so comparative huge negative effect on category 1 links (around 30% decrease in average link travel speed when micro-car rate is higher than 15%).

Figure 4-26 shows the detailed average link travel speed changing trend by different micro-car rate. The increase of category 2 and 3 is higher than that of 4, which is due to little traffic demand on those roads belong to category 4, and micro-cars do not have better performance than conventional cars in free flow traffic according to the previous analysis in road segment level.

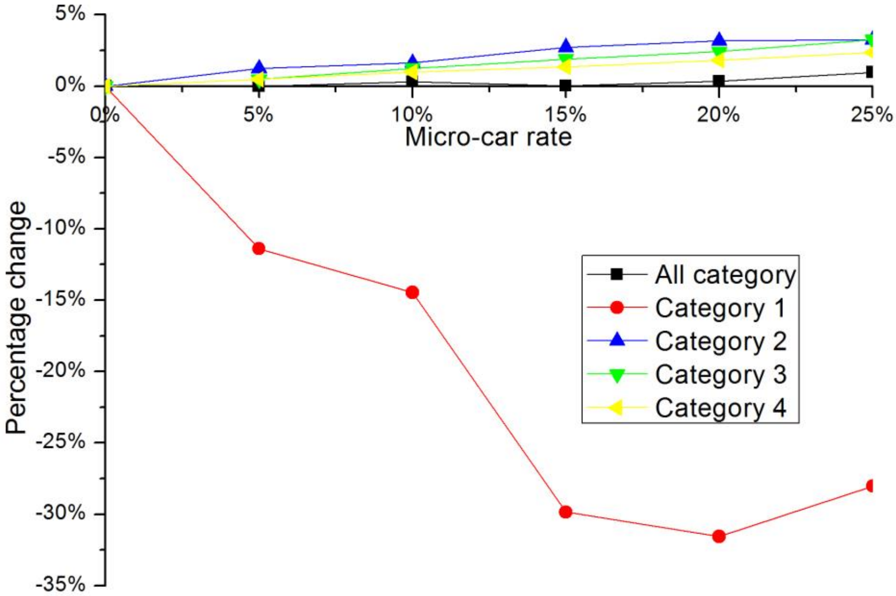


Figure 4-25 Average link travel speed for different category by micro-car rate in Nagoya metropolitan network

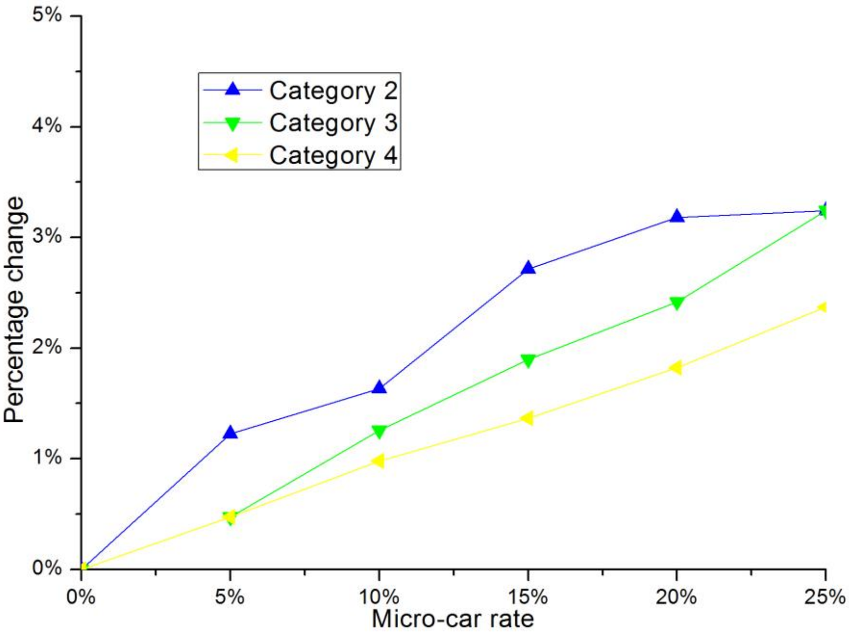


Figure 4-26 Average link travel speed for category 2, 3, and 4 by micro-car rate in Nagoya metropolitan network

So if government continues to forbid micro-cars driven on expressway, it will be good news, because micro-car would decrease the average speed if they are allowed to be driven on expressway. On the contrary, it is acceptable if individuals use micro-cars in normal urban traffic network, and mostly they will bring positive effect on traffic flow.

Figure 4-27 demonstrates micro-cars ability to decrease total travel time of the whole network.

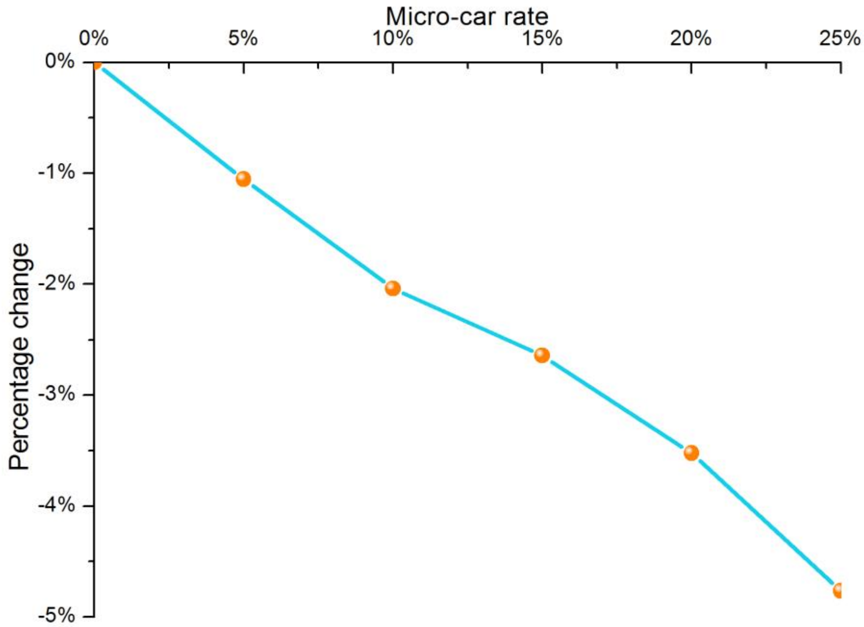


Figure 4-27 Percentage change of total travel time by micro-car rate in Nagoya metropolitan network

4.4 Summary of this chapter

Influence of micro-cars to traffic flow is separately analyzes in segment and network level in this chapter. The introduction of micro-cars may slower the traffic because of their lower speed which will give reason to the following conventional vehicles to slower their speed or change lane, especially on expressway, where the limited speed is usually 100 km/h, higher than the highest design speed of micro-cars, 60 km/h. On the contrast, in urban traffic, introducing micro-cars may alleviate the congestion according to their smaller size which provides more space for driving, also due to their similar maximum speed compared to limited speed in urban traffic network, which does not supply chance for overtaking or deceleration because of the two types of vehicles' maximum speed difference.

References

Kanamori, R., Morikawa, T., Yamamoto, T. (2011): The impact of the difference in EV owners' attributes on vehicle usage patterns and environmental improvement. The 10th ITS Symposium, Tokyo, Japan.

CHAPTER 5

ANALYSIS OF INFLUENCE ON TRAFFIC SAFETY

Micro-cars' lower speed may cause the succeeding conventional vehicles to change lane or have deceleration, and these kind of driving behavior provide negative effect to traffic flow, accidents are easier to happen in the cases. This chapter analyzes the safety influence of micro-cars separately in road segment level and downtown small network level. First, number of lane changing, number of deceleration, as well as coefficient of speed variation is defined to be the three indicators to assess micro-cars' influence to traffic safety. Second, calculation results from TCA are demonstrated and analyzed to conclude micro-cars' safety effect on road segment level consideration. Third, the same three factors are computed from the VISSIM small network to analyze safety effect of micro-cars in downtown small network point of view.

5.1 Assessment of accident risk

5.1.1 Number of lane changing

Assessment of crash risk receives attention all along, and it is a pathway to avoid accidents. Based on 1999 General Estimates System (GES) data, the universe of two-vehicle lane-change crashes in the US consists of 539,000 events, involving 1,078,000 vehicles. This constitutes about 10% of the 12.1 million vehicles appearing in the 1999 GES, and about 9% of the 6.3 million crashes (Sen et al., 2003). Based on Wang and Knipling (1994), it can be safely hypothesized that sideswipe crashes occur when one vehicle intentionally changes lane. Angle crashes, which occur on the inner through lanes of a freeway, are also assumed to be lane-changing related (Pande and Abdel-Aty, 2006). So more dangerousness will exsit, if there are more lane changing behaviors in traffic. Number of lane changing per vehicle per kilometer is calculated as a risk assessment indicator for micro-cars' introduction.

5.1.2 Number of deceleration

According to the US National Expressway Traffic Safety Association (National Center for Statistics and Analysis, 2005), in 2003 rear-end collisions accounted for 29.6% of all crashes (1.9 million), 29.6% of all injury crashes (0.57 million), and 29.8% of all property-damage-only crashes (1.3 million). And the major causal factor in rear-end collisions is incorrect driver reaction to the behavior of the vehicle in front, due to either inadequate or late detection of the forward vehicle's deceleration (Li and Milgram, 2008). So frequency of deceleration is calculated as the second traffic risk assessment indicator in unit of per vehicle per kilometer.

5.1.3 Coefficient of variation of speed

Taylor et al. (2000) analyzed the speed-accident relationship, finding that accident frequency rises exponentially as the coefficient of speed variation increases. Numerous studies identify potential relationships between speed characteristics and roadway safety. More specifically, the risk of crash involvement may be positively correlated with speed variation and higher vehicle speeds are generally correlated with increased crash severity (Boonsiripant et al., 2007). Speed inconsistency is a common contributing factor to crashes on two-lane rural expressways (Mattar-Habib et al., 2008). Consequently, coefficient of variation of speed (C_v) is calculated as the third risk assessment indicator for safety analysis.

5.2 Road segment level

5.2.1 Number of lane-changing

Before calculation of this indicator, validation of the calculation simulator, TCA, is needed. The available of TCA has been validated in Section 3.2.4 in traffic flow point of view. Whether it can simulate a correct trend of lane changing is demonstrated in Figure 5-1. The left hand figure is observed realistic data from two test sites selected from the main segment of I-20 between Dallas and Arlington (Chang and Kao, 1991). Each location was observed for l hour period from 5:00 to 6:00 P.M., and the right hand one is simulated results from TCA. Number of lane changing in TCA is found about half of that in observed data from the red and blue dotted line, however, the changing trend of lane changing is the same, which proof the available of TCA to simulate realistic traffic flow in lane changing point of view.

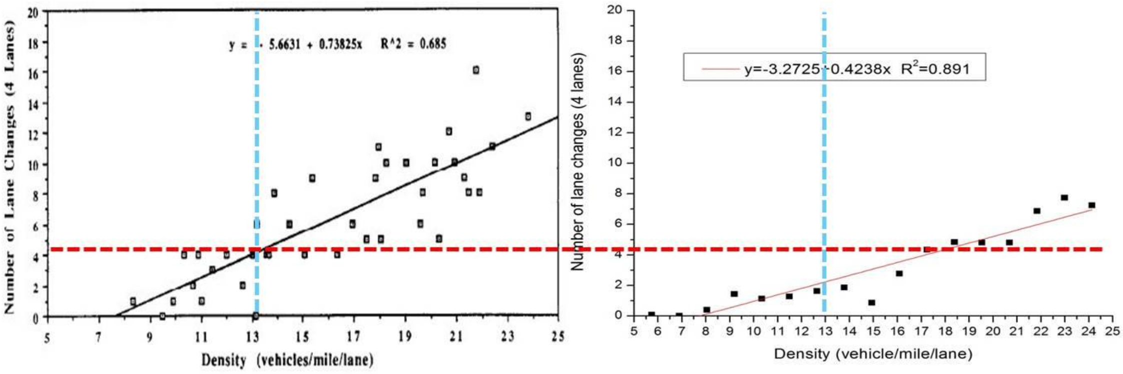


Figure 5-1 Validation for TCA in lane changing point of view

In Figure 5-2, we can see that every curve of lane changes against vehicle density has a shape like an “S”. All of them increase from 0 to a certain value conjugating density increase until 7 veh/km/lane for 40~80% micro-car case, 14 veh/km/lane for 0~20% case, and 21 veh/km/lane for 100% micro-car case. Then decrease until 28 veh/km/lane except that no-micro-car case decrease until 21 veh/km/lane. Following that is increase again until around 90 veh/km/lane, then coming the second decrease trend until maximum density. These S-curves converge when the traffic density ranges from 60 to is 90 veh/km/lane.

As traffic with more micro-cars have higher maximum lane changing number, which happens in congestion regime, there must be a transition regime for more-micro-car-ratio cases transfer from less lane changing to more. From 30 to 90 veh/km is the transition regime. Micro-cars have an extremely diverse effect on the number of lane changes as the traffic density ranges from 0 to 143 veh/km/lane. In free flow, traffic without micro-cars exhibits the fewest lane changing, while for with-micro-car traffic, a greater ratio of micro-cars results in less lane changing. On the contrary, more micro-cars result in more lane changing when the traffic density is more than 90 veh/km/lane, and the 60~100% micro-car curve show small fluctuant changes, meanwhile the without-micro-car traffic reveals fewest lane changing again.

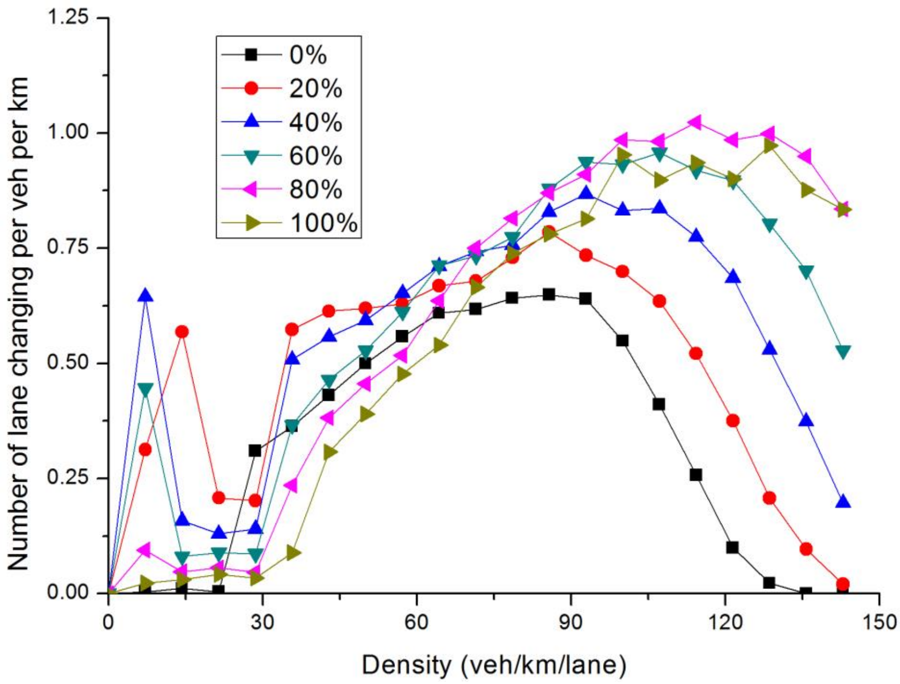


Figure 5-2 Number of lane changes per vehicle per kilometer by vehicle density and micro-car ratio on expressway

The traffic flow will stay still if there are no micro-cars when there are 200 vehicles on assumed road, which denotes the density of about 143 veh/km/lane. Thus the input of maximum density in with-micro-car flow is also set as 143 veh/km/lane, for better comparison with no-micro-car flow. The maximum density can augment to 250 veh/km/lane in only-micro-car flow

This occurs because a greater proportion of micro-cars presents more space, thus provide better opportunities for lane changing than when there are fewer micro-cars in the case of high total demand, where the traffic conditions are worse with less micro-cars than with more. The static state for no-micro-car case has half empty lattice for full-micro-car case, then number of lane changing being high when there are micro-cars, while no flow and lane changing when there are no micro-cars.

The maximum number of lane changes, about 1.02 per vehicle per km, arises when the two conditions are 80% micro-car ratio and 90 veh/km/lane. In the case of a traffic density of 7 veh/km/lane, the number of lane changes ranges from 0.04 to 0.64. This range is so great because vehicles have plenty of space to change lane when there are only 7 vehicles per km of road, and many conventional cars are inclined to change lane for higher speed when there are 20% to 60% of micro-cars, especially 40%.

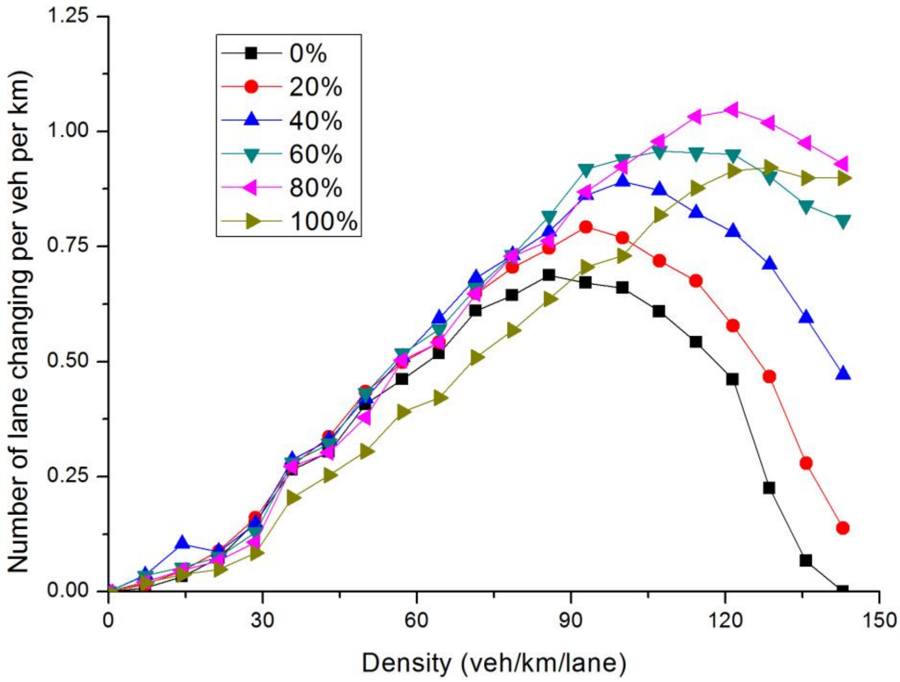


Figure 5-3 Number of lane changes per vehicle per kilometer by vehicle density and micro-car ratio on arterial road

In brief, when the traffic density range from 30 to 90 veh/km/lane, introduction of micro-cars have no evident negative effect for safety, while a higher proportion of micro-cars is better for 0 to 70 veh/km/lane, being worse in the other density field for with-micro-car flows. However, without-micro-car traffic give the least lane changing in free flow, and number of lane changing does not have so much meaning on safety in congestion traffic, because of the low speed (about 10 km/h for 90 veh/km/lane, and lower for higher density), so it is turned out that introduction of micro-car to expressway has negative effect on safety.

Figure 5-3 shows the similar relationship between density and number of lane changes under different micro-car ratios with that of expressway. But for the arterial road, there is no obvious “S” trend in this case, and the number of lane changes increase and then decrease as density becomes larger. It is possible that this is a result of the traffic signal. Traffic flows with only micro-cars generally exhibit the lowest number of lane changes when density ranges from 0 to 90 veh/km/lane, while the other curves concentrate at same value under same density in this range.

When density is larger than 90 veh/km/lane, longitudinal value of with-micro-car case is larger, and more micro-car ratio gives higher value because of more space for lane changing, but it is still not so meaningful to safety because of the low speed. In general, a higher micro-car ratio results in fewer lane changes, especially when the density is less than 90 veh/km. It can be concluded that introducing micro-cars have no safety effect on urban roads with signals when density is less than 90 veh/km/lane, and no evident effect when density is more than 90 veh/km/lane, even if more lane changing for higher micro-cars ratio, because it is in congestion regime.

