Chapter 5

Simulation Analysis

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CHAPTER 5
Simulation Analysis

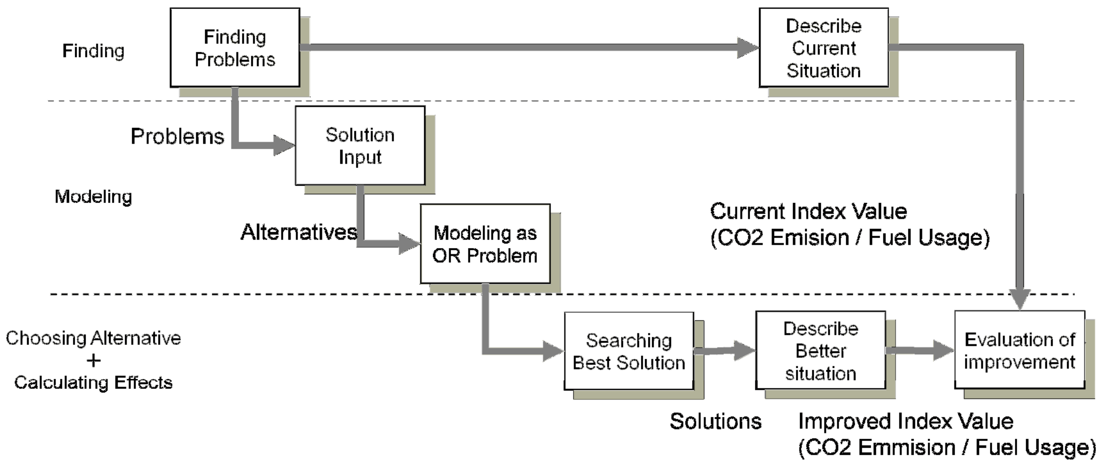
1. The Purpose of this Chapter

A number of options are available to cope with the congestion problems, which would have different impacts with different costs. Given budget limitation, city planners or national/municipal policy-makers would have to choose the options that can generate maximum impacts given the budget limitations. In other words, it is important for city planners or national/municipal policy-makers to know the impacts of each available option prior to their decision making.

This chapter tries to analyze the impacts of available infrastructure development options that can cope with traffic congestion problems, taking the Kuningan area in Jakarta of Indonesia as a model city. While caution needs to be paid in interpreting the analysis results, nevertheless, these would provide a useful basis for the other cities that share the similar road transport related problems. It is important to note that the similar analysis methods could be applied to the other cities in consideration for the location specific transport related factors.

Figure 5-1 shows the analysis method. Firstly, the traffic problems are investigated to identify the factors behind the issues. Secondly, several options to cope with the traffic problems are listed. Thirdly, the analyzed area's traffic situation is modeled as the basis and the optimal combination of solutions is calculated given certain budget limitation with the use of mathematical programming. Lastly, the effects of the selected options on the fuel consumption are estimated with the traffic simulation.

Figure 5-1: Flow of the simulation analysis



2. Target of Simulation

2.1 Traffic problem and Ideas for Improving Road Infrastructure

The analysis in this chapter focuses on the area located 2 km north from the Kuningan intersection in Jakarta city, which is shown in the blue line (Figure 5-2).

Figure 5-2: Target area for simulation analysis

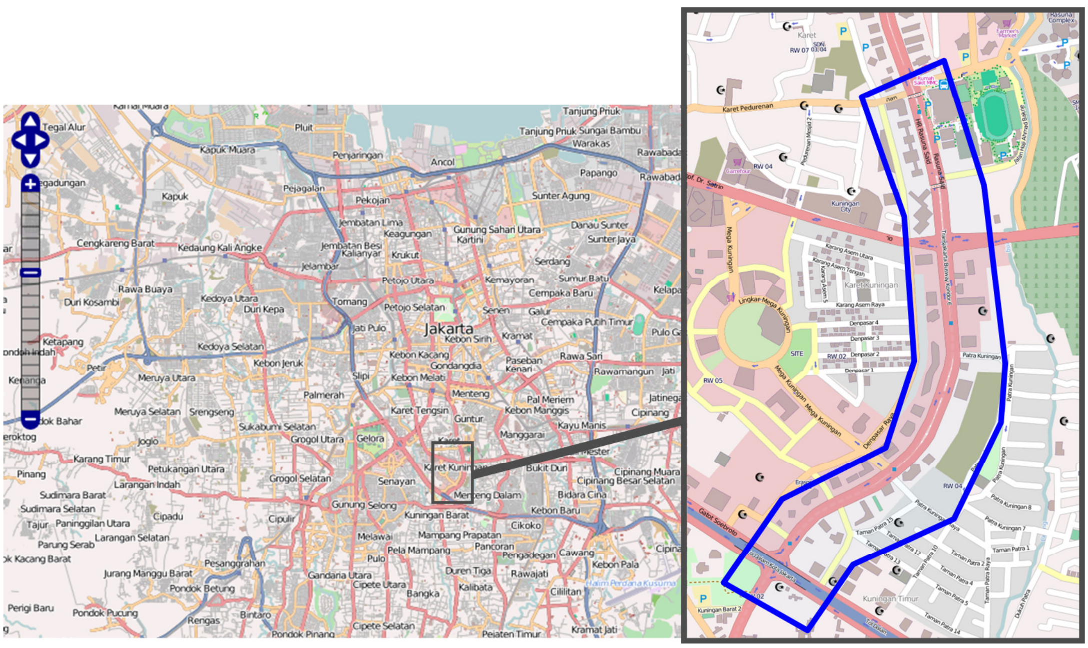
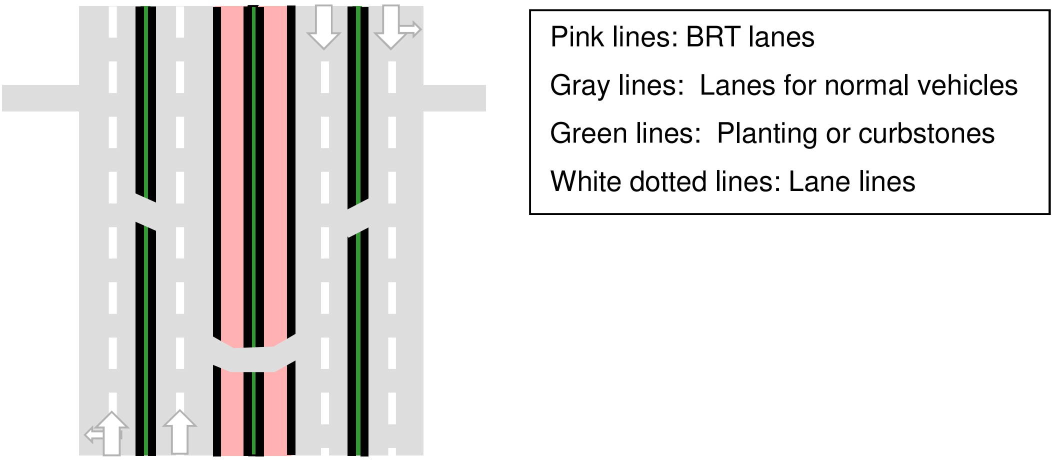


Figure 5-3 shows the road structure. Each side has the four lanes for vehicles and one BRT lane. BRT lanes are separated by planting or curbstone at the center. Basically, there is little intersection to turn right in this area. Instead, some points for making U-turn are available, where drivers can intersect with BRT through a gap of the curbstone. Also four lanes of each side are separated into two lanes by curbstones; it is possible to change lanes from inner/outer to outer/inner at the gap of curbstones. This described structure of the arterial road represents a typical one in Jakarta.

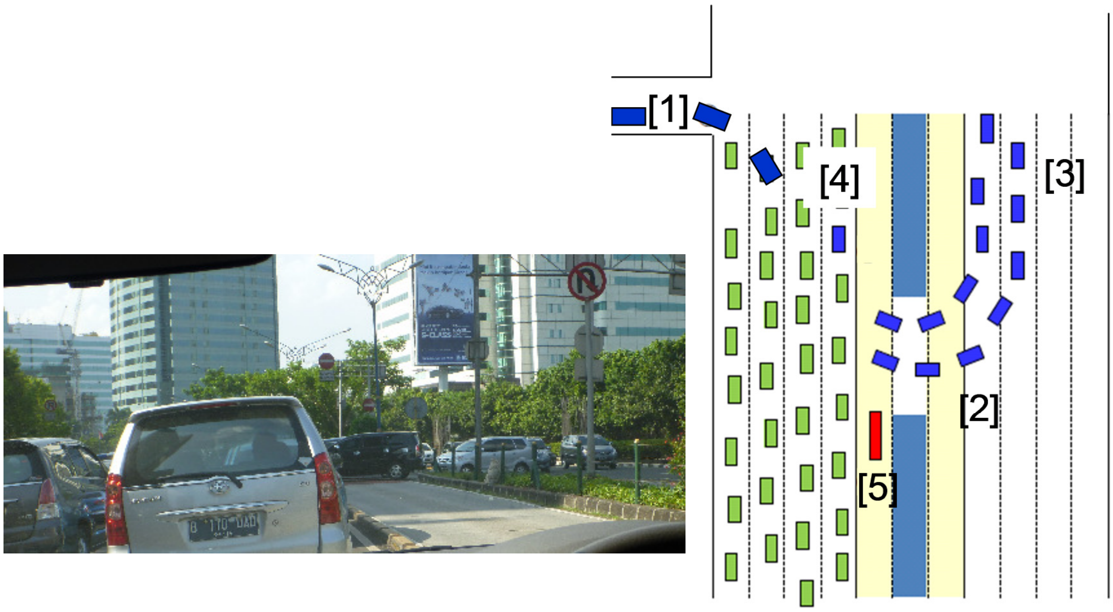
Figure 5-3: Illustration of the road structure



Traffic volume is very large in this area especially in the morning and evening rush hours. Traffic congestions are mostly attributed to the road structure. Factors affecting the road congestion can be summarized as follows (Figure 5-4):

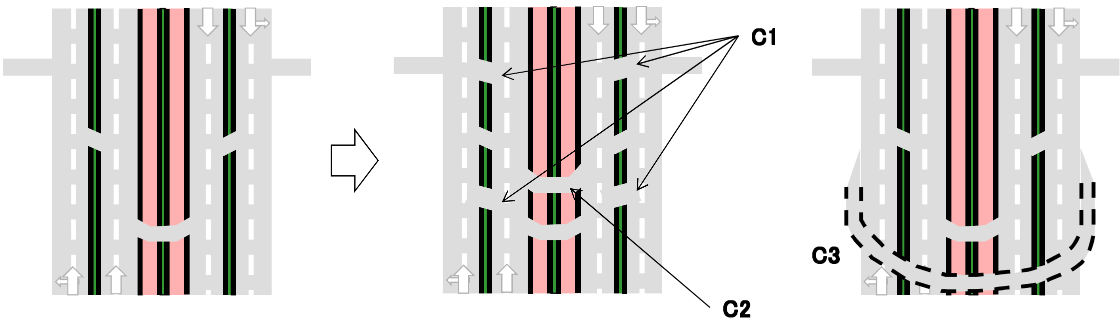
Vehicles on the way to point [1] make U-turn at point [2]. These vehicles block following vehicles around [3] and disturb the bus way at [5]. After making a U-turn, they change lanes from inner lanes to outer lanes at the point [4], which interferes with the passing vehicles.

Figure 5-4: Understanding of traffic congestion



To remove or alleviate these traffic congestions, two types of improvement options could be proposed. One is to build additional U-turn and/or lane-change points (C1 and C2 in Figure 5-5). Since traffic volume that passes through the point of U-turn and lane-change are limited, additional U-turn and lane-change points have the potential to reduce the burden of each point. The other is to construct an under/overpass (C3 in Figure 5-5). If U-turn point is altered to underpass or overpass, the interferences between vehicles making a U-turn and going straight can be reduced.

Figure 5-5. Types of improvement of road infrastructure



Construction costs of each improvement options are shown in Table 5-1, whose value is roughly estimated by PUSTRAL-UGM.

Table 5-1. Construction cost

Type of construction	Unit Cost (thousand IDR / m)	Quantity in one point	Cost per one improvement point (IDR)	Cost in Optimization Analyses / Simulation (IDR)
C1: Lane change	1,500 – 2,000	1 lane x 24m	36 – 48 million	40 million (4120 USD)
C2: U-turn	1,500 – 2,000	3 lanes x 16m	72 – 96 million	80 million (8240 USD)
C3: Under/Overpass	250,000 – 350,000	125 m	31.25 - 43.75 billion	40 billion (4.12 B USD)

10 thousand IDR = 1.03 USD
Source: PUSTRAL-UGM

2.2 Simulation Strategy

Measures for the traffic problems improvement can be classified into two types. One measure can be implemented in small scale, low cost, and short implementation period, and the other is large scale, high cost, and long period with fundamental transformations. The cost of options under/overpass (C3) is estimated to represent three thousand times larger than the cost of lane-change (C1) and U-turn (C2). Other options in even larger scale are traffic demand management such as modal shifts mass rapid transits discussed in Chapter 3.

Table 5-2 shows the combination of options to ease the traffic problems in Jakarta. Case A represents the small-scale investment options that combines the lane-changes (C1) and U-turns (C2). In this case, the best improvement plans are selected from several lane-cahnges and U-turns by mathematical programming and the effect of the plans are simulated. The budget varies from 40 million IDR to 720 million IDR. Case B is a relatively large-scale investment option on under/overpass (C3), which is combined with the lane-changes (C1). In this case, construction of one under/overpass is simulated to examine its effect, since it is difficult to construct several under/overpasses. The budget is 40 billion IDR. Lastly, combination of Case A, B and large traffic volume options of traffic management such as modal shift is discussed.

Table 5-2: Case setting

	Budget	Available Options		
		Lane change	U-turn	Under/overpass
Case A (small scale)	40 -720 million IDR	Yes	Yes	No
Case B (relatively large scale)	40 billion IDR	Yes	No	Yes

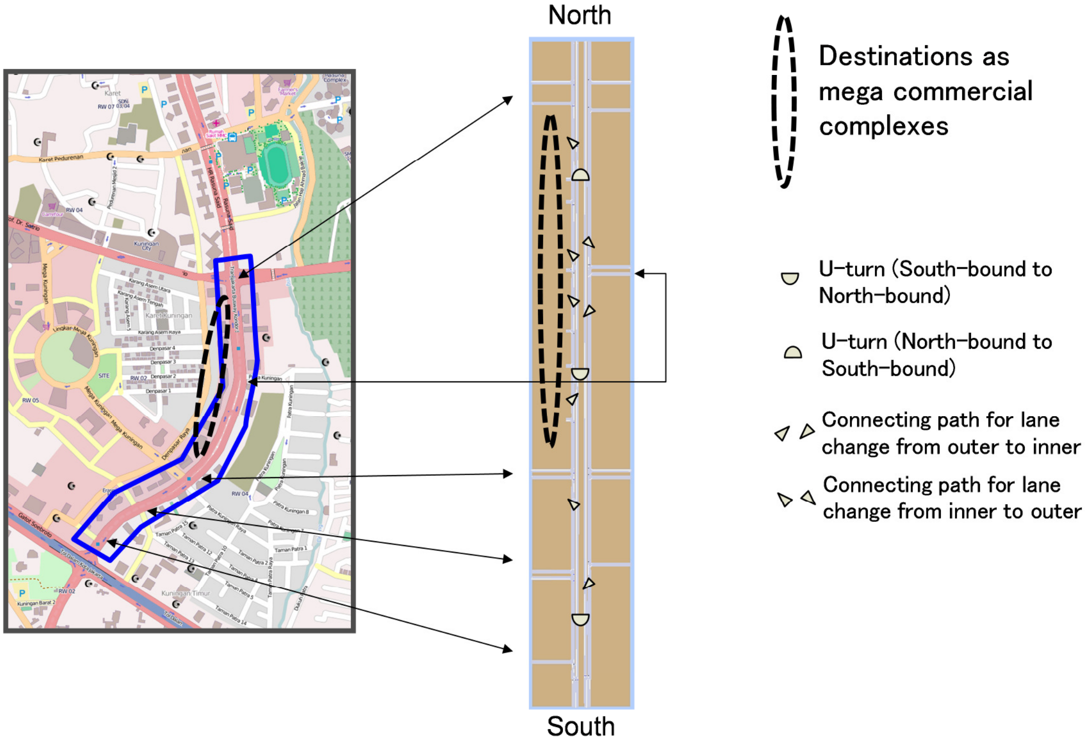
3. Traffic Simulation of Current Situation

Before simulation analysis of Case A and B, the ability to simulate current traffic situation is verified by comparing the simulated results with observed data. If the simulation results duplicate the observed data, the effect of improvement can also be estimated with accuracy.