5.2.2 Number of deceleration

The number of deceleration counts is a maximum, at about 430 per vehicle per kilometer, when the micro-car ratio is 0% in dense traffic. From Figure 5-4, we can see that the deceleration count on the expressway increased positively with the addition of vehicles except the density being 143 veh/km/lane and only-conventional-car case (the vehicles are completely stationary because all cells are occupied). Generally, a higher proportion of micro-cars results in fewer decelerations, and this trend is particularly clear in the higher density ranges from 57 to 143 veh/km/lane.

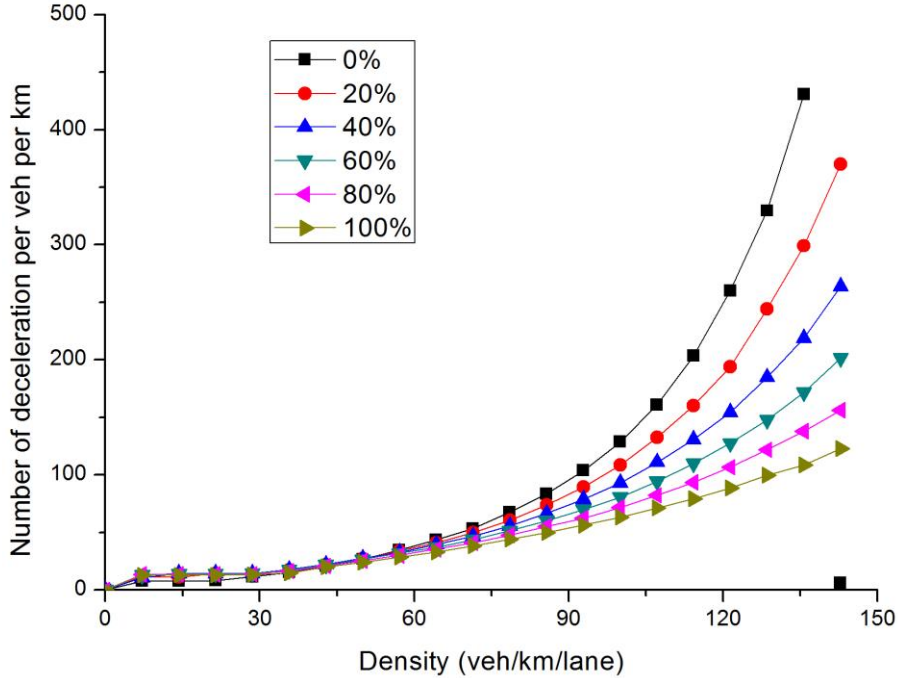


Figure 5-4 Number of decelerations per vehicle per kilometer by number of vehicles and micro-car ratio on the expressway

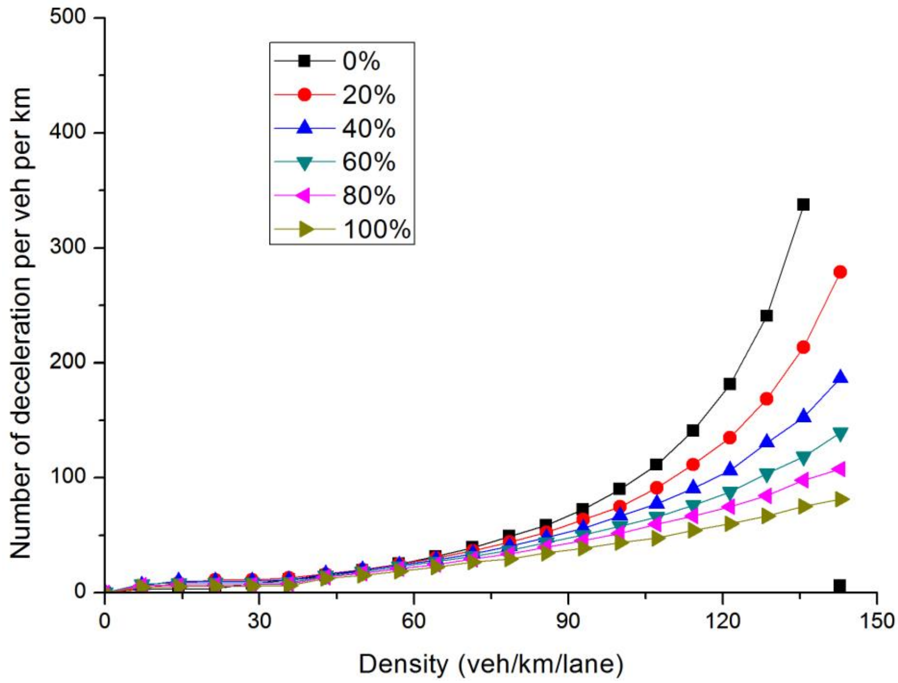


Figure 5-5 Number of decelerations per vehicle per kilometer by number of vehicles and micro-car ratio on the arterial road

The explanation for this behavior is that, with a certain number of vehicles, the lower the proportion of micro-cars, then the more congested the traffic is, which cause more decelerations. Figure 5-4 demonstrates that when there are more vehicles on the roadway, more decelerations take place, while a greater number of micro-cars results in fewer decelerations. Figure 5-5 shows a similar trend for the arterial road, with only one significantly different characteristic: that the rising trend is less steep than that of expressway. It can be concluded that the number of decelerations manifolds as density increases especially when congestion comes, more micro-cars is better for safety.

5.2.3 Coefficient of speed variation

The coefficient of speed variation (C_v) is used here to analyze the effect of speed variation on safety. C_v is calculated by the following equation:

$$C_v = SD/V \tag{5-1}$$

where *SD* is standard deviation of speed and *V* is the mean speed.

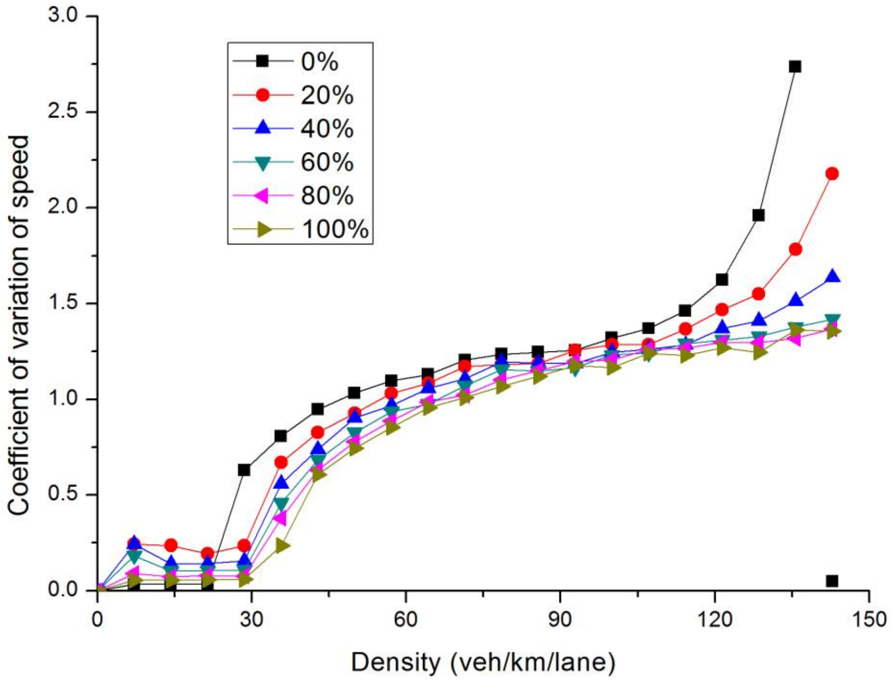


Figure 5-6 Coefficient of variation of speed by density and micro-car ratio on the expressway

The speed of all vehicles on the expressway and arterial road in each unit time in one hour is obtained as a sample, and then C_v is computed for the sample. The results for the expressway case are shown in Figure 5-6, C_v keep small value in free flow (density being less than 21 veh/km/lane for no-micro-car case and 28 veh/km/lane for with-micro-car case). Then climb intensely until 50 veh/km/lane, and continue to increase, slowly, however, until 114 veh/km/lane, afterwards, grow quickly up to maximum density, especially for no-micro-car case, which is attributed to the sharp decrease of average speed.

All the curves have the same trend as the density increase, and have close values for the same density. When the vehicle density is less than 21 veh/km/lane, traffic without micro-cars gives the lowest C_v, which demonstrates that mixed flow with micro-cars have more hazard than one without. As the vehicle density increases, a higher proportion of micro-cars results in a lower C_v (ignoring the sharp fall in the non-micro-car flow curve when the traffic flow is 0), but again, it does not have much positive effect on safety when considering the low average speed.

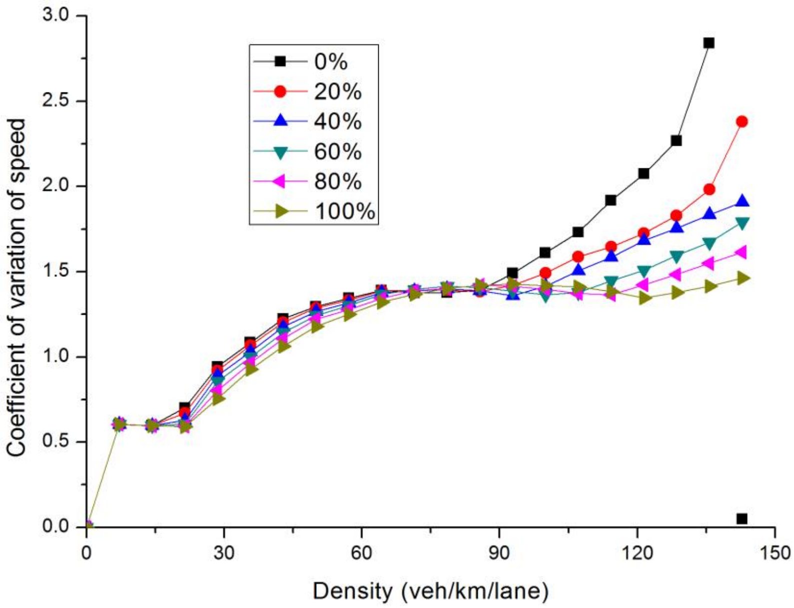
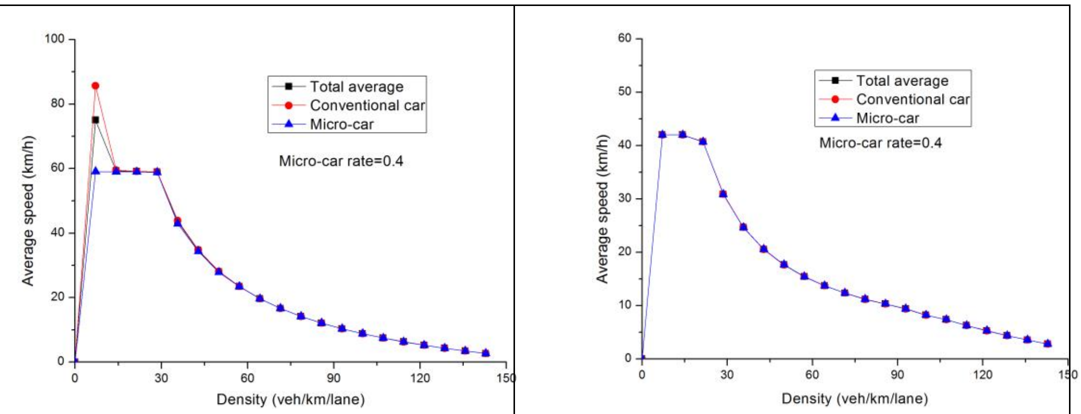


Figure 5-7 Coefficient of variation of speed by density and micro-car ratio on the arterial road

Figure 5-7, for the arterial road, is similar except that the superiority of non-micro-car flow is not obvious even when traffic density is less than 21 veh/km/lane, and the curves are more concentrated than those in Figure 5-6 when density ranging from 7 to 90 veh/km/lane. The average speed for the assumed two kinds of vehicles (Figure 5-8) are very close except density being less than 14 veh/km/lane on expressway, and almost join to be only one curve for all density regime on the arterial road. The reason is that conventional cars have their maximum speed higher than micro-cars', but cannot get it when traffic becomes congested, however. And both conventional cars and micro-cars cannot always drive with the highest speed even in free flow because of the traffic signal on the arterial road.

Figure 5-6, 5-7 ,5-8 demonstrate that, in free flow, with-micro-car flow have higher coefficient of speed variation than without one, and a higher proportion of micro-cars yields a lower coefficient of speed variation. In stop-and-go and jammed traffic, lower C_v accompanies with more micro-cars. Thus, to conclude, the presence of micro-cars has a negative effect on safety in free flow on expressway, but has positive or no obvious negative effect on arterial road.



a) on expressway

b) on arterial road

Figure 5-8 Speed difference for conventional car and micro-car for 40% micro-car case

5.3 Downtown small network level

5.3.1 Number of lane changing

Figure 5-9 demonstrates us tiny change of number of lane changing for different micro-car rate as well as different assumption. For more precise analysis, Figure 5-9 shows the percentage change of it. Number of lane changing decreases for assumption 1 and 2 for all micro-car rates, while it increases for assumption 3 for all micro-car rates. Nevertheless, the absolute value of the increase or decrease is less than 3% for all situations.

The results on arterial road segment with a traffic light in the middle of that in previous study demonstrates that the number of lane changing rises as micro-car rate increases for micro-car rate lower than 0.4 condition, except that a few plots have tiny decrease compared to that of micro-car rate being 0.2 when micro-car rate equals 0.4. The increase is attributed to micro-cars' smaller size which provide more space and accordingly more chance for lane changing when the two types of vehicle have the same desired speed, and that is reasonable (here ignore the actual number from simulation results, because of the different characteristics and driving behavior settings of the two simulation models, just focus on the curves' trends). However, the results here show decrease of number of lane changing for the same desired speed in assumption 1 and a little difference between two desired speeds in Assumption 2. It is also strange that there are so few increase for lane changing behavior even when the desired speed difference between the two kinds of investigated vehicles is very huge in Assumption 3.

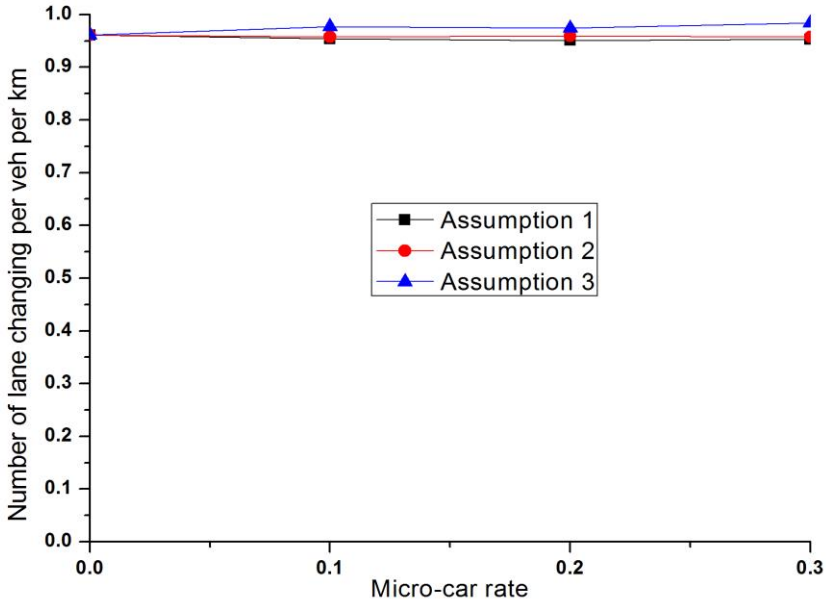


Figure 5-9 Number of lane changing for different micro-car rate and assumption

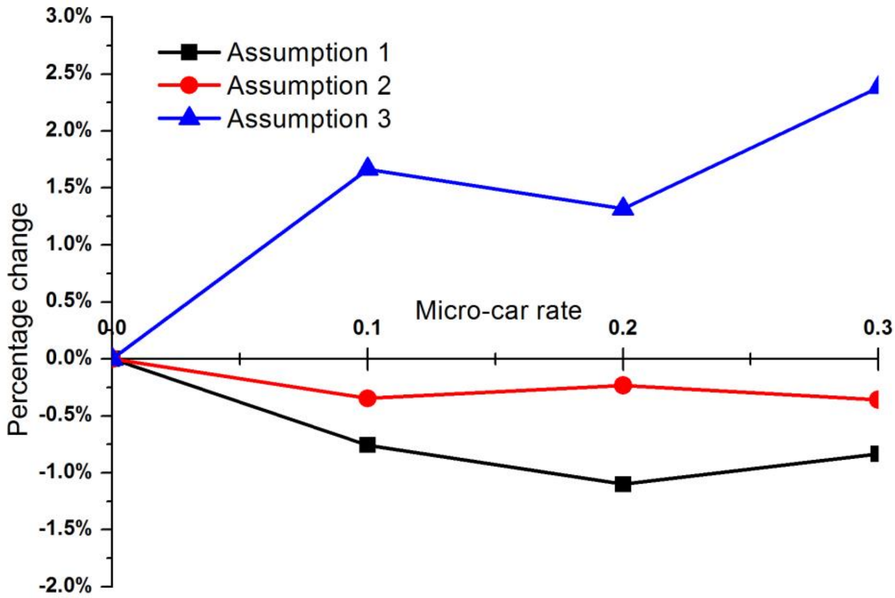


Figure 5-10 Percentage change of number of lane changing for different micro-car rate and assumption

There are only 14.9% multi-lane for each driving direction on every link if count by their length. So the percentage change of lane changing number for different micro-car rate for Assumption 3 is very tiny, and the maximum value is only 2.38%. And the decrease for Assumption 1 and 2 may due to random factor, after all, the decrease percentage is only about 1% for the maximum situation. In brief, the number of lane changing will change in a small range after micro-cars' introduction in the investigated network, and in the urban traffic networks with minority multi-lane for each driving direction on every link, which is like in Japan, micro-cars will not bring negative effect for safety if only consider number of lane changing, even if micro-cars have much lower desired speed than conventional cars.

5.3.2 Number of deceleration

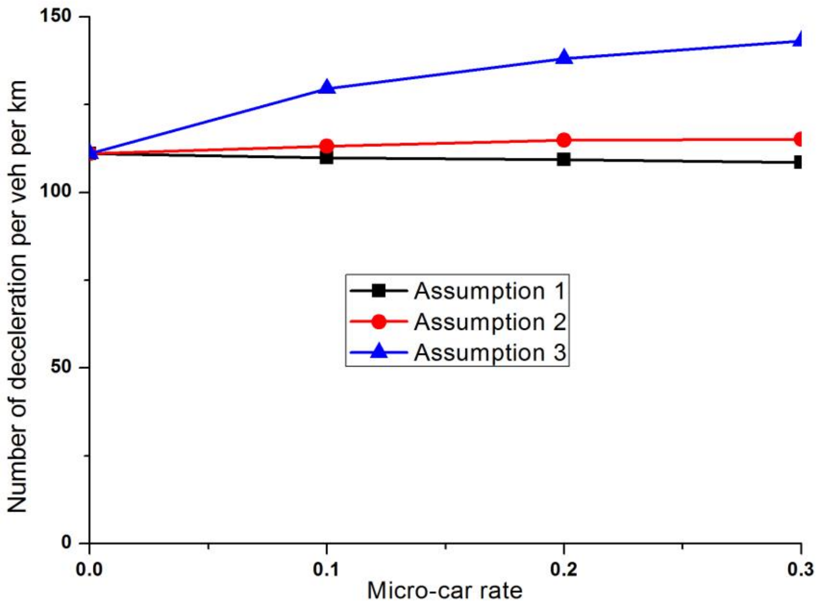


Figure 5-11 Number of deceleration for different micro-car rate and assumption

The number of deceleration decreases as micro-car rate rise for Assumption 1, which ascribes to micro-cars' smaller foot print providing more space for drivers to higher their speed. For Assumption 2, the desired speed of micro-cars is a little lower than that of conventional cars, drivers of conventional cars cannot change lane in most links for the road structure condition mentioned in section 5.3.1, if they want to achieve their desired speed. They have to decelerate when the preceding micro-car's speed is lower than their desired speed in most time, then there are more deceleration amount for more micro-car rate. The deceleration amount do not increase too much because of the small difference between the desired speed of the two investigated types of vehicles. However, for Assumption 3, conventional vehicles have to have much more deceleration, up to 28.9% when micro-car rate being 0.3, because of much difference between the two desired speeds and the forbidden for lane changing, and the blue curve in Figure 5-11 and 5-12 attests it.

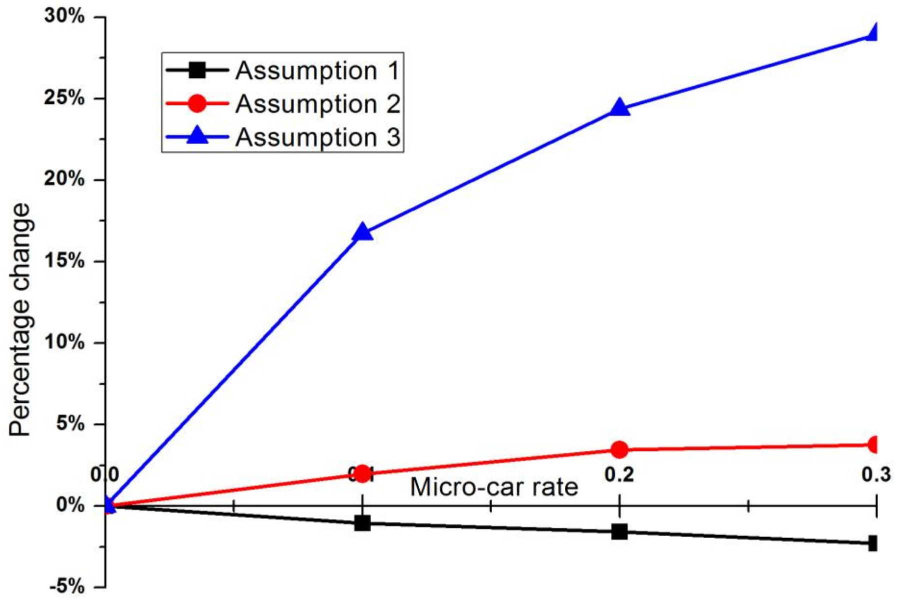


Figure 5-12 Percentage change of deceleration number for different micro-car rate and assumption

In short, the deceleration number will decrease after micro-cars' acceding to the traffic if they have the same desired speed with conventional vehicles, while the change direction will convert if they have lower desired speed than conventional cars, and the more the difference between desired speeds, the more decelerations. So micro-cars will bring about negative effect to traffic safety if their speed are limited lower than other conventional passenger cars.

5.3.3 Coefficient of speed variation

Figure 5-13 and 5-14 reveal decrease of C_v as micro-car rate's increase. And also decrease as micro-cars' desired speed decrease except micro-car rate being 0.2 in Assumption 3. Vehicles have to stop in front of red light, and this point results in the much lower average speed than all vehicles' desired speed.

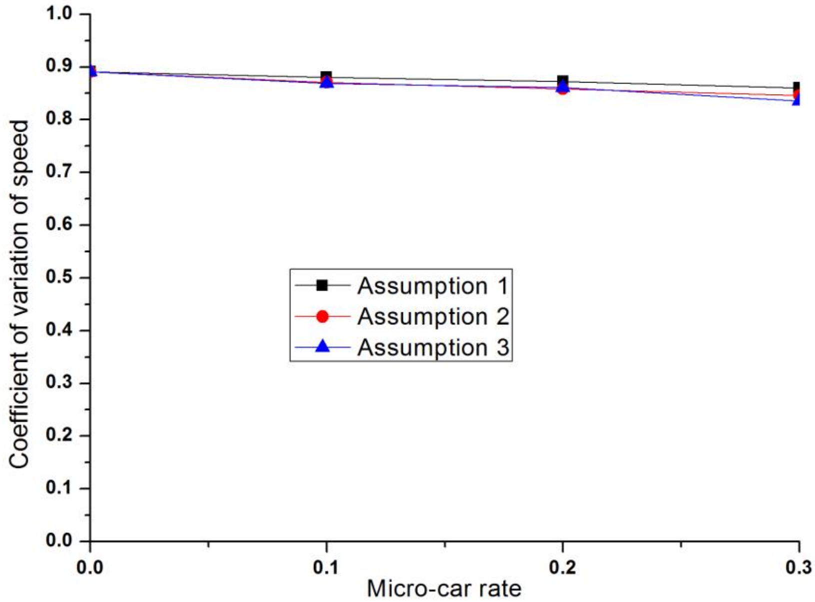


Figure 5-13 Coefficient of variation of speed for different micro-car rate and assumption

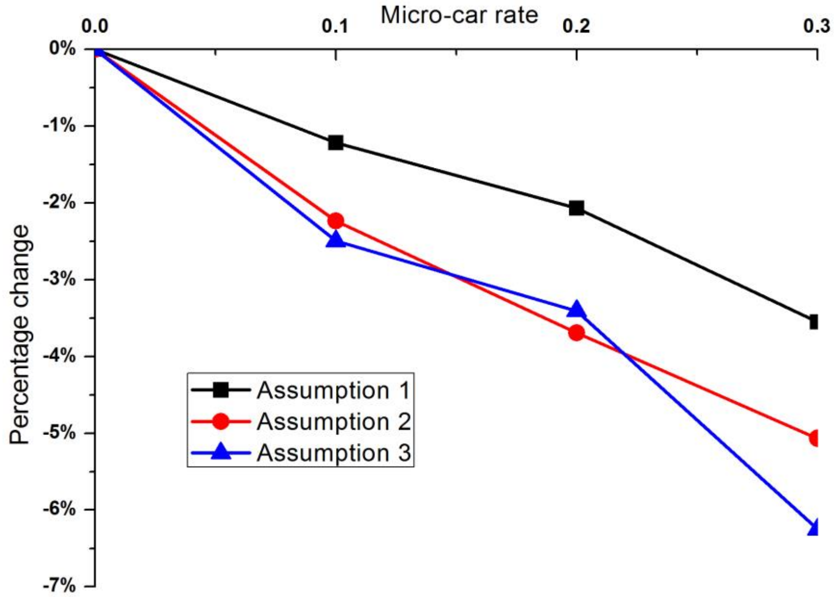


Figure 5-14 Percentage change of coefficient of variation of speed for different micro-car rate and assumption

Check Table 5-1, the average speed for all vehicle types is around 25 km/h for Assumption 1 and 2, and around 22 km/h for Assumption 3, always lower than their desired speed. The average speeds for the three assumptions are close, if compared to the difference of desired speeds setting for micro-cars. Also, the desired speed of micro-cars becomes closer to the average speed when it is decreased from 48-58 km/h to 25-30 km/h, from Assumption 1 to 3.

The traffic signal make the speeds vary from desired speed to 0 km/h, so if the desired speed of micro-cars decrease, the speed range of them from the traffic network will decrease, accordingly the standard deviation of speed will decrease. As mentioned above, the decrease of average speed is small, and has a lower decrease speed than the standard deviation of speed as the desired speed of micro-cars decrease, mostly due to the more and more closer desired speed setting for micro-cars to the system average speed. For no desired speed difference condition, in Assumption 1, the C_v decreases after micro-cars' introduction because of higher average speed of the network, which is ascribed to micro-cars smaller size radically. In brief, micro-cars will cause positive effect to the small network, if only consider C_v of the system.

Table 5-1 Average speed of conventional cars and micro-cars by the three assumptions

(1) micro-cars' desired speed being 48-58km/h; (2) micro-cars' desired speed being 40-45km/h; (3) micro-cars' desired speed being 25-30km/h. MC: micro-car rate; All: all vehicle types; C: conventional car; M: Micro-car. The unit for each value is km/h.

	Assumption 1			Assumption 2			Assumption 3		
MC	All	C	M	All	C	M	All	C	M
0	24.54	24.54	0	24.54	24.54	0	24.54	24.54	0
0.1	24.863	24.875	24.751	24.654	24.775	23.64	22.938	23.296	20.213
0.2	25.104	25.092	25.149	24.602	24.777	23.927	21.915	22.441	20.052
0.3	25.439	25.427	25.464	24.641	24.908	24.052	21.463	22.199	19.94

5.4 Summary of this chapter

Number of lane changing, number of deceleration per vhehicle per kilometer, as well as coefficient of variation of speed (C_v) are applied as indicators to assess the traffic safety influence of micro-cars, for the first one is related to sidewipe and angle crashes, the second have strong relationship with rear-end accidents, and the third make accident frequency rise given an increased value of it.

Table 5-2 Microcars' safety effect for different traffic flow type

NL: Number of lane changing; ND: Number of deceleration; C_v: Coefficient of variation of speed. P: Positive effect; N: Negative effect; Ne: Neutral.

	On expressway			On arterial road		
Indicator	NL	ND	Cv	NL	ND	Cv
Free flow	N	N	N	N	Ne	Ne
Stop-and-go 1	Ne	Ne	P	Ne	P	P
Stop-and-go 2	N	P	P	N	P	P

For segment level analysis, Table 5-2 shows the detail. Traffic flow can be categorized into three types in this research according to different range of density, free flow corresponding to density 0-25 veh/km/lane, stop-and-go 1 corresponding to density 25-90 veh/km/lane, stop-and-go 2 corresponding to density 90-140 veh/km/lane. Micro-cars have different performance in the three types of flows. On expressway, they have all negative effect in free flow; have neutral effect if consider number of lane changing and number of deceleration when density ranging from 25 to 90 veh/km/lane, and have positive effect if just focus on C_v of the traffic; have negative effect for number of lane changing consideration, while positive one if consider the other two indicators when density is 90-140 veh/km/lane. On arterial road, have neutral effect for two indicators, and negative one for number of lane changing in free flow; have positive effect for two indicators, and neutral one for number of lane changing when density ranging from 25 to 90 veh/km/lane; have the same effect as that on expressway when density is 90-140 veh/km/lane.

For network level analysis, the results suggest that, in terms of the frequency of lane changing, micro-cars will not cause negative effect to traffic safety in urban traffic networks like in Japan due to their few amount of multi-lane for each driving direction on road, even when the desired speed of micro-cars is much lower than conventional passenger cars. Micro-cars' introduction does not bring about negative effect if the difference in the desired speeds between conventional cars and micro-cars is small from the view point of the frequency of deceleration. However, they will significantly negatively affect traffic safety if their desired speed is 25-30 km/h, which is much lower than that of the conventional cars, 48-58 km/h. On the other hand, from the view point of speed variation, a positive effect will be produced for all condition. A higher micro-car rate provides a larger positive effect. The reason is the range of average speed in urban traffic network caused by traffic light. In total, micro-car will not cause safety hazards except for the desired speed of 30 km/h or less at downtown area.

References

Chang, G., and Kao, Y. (1991): An empirical investigation of macroscopic lane-changing characteristics on uncongested multilane freeways. Transprtation research Part A: Policy and Practice, Vol. 25A, No. 6, pp. 375-389.

CHAPTER 6

ANALYSIS OF INFLUENCE ON ENVIRONMENT

This chapter describes the road segment level, downtown small network level as well as and metropolitan network level environmental effects caused by micro-cars. The segment level analysis comes first, and then following the two network level ones, separately for Kichijoji area and Nagoya metropolitan area.

6.1 Road segment level

VSP is defined as the instantaneous power per unit mass of the vehicle and is a core parameter of MOVES (Koupal et al. 2002). This parameter is very useful in emissions modeling, analysis of remote sensing data, and chassis dynamometer data, as it captures most of the dependence of light-duty vehicle emissions on driving conditions, and it is directly specified in emissions certification cycles. MOVES supply the emission rate for HC, CO, and NO_x for different operating mode (VSP combining speed ranges) and different age vehicles. As the average vehicle age is about 8 to 9 years, the emission rates (see Appendix A.) for this range are obtained to calculate total emission for the three kinds of discharges in counting time. We assume a typical micro-car here to simplify the calculation, the famous Smart For-two 2012, weighing 750 kg; the conventional car's substitute for hypothesis is Toyota Camry 2012, weighing 1490 kg. The VSP for each vehicle in each second is calculated by using the following equations proposed by Jimenez-Palacios (1999):

$$\mathrm{VSP} = \mathrm{v} \cdot (\mathrm{a} \cdot (1+\varepsilon) + \mathrm{g} \cdot \mathrm{grade} + \mathrm{g} \cdot \mathrm{C_R}) + \frac{1}{2}\rho \frac{C_D \cdot A_F}{m} v^3 \tag{6-1}$$

where, v and a are the vehicle's speed and acceleration in m/s and m/s^2. ε is mass factor accounting for the rotational masses, assumed to be 0.1. g is acceleration due to gravity (9.8 m/s2). Grade is road grade. C_R is rolling resistance for radial tires, can range from 0.008 – 0.013 for a majority of the on- road passenger car tires, assumed to be 0.013 here. ρ is ambient air density, valuing 1.207kg/m^3 (at 20℃=68℉). C_D is aerodynamic drag coefficient, assumed to be 0.3. A_F is the frontal area in m^2 (calculated by equation 14). m is vehicle mass in kg; and slope is the road gradient in degrees, assumed to be 0.

$$A_F = (H - GC) \cdot W \cdot 0.93 \tag{6-2}$$

where H is the vehicle height. GC is the ground clearance. W is the width.

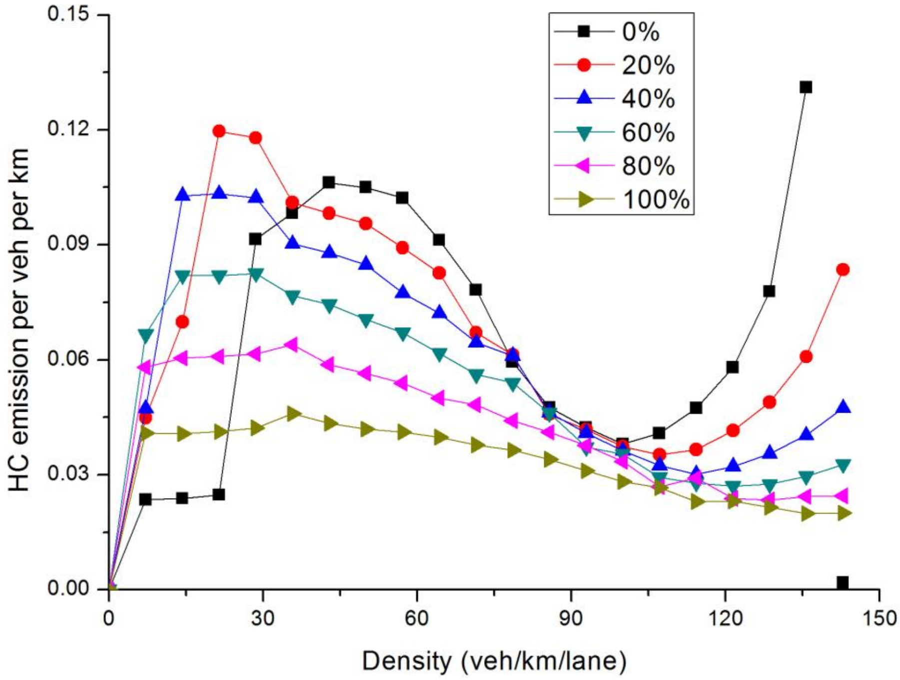


Figure 6-1 HC emission by density and micro-car ratio on the expressway

Using the set values for all parameters we arrive to the following expression, equation 15 for conventional car, and equation 16 for micro-car:

$$VSP = v \cdot (a \cdot 1.1 + 0.1275) + 2.735 \cdot 10^{-4} \cdot v^3 \tag{6-3}$$

$$VSP = v \cdot (a \cdot 1.1 + 0.1275) + 4.987 \cdot 10^{-4} \cdot v^3 \tag{6-4}$$

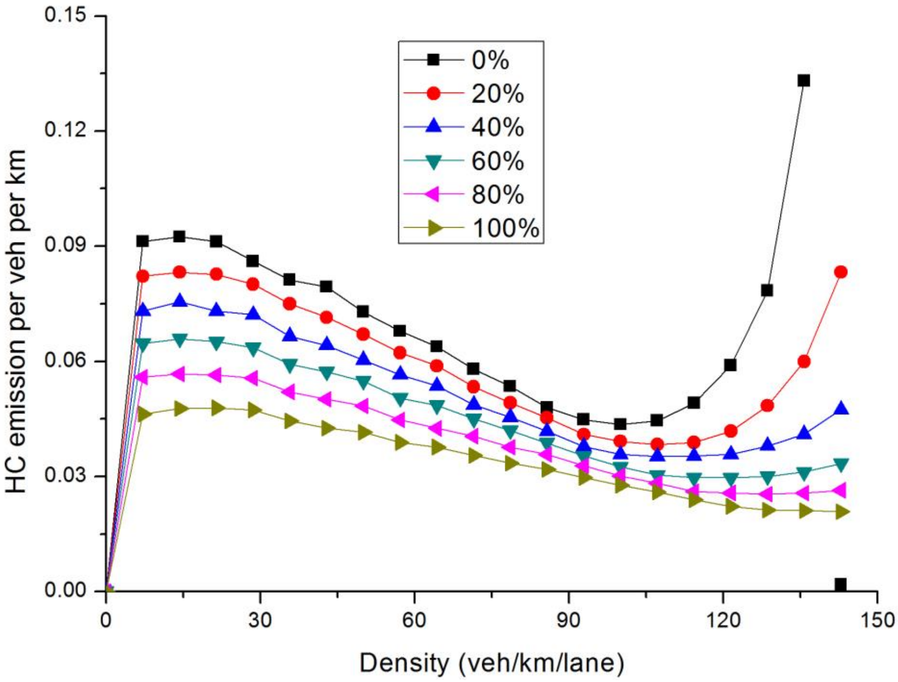


Figure 6-2 HC emission by density and micro-car ratio on the arterial road

In Figure 6-1, all curves are like "S" shape, increase, decrease and increase again. HO emission is much less for no-micro-car case than the other case when density is less than 30 veh/km/lane, i.e., in free flow, but is more than the other when density ranging from 43 to 71 veh/km/lane, and become less until 100 veh/km/lane, then be especially higher up to the highest density, which prove that congestion cause more emission. For the with-micro-car traffic, more micro-car ratio case gives better condition mostly, except density ranging from 71 to 143 veh/km/lane, but do not show great disadvantage in this regime. On arterial road, there is still "S" shape (Figure 6-2). No-micro-car case has more emission in all traffic flow phase. CO emission (Figure 6-3 and 6-4) is similar to that of HC, except that there is no sharply increase near the highest density. NO_x emission (Figure 6-5 and 6-6) is more similar to that of CO than HC. In conclusion, traffic with micro-cars has more emissions on expressway in free flow, and has less emission on arterial road.