The simulator used for this chapter is a microscopic traffic simulator, MATES (Fujii and Yoshimura 2010). Since microscopic simulator calculates the detailed action of each vehicle, the amount of gasoline consumption can be calculated accurately.

The road network in the area is modelled as shown in Figure 5-6. On the left side of the straight arterial road, some commercial mega complexes are located. Some vehicles utilize this road as they go to these mega complexes.

Figure 5-6. Model of road network



The traffic volume, which goes straight, is estimated roughly as 3,600 vehicles/h in both directions from Table 5-3. This is referred in the Sec 3.1.2-4 and 3.4.2 of "Preparatory Survey for Metropolitan Arterial Road Improvement Project, March 2012". Hereinafter traffic flow going straight is referred as the background traffic flow.

Table 5-3: Observed traffic volume at Kuningan intersection

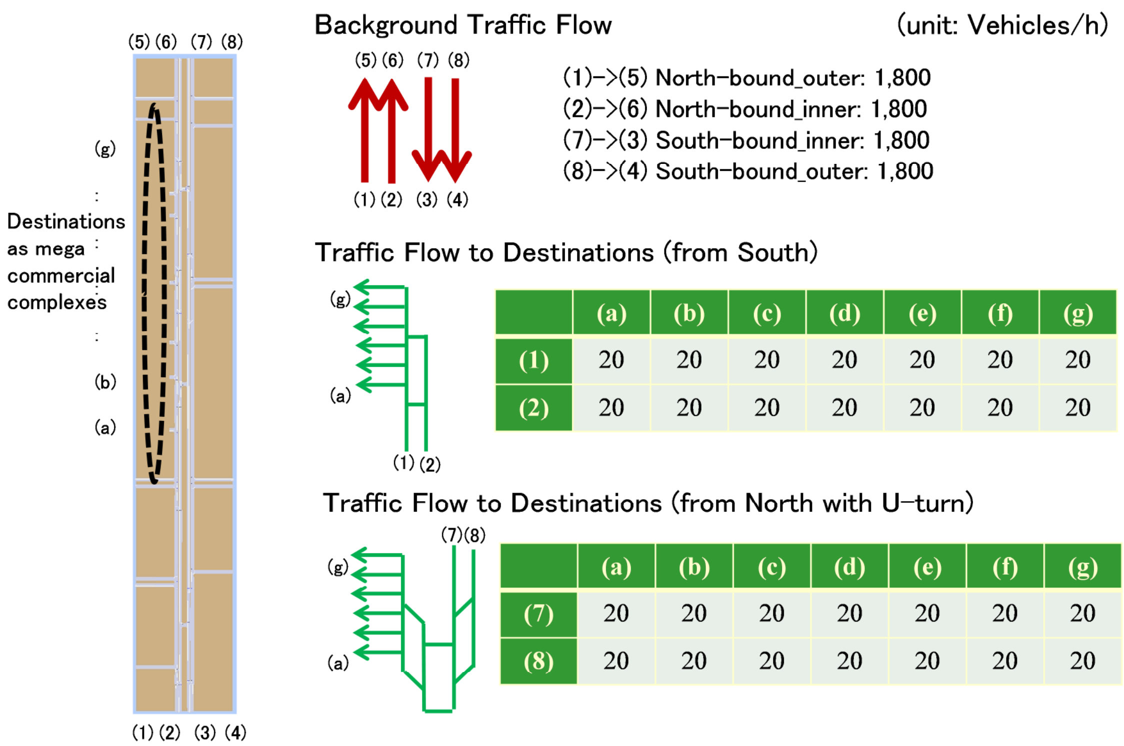
	Traffic volume for 16 hours in cross-section [vehicle number]	Averaged travel speed (evening) [km/h]	Length of traffic jam (evening) [m]	Signal cycle (evening) [sec]
north ⇒south	37,545	9.0	380	219 (We observed that signal shows "go" sign to north-south flow for 1/3 of the total period and to east-west flow for 2/3 of the total)
South ⇒north	57,873	12.5	240	

Average:
2,300 num/hour
3,600 num/hour

Source: Preparatory Survey for Metropolitan Arterial Road Improvement Project, March 2012.

Because no traffic volume for going to the mega commercial complexes was obtained, it is estimated that 40 vehicles/h going to seven entrance gates each from south and north. The summary of Origin-Destination input data are shown in Figure 5-7.

Figure 5-7: Input of OD data



	(a)	(b)	(c)	(d)	(e)	(f)	(g)
(1)	20	20	20	20	20	20	20
(2)	20	20	20	20	20	20	20

	(a)	(b)	(c)	(d)	(e)	(f)	(g)
(7)	20	20	20	20	20	20	20
(8)	20	20	20	20	20	20	20

Simulation results on the above condition are shown in Table 5-4. The traffic volumes in the cross section are about 3000 vehicles/h. These are lower than the observed traffic volume, but are considered to be acceptable. Average travel time in this area is consistent with the observed data.

The simulated traffic situation is consistent with the above stated observed situation. Thus, it is confirmed that developed traffic model can be utilized for the real traffic situation although traffic volume going to the mega commercial complexes remains unknown.

Table 5-4: Simulation result and observed data

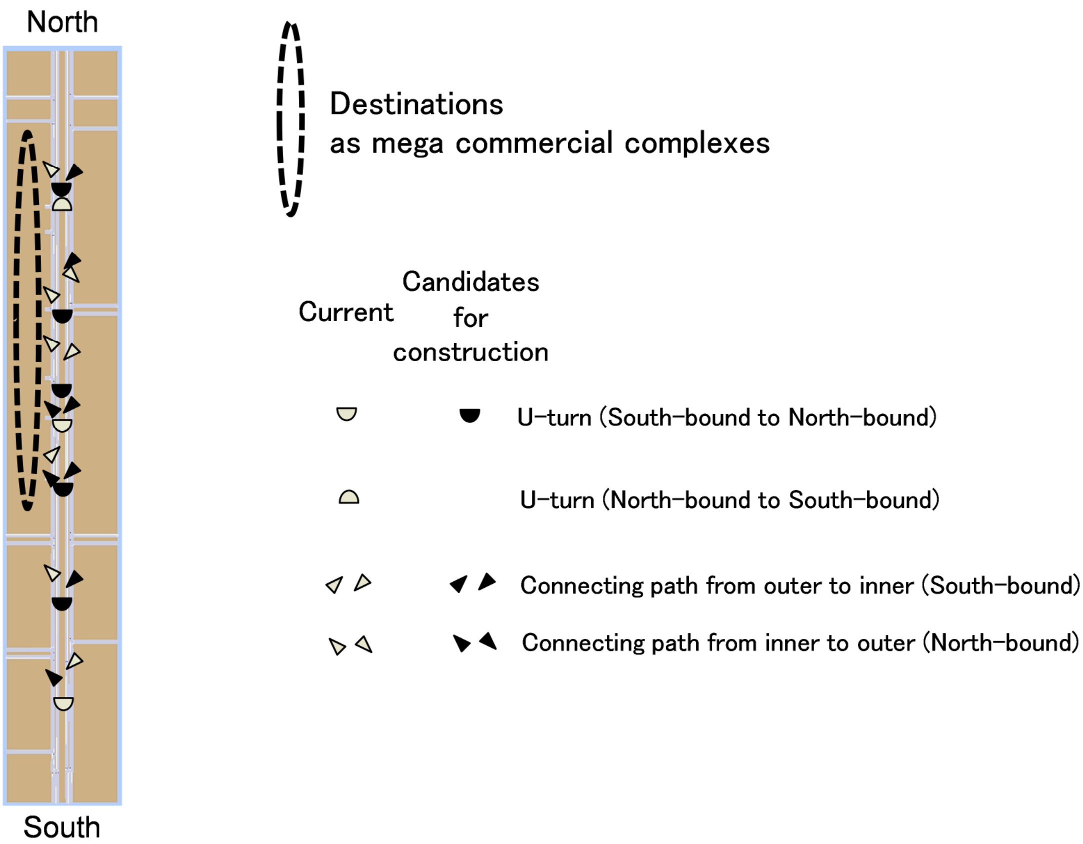
	Simulated value	Measured / Target value	Evaluation
Outgoing Flow: North-bound at north end	2,950 /h	3,600 /h	Acceptable
Outgoing Flow: South-bound at Kuningan	2,713 /h	3,000 /h	OK
Length of South-bound Traffic Jam	300-500 m	380 m	OK
Traveling Time from north end to Kuningan (South-bound, inner lane)	5-10 min	10min	OK