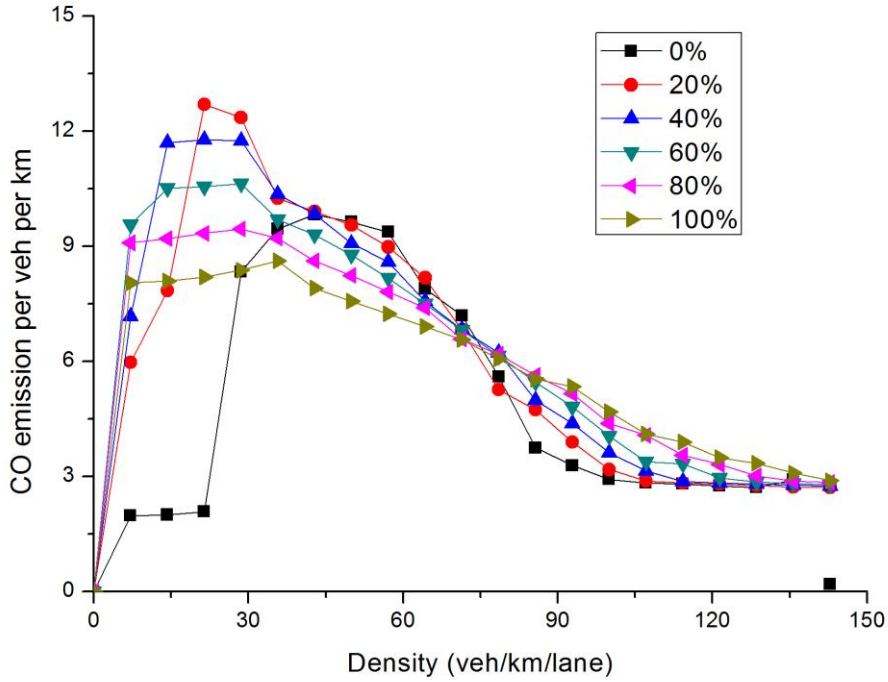


Figure 6-3 CO emission by density and micro-car ratio on the expressway

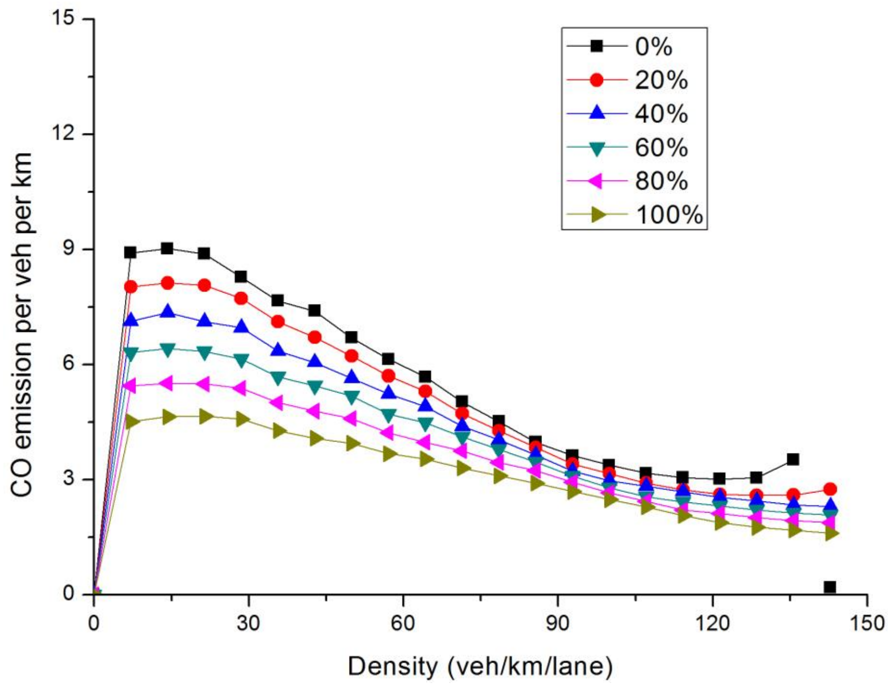


Figure 6-4 CO emission by density and micro-car ratio on the arterial road

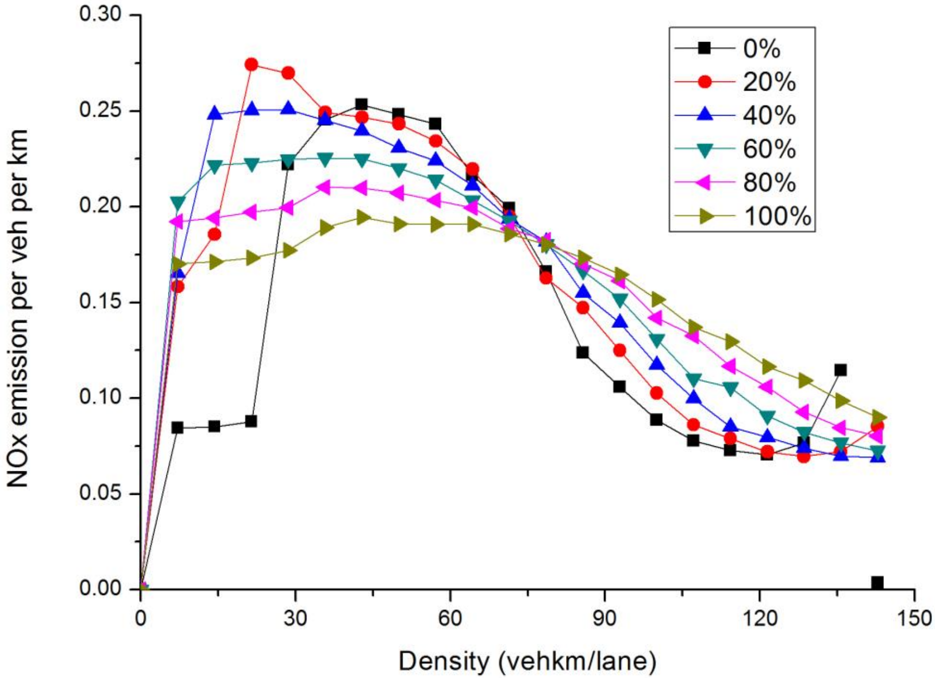


Figure 6-5 NOx emission by density and micro-car ratio on the expressway

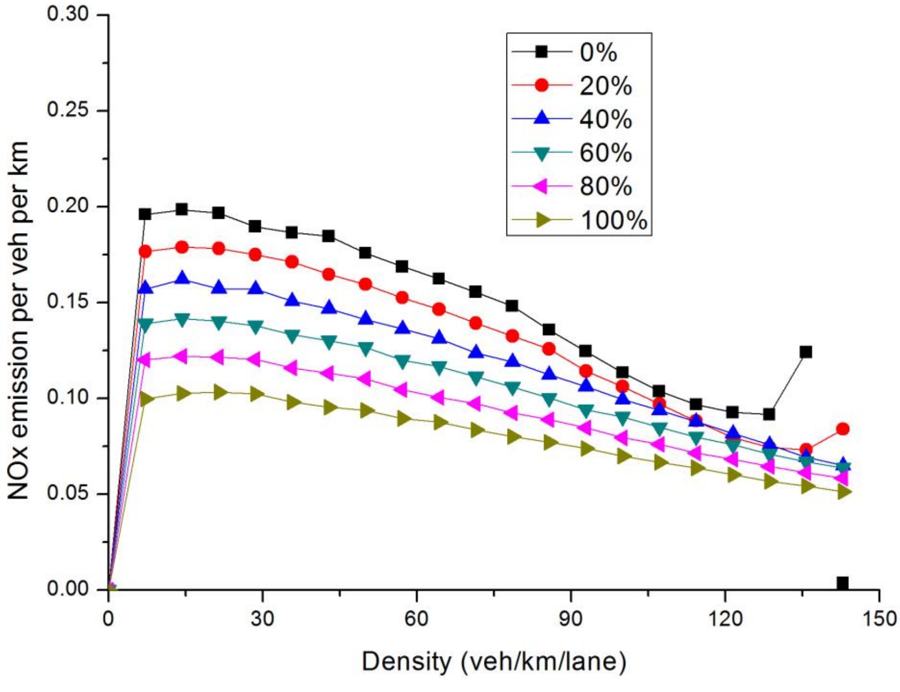


Figure 6-6 NOx emission by density and micro-car ratio on the arterial road

6.2 Downtown small network level

Figure 6-7 shows an obvious decrease in the condition of higher micro-car rate as well as lower desired speed for micro-cars. Assumption 1 and 2 has closer decrease percentage, which is attributed to closer desired speed for micro-cars between them. And the maximum decrease is about 25% when micro-car rate is 0.3 in traffic and their desired speed is set as 25 to 30km/h. Xu et, al. (2010) did experiments to get the relationship between CO_2 emission and VSP, and found that the CO_2 emission keep values in a small range when VSP being lower than 0 kw/metric ton. They track virtually a linear relationship when VSP being higher than 0 kw/metric ton, however. VSP were used before to calculate emission on condition that all vehicles have the similar weight, but the weight of vehicles in this study has a huge difference. The mass of Camry is nearly two times of Smart for-two's, so the power needed (Equation 6-5, where m is the weight of vehicles) is used instead of VSP here. If just use the power needed to infer the vehicles' emission, and assume that the two have a linear relationship, it can be concluded that micro-cars have higher fuel efficiency.

$$Power\ needed = VSP * m \tag{6-5}$$

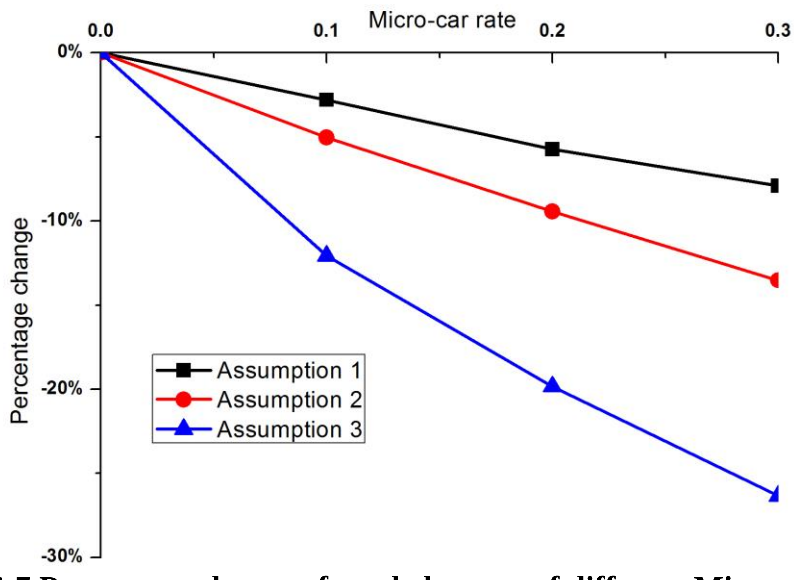


Figure 6-7 Percentage change of needed power of different Micro-car rates

6.3 Metropolitan network level

Figure 6-8 demonstrates that vehicle emission will decrease after introduction of micro-car, and lead to a maximum percentage change about 8% when micro-car rate being 25%. Figure 6-9 to Figure 6-13 show the decrease of needed power in network.

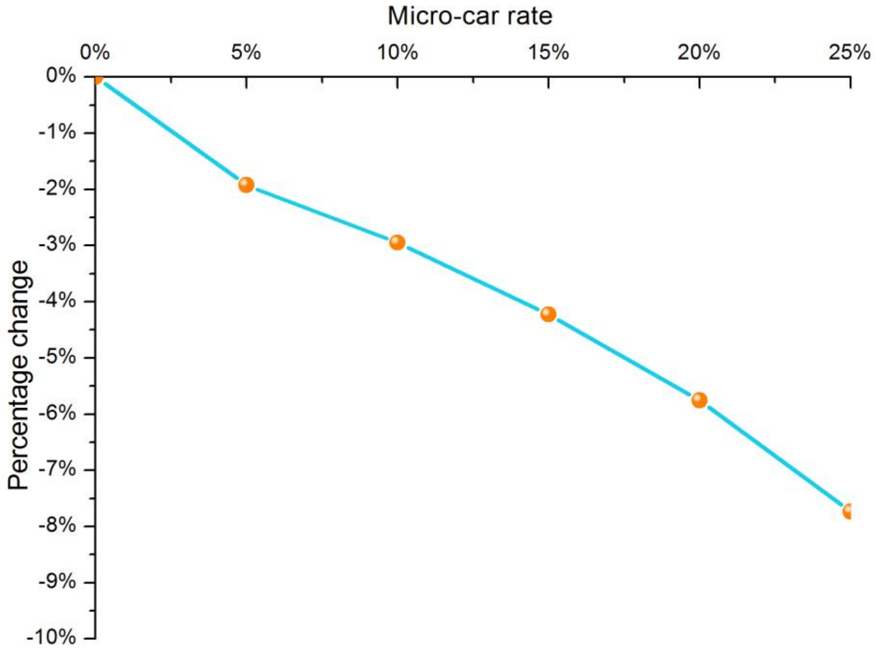


Figure 6-8 Percentage change of needed power for different micro-car demand rate of whole network

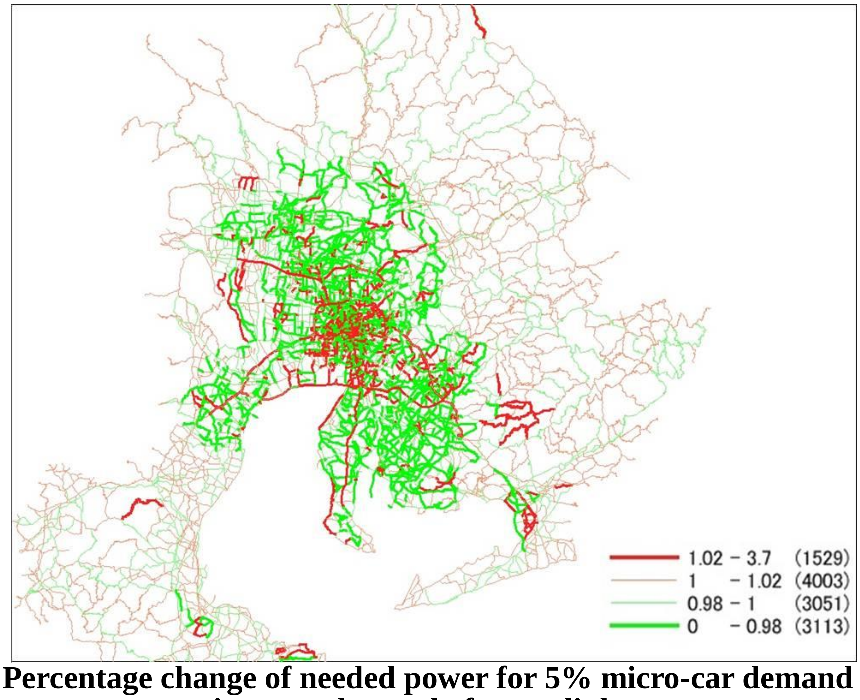


Figure 6-9 Percentage change of needed power for 5% micro-car demand by 0% micro-car demand of every link

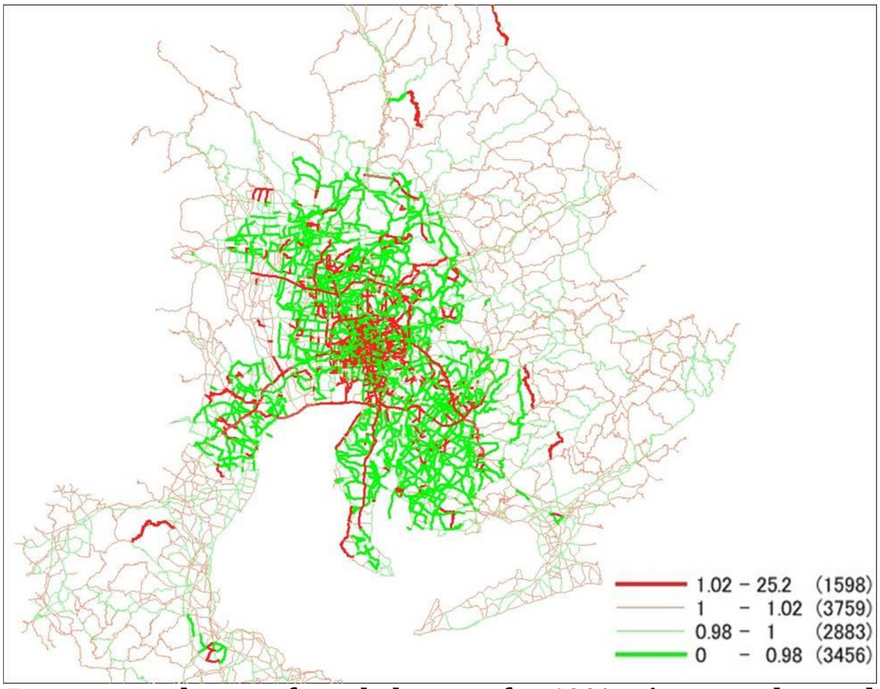


Figure 6-10 Percentage change of needed power for 10% micro-car demand by 0% micro-car demand of every link

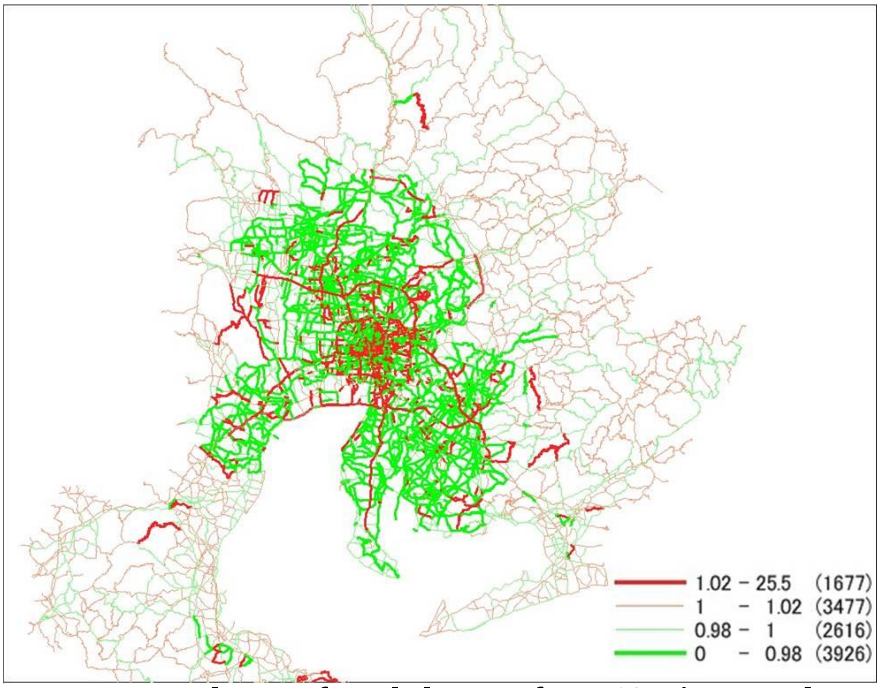


Figure 6-11 Percentage change of needed power for 15% micro-car demand by 0% micro-car demand of every link

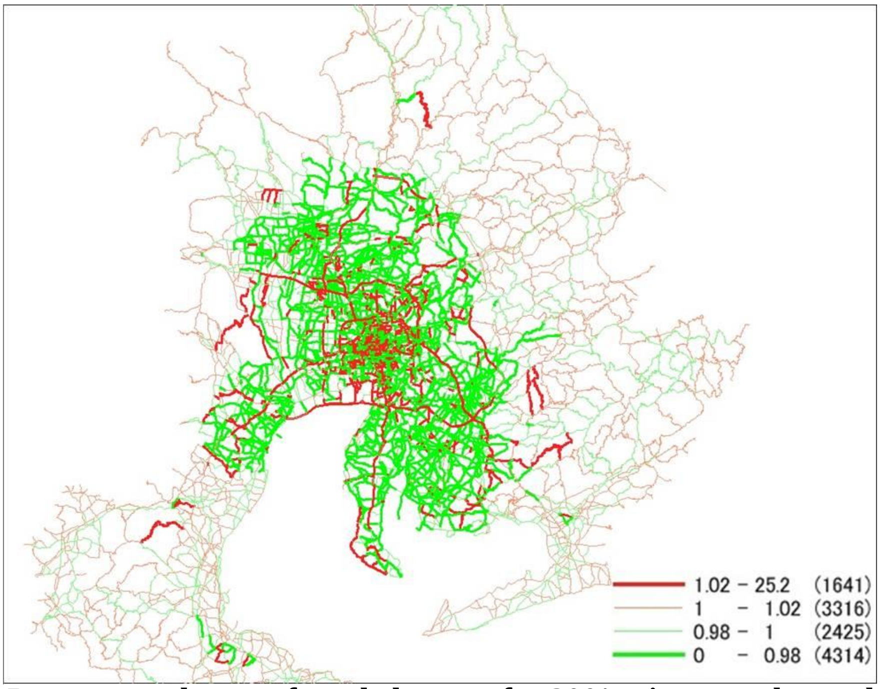


Figure 6-12 Percentage change of needed power for 20% micro-car demand by 0% micro-car demand of every link

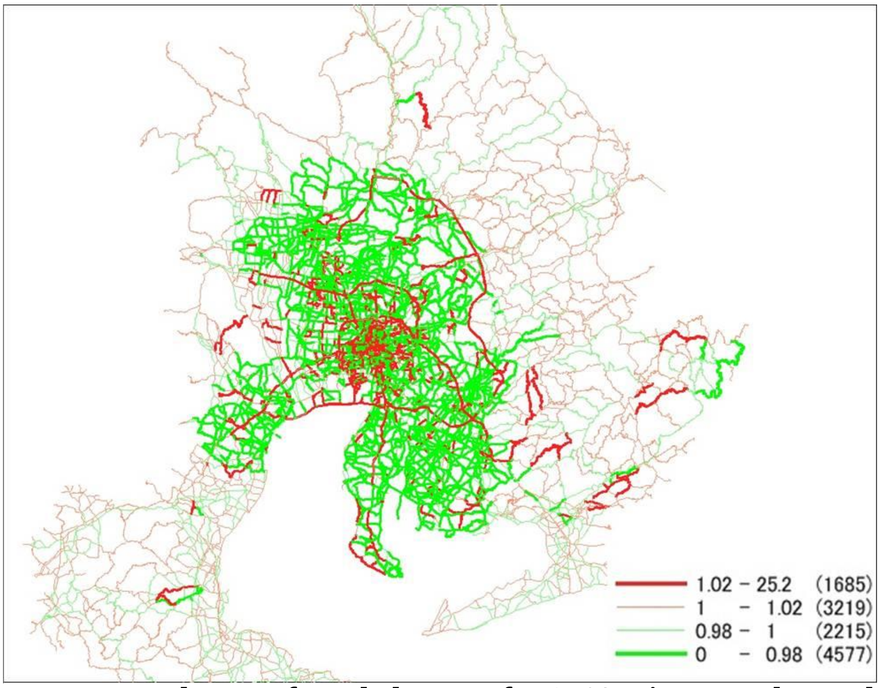


Figure 6-13 Percentage change of needed power for 25% micro-car demand by 0% micro-car demand of every link

6.4 Summary of this chapter

This chapter describes the results for environmental influence analysis of micro-cars in segment level and network level continuously. Vehicle emissions, HC, CO, and NO_x are figured up using VSP, instantaneous speed and acceleration calculated from TCA, as well as the corresponding emission rate from MOVES database. That is the segment level computation, and the three emissions of mixed traffic flow of conventional vehicles and micro-cars on expressway are predicted to be higher than only conventional vehicle flow in free flow, then not stable in congested flow. However, emissions will be lower on arterial road for all density regions. Then the prediction of environmental influence of micro-cars on Kichijoji area and Nagoya metropolitan network is demonstrated, using the calculated needed power, and both demonstrate lower needed power for with-micro-car flow than without-micro-car flow.

References

Jimenez-Palacios, J.L. (1999): Understanding and Quantifying Motor Vehicle Emissions with Vehicle Specific Power and TILDAS Remote Sensing. Doctor dissertation, Massachusetts: Institute of Technology, Cambrige.

Koupal, J., Michaels, H., Cumberworth, H., Bailey, C., and Brzezinski, D. (2002): EPA's Plan for MOVES: A Comprehensive Mobile Source Emissions Model.

Xu, Y., Yu, L., Song, G. Hao, Y. (2010): VSP-Bin division for light-duty vehicles oriented to carbon dioxide. Acta Scientiae Circumstantiae, Vol.30, Issue 7, pp. 1358-1365.

CHAPTER 7

CONCLUSION AND FUTURE STUDY

Conventional cars are well suited to conveying multiple passengers over long distances at high speeds, but inefficient as providers of personal mobility within cities, where most of the world's people now live. Many automobile manufacturers and academics have re-image the automobile, describing vehicles of the near future that are green, smart, connected and fun to drive.

An increasingly diverse range of alternatives are becoming available, promising more diverse transport options in the face of the climatic, social and financial issues facing society. Recent international motor shows have demonstrated a marginal increase in OEM alternative vehicle concepts that have trended towards two vehicle types: micro-cars and personal mobility devices (PMDs). While PMDs have many limitations, micro-cars offer a small spatial footprint that eases congestion and parking concerns, greater fuel efficiency, weather protection and some luggage capacity. Thus micro-cars are the most likely alternative vehicle to replace cars.

7.1 Finished work

To prepare the way for greater use of micro-cars, especially on city roads, this research analyzed the impact of micro-cars on traffic flow, safety and environmental impact. This is an area that has not been studied before, although other researches have looked into their impact on safety in 1980s. Those analysis either rely on the crash experiment, or based on the history statistic accidents data, or just discuss in political point of view. Indubitable there are shining points valuable to learn in their researches, however, no scientific approach has been used to do prediction work to explore the effects of micro-cars. Simulation is an alternative tool for complex and prospect hypotheses. And it is an important pathway to solve the problems and answer the questions in traffic engineering.

TCA model and VISSIM are chosen as the basis simulators for segment level analysis. Two-lane TCA models are developed one by one for purpose of representing traffic flow on road segment as precise as possible. After set the unit length of cell as 1 meter, vehicles have more realistic accelerations and decelerations, and have more speed choices. The model is so elaborate that the number of lane changes, the number of decelerations, the speed distribution, and instantaneous power per unit mass (VSP) are able to be obtained from the simulations, allowing for safety and environmental analysis of the introduction of micro-cars. A simulation model on road segment in VISSIM is also developed to achieve validation and comparison job with TCA. The results are similar, and demonstrate the weaknesses and strengths for each kind of model. The VISSIM can imitate drivers' behavior more detailed, while TCA have a faster calculation speed, and it is capable to simulate hysteresis loop and metastable state, which is enough for the aimed analysis level. However, as TCA have simpler rules than car following model in VISSIM, it is deficient to get more stochastic results. Another advantage using TCA is that the input of model is density, so fundamental diagram can be easier got, but in VISSIM the input is traffic volume or demand, the density is various following the time and location.

A base model in VISSIM is developed and calibrated for analysis on the influence of micro-cars to small network, by changing the parameters in the model time and again to obtain the most appropriate combination. Different scenarios are assumed according to the research goals, and many trials are made to perfect the excogitation to provide an excellent groundwork for comprehensive analysis on the results as far as possible. Finally three assumptions are confirmed. Keep the desired speed of conventional cars constant, and set that of micro-cars as 48-58km/h, 40-45km/h and 25-30km/h severally as the assumptions.

For the Nagoya metropolitan network analysis, amount of calculation works are executed to achieve the goal. In brief, a mass of programing, calculating, as well as designing works are handled to complete the prediction and analysis.

7.2 Conclusions

On road segment, mixed flows of conventional cars and micro-cars will relieve congestion in high density traffic, especially on urban road, and result in a negative effect on safety as measured by the number of lane changes and coefficient of variation of speed on expressway, while a higher density is safer both on expressways and arterial roads. However, micro-cars have a positive effect or no negative one on safety on arterial road. The introduction of micro-cars have evident positive influence on environment when consider HC, CO, NO_x emissions as a measurement, on arterial roads, but have negative effect on expressway in free flow. So driving micro-cars on expressway is not recommended, while on arterial road is recommended.

The results in small network suggest that higher micro-car rate and lower desired speed of micro-cars will bring about less needed power, thereby less emissions and higher fuel efficiency. For traffic point of view, micro-cars' introduction decreases the total network travel time when their desired speed are set as 48-58km/h or 40-45km/h, and the decrease is higher if the two vehicle types have the same desired speed. In the case of micro-cars' desired speed being 25-30km/h, the total network travel time will increase, and attains the highest percentage change at about 14% when there are 30% micro-cars in traffic, and will increase more if there are more micro-cars in the system. So it is not a sensible choice to limit micro-cars' speed lower than 30km/h. The results and analysis for environmental and traffic points of view demonstrate an opposite recommendation for micro-cars' desired speed setting. Also for safety analysis, results for micro-cars' desired speed being 48-58 and 40-45 km/h is similar, and have small effect on safety, but obvious negative influence if 25-30 km/h. So as a trade-off, we suggest the desired speed of micro-cars as 40-45km/h. In this case, the micro-cars have higher fuel efficiency, and also have no negative effect on the total travel efficiency for system optimum consideration.

The result from Nagoya metropolitan network illustrates that micro-cars have no obvious negative effect on traffic flow, and their introduction will not aggravate or alleviate congestion. If there are more micro-cars on road network, the vehicle emission will decrease. It is better to drive micro-cars to reduce vehicle emission.

7.3 Future study

This research analyzes the effects of micro-cars on traffic flow, also safety and emissions both in segment and network level. The TCA model can be improved by setting more detailed rules that more realistically to simulate actual traffic flows. Also, we can try different setting in the VISSIM to represent the driving behavior of micro-cars, as well as the difference between it and that of conventional vehicles. The traffic assignment with the prediction of micro-cars' demand is also an interesting topic to study, as micro-cars' returning to popular. Following the flush of alternative automobile, analysis on one-seat machines are also necessary to do, especially focus on the elders, or disabilities, etc.

APPENDIX

A. Operating mode and emission rates used in MOVES

Table 1 Operating mode table in MOVES

The unit of VSP is kw/metric ton, and unit of speed is mile/hour, unit of brakerate is m/s^2.

opMode ID	VSP Lower	VSP Upper	Speed Lower	Speed Upper	brakeRate 1Sec	brakeRate 3Sec
0				1	-2	-1
1			-1	25		
11		0	1	25		
12	0	3	1	25		
13	3	6	1	25		
14	6	9	1	25		
15	9	12	1	25		
16	12		1	50		
21		0	25	50		
22	0	3	25	50		
23	3	6	25	50		
24	6	9	25	50		
25	9	12	25	50		
27	12	18	25	50		
28	18	24	25	50		
29	24	30	25	50		
30	30		25	50		
33		6	50			
35	6	12	50			
37	12	18	50			
38	18	24	50			
39	24	30	50			
40	30		50			

Table 2 HC, CO, NO_x emission rate for every operating mode

opModeID	HC (g/h)	CO (g/h)	NO_x (g/h)
0	0.353795	7.1543	0.192248
1	0.0858163	1.23522	0.0814696
11	0.241301	24.5962	0.28505
12	0.184902	40.1554	0.435169
13	0.349473	37.0225	1.01872
14	0.475373	53.1206	1.79855
15	0.662705	77.0296	3.18762
16	1.05858	129.973	6.64782
21	0.361203	32.0581	0.563708
22	0.331722	42.4752	0.915601
23	0.357631	54.6246	1.38419
25	0.679884	90.624	3.2718
27	1.07442	136.097	5.15182
28	7.25265	282.644	18.9607
29	12.8765	598.595	33.2899
30	21.2585	2102.39	43.7974
33	0.346978	24.0698	1.20145
35	0.48184	41.0996	3.31438
37	0.617436	60.498	4.63148
38	4.89748	259.062	16.0997
39	7.11133	273.353	23.9662
40	9.29769	803.373	30.1851