4. Case A: Small-scale Improvements (U-turn and Lane-Change)

4.1 Modelling

Locations of the candidate U-turns and lane-changes are decided as follows. Vehicles making a U-turn in the current traffic situation are the vehicles travelling to commercial mega complexes from north end, therefore, five new U-turn points from southward to northward are listed as candidates. New U-turn points are placed not to overlap the BRT stations. Then, for the vehicles on the way to the U-turn points, five new points of lane-change from outer lanes to inner lanes are listed at southward road. For the vehicles after making a U-turn, three new points of lane-change from inner lanes to outer lanes are listed on the northward road, which enables vehicles to enter the gate of mega commercial complexes (Figure 5-8).

Figure 5-8. Candidates for construction



Calculation flow to select optimal combination of candidate of U-turns and lane-changes under the limit of budget is shown in Figure 5-9. If road network, traffic demand, construction cost, and budget of the current traffic are input to a solver (GUROBI OPTIMIZER are used in this chapter), then optimal solution, that is, optimal combination of U-turn and lane change points could be derived as the outputs. The meaning of "optimal" is defined as the minimized total travel time. The purpose of this chapter is to reduce fuel consumption, therefore, optimal solution should be defined as to minimize the total gasoline consumption. However it is difficult to formulate total gasoline consumption compared to total travel time. This is because that travel time depends only on the vehicle speed, but gasoline consumption depends not only on speed but also acceleration and deceleration. Thus, after solving the problem of minimizing total travel time, gasoline consumption is simulated by microscopic traffic simulation.

To calculate travel time, it is necessary to develop an interference model between vehicles going straight and vehicles making a lane-change at a lane change point. An interference model is formulated by simulation changing traffic volume little by little (Figure 5-10).

Budget is set to be changed little by little from 40,000 thousand IDR which equals to the construction cost of a lane change point, to 720,000 thousand IDR, which equals to the construction cost of all candidates of U-turn and lane change points.

Figure 5-9: Calculation flow to select optimal improvement plan

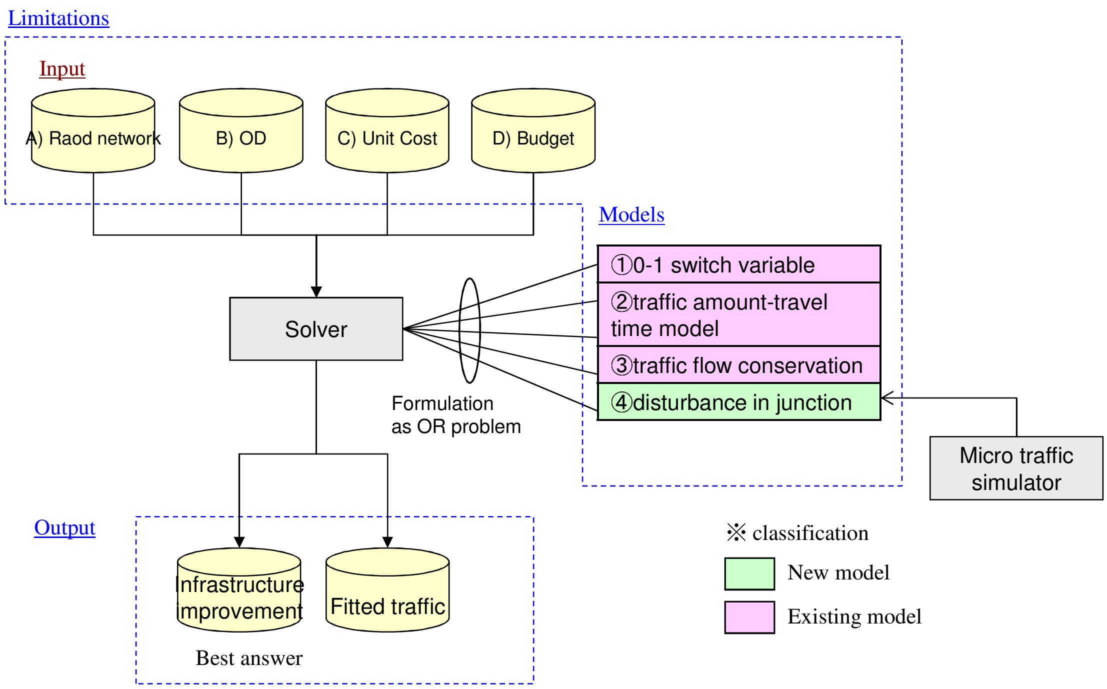
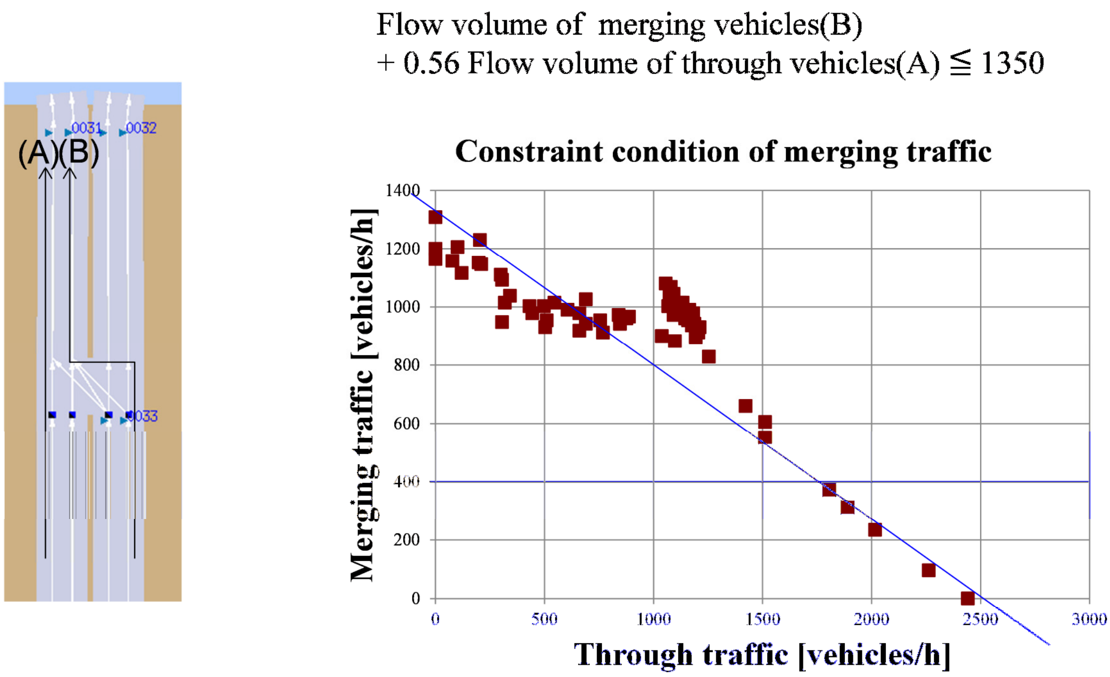


Figure 5-10: Interference model at lane change point



4.2 Result: Reduction of total trip time

The optimization results are shown in both total travel time (Figure 5-11) and selected combination of U-turn and lane change points (Figure 5-12). As shown in Figure 5-11, the budget increases, the total travel time is shortened. This means that adding U-turns and lane-change make the traffic flow smooth and reduce travel time of vehicles passing through the area. The total travel time is shortened by up to 2% of the original travel time. Figure 5-12 shows that most effective U-turn candidates are the southernmost one, and the most effective lane-change candidate is the second southern one.

It is important to note that the length of travel time decreases in proportion to the amount of budget for improvement. Nevertheless, the improvement effect is not expected even though additional investments – above 400 million IDR – are made. That is, improvement with budget over 400 million IDR is not worthy of investment from cost-effectiveness. This shows that the minimum investment is adding 4 U-turns and 2 lane-changes (=400 million IDR) to distribute the current traffic load. This is why it is important to assess cost-effectiveness of infrastructure improvement. For the assessment, quantitative simulation analysis in this study is useful.