B. Program Source Code

```
#ifndef _MCARLIGHT
#define _MCARLIGHT
# include <stdio.h>
# include <stdlib.h>
# include <time.h>
# include <math.h>
# include "alloc.c"
double mcarlight(int quantity,float mcarrate,int length,int lightcycle,int greentime,int redtime,int
totaltime,int counttime,int countunit, float lowerprob_r,float lowerprob_l,float lowerp,float
chanprob_rl,float chanprob_lr,int lc,int lm,int v_max_c,int v_max_m,int ac,int am,int ud,int la,char
initialmode,char printout,char *outputfile, char *outputfile_r,char *outputfile_l)
{
int i,j,jr,jl,jj,f,of,ob,r1,r2,l1,l2,k,e,condition,fr,fl,ppm,ppc,svml,svmr,svcl,svcr,interval;     int
*frd,*fld,*svmld,*svmrd,*svcld,*svcrd;
int nr,nl,tm,tc;
int totalvehicle_r;
int totalvehicle_l;
int totalvehicle;
int *vehiclelocation_r;
int *vehiclelocation_l;
int *vehiclespeed_r;
int *vehiclespeed_l;
int *locationspeed_r;
int *locationspeed_l;
int *locationstyle_l;
int *locationstyle_r;
int totalcar,totalmcar;
int gap,gap1,gap2,vv;
int nlc;
int nd;
int *s;
int opmode_c[23], opmode_m[23];
float p,pp,pm,pc;
float my_rand,my_rand1,my_rand2;
double flow_r;
double flow_l;
double flow,flowv,averagespeed;
float asm,asc;
char tr;
FILE *fp;
FILE *fp_r;
FILE *fp_l;
extern void  *Alloc_1D(int, size_t );
extern void **Alloc_2D(int,int, size_t);
extern void Free_2D(void **, int , int );
fp=fopen(outputfile,"a");
fp_r=fopen(outputfile_r,"a");
fp_l=fopen(outputfile_l,"a");
totalcar=(int)(quantity*(1-mcarrate)+0.5);
totalmcar=(int)(quantity*mcarrate+0.5);
totalvehicle=quantity;
locationspeed_r=(int *)Alloc_1D(length,sizeof(int));
locationspeed_l=(int *)Alloc_1D(length,sizeof(int));
```

```
locationstyle_r=(int *)Alloc_1D(length,sizeof(int));
locationstyle_l=(int *)Alloc_1D(length,sizeof(int));
s=(int *)Alloc_1D(v_max_c+1,sizeof(int));
frd=(int *)Alloc_1D((floor)(counttime/countunit),sizeof(int));
fld=(int *)Alloc_1D((floor)(counttime/countunit),sizeof(int));
svmld=(int *)Alloc_1D((floor)(counttime/countunit),sizeof(int));
svmrd=(int *)Alloc_1D((floor)(counttime/countunit),sizeof(int));
svcld=(int *)Alloc_1D((floor)(counttime/countunit),sizeof(int));
svcrd=(int *)Alloc_1D((floor)(counttime/countunit),sizeof(int));
if (initialmode=='A')
{
if (quantity>1)
interval=(floor)((length*2-(totalcar*lc+totalmcar*lm))/(totalcar+totalmcar));
else interval=0;
printf("interval=%d\t",interval);
for (i=0;i<length;i++)
{
locationspeed_r[i]=0;
locationspeed_l[i]=0;
locationstyle_r[i]=-1;
locationstyle_l[i]=-1;
}
jr=0;
jl=0;
tm=0;
tc=0;
    srand( (unsigned)time( NULL ) );
for (i=0;i<totalvehicle;i++)
{
my_rand=(float)(rand()/32767.0);
            my_rand1=(float)(rand()/32767.0);
if (tm<totalmcar && tc<totalcar)
{
                if (my_rand<=mcarrate)
{
if (jr<=(length-lm) && jl<=(length-lm))
{
if (my_rand1<0.5)
{
    for (jj=0;jj<lm;jj++)
{
     locationstyle_r[jr+jj]=10+lm-jj;
             locationspeed_r[jr+jj]=v_max_m;
}
            jr=jr+lm+interval;
            tm=tm+1;
}
else if (my_rand1>=0.5)
{
    for (jj=0;jj<lm;jj++)
{
     locationstyle_l[jl+jj]=10+lm-jj;
             locationspeed_l[jl+jj]=v_max_m;
}
            jl=jl+lm+interval;
```

```
                tm=tm+1;
}
}
else if (jr<=(length-lm) && jl>(length-lm))
{
     for (jj=0;jj<lm;jj++)
{
      locationstyle_r[jr+jj]=10+lm-jj;
                 locationspeed_r[jr+jj]=v_max_m;
}
                jr=jr+lm+interval;
                tm=tm+1;
}
     else if (jr>(length-lm) && jl<=(length-lm))
{
     for (jj=0;jj<lm;jj++)
{
      locationstyle_l[jl+jj]=10+lm-jj;
                 locationspeed_l[jl+jj]=v_max_m;
}
                jl=jl+lm+interval;
                tm=tm+1;
}
}
     else if (my_rand>mcarrate)
{
if (jr<=(length-lc) && jl<=(length-lc))
{
     if (my_rand1<0.5)
{
     for (jj=0;jj<lc;jj++)
{
      locationstyle_r[jr+jj]=20+lc-jj;
                      locationspeed_r[jr+jj]=v_max_c;
}
                jr=jr+lc+interval;
                tc=tc+1;
}
else if (my_rand1>=0.5)
{
     for (jj=0;jj<lc;jj++)
{
      locationstyle_l[jl+jj]=20+lc-jj;
                      locationspeed_l[jl+jj]=v_max_c;
}
                jl=jl+lc+interval;
                tc=tc+1;
}
}
else if (jr<=(length-lc) && jl>(length-lc))
{
     for (jj=0;jj<lc;jj++)
{
      locationstyle_r[jr+jj]=20+lc-jj;
                      locationspeed_r[jr+jj]=v_max_c;
```

```
}
            jr=jr+lc+interval;
            tc=tc+1;
}
else if (jr>(length-lc) && jl<=(length-lc))
{
    for (jj=0;jj<lc;jj++)
{
     locationstyle_l[jl+jj]=20+lc-jj;
                 locationspeed_l[jl+jj]=v_max_c;
}
            jl=jl+lc+interval;
            tc=tc+1;
}
}
}
    else if (tm==totalmcar && tc<totalcar)
{
if (jr<=(length-lc) && jl<=(length-lc))
{
if (my_rand1<0.5)
{
    for (jj=0;jj<lc;jj++)
{
     locationstyle_r[jr+jj]=20+lc-jj;
                 locationspeed_r[jr+jj]=v_max_c;
}
            jr=jr+lc+interval;
            tc=tc+1;
}
else if (my_rand1>=0.5)
{
    for (jj=0;jj<lc;jj++)
{
     locationstyle_l[jl+jj]=20+lc-jj;
                 locationspeed_l[jl+jj]=v_max_c;
}
            jl=jl+lc+interval;
            tc=tc+1;
}
}
else if (jr<=(length-lc) && jl>(length-lc))
{
        for (jj=0;jj<lc;jj++)
{
     locationstyle_r[jr+jj]=20+lc-jj;
                 locationspeed_r[jr+jj]=v_max_c;
}
            jr=jr+lc+interval;
            tc=tc+1;
}
    else if (jr>(length-lc) && jl<=(length-lc))
{
    for (jj=0;jj<lc;jj++)
{
```

```
        locationstyle_l[jl+jj]=20+lc-jj;
                    locationspeed_l[jl+jj]=v_max_c;
}
            jl=jl+lc+interval;
            tc=tc+1;
}
}
else if (tc==totalcar && tm<totalmcar)
{
if (jr<=(length-lm) && jl<=(length-lm))
{
if (my_rand1<0.5)
{
      for (jj=0;jj<lm;jj++)
{
        locationstyle_r[jr+jj]=10+lm-jj;
             locationspeed_r[jr+jj]=v_max_m;
}
            jr=jr+lm+interval;
            tm=tm+1;
}
else if (my_rand1>=0.5)
{
for (jj=0;jj<lm;jj++)
{
        locationstyle_l[jl+jj]=10+lm-jj;
             locationspeed_l[jl+jj]=v_max_m;
}
            jl=jl+lm+interval;
            tm=tm+1;
}
}
else if (jr<=(length-lm) && jl>(length-lm))
{
        for (jj=0;jj<lm;jj++)
  {
          locationstyle_r[jr+jj]=10+lm-jj;
               locationspeed_r[jr+jj]=v_max_m;
  }
              jr=jr+lm+interval;
              tm=tm+1;
}
      else if (jr>(length-lm) && jl<=(length-lm))
{
        for (jj=0;jj<lm;jj++)
  {
          locationstyle_l[jl+jj]=10+lm-jj;
               locationspeed_l[jl+jj]=v_max_m;
  }
              jl=jl+lm+interval;
              tm=tm+1;
}
}
            }
}
```

```
        nr=0.0;
        nl=0.0;
        for (j=0;j<length;j++)
{
if (locationstyle_r[j]==21 || locationstyle_r[j]==22)
nr=nr+1;
            if (locationstyle_l[j]==21 || locationstyle_l[j]==22)
        nl=nl+1;
}

if (initialmode=='B')
{
for (i=0;i<length;i++)
{
locationspeed_r[i]=0;
locationspeed_l[i]=0;
locationstyle_r[i]=-1;
locationstyle_l[i]=-1;
}
jr=0;
jl=0;
tm=0;
tc=0;
interval=0;
    srand( (unsigned)time( NULL ) );
for (i=0;i<totalvehicle;i++)
{
my_rand=(float)(rand()/32767.0);
            my_rand1=(float)(rand()/32767.0);
if (tm<totalmcar && tc<totalcar)
{
                if (my_rand<=mcarrate)
{
if (jr<=(length-lm) && jl<=(length-lm))
{
if (my_rand1<0.5)
{
    for (jj=0;jj<lm;jj++)
{
     locationstyle_r[jr+jj]=10+lm-jj;
             locationspeed_r[jr+jj]=0;
}
            jr=jr+lm+interval;
            tm=tm+1;
}
else if (my_rand1>=0.5)
{
    for (jj=0;jj<lm;jj++)
{
     locationstyle_l[jl+jj]=10+lm-jj;
             locationspeed_l[jl+jj]=0;
}
            jl=jl+lm+interval;
            tm=tm+1;
}
```

```
}
else if (jr<=(length-lm) && jl>(length-lm))
{
      for (jj=0;jj<lm;jj++)
{
        locationstyle_r[jr+jj]=10+lm-jj;
                    locationspeed_r[jr+jj]=0;
}
                  jr=jr+lm+interval;
                  tm=tm+1;
}
      else if (jr>(length-lm) && jl<=(length-lm))
{
      for (jj=0;jj<lm;jj++)
{
        locationstyle_l[jl+jj]=10+lm-jj;
                    locationspeed_l[jl+jj]=0;
}
                  jl=jl+lm+interval;
                  tm=tm+1;
}
}
      else if (my_rand>mcarrate)
{
if (jr<=(length-lc) && jl<=(length-lc))
{
      if (my_rand1<0.5)
{
      for (jj=0;jj<lc;jj++)
{
        locationstyle_r[jr+jj]=20+lc-jj;
                          locationspeed_r[jr+jj]=0;
}
                  jr=jr+lc+interval;
                  tc=tc+1;
}
else if (my_rand1>=0.5)
{
      for (jj=0;jj<lc;jj++)
{
        locationstyle_l[jl+jj]=20+lc-jj;
                          locationspeed_l[jl+jj]=0;
}
                  jl=jl+lc+interval;
                  tc=tc+1;
}
}
else if (jr<=(length-lc) && jl>(length-lc))
{
      for (jj=0;jj<lc;jj++)
{
        locationstyle_r[jr+jj]=20+lc-jj;
                          locationspeed_r[jr+jj]=0;
}
                  jr=jr+lc+interval;
```

```
                  tc=tc+1;
}
else if (jr>(length-lc) && jl<=(length-lc))
{
      for (jj=0;jj<lc;jj++)
{
        locationstyle_l[jl+jj]=20+lc-jj;
                          locationspeed_l[jl+jj]=0;
}
                  jl=jl+lc+interval;
                  tc=tc+1;
}
}
}
      else if (tm==totalmcar && tc<totalcar)
{
if (jr<=(length-lc) && jl<=(length-lc))
{
if (my_rand1<0.5)
{
      for (jj=0;jj<lc;jj++)
{
        locationstyle_r[jr+jj]=20+lc-jj;
                          locationspeed_r[jr+jj]=0;
}
                  jr=jr+lc+interval;
                  tc=tc+1;
}
else if (my_rand1>=0.5)
{
      for (jj=0;jj<lc;jj++)
{
        locationstyle_l[jl+jj]=20+lc-jj;
                          locationspeed_l[jl+jj]=0;
}
                  jl=jl+lc+interval;
                  tc=tc+1;
}
}
else if (jr<=(length-lc) && jl>(length-lc))
{
            for (jj=0;jj<lc;jj++)
{
        locationstyle_r[jr+jj]=20+lc-jj;
                          locationspeed_r[jr+jj]=0;
}
                  jr=jr+lc+interval;
                  tc=tc+1;
}
      else if (jr>(length-lc) && jl<=(length-lc))
{
      for (jj=0;jj<lc;jj++)
{
        locationstyle_l[jl+jj]=20+lc-jj;
                          locationspeed_l[jl+jj]=0;
```

```
}
            jl=jl+lc+interval;
            tc=tc+1;
}
}
else if (tc==totalcar && tm<totalmcar)
{
if (jr<=(length-lm) && jl<=(length-lm))
{
if (my_rand1<0.5)
{
    for (jj=0;jj<lm;jj++)
{
     locationstyle_r[jr+jj]=10+lm-jj;
             locationspeed_r[jr+jj]=0;
}
            jr=jr+lm+interval;
            tm=tm+1;
}
else if (my_rand1>=0.5)
{
for (jj=0;jj<lm;jj++)
{
     locationstyle_l[jl+jj]=10+lm-jj;
             locationspeed_l[jl+jj]=0;
}
            jl=jl+lm+interval;
            tm=tm+1;
}
}
else if (jr<=(length-lm) && jl>(length-lm))
{
     for (jj=0;jj<lm;jj++)
 {
      locationstyle_r[jr+jj]=10+lm-jj;
              locationspeed_r[jr+jj]=0;
 }
             jr=jr+lm+interval;
             tm=tm+1;
}
    else if (jr>(length-lm) && jl<=(length-lm))
{
     for (jj=0;jj<lm;jj++)
 {
      locationstyle_l[jl+jj]=10+lm-jj;
              locationspeed_l[jl+jj]=0;
 }
             jl=jl+lm+interval;
             tm=tm+1;
}
}
        }
}
flow=0.0;
fr=0;
```

```
fl=0;
flowv=0.0;
flow_r=0.0;
flow_l=0.0;
averagespeed=0.0;
asm=0.0;
asc=0.0;
svml=0;
svmr=0;
svcl=0;
svcr=0;
for (i=0;i<floor(counttime/countunit);i++)
{
        frd[i]=0;
  fld[i]=0;
  svmld[i]=0;
  svmrd[i]=0;
  svcld[i]=0;
  svcrd[i]=0;
}
nlc=0;
nd=0;
for (i=0;i<=v_max_c;i++)
s[i]=0;
for (i=0;i<23;i++)
{
opmode_c[i]=0;
opmode_m[i]=0;
}
p=0.0;
pm=0.0;
pc=0.0;
for (i=1;i<=totaltime;i++)
{
for (j=0;j<length;j++)
{
condition=0;
                  if (locationstyle_r[j]==11)
{
for (k=1;k<=min(locationspeed_r[j]+am,v_max_m);k++)
{
f=j+k;
if (f>=length)
f=f-length;       if (locationstyle_r[f]!=0)
{
condition=condition+1;
break;
}
}
}
else if (locationstyle_r[j]==21)
{
for (k=1;k<=min(locationspeed_r[j]+ac,v_max_c);k++)
{
f=j+k;
```

```
if (f>=length)
f=f-length;
      if (locationstyle_r[f]!=0)
{
condition=condition+1;
break;
}
}
}
if (condition==1)
{
          if (locationstyle_r[j]==11)
     {
      jj=0;
      for (k=1-lm;k<=min(locationspeed_r[j]+am,v_max_m)+1;k++)
{
      of=j+k;
      if (of>=length)
      of=of-length;
            if (locationstyle_l[of]==0)
{
jj=jj+1;
continue;
}
}
       if (jj==min(locationspeed_r[j]+am,v_max_m)+lm+1)
         condition=condition+1;
     }
     else if (locationstyle_r[j]==21)
     {
      jj=0;
         for (k=1-lc;k<=min(locationspeed_r[j]+ac,v_max_c)+1;k++)
{
       of=j+k;
       if (of>=length)
         of=of-length;
             if (locationstyle_l[of]==0)
 {
jj=jj+1;
continue;
 }
}
      if (jj==min(locationspeed_r[j]+ac,v_max_c)+lc+1)
         condition=condition+1;
     }
}
if (condition==2)
{
      if (locationstyle_r[j]==11)
{
       jj=j-lm;
       if (jj<0)
      jj=jj+length;
             while (locationstyle_l[jj]==0)
 {
```

```
            jj=jj-1;
        if (jj<0)
 jj=jj+length;
        if (jj==j)
 {
 condition=condition+1;
        break;
 }
 }
        if (locationstyle_l[jj]==11)
 {
            ob=j-jj-lm;
            if (ob<0)
           ob=ob+length;
            if (ob>min(locationspeed_l[jj]+am,v_max_m))
           condition=condition+1;
 }
            else if (locationstyle_l[jj]==21)
 {
            ob=j-jj-lm;
            if (ob<0)
        ob=ob+length;
            if (ob>min(locationspeed_l[jj]+ac,v_max_c))
            condition=condition+1;
 }
}
      else if (locationstyle_r[j]==21)
{
        jj=j-lc;
        if (jj<0)
         jj=jj+length;
             while (locationstyle_l[jj]==0)
  {
         jj=jj-1;
         if (jj<0)
   jj=jj+length;
         if (jj==j)
   {
   condition=condition+1;
         break;
   }
  }
        if (locationstyle_l[jj]==11)
  {
              ob=j-jj-lc;
              if (ob<0)
              ob=ob+length;
              if (ob>min(locationspeed_l[jj]+am,v_max_m))
              condition=condition+1;
  }
             else if (locationstyle_l[jj]==21)
  {
             ob=j-jj-lc;
             if (ob<0)
        ob=ob+length;
```

```
              if (ob>min(locationspeed_l[jj]+ac,v_max_c))
               condition=condition+1;
   }
}
}
if (condition==3)
{
my_rand2=(float)(rand()/32767.0);
            if (my_rand2<chanprob_rl)
{
locationspeed_l[j]=-2;
      if (i>(totaltime-counttime))
            nlc=nlc+1;
}
}
}
for (j=0;j<length;j++)
{
condition=0;
                  if (locationstyle_l[j]==11)
{
for (k=1;k<=min(locationspeed_l[j]+am,v_max_m);k++)
{
f=j+k;
if (f>=length)
f=f-length;
      if (locationstyle_l[f]!=0)
{
condition=condition+1;
break;
}
}
}
else if (locationstyle_l[j]==21)
{
for (k=1;k<=min(locationspeed_l[j]+ac,v_max_c);k++)
{
f=j+k;
if (f>=length)
f=f-length;
      if (locationstyle_l[f]!=0)
{
condition=condition+1;
break;
}
}
}
if (condition==1)
{
             if (locationstyle_l[j]==11)
  {
         jj=0;
         for (k=1-lm;k<=min(locationspeed_l[j]+am,v_max_m)+1;k++)
   {
            of=j+k;
```

```
            if (of>=length)
          of=of-length;
              if (locationstyle_r[of]==0)
{
          jj=jj+1;
      continue;
}
   }
        if (jj==min(locationspeed_l[j]+am,v_max_m)+lm+1)
         condition=condition+1;
 }
       else if (locationstyle_l[j]==21)
 {
         jj=0;
            for (k=1-lc;k<=min(locationspeed_l[j]+ac,v_max_c)+1;k++)
    {
          of=j+k;
          if (of>=length)
      of=of-length;
              if (locationstyle_r[of]==0)
{
      jj=jj+1;
      continue;
}
    }
         if (jj==min(locationspeed_l[j]+ac,v_max_c)+lc+1)
          condition=condition+1;
 }
}
if (condition==2)
{
        if (locationstyle_l[j]==11)
   {
         jj=j-lm;
         if (jj<0)
         jj=jj+length;
             while (locationstyle_r[jj]==0)
    {
         jj=jj-1;
         if (jj<0)
         jj=jj+length;
         if (jj==j)
    {
    condition=condition+1;
         break;
    }
    }
         if (locationstyle_r[jj]==11)
    {
             ob=j-jj-lm;
             if (ob<0)
         ob=ob+length;
             if (ob>min(locationspeed_r[jj]+am,v_max_m))
             condition=condition+1;
    }
```

```
            else if (locationstyle_r[jj]==21)
    {
             ob=j-jj-lm;
             if (ob<0)
         ob=ob+length;
             if (ob>min(locationspeed_r[jj]+ac,v_max_c))
         condition=condition+1;
    }
   }
       else if (locationstyle_l[j]==21)
   {
         jj=j-lc;
         if (jj<0)
     jj=jj+length;
             while (locationstyle_r[jj]==0)
{
           jj=jj-1;
           if (jj<0)
       jj=jj+length;
           if (jj==j)
   {
   condition=condition+1;
           break;
   }
}
         if (locationstyle_r[jj]==11)
{
              ob=j-jj-lc;
              if (ob<0)
               ob=ob+length;
              if (ob>min(locationspeed_r[jj]+am,v_max_m))
               condition=condition+1;
}
             else if (locationstyle_r[jj]==21)