Figure 5-11: Reduction of total trip time

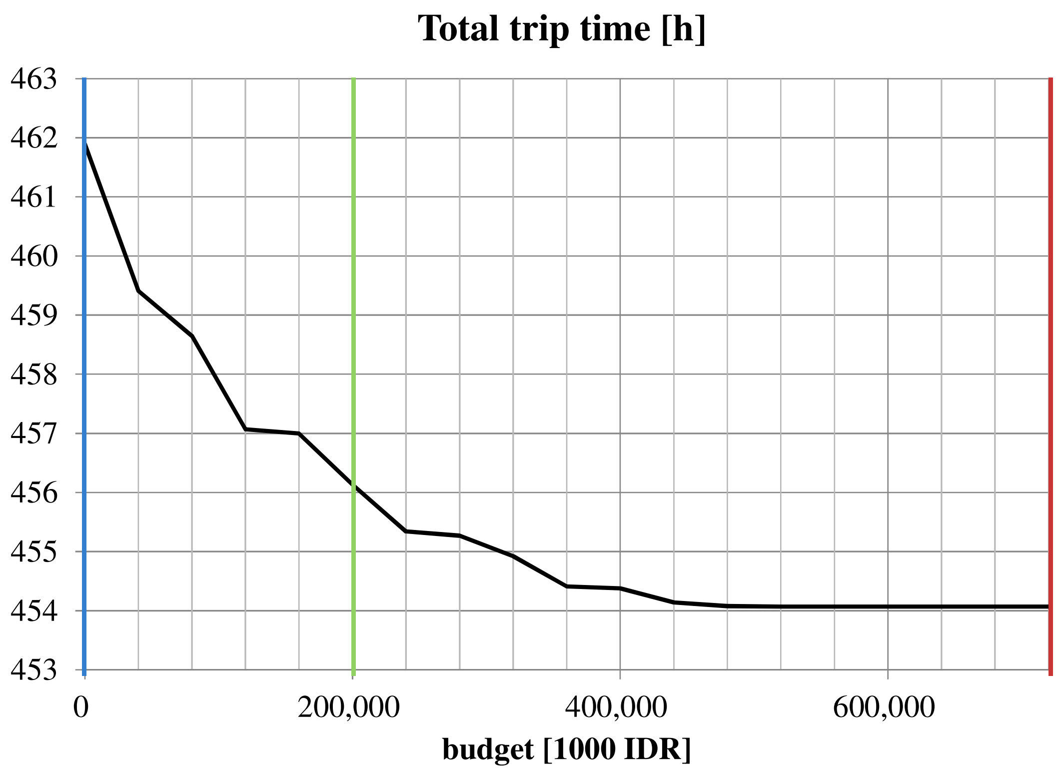
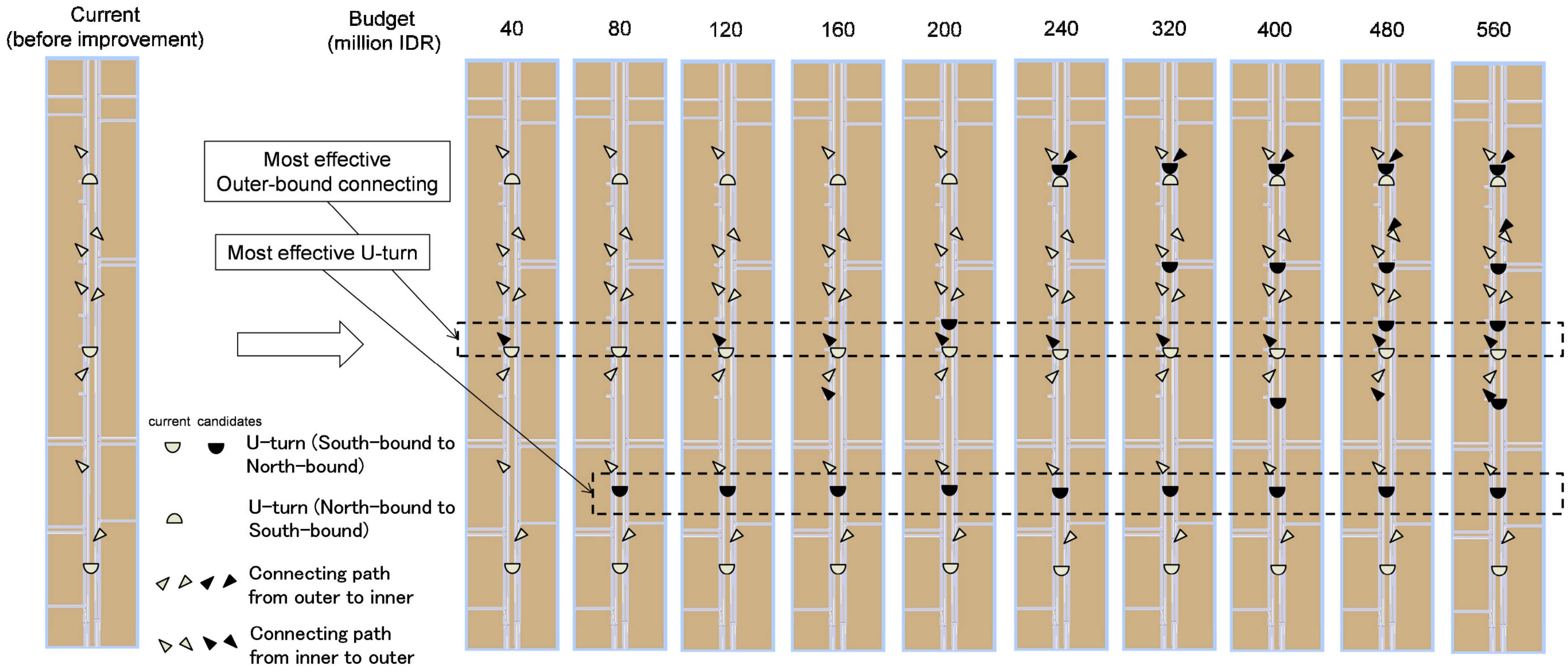


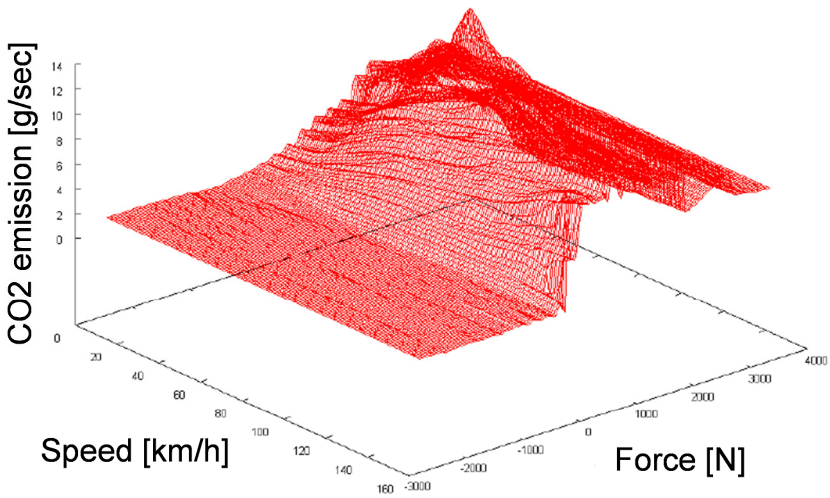
Figure 5-12: Optimization results



4.3 Result: Savings of gasoline consumption

Optimization results are evaluated in terms of gasoline consumption, building on the calculation method as follows. Firstly, traffic flow with optimized road network is simulated by MATES. It generates the speed and acceleration of each vehicle in each time step. Secondly, the data are converted to CO_2 emissions with reference to an emission table of a specific car model. The study referred the JCAPII, which is the open information by Japan Petroleum Energy Center. Thirdly, total CO_2 emissions of all vehicles in the simulation area are calculated. Lastly, CO_2 emissions are converted to gasoline consumption: one kl of gasoline equals to 2.32 tons of CO_2 emissions.

Figure 5-13: Example of emission table



The simulated traffic flow is shown in Figure 5-15, where red dots show those vehicles traveling at slow speed and green dots shows the vehicles with fast traveling speed. Comparing to the traffic situation with the current road network, the traffic flow with the budget 400 million IDR reduce traffic congestion and improves the flow smoothly. Especially in the area marked as (a) in Figure 5-15, traffic congestion waiting for lane-change (a line of red dots) disappears after the improvement. Similarly, in the area marked (b), long intermittent traffic congestion caused by U-turn nearly disappears. Improvement of the traffic jam is expected to raise the average speed of traffic flow and to reduce the frequency of stop and go, which leads to reduce waste of gasoline.

In fact, the simulated gasoline consumption in Figure 5-15 shows that the amount of gasoline consumption with the budget 200 million IDR is about 10% reduction of current traffic. The case with budget 720 million IDR saves about 15% of fuel consumption.

Figure 5-14. Microscopic traffic simulation

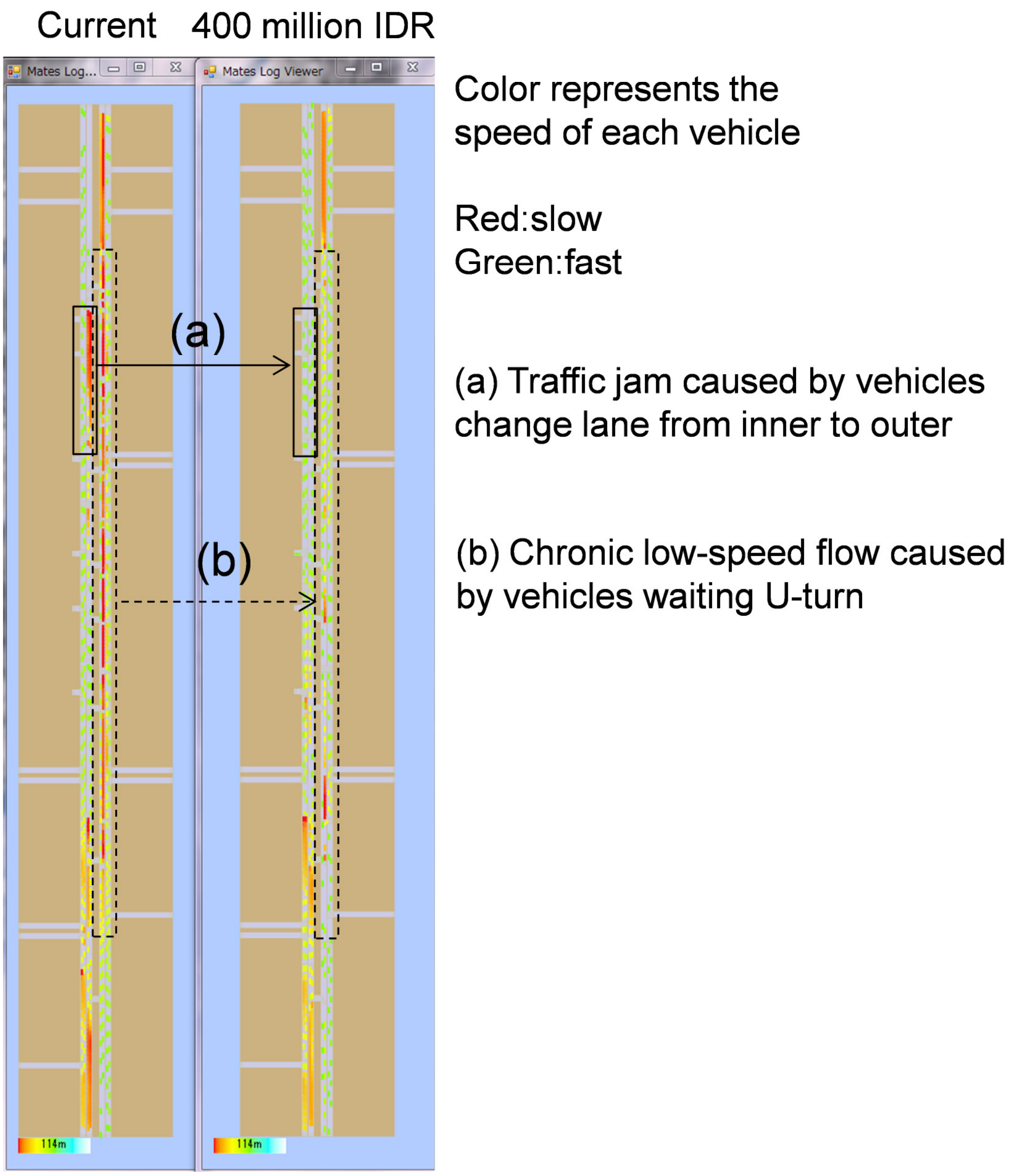
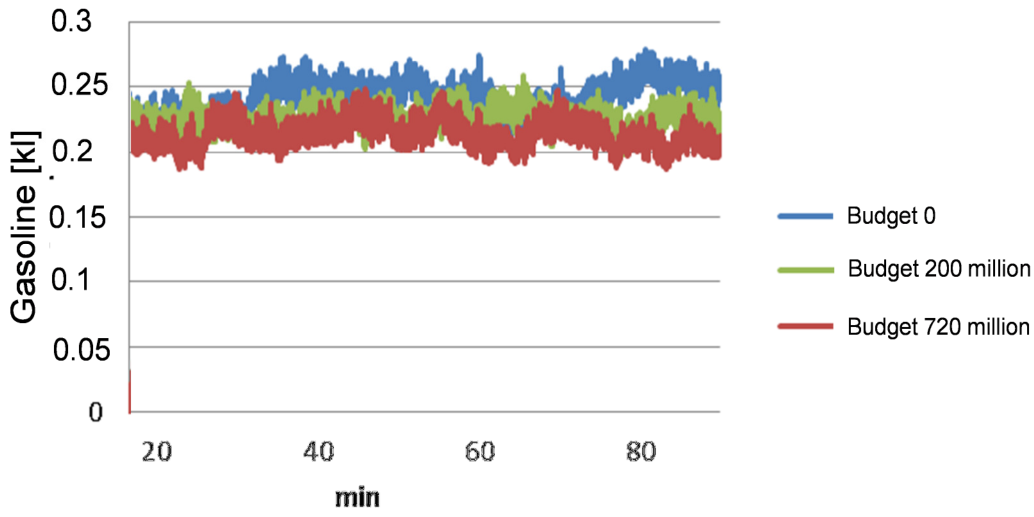


Figure 5-15. Time variation of gasoline consumption



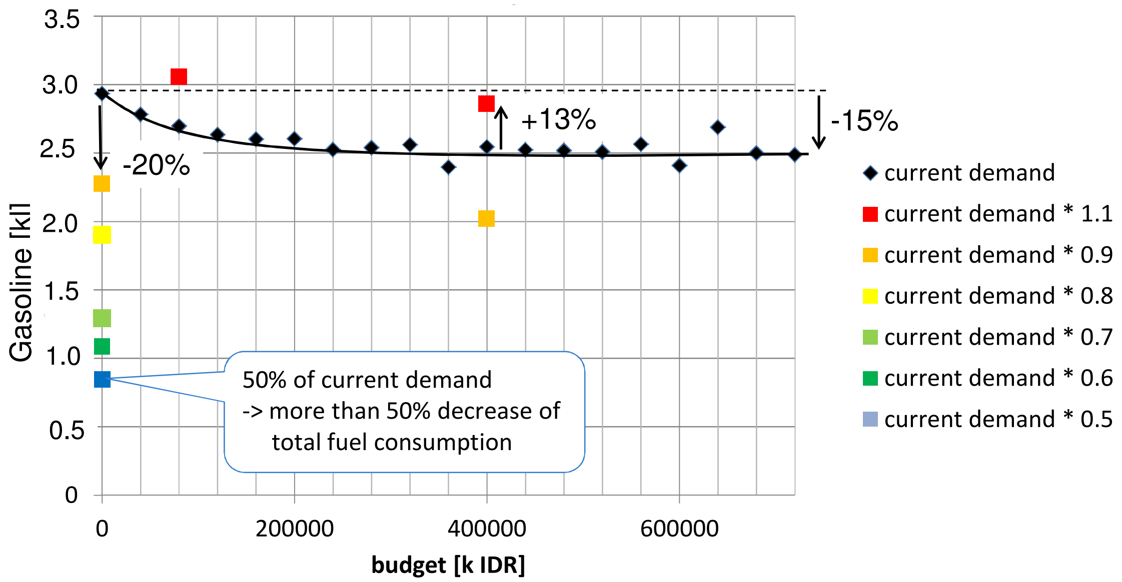
4.4 Result: Effect of traffic flow amount

In the above discussion, improvement plans for the current traffic demand are examined. However, the variation of traffic demand should be taken into consideration. This is because the traffic demand in Jakarta may continue increasing in line with the income growth, and more fundamental solutions such as traffic demand management would be necessary. In fact, several measures for traffic demand management are studied and implemented: 3 in 1, odd-even license plate number regulation, road pricing, etc. Thus, optimal improvement plans and fuel consumption were calculated by varying the amount of traffic demand

The traffic situation is examined by varying traffic demand from 50% of current traffic demand to 120% with 10% increments, while the case of 120% is not shown in Figure 5-16. It is because under the assumption for 120% traffic demand, the solution cannot be obtained mathematically as the traffic demand exceeds traffic capacity of the road network. In order to absorb traffic demand over 120% of current demand, the road network needs further capacity expansion.

Simulated results are shown in Figure 5-16 where total gasoline consumption in Kuningan area during two hours of rush hour is plotted. Black dots are gasoline consumption to the current traffic demand, and other colour dots show the changes in the traffic demand. In the case of current traffic demand, investment up to 200 million IDR is cost-effective and can save 15% of gasoline consumption. If traffic demand is reduced by 10 %, gasoline consumption decreases by 20%. Considering the fact that the number of vehicles increased by 8% per year over the past years (source: BSP Statistics of DKI Jakarta Province, 2010), the improvement effect by adding U-turns and lane-changes are almost the same as the ability to absorb traffic increase for one year. For getting further improvement effect, larger-scale solutions are required.

Figure 5-16: Gasoline consumption



5. Case B: Relatively large-scale improvements (Under/Overpass)

From the simulation analysis of Case A, it became evident that improvement by adding U-turns and lane-changes can cope with the only one year increase of traffic demand, and that the road network needs further capacity in order to absorb traffic demand of above 120% of current demand. Thus, under/overpass, which may cost high but has relatively large capacity, is examined in this section.

In simulation analysis, only one underpass is examined because of the high cost of constructing an underpass. As shown in Figure 5-17, all the current points for making a U-turn from southward lanes to northward lanes are deleted. This is because vehicles making U-turn and vehicles going straight interfere with each other at a U-turn point, which makes a negative influence to the traffic flow in the whole area. Instead, an underpass is set for vehicles on the way to the mega commercial complexes from the north. Because the underpass connects with the outer southward lanes to the outer northward lanes (Figure 5-18), a point for lane-change is also set from inner southward lanes to outer southward lanes.

Figure 5-17. Road network with an under/overpass

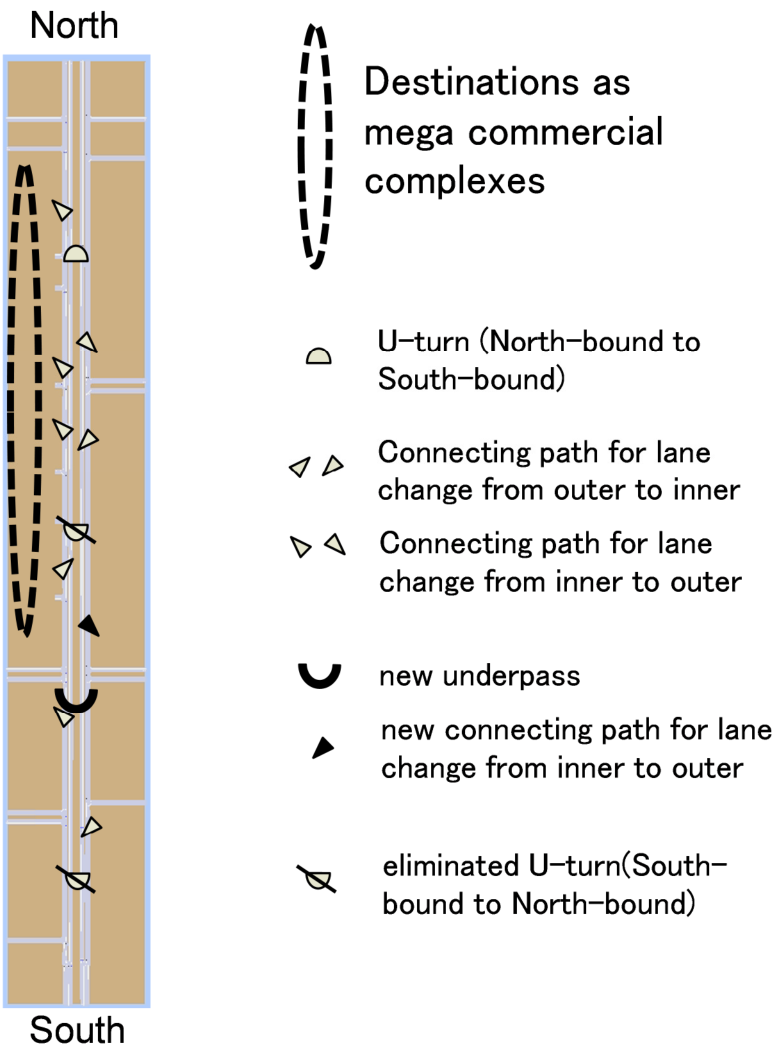
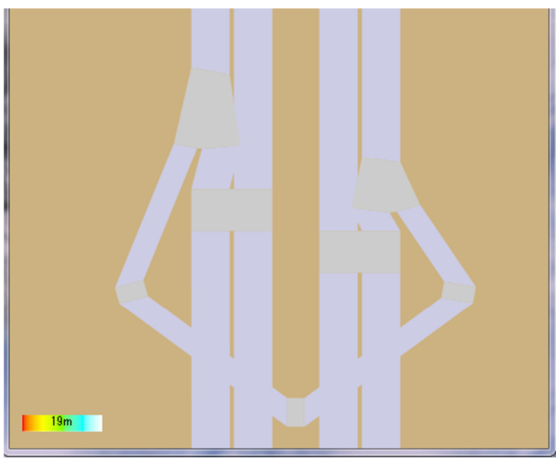


Figure 5-18. Design of under/overpass



This placement of an underpass is simulated by traffic simulator and examined by varying traffic demand from 50% to 150% of current demand with 10% increments.

In the case of current traffic demand, the simulated traffic situation shows that entire flow makes improvements by the decrease of interaction between vehicles making U-turn and vehicles going straight (Figure 5-19). Long intermittent traffic jam caused by vehicles making U-turn disappears after deleting current U-turn points. Traffic flows smoothly on the under/overpass instead.