{
              ob=j-jj-lc;
              if (ob<0)
          ob=ob+length;
              if (ob>min(locationspeed_r[jj]+ac,v_max_c))
               condition=condition+1;
}
   }
}
     if (condition==3)
{
     my_rand2=(float)(rand()/32767.0);
         if (my_rand2<chanprob_lr)
{
locationspeed_r[j]=-2;
     if (i>(totaltime-counttime))
     nlc=nlc+1;
}
}
}
for (j=0;j<length;j++)
```

```
{
if (locationspeed_l[j]==-2)
{
if (locationstyle_r[j]==11)
{
for (jj=j-lm+1;jj<=j;jj++)
{
if (jj<0)
jj=jj+length;
locationspeed_l[jj]=locationspeed_r[jj];
        locationstyle_l[jj]=locationstyle_r[jj];
            locationspeed_r[jj]=-1;
         locationstyle_r[jj]=0;
}
}
else if (locationstyle_r[j]==21)
{
    for (jj=j-lc+1;jj<=j;jj++)
{
if (jj<0)
jj=jj+length;
locationspeed_l[jj]=locationspeed_r[jj];
        locationstyle_l[jj]=locationstyle_r[jj];
            locationspeed_r[jj]=-1;
         locationstyle_r[jj]=0;
}
}
}
    if (locationspeed_r[j]==-2)
{
if (locationstyle_l[j]==11)
{
for (jj=j-lm+1;jj<=j;jj++)
{
if (jj<0)
jj=jj+length;
    locationspeed_r[jj]=locationspeed_l[jj];
        locationstyle_r[jj]=locationstyle_l[jj];
            locationspeed_l[jj]=-1;
         locationstyle_l[jj]=0;
}
}
else if (locationstyle_l[j]==21)
{
for (jj=j-lc+1;jj<=j;jj++)
{
if (jj<0)
jj=jj+length;
    locationspeed_r[jj]=locationspeed_l[jj];
        locationstyle_r[jj]=locationstyle_l[jj];
            locationspeed_l[jj]=-1;
         locationstyle_l[jj]=0;
}
}
}
```

```
}
        nr=0;
        nl=0;
        for (j=0;j<length;j++)
{
if (locationstyle_r[j]==11 || locationstyle_r[j]==21)
nr=nr+1;
            if (locationstyle_l[j]==11 || locationstyle_l[j]==21)
        nl=nl+1;
}
            totalvehicle_r=(int)(nr);
        totalvehicle_l=(int)(nl);
            vehiclelocation_r=(int *)Alloc_1D(totalvehicle_r,sizeof(int));
        vehiclelocation_l=(int *)Alloc_1D(totalvehicle_l,sizeof(int));
        vehiclespeed_r=(int *)Alloc_1D(totalvehicle_r,sizeof(int));
        vehiclespeed_l=(int *)Alloc_1D(totalvehicle_l,sizeof(int));
r1=0;
r2=0;
        while (r1<length)
{
if (locationstyle_r[r1]==11 || locationstyle_r[r1]==21)
{
                vehiclelocation_r[r2]=r1;
    vehiclespeed_r[r2]=locationspeed_r[r1];
    r2=r2+1;
}
            r1=r1+1;
}
l1=0;
l2=0;
while (l1<length)
{
if (locationstyle_l[l1]==11 || locationstyle_l[l1]==21)
{
                vehiclelocation_l[l2]=l1;
    vehiclespeed_l[l2]=locationspeed_l[l1];
    l2=l2+1;
}
l1=l1+1;
}
   if ((i%lightcycle)>=greentime)
   {
   if (totalvehicle_r>0)
   {
   if (totalvehicle_r==1)
   {
           if (locationstyle_r[vehiclelocation_r[0]]==11)
           gap2=length-lm;
           if (locationstyle_r[vehiclelocation_r[0]]==21)
           gap2=length-lc;
   }
       if (totalvehicle_r>1)
   {
       if (locationstyle_r[vehiclelocation_r[1]]==11)
           gap2=vehiclelocation_r[1]-vehiclelocation_r[0]-lm;
```

```
            if (locationstyle_r[vehiclelocation_r[1]]==21)
            gap2=vehiclelocation_r[1]-vehiclelocation_r[0]-lc;
  }
        for (j=totalvehicle_r-1;j>=0;j--)
  {
        vv=max(0,gap2-ud);
        if (j==totalvehicle_r-1)
{
        vv=min(vv,vehiclespeed_r[0]);
        if (locationstyle_r[vehiclelocation_r[0]]==11)
{
        vv=min(vv,v_max_m-ud);
        gap=vehiclelocation_r[0]+length-vehiclelocation_r[j]-lm;
}
        else
{
        vv=min(vv,v_max_c-ud);
        gap=vehiclelocation_r[0]+length-vehiclelocation_r[j]-lc;
}
}
        else
{
        vv=min(vv,vehiclespeed_r[j+1]);
        if (locationstyle_r[vehiclelocation_r[j+1]]==11)
{
        vv=min(vv,v_max_m-ud);
        gap=vehiclelocation_r[j+1]-vehiclelocation_r[j]-lm;
}
        else
{
        vv=min(vv,v_max_c-ud);
        gap=vehiclelocation_r[j+1]-vehiclelocation_r[j]-lc;
}
}
        e=vehiclespeed_r[j];
            if (locationstyle_r[vehiclelocation_r[j]]==11)
vehiclespeed_r[j]=min(locationspeed_r[vehiclelocation_r[j]]+am,v_max_m);
            else vehiclespeed_r[j]=min(locationspeed_r[vehiclelocation_r[j]]+ac,v_max_c);
        vehiclespeed_r[j]=min(vehiclespeed_r[j],gap);
                gap1=(length/2)-vehiclelocation_r[j]-1;
        if (gap1<0)
        gap1=gap1+length;
                vehiclespeed_r[j]=min(vehiclespeed_r[j],gap1);
my_rand1=(float)(rand()/32767.0);
        if (((length/2)-vehiclelocation_r[j])>30 || ((length/2)-vehiclelocation_r[j])<=0)
{
if (vehiclespeed_r[j]<=e)
{
    if (my_rand1<lowerp)
vehiclespeed_r[j]=max(vehiclespeed_r[j]-ud,0);
}
else
{
                if (my_rand1<lowerprob_r)
{
```

```
        vehiclespeed_r[j]=max(vehiclespeed_r[j]-ud,0);
}
}
}
        gap2=gap;
        if (vehiclespeed_r[j]<e && i>(totaltime-counttime))
        nd=nd+1;
        if (i>(totaltime-counttime))
        s[vehiclespeed_r[j]]=s[vehiclespeed_r[j]]+1;
        if (i>(totaltime-counttime))
{
                if (locationstyle_r[vehiclelocation_r[j]]==11)
{
pp=e*((vehiclespeed_r[j]-e)*1.1+0.1275)+0.0004987*e*e*e;
}
        if (locationstyle_r[vehiclelocation_r[j]]==21)
{
pp=e*((vehiclespeed_r[j]-e)*1.1+0.1275)+0.0002735*e*e*e;
}
if (locationstyle_r[vehiclelocation_r[j]]==21)
{
    if ((vehiclespeed_r[j]-e)<=-2) opmode_c[0]=opmode_c[0]+1;
    else if (e>=-0.447 && e<0.447) opmode_c[1]=opmode_c[1]+1;
    else if (pp<0 && e>=0.447 && e<11.175) opmode_c[2]=opmode_c[2]+1;
    else if (pp>=0 && pp<3 && e>=0.447 && e<11.175) opmode_c[3]=opmode_c[3]+1;
    else if (pp>=3 && pp<6 && e>=0.447 && e<11.175) opmode_c[4]=opmode_c[4]+1;
    else if (pp>=6 && pp<9 && e>=0.447 && e<11.175) opmode_c[5]=opmode_c[5]+1;
    else if (pp>=9 && pp<12 && e>=0.447 && e<11.175) opmode_c[6]=opmode_c[6]+1;
    else if (pp>=12 && e>=0.447 && e<11.175) opmode_c[7]=opmode_c[7]+1;
    else if (pp<0 && e>=11.175 && e<22.35) opmode_c[8]=opmode_c[8]+1;
    else if (pp>=0 && pp<3 && e>=11.175 && e<22.35) opmode_c[9]=opmode_c[9]+1;
    else if (pp>=3 && pp<6 && e>=11.175 && e<22.35) opmode_c[10]=opmode_c[10]+1;
    else if (pp>=6 && pp<9 && e>=11.175 && e<22.35) opmode_c[11]=opmode_c[11]+1;
    else if (pp>=9 && pp<12 && e>=11.175 && e<22.35) opmode_c[12]=opmode_c[12]+1;
     else if (pp>=12 && pp<18 && e>=11.175 && e<22.35) opmode_c[13]=opmode_c[13]+1;
    else if (pp>=18 && pp<24 && e>=11.175 && e<22.35) opmode_c[14]=opmode_c[14]+1;
    else if (pp>=24 && pp<30 && e>=11.175 && e<22.35) opmode_c[15]=opmode_c[15]+1;
    else if (pp>=30 && e>=11.175 && e<22.35) opmode_c[16]=opmode_c[16]+1;
    else if (pp<6 && e>=22.35) opmode_c[17]=opmode_c[17]+1;
    else if (pp>=6 && pp<12 && e>=22.35) opmode_c[18]=opmode_c[18]+1;
    else if (pp>=12 && pp<18 && e>=22.35) opmode_c[19]=opmode_c[19]+1;
    else if (pp>=18 && pp<24 && e>=22.35) opmode_c[20]=opmode_c[20]+1;
    else if (pp>=24 && pp<30 && e>=22.35) opmode_c[21]=opmode_c[21]+1;
    else if (pp>=30 && e>=22.35) opmode_c[22]=opmode_c[22]+1;
}
else
{
if ((vehiclespeed_r[j]-e)<=-2) opmode_m[0]=opmode_m[0]+1;
    else if (e>=-0.447 && e<0.447) opmode_m[1]=opmode_m[1]+1;
    else if (pp<0 && e>=0.447 && e<11.175) opmode_m[2]=opmode_m[2]+1;
    else if (pp>=0 && pp<3 && e>=0.447 && e<11.175) opmode_m[3]=opmode_m[3]+1;
    else if (pp>=3 && pp<6 && e>=0.447 && e<11.175) opmode_m[4]=opmode_m[4]+1;
    else if (pp>=6 && pp<9 && e>=0.447 && e<11.175) opmode_m[5]=opmode_m[5]+1;
    else if (pp>=9 && pp<12 && e>=0.447 && e<11.175) opmode_m[6]=opmode_m[6]+1;
    else if (pp>=12 && e>=0.447 && e<11.175) opmode_m[7]=opmode_m[7]+1;
```

```
      else if (pp<0 && e>=11.175 && e<22.35) opmode_m[8]=opmode_m[8]+1;
      else if (pp>=0 && pp<3 && e>=11.175 && e<22.35) opmode_m[9]=opmode_m[9]+1;
      else if (pp>=3 && pp<6 && e>=11.175 && e<22.35) opmode_m[10]=opmode_m[10]+1;
      else if (pp>=6 && pp<9 && e>=11.175 && e<22.35) opmode_m[11]=opmode_m[11]+1;
      else if (pp>=9 && pp<12 && e>=11.175 && e<22.35) opmode_m[12]=opmode_m[12]+1;
       else if (pp>=12 && pp<18 && e>=11.175 && e<22.35) opmode_m[13]=opmode_m[13]+1;
      else if (pp>=18 && pp<24 && e>=11.175 && e<22.35) opmode_m[14]=opmode_m[14]+1;
      else if (pp>=24 && pp<30 && e>=11.175 && e<22.35) opmode_m[15]=opmode_m[15]+1;
      else if (pp>=30 && e>=11.175 && e<22.35) opmode_m[16]=opmode_m[16]+1;
      else if (pp<6 && e>=22.35) opmode_m[17]=opmode_m[17]+1;
      else if (pp>=6 && pp<12 && e>=22.35) opmode_m[18]=opmode_m[18]+1;
      else if (pp>=12 && pp<18 && e>=22.35) opmode_m[19]=opmode_m[19]+1;
      else if (pp>=18 && pp<24 && e>=22.35) opmode_m[20]=opmode_m[20]+1;
      else if (pp>=24 && pp<30 && e>=22.35) opmode_m[21]=opmode_m[21]+1;
      else if (pp>=30 && e>=22.35) opmode_m[22]=opmode_m[22]+1;
}
}
    }
    }
    if (totalvehicle_l>0)
    {
    if (totalvehicle_l==1)
    {
            if (locationstyle_l[vehiclelocation_l[0]]==11)
            gap2=length-lm;
            if (locationstyle_l[vehiclelocation_l[0]]==21)
            gap2=length-lc;
    }
        if (totalvehicle_l>1)
    {
        if (locationstyle_l[vehiclelocation_l[1]]==11)
            gap2=vehiclelocation_l[1]-vehiclelocation_l[0]-lm;
            if (locationstyle_l[vehiclelocation_l[1]]==21)
            gap2=vehiclelocation_l[1]-vehiclelocation_l[0]-lc;
    }
        for (j=totalvehicle_l-1;j>=0;j--)
    {
         vv=max(0,gap2-ud);
         if (j==totalvehicle_l-1)
{
         vv=min(vv,vehiclespeed_l[0]);
         if (locationstyle_l[vehiclelocation_l[0]]==11)
{
         vv=min(vv,v_max_m-ud);
         gap=vehiclelocation_l[0]+length-vehiclelocation_l[j]-lm;
}
         else
{
         vv=min(vv,v_max_c-ud);
         gap=vehiclelocation_l[0]+length-vehiclelocation_l[j]-lc;
}
}
         else
{
         vv=min(vv,vehiclespeed_l[j+1]);
```

```
            if (locationstyle_l[vehiclelocation_l[j+1]]==11)
{
            vv=min(vv,v_max_m-ud);
            gap=vehiclelocation_l[j+1]-vehiclelocation_l[j]-lm;
}
            else
{
            vv=min(vv,v_max_c-ud);
            gap=vehiclelocation_l[j+1]-vehiclelocation_l[j]-lc;
}
}
            e=vehiclespeed_l[j];
                  if (locationstyle_l[vehiclelocation_l[j]]==11)
                        vehiclespeed_l[j]=min(locationspeed_l[vehiclelocation_l[j]]+am,v_max_m);
                  else vehiclespeed_l[j]=min(locationspeed_l[vehiclelocation_l[j]]+ac,v_max_c);
            vehiclespeed_l[j]=min(vehiclespeed_l[j],gap);
                              gap1=(length/2)-vehiclelocation_l[j]-1;
            if (gap1<0)
            gap1=gap1+length;
                              vehiclespeed_l[j]=min(vehiclespeed_l[j],gap1);
my_rand1=(float)(rand()/32767.0);
            if (((length/2)-vehiclelocation_l[j])>30 || ((length/2)-vehiclelocation_l[j])<=0)
{
if (vehiclespeed_l[j]<=e)
{
//my_rand1=(float)(rand()/32767.0);
      if (my_rand1<lowerp)
vehiclespeed_l[j]=max(vehiclespeed_l[j]-ud,0);
}
else
{
//my_rand1=(float)(rand()/32767.0);
                              if (my_rand1<lowerprob_l)
{
//              if (locationstyle_l[vehiclelocation_l[j]]==11)
            vehiclespeed_l[j]=max(vehiclespeed_l[j]-ud,0);
//              else vehiclespeed_l[j]=max(vehiclespeed_l[j]-ac,0);
}
}
}
            gap2=gap;
            if (vehiclespeed_l[j]<e && i>(totaltime-counttime))
            nd=nd+1;
            if (i>(totaltime-counttime))
            s[vehiclespeed_l[j]]=s[vehiclespeed_l[j]]+1;
            if (i>(totaltime-counttime))
{
                                    if (locationstyle_l[vehiclelocation_l[j]]==11)
{
pp=e*((vehiclespeed_l[j]-e)*1.1+0.1275)+0.0004987*e*e*e;
}
            if (locationstyle_l[vehiclelocation_l[j]]==21)
{
pp=e*((vehiclespeed_l[j]-e)*1.1+0.1275)+0.0002735*e*e*e;
}
```

```
if (locationstyle_l[vehiclelocation_l[j]]==21)
{
    if ((vehiclespeed_l[j]-e)<=-2) opmode_c[0]=opmode_c[0]+1;
    else if (e>=-0.447 && e<0.447) opmode_c[1]=opmode_c[1]+1;
    else if (pp<0 && e>=0.447 && e<11.175) opmode_c[2]=opmode_c[2]+1;
    else if (pp>=0 && pp<3 && e>=0.447 && e<11.175) opmode_c[3]=opmode_c[3]+1;
    else if (pp>=3 && pp<6 && e>=0.447 && e<11.175) opmode_c[4]=opmode_c[4]+1;
    else if (pp>=6 && pp<9 && e>=0.447 && e<11.175) opmode_c[5]=opmode_c[5]+1;
    else if (pp>=9 && pp<12 && e>=0.447 && e<11.175) opmode_c[6]=opmode_c[6]+1;
    else if (pp>=12 && e>=0.447 && e<11.175) opmode_c[7]=opmode_c[7]+1;
    else if (pp<0 && e>=11.175 && e<22.35) opmode_c[8]=opmode_c[8]+1;
    else if (pp>=0 && pp<3 && e>=11.175 && e<22.35) opmode_c[9]=opmode_c[9]+1;
    else if (pp>=3 && pp<6 && e>=11.175 && e<22.35) opmode_c[10]=opmode_c[10]+1;
    else if (pp>=6 && pp<9 && e>=11.175 && e<22.35) opmode_c[11]=opmode_c[11]+1;
    else if (pp>=9 && pp<12 && e>=11.175 && e<22.35) opmode_c[12]=opmode_c[12]+1;
     else if (pp>=12 && pp<18 && e>=11.175 && e<22.35) opmode_c[13]=opmode_c[13]+1;
    else if (pp>=18 && pp<24 && e>=11.175 && e<22.35) opmode_c[14]=opmode_c[14]+1;
    else if (pp>=24 && pp<30 && e>=11.175 && e<22.35) opmode_c[15]=opmode_c[15]+1;
    else if (pp>=30 && e>=11.175 && e<22.35) opmode_c[16]=opmode_c[16]+1;
    else if (pp<6 && e>=22.35) opmode_c[17]=opmode_c[17]+1;
    else if (pp>=6 && pp<12 && e>=22.35) opmode_c[18]=opmode_c[18]+1;
    else if (pp>=12 && pp<18 && e>=22.35) opmode_c[19]=opmode_c[19]+1;
    else if (pp>=18 && pp<24 && e>=22.35) opmode_c[20]=opmode_c[20]+1;
    else if (pp>=24 && pp<30 && e>=22.35) opmode_c[21]=opmode_c[21]+1;
    else if (pp>=30 && e>=22.35) opmode_c[22]=opmode_c[22]+1;
}
else
{
if ((vehiclespeed_l[j]-e)<=-2) opmode_m[0]=opmode_m[0]+1;
    else if (e>=-0.447 && e<0.447) opmode_m[1]=opmode_m[1]+1;
    else if (pp<0 && e>=0.447 && e<11.175) opmode_m[2]=opmode_m[2]+1;
    else if (pp>=0 && pp<3 && e>=0.447 && e<11.175) opmode_m[3]=opmode_m[3]+1;
    else if (pp>=3 && pp<6 && e>=0.447 && e<11.175) opmode_m[4]=opmode_m[4]+1;
    else if (pp>=6 && pp<9 && e>=0.447 && e<11.175) opmode_m[5]=opmode_m[5]+1;
    else if (pp>=9 && pp<12 && e>=0.447 && e<11.175) opmode_m[6]=opmode_m[6]+1;
    else if (pp>=12 && e>=0.447 && e<11.175) opmode_m[7]=opmode_m[7]+1;
    else if (pp<0 && e>=11.175 && e<22.35) opmode_m[8]=opmode_m[8]+1;
    else if (pp>=0 && pp<3 && e>=11.175 && e<22.35) opmode_m[9]=opmode_m[9]+1;
    else if (pp>=3 && pp<6 && e>=11.175 && e<22.35) opmode_m[10]=opmode_m[10]+1;
    else if (pp>=6 && pp<9 && e>=11.175 && e<22.35) opmode_m[11]=opmode_m[11]+1;
    else if (pp>=9 && pp<12 && e>=11.175 && e<22.35) opmode_m[12]=opmode_m[12]+1;
     else if (pp>=12 && pp<18 && e>=11.175 && e<22.35) opmode_m[13]=opmode_m[13]+1;
    else if (pp>=18 && pp<24 && e>=11.175 && e<22.35) opmode_m[14]=opmode_m[14]+1;
    else if (pp>=24 && pp<30 && e>=11.175 && e<22.35) opmode_m[15]=opmode_m[15]+1;
    else if (pp>=30 && e>=11.175 && e<22.35) opmode_m[16]=opmode_m[16]+1;
    else if (pp<6 && e>=22.35) opmode_m[17]=opmode_m[17]+1;
    else if (pp>=6 && pp<12 && e>=22.35) opmode_m[18]=opmode_m[18]+1;
    else if (pp>=12 && pp<18 && e>=22.35) opmode_m[19]=opmode_m[19]+1;
    else if (pp>=18 && pp<24 && e>=22.35) opmode_m[20]=opmode_m[20]+1;
    else if (pp>=24 && pp<30 && e>=22.35) opmode_m[21]=opmode_m[21]+1;
    else if (pp>=30 && e>=22.35) opmode_m[22]=opmode_m[22]+1;
}
}
   }
   }
```

```
    }
    if ((i%lightcycle)<greentime)
    {
    if (totalvehicle_r>0)
    {
    if (totalvehicle_r==1)
    {
            if (locationstyle_r[vehiclelocation_r[0]]==11)
            gap2=length-lm;
            if (locationstyle_r[vehiclelocation_r[0]]==21)
            gap2=length-lc;
    }
        if (totalvehicle_r>1)
    {
        if (locationstyle_r[vehiclelocation_r[1]]==11)
            gap2=vehiclelocation_r[1]-vehiclelocation_r[0]-lm;
            if (locationstyle_r[vehiclelocation_r[1]]==21)
            gap2=vehiclelocation_r[1]-vehiclelocation_r[0]-lc;
    }
            for (j=totalvehicle_r-1;j>=0;j--)
    {
         vv=max(0,gap2-ud);
         if (j==totalvehicle_r-1)
{
         vv=min(vv,vehiclespeed_r[0]);
         if (locationstyle_r[vehiclelocation_r[0]]==11)
{
         vv=min(vv,v_max_m-ud);
         gap=vehiclelocation_r[0]+length-vehiclelocation_r[j]-lm;
}
         else
{
         vv=min(vv,v_max_c-ud);
         gap=vehiclelocation_r[0]+length-vehiclelocation_r[j]-lc;
}
}
         else
{
         vv=min(vv,vehiclespeed_r[j+1]);
         if (locationstyle_r[vehiclelocation_r[j+1]]==11)
{
         vv=min(vv,v_max_m-ud);
         gap=vehiclelocation_r[j+1]-vehiclelocation_r[j]-lm;
}
         else
{
         vv=min(vv,v_max_c-ud);
         gap=vehiclelocation_r[j+1]-vehiclelocation_r[j]-lc;
}
}
         e=vehiclespeed_r[j];
my_rand1=(float)(rand()/32767.0);
if (vehiclelocation_r[j]>=(length/2-50) && vehiclelocation_r[j]<(length/2+50))
{
if (locationstyle_r[vehiclelocation_r[j]]==11)
```

```
                    vehiclespeed_r[j]=min(locationspeed_r[vehiclelocation_r[j]]+la,v_max_m);