Figure 5-19: Traffic flows before and after improvement

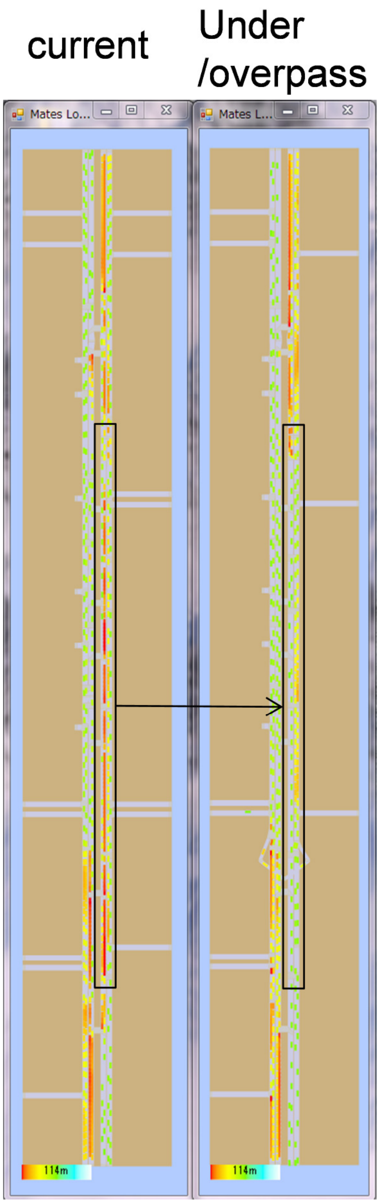
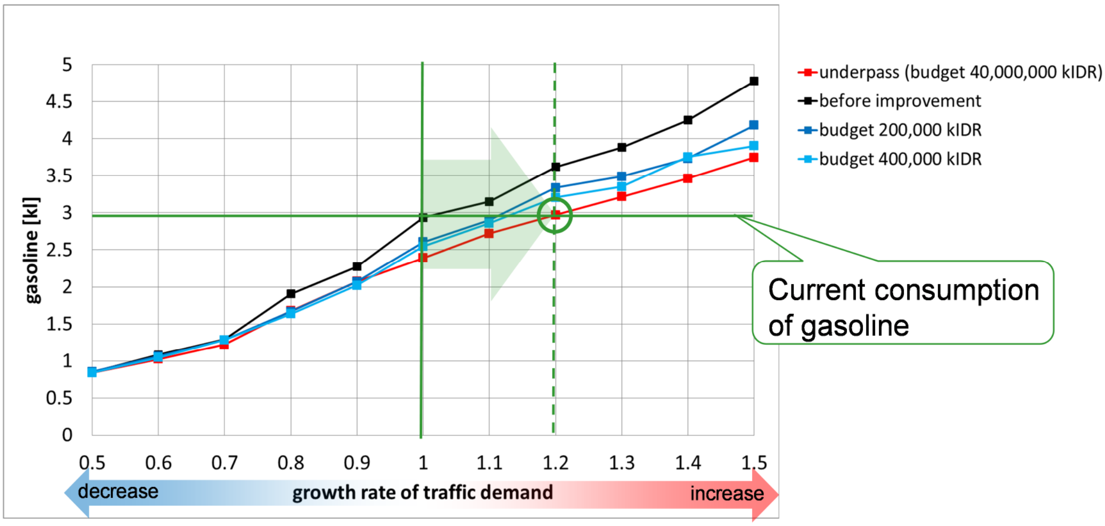


Figure 5-20 shows the change of gasoline consumption with respect to growth rate of traffic demand. Here, the black line shows the gasoline consumption before improvement, and the red line shows that of after construction of an under/overpass. When the traffic demand is 50-70% of current demand, the difference of gasoline consumption between before and after under/overpass construction is very small. When the traffic demand increases more than the present level, an under/overpass construction would reduce gasoline consumption obviously. Construction of an under/overpass keeps the gasoline consumption at the current level even if traffic demand increase 20% from now (light green arrow in Figure 5-20). It means that an additional under/overpass has the ability to manage traffic demand increase for 2.5 years (converted by traffic increase rate 8%/year).

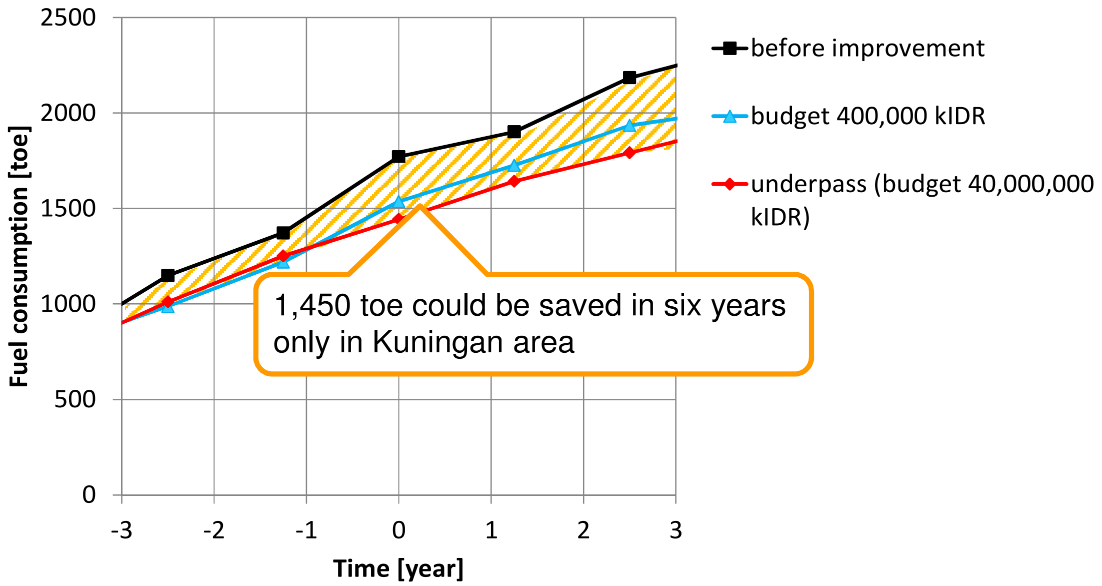
Figure 5-20: Gasoline consumption



Then, how much fuel consumption can be saved by the construction of a under/overpass? Figure 5-21 shows the estimated annual fuel consumption, where it is assumed that the traffic demand in Kuningan area increases by 8% per year and annual consumption equals to multiplying gasoline consumption during 2 hours of rush hour by 2 x 365 (2 means morning and evening rush hour). The shaded area in Figure 5-21 indicates the difference of gasoline consumption between current road infrastructure and an additional under/overpasses construction. As it stands now, it is estimated that 400 tons of oil equivalent (toe) per year is wasted.

Now, the case that construction of under/overpasses is analyzed to all the main road in Jakarta is discussed. The total length of primary arterial roads and primary collector roads is 164 km (See Chapter 4), which is 82 times longer than 2 km of the road length in Kuningan area. Thus, it is estimated that fuel consumption 400 toe multiplied by 82 is about 30 thousand toe can be saved by the construction of under/overpass in whole Jakarta. Annual fuel consumption in the transport sector of Jakarta is about 600 toe, calculated by the multiplication of gasoline consumption for the 2009 in Jakarta: 200 toe/1,000 population), population in 2010 in Jakarta: 9.6 million (see Chapter 4), and the share of Jakarta's transport sector fuel was 30% in 2010. Thus, implementation of under/overpasses in the whole Jakarta would save the amount equivalent to 5% of fuel consumption in the transport sector of Indonesia. Considering further increase of traffic demand in the future, early construction of under/overpasses will prevent waste of fuel from being accumulated.

Figure 5-21. Estimated annual fuel consumption



6. Key Findings

Case A: Selection of lane-changing points and U-turn points has been optimized under the limitation of budget (40 – 720 million IDR). Gasoline consumption decreases about 15% by additional U-turn and lane-changing points. Gasoline consumption decreases more effectively by raising the budget until 400 million IDR. Further investment is not so effective for the decrease of consumption. It is important to assess cost-effectiveness of infrastructure improvement. For the assessment, quantitative simulation analysis like this chapter is useful.

Case B: The construction of an underpass is evaluated (budget 40 billion IDR). Entire flow would improve by deleting the existing U-turn points and placing an underpass. Construction of an underpass keeps the gasoline consumption at the current level even if the traffic demand increases by 20% from the current demand. Oil savings is estimated to reach 400 toe per year only in the Kuningan area with the construction of an under/overpass. If plans for construction exist, it is necessary to act as soon as possible to minimize the congestion as well as wasteful use of fuel.

Comparing these results to the fact that the number of vehicles increase by 8% per year, proposed plans in case A and B can be considered as measures that can handle the traffic increase for 1 year and 2.5 years, respectively. As stated in section 2.2, large-scale investment measures take longer time to implement. Thus, the followings are suggested:

1. Implementation of small-scale investment options as discussed in Case A as soon as possible,
2. Implementation of relatively large-scale investment options as shown in Case B when the effect of Case A investment is being felt, and
3. Implementation of fundamental measures to assist passengers shifts toward the other transport mode when the effect of Case B investment is being felt.

In view of the long-term increases in the transport demand and resulting energy demand, it is important to implement the available options from the ones that can achieve the maximum impacts for easing congestion and saving fuels with least cost. Step-wise approach is deemed necessary for Jakarta to cope with the congestion problems and resulting wasteful use of fuels as highlighted above. The city could start from the least cost option, and moves to higher cost options when the effects of lower cost options are being felt. Earlier implementation of the entire approach is necessary before the transport system in the city faces gridlock.

It is important to note that the implementation of the comprehensive package of policies and measures, aside