                else vehiclespeed_r[j]=min(locationspeed_r[vehiclelocation_r[j]]+la,v_max_c);
vehiclespeed_r[j]=min(vehiclespeed_r[j],gap);
if (vehiclespeed_r[j]<=e)
{
//my_rand1=(float)(rand()/32767.0);
    if (my_rand1<lowerp)
vehiclespeed_r[j]=max(vehiclespeed_r[j]-ud,0);
}
else
{
//my_rand1=(float)(rand()/32767.0);
                    if (my_rand1<lowerprob_r)
{
//          if (locationstyle_r[vehiclelocation_r[j]]==11)
        vehiclespeed_r[j]=max(vehiclespeed_r[j]-ud,0);
//          else vehiclespeed_r[j]=max(vehiclespeed_r[j]-ac,0);
}
}
}
else
{
                if (locationstyle_r[vehiclelocation_r[j]]==11)
                    vehiclespeed_r[j]=min(locationspeed_r[vehiclelocation_r[j]]+am,v_max_m);
                else vehiclespeed_r[j]=min(locationspeed_r[vehiclelocation_r[j]]+ac,v_max_c);
            vehiclespeed_r[j]=min(vehiclespeed_r[j],gap);
if (vehiclespeed_r[j]<=e)
{
//my_rand1=(float)(rand()/32767.0);
    if (my_rand1<lowerp)
vehiclespeed_r[j]=max(vehiclespeed_r[j]-ud,0);
}
else
{
//my_rand1=(float)(rand()/32767.0);
                    if (my_rand1<lowerprob_r)
{
//          if (locationstyle_r[vehiclelocation_r[j]]==11)
        vehiclespeed_r[j]=max(vehiclespeed_r[j]-ud,0);
//          else vehiclespeed_r[j]=max(vehiclespeed_r[j]-ac,0);
}
}
}
        gap2=gap;
        if (vehiclespeed_r[j]<e && i>(totaltime-counttime))
        nd=nd+1;
        if (i>(totaltime-counttime))
            s[vehiclespeed_r[j]]=s[vehiclespeed_r[j]]+1;
        if (i>(totaltime-counttime))
{
                        if (locationstyle_r[vehiclelocation_r[j]]==11)
{
pp=e*((vehiclespeed_r[j]-e)*1.1+0.1275)+0.0004987*e*e*e;
}
        if (locationstyle_r[vehiclelocation_r[j]]==21)
```

```
{
pp=e*((vehiclespeed_r[j]-e)*1.1+0.1275)+0.0002735*e*e*e;
}
if (locationstyle_r[vehiclelocation_r[j]]==21)
{
    if ((vehiclespeed_r[j]-e)<=-2) opmode_c[0]=opmode_c[0]+1;
    else if (e>=-0.447 && e<0.447) opmode_c[1]=opmode_c[1]+1;
    else if (pp<0 && e>=0.447 && e<11.175) opmode_c[2]=opmode_c[2]+1;
    else if (pp>=0 && pp<3 && e>=0.447 && e<11.175) opmode_c[3]=opmode_c[3]+1;
    else if (pp>=3 && pp<6 && e>=0.447 && e<11.175) opmode_c[4]=opmode_c[4]+1;
    else if (pp>=6 && pp<9 && e>=0.447 && e<11.175) opmode_c[5]=opmode_c[5]+1;
    else if (pp>=9 && pp<12 && e>=0.447 && e<11.175) opmode_c[6]=opmode_c[6]+1;
    else if (pp>=12 && e>=0.447 && e<11.175) opmode_c[7]=opmode_c[7]+1;
    else if (pp<0 && e>=11.175 && e<22.35) opmode_c[8]=opmode_c[8]+1;
    else if (pp>=0 && pp<3 && e>=11.175 && e<22.35) opmode_c[9]=opmode_c[9]+1;
    else if (pp>=3 && pp<6 && e>=11.175 && e<22.35) opmode_c[10]=opmode_c[10]+1;
    else if (pp>=6 && pp<9 && e>=11.175 && e<22.35) opmode_c[11]=opmode_c[11]+1;
    else if (pp>=9 && pp<12 && e>=11.175 && e<22.35) opmode_c[12]=opmode_c[12]+1;
     else if (pp>=12 && pp<18 && e>=11.175 && e<22.35) opmode_c[13]=opmode_c[13]+1;
    else if (pp>=18 && pp<24 && e>=11.175 && e<22.35) opmode_c[14]=opmode_c[14]+1;
    else if (pp>=24 && pp<30 && e>=11.175 && e<22.35) opmode_c[15]=opmode_c[15]+1;
    else if (pp>=30 && e>=11.175 && e<22.35) opmode_c[16]=opmode_c[16]+1;
    else if (pp<6 && e>=22.35) opmode_c[17]=opmode_c[17]+1;
    else if (pp>=6 && pp<12 && e>=22.35) opmode_c[18]=opmode_c[18]+1;
    else if (pp>=12 && pp<18 && e>=22.35) opmode_c[19]=opmode_c[19]+1;
    else if (pp>=18 && pp<24 && e>=22.35) opmode_c[20]=opmode_c[20]+1;
    else if (pp>=24 && pp<30 && e>=22.35) opmode_c[21]=opmode_c[21]+1;
    else if (pp>=30 && e>=22.35) opmode_c[22]=opmode_c[22]+1;
}
else
{
if ((vehiclespeed_r[j]-e)<=-2) opmode_m[0]=opmode_m[0]+1;
    else if (e>=-0.447 && e<0.447) opmode_m[1]=opmode_m[1]+1;
    else if (pp<0 && e>=0.447 && e<11.175) opmode_m[2]=opmode_m[2]+1;
    else if (pp>=0 && pp<3 && e>=0.447 && e<11.175) opmode_m[3]=opmode_m[3]+1;
    else if (pp>=3 && pp<6 && e>=0.447 && e<11.175) opmode_m[4]=opmode_m[4]+1;
    else if (pp>=6 && pp<9 && e>=0.447 && e<11.175) opmode_m[5]=opmode_m[5]+1;
    else if (pp>=9 && pp<12 && e>=0.447 && e<11.175) opmode_m[6]=opmode_m[6]+1;
    else if (pp>=12 && e>=0.447 && e<11.175) opmode_m[7]=opmode_m[7]+1;
    else if (pp<0 && e>=11.175 && e<22.35) opmode_m[8]=opmode_m[8]+1;
    else if (pp>=0 && pp<3 && e>=11.175 && e<22.35) opmode_m[9]=opmode_m[9]+1;
    else if (pp>=3 && pp<6 && e>=11.175 && e<22.35) opmode_m[10]=opmode_m[10]+1;
    else if (pp>=6 && pp<9 && e>=11.175 && e<22.35) opmode_m[11]=opmode_m[11]+1;
    else if (pp>=9 && pp<12 && e>=11.175 && e<22.35) opmode_m[12]=opmode_m[12]+1;
     else if (pp>=12 && pp<18 && e>=11.175 && e<22.35) opmode_m[13]=opmode_m[13]+1;
    else if (pp>=18 && pp<24 && e>=11.175 && e<22.35) opmode_m[14]=opmode_m[14]+1;
    else if (pp>=24 && pp<30 && e>=11.175 && e<22.35) opmode_m[15]=opmode_m[15]+1;
    else if (pp>=30 && e>=11.175 && e<22.35) opmode_m[16]=opmode_m[16]+1;
    else if (pp<6 && e>=22.35) opmode_m[17]=opmode_m[17]+1;
    else if (pp>=6 && pp<12 && e>=22.35) opmode_m[18]=opmode_m[18]+1;
    else if (pp>=12 && pp<18 && e>=22.35) opmode_m[19]=opmode_m[19]+1;
    else if (pp>=18 && pp<24 && e>=22.35) opmode_m[20]=opmode_m[20]+1;
    else if (pp>=24 && pp<30 && e>=22.35) opmode_m[21]=opmode_m[21]+1;
    else if (pp>=30 && e>=22.35) opmode_m[22]=opmode_m[22]+1;
}
```

```
}
    }
    }
    if (totalvehicle_l>0)
    {
    if (totalvehicle_l==1)
    {
            if (locationstyle_l[vehiclelocation_l[0]]==11)
            gap2=length-lm;
            if (locationstyle_l[vehiclelocation_l[0]]==21)
            gap2=length-lc;
    }
        if (totalvehicle_l>1)
    {
        if (locationstyle_l[vehiclelocation_l[1]]==11)
            gap2=vehiclelocation_l[1]-vehiclelocation_l[0]-lm;
            if (locationstyle_l[vehiclelocation_l[1]]==21)
            gap2=vehiclelocation_l[1]-vehiclelocation_l[0]-lc;
    }
        for (j=totalvehicle_l-1;j>=0;j--)
    {
         vv=max(0,gap2-ud);
         if (j==totalvehicle_l-1)
{
         vv=min(vv,vehiclespeed_l[0]);
         if (locationstyle_l[vehiclelocation_l[0]]==11)
{
         vv=min(vv,v_max_m-ud);
         gap=vehiclelocation_l[0]+length-vehiclelocation_l[j]-lm;
}
         else
{
         vv=min(vv,v_max_c-ud);
         gap=vehiclelocation_l[0]+length-vehiclelocation_l[j]-lc;
}
}
         else
{
         vv=min(vv,vehiclespeed_l[j+1]);
         if (locationstyle_l[vehiclelocation_l[j+1]]==11)
{
         vv=min(vv,v_max_m-ud);
         gap=vehiclelocation_l[j+1]-vehiclelocation_l[j]-lm;
}
         else
{
         vv=min(vv,v_max_c-ud);
         gap=vehiclelocation_l[j+1]-vehiclelocation_l[j]-lc;
}
}
         e=vehiclespeed_l[j];
my_rand1=(float)(rand()/32767.0);
if (vehiclelocation_l[j]>=(length/2-50) && vehiclelocation_l[j]<(length/2+50))
{
if (locationstyle_l[vehiclelocation_l[j]]==11)
```

```
                    vehiclespeed_l[j]=min(locationspeed_l[vehiclelocation_l[j]]+la,v_max_m);
                else vehiclespeed_l[j]=min(locationspeed_l[vehiclelocation_l[j]]+la,v_max_c);
vehiclespeed_l[j]=min(vehiclespeed_l[j],gap);
if (vehiclespeed_l[j]<=e)
{
//my_rand1=(float)(rand()/32767.0);
    if (my_rand1<lowerp)
vehiclespeed_l[j]=max(vehiclespeed_l[j]-ud,0);
}
else
{
//my_rand1=(float)(rand()/32767.0);
                    if (my_rand1<lowerprob_l)
{
//          if (locationstyle_l[vehiclelocation_l[j]]==11)
        vehiclespeed_l[j]=max(vehiclespeed_l[j]-ud,0);
//          else vehiclespeed_l[j]=max(vehiclespeed_l[j]-ac,0);
}
}
}
else
{
                if (locationstyle_l[vehiclelocation_l[j]]==11)
vehiclespeed_l[j]=min(locationspeed_l[vehiclelocation_l[j]]+am,v_max_m);
                else vehiclespeed_l[j]=min(locationspeed_l[vehiclelocation_l[j]]+ac,v_max_c);
            vehiclespeed_l[j]=min(vehiclespeed_l[j],gap);
if (vehiclespeed_l[j]<=e)
{
    if (my_rand1<lowerp)
vehiclespeed_l[j]=max(vehiclespeed_l[j]-ud,0);
}
else
{
                    if (my_rand1<lowerprob_l)
{
        vehiclespeed_l[j]=max(vehiclespeed_l[j]-ud,0);
}
}
}
        gap2=gap;
        if (vehiclespeed_l[j]<e && i>(totaltime-counttime))
        nd=nd+1;
        if (i>(totaltime-counttime))
        s[vehiclespeed_l[j]]=s[vehiclespeed_l[j]]+1;
        if (i>(totaltime-counttime))
{
                        if (locationstyle_l[vehiclelocation_l[j]]==11)
{
pp=e*((vehiclespeed_l[j]-e)*1.1+0.1275)+0.0004987*e*e*e;
}
        if (locationstyle_l[vehiclelocation_l[j]]==21)
{
pp=e*((vehiclespeed_l[j]-e)*1.1+0.1275)+0.0002735*e*e*e;
}
if (locationstyle_l[vehiclelocation_l[j]]==21)
```

```
{
      if ((vehiclespeed_l[j]-e)<=-2) opmode_c[0]=opmode_c[0]+1;
      else if (e>=-0.447 && e<0.447) opmode_c[1]=opmode_c[1]+1;
      else if (pp<0 && e>=0.447 && e<11.175) opmode_c[2]=opmode_c[2]+1;
      else if (pp>=0 && pp<3 && e>=0.447 && e<11.175) opmode_c[3]=opmode_c[3]+1;
      else if (pp>=3 && pp<6 && e>=0.447 && e<11.175) opmode_c[4]=opmode_c[4]+1;
      else if (pp>=6 && pp<9 && e>=0.447 && e<11.175) opmode_c[5]=opmode_c[5]+1;
      else if (pp>=9 && pp<12 && e>=0.447 && e<11.175) opmode_c[6]=opmode_c[6]+1;
      else if (pp>=12 && e>=0.447 && e<11.175) opmode_c[7]=opmode_c[7]+1;
      else if (pp<0 && e>=11.175 && e<22.35) opmode_c[8]=opmode_c[8]+1;
      else if (pp>=0 && pp<3 && e>=11.175 && e<22.35) opmode_c[9]=opmode_c[9]+1;
      else if (pp>=3 && pp<6 && e>=11.175 && e<22.35) opmode_c[10]=opmode_c[10]+1;
      else if (pp>=6 && pp<9 && e>=11.175 && e<22.35) opmode_c[11]=opmode_c[11]+1;
      else if (pp>=9 && pp<12 && e>=11.175 && e<22.35) opmode_c[12]=opmode_c[12]+1;
       else if (pp>=12 && pp<18 && e>=11.175 && e<22.35) opmode_c[13]=opmode_c[13]+1;
      else if (pp>=18 && pp<24 && e>=11.175 && e<22.35) opmode_c[14]=opmode_c[14]+1;
      else if (pp>=24 && pp<30 && e>=11.175 && e<22.35) opmode_c[15]=opmode_c[15]+1;
      else if (pp>=30 && e>=11.175 && e<22.35) opmode_c[16]=opmode_c[16]+1;
      else if (pp<6 && e>=22.35) opmode_c[17]=opmode_c[17]+1;
      else if (pp>=6 && pp<12 && e>=22.35) opmode_c[18]=opmode_c[18]+1;
      else if (pp>=12 && pp<18 && e>=22.35) opmode_c[19]=opmode_c[19]+1;
      else if (pp>=18 && pp<24 && e>=22.35) opmode_c[20]=opmode_c[20]+1;
      else if (pp>=24 && pp<30 && e>=22.35) opmode_c[21]=opmode_c[21]+1;
      else if (pp>=30 && e>=22.35) opmode_c[22]=opmode_c[22]+1;
}
else
{
if ((vehiclespeed_l[j]-e)<=-2) opmode_m[0]=opmode_m[0]+1;
      else if (e>=-0.447 && e<0.447) opmode_m[1]=opmode_m[1]+1;
      else if (pp<0 && e>=0.447 && e<11.175) opmode_m[2]=opmode_m[2]+1;
      else if (pp>=0 && pp<3 && e>=0.447 && e<11.175) opmode_m[3]=opmode_m[3]+1;
      else if (pp>=3 && pp<6 && e>=0.447 && e<11.175) opmode_m[4]=opmode_m[4]+1;
      else if (pp>=6 && pp<9 && e>=0.447 && e<11.175) opmode_m[5]=opmode_m[5]+1;
      else if (pp>=9 && pp<12 && e>=0.447 && e<11.175) opmode_m[6]=opmode_m[6]+1;
      else if (pp>=12 && e>=0.447 && e<11.175) opmode_m[7]=opmode_m[7]+1;
      else if (pp<0 && e>=11.175 && e<22.35) opmode_m[8]=opmode_m[8]+1;
      else if (pp>=0 && pp<3 && e>=11.175 && e<22.35) opmode_m[9]=opmode_m[9]+1;
      else if (pp>=3 && pp<6 && e>=11.175 && e<22.35) opmode_m[10]=opmode_m[10]+1;
      else if (pp>=6 && pp<9 && e>=11.175 && e<22.35) opmode_m[11]=opmode_m[11]+1;
      else if (pp>=9 && pp<12 && e>=11.175 && e<22.35) opmode_m[12]=opmode_m[12]+1;
       else if (pp>=12 && pp<18 && e>=11.175 && e<22.35) opmode_m[13]=opmode_m[13]+1;
      else if (pp>=18 && pp<24 && e>=11.175 && e<22.35) opmode_m[14]=opmode_m[14]+1;
      else if (pp>=24 && pp<30 && e>=11.175 && e<22.35) opmode_m[15]=opmode_m[15]+1;
      else if (pp>=30 && e>=11.175 && e<22.35) opmode_m[16]=opmode_m[16]+1;
      else if (pp<6 && e>=22.35) opmode_m[17]=opmode_m[17]+1;
      else if (pp>=6 && pp<12 && e>=22.35) opmode_m[18]=opmode_m[18]+1;
      else if (pp>=12 && pp<18 && e>=22.35) opmode_m[19]=opmode_m[19]+1;
      else if (pp>=18 && pp<24 && e>=22.35) opmode_m[20]=opmode_m[20]+1;
      else if (pp>=24 && pp<30 && e>=22.35) opmode_m[21]=opmode_m[21]+1;
      else if (pp>=30 && e>=22.35) opmode_m[22]=opmode_m[22]+1;
}
}
   }
   }
}
```

```
            k=floor((i+counttime-totaltime)/countunit);
    for(j=0;j<totalvehicle_r;j++)
    {
     e=locationstyle_r[vehiclelocation_r[j]];
     vehiclelocation_r[j]=vehiclelocation_r[j]+vehiclespeed_r[j];
     if (vehiclelocation_r[j]>=length)
      vehiclelocation_r[j]=vehiclelocation_r[j]-length;
     locationstyle_r[vehiclelocation_r[j]]=e;
     if(i>totaltime-counttime)
{
                    if (locationstyle_r[vehiclelocation_r[j]]==11)
 {
          fr=fr+vehiclespeed_r[j];
 svmr=svmr+vehiclespeed_r[j];
 frd[k]=frd[k]+vehiclespeed_r[j];
 svmrd[k]=svmrd[k]+vehiclespeed_r[j];
 }
      else
 {
 fr=fr+vehiclespeed_r[j];
 svcr=svcr+vehiclespeed_r[j];
 frd[k]=frd[k]+vehiclespeed_r[j];
 svcrd[k]=svcrd[k]+vehiclespeed_r[j];
 }
}
    }
    for(j=0;j<totalvehicle_l;j++)
    {
     e=locationstyle_l[vehiclelocation_l[j]];
     vehiclelocation_l[j]=vehiclelocation_l[j]+vehiclespeed_l[j];
     if (vehiclelocation_l[j]>=length)
      vehiclelocation_l[j]=vehiclelocation_l[j]-length;
     locationstyle_l[vehiclelocation_l[j]]=e;
     if (i>totaltime-counttime)
{
                     if (locationstyle_l[vehiclelocation_l[j]]==11)
  {
           fl=fl+vehiclespeed_l[j];
  svml=svml+vehiclespeed_l[j];
  fld[k]=fld[k]+vehiclespeed_l[j];
  svmld[k]=svmld[k]+vehiclespeed_l[j];
  }
       else
  {
  fl=fl+vehiclespeed_l[j];
  svcl=svcl+vehiclespeed_l[j];
  fld[k]=fld[k]+vehiclespeed_l[j];
  svcld[k]=svcld[k]+vehiclespeed_l[j];
  }
}
    }
 for (j=0;j<length;j++)
 {
locationspeed_r[j]=-1;
locationspeed_l[j]=-1;
```

```
 }
 for (j=0;j<totalvehicle_r;j++)
 {
     locationspeed_r[vehiclelocation_r[j]]=vehiclespeed_r[j];
 }
 for (j=0;j<totalvehicle_l;j++)
 {
     locationspeed_l[vehiclelocation_l[j]]=vehiclespeed_l[j];
 }
 for (j=0;j<length;j++)
 {
     if (locationspeed_r[j]>=0 && locationstyle_r[j]==11)
{
for (jj=0;jj<lm;jj++)
{
e=j-jj;
if (e<0)
e=e+length;
locationstyle_r[e]=11+jj;
locationspeed_r[e]=locationspeed_r[j];
}
}
                else if (locationspeed_r[j]>=0 && locationstyle_r[j]==21)
{
for (jj=0;jj<lc;jj++)
{
e=j-jj;
if (e<0)
e=e+length;
locationstyle_r[e]=21+jj;
locationspeed_r[e]=locationspeed_r[j];
}
}
if (locationspeed_l[j]>=0 && locationstyle_l[j]==11)
{
for (jj=0;jj<lm;jj++)
{
e=j-jj;
if (e<0)
e=e+length;
locationstyle_l[e]=11+jj;
locationspeed_l[e]=locationspeed_l[j];
}
}
                else if (locationspeed_l[j]>=0 && locationstyle_l[j]==21)
{
for (jj=0;jj<lc;jj++)
{
e=j-jj;
if (e<0)
e=e+length;
locationstyle_l[e]=21+jj;
locationspeed_l[e]=locationspeed_l[j];
}
}
```

```
 }
 for (j=0;j<length;j++)
 {
 if (locationspeed_r[j]<0)
 locationstyle_r[j]=0;
 if (locationspeed_l[j]<0)
 locationstyle_l[j]=0;
 }
if (printout=='S')
{
if (i>totaltime-counttime)
{
for (j=0;j<length;j++)
{
fprintf(fp_r,"%d\t",locationstyle_r[j]);
}
fprintf(fp_r,"\n");
			for (j=0;j<length;j++)
{
fprintf(fp_l,"%d\t",locationstyle_l[j]);
}
fprintf(fp_l,"\n");
}
}
if (printout=='S')
{
if (i>totaltime-counttime)
{
for (j=0;j<totalvehicle_r;j++)
{
fprintf(fp,"%d,%d,%d,%d\t",vehiclespeed_r[j],vehiclelocation_r[j],j,locationstyle_r[vehiclelocation_r[j]]);
}
fprintf(fp,"\n");
for (j=0;j<totalvehicle_l;j++)
{
 fprintf(fp,"%d,%d,%d,%d\t",vehiclespeed_l[j],vehiclelocation_l[j],j,locationstyle_l[vehiclelocation_l[j]]);
}
fprintf(fp,"\n");
}
}
}
if (printout=='S')
{
fprintf(fp_r,"-----------end----------\n");
fprintf(fp_l,"-----------end----------\n");
}
if (quantity!=0)
{
flow_r=fr/(length*counttime*1.0);
	flow_l=fl/(length*counttime*1.0);
flow=(flow_r+flow_l)/2.0;
	flowv=(svmr+svml+svcr+svcl)/(length*counttime*2.0)*3600;
	averagespeed=(svmr+svml+svcr+svcl)/((totalvehicle_r+totalvehicle_l)*counttime*1.0);
asm=(svmr+svml)/(totalmcar*counttime*1.0);
asc=(svcr+svcl)/(totalcar*counttime*1.0);
```

```
p=pc+pm;
}
    else
{
flow_r=0.0;
flow_l=0.0;
flow=0.0;
    flowv=0.0;
    averagespeed=0.0;
}
if (printout=='A')
{
fprintf(fp,"%d\t%f\t%f\t%f\t%f\t%d\t%d\t",quantity,flowv,averagespeed,asc,asm,nlc,nd);
for (j=0;j<=v_max_c;j++)
{
fprintf(fp,"%d\t",s[j]);
}
for (j=0;j<23;j++)
{
fprintf(fp,"%d\t",opmode_c[j]);
}
for (j=0;j<23;j++)
{
fprintf(fp,"%d\t",opmode_m[j]);
}
fprintf(fp,"\n");
}
if (printout=='D')
{
k=floor(counttime/countunit);
for (j=0;j<k;j++)
{
fprintf(fp,"%f\t",(svmrd[j]+svmld[j]+svcrd[j]+svcld[j])/(length*countunit*2.0)*3600);
}
fprintf(fp,"\n");
}
printf("quantity=%d\t",quantity);
    free(vehiclespeed_r);
free(vehiclespeed_l);
free(vehiclelocation_r);
free(vehiclelocation_l);
free(locationspeed_r);
free(locationspeed_l);
free(locationstyle_r);
free(locationstyle_l);
fclose(fp_r);
fclose(fp_l);
return (flowv);
}
#endif
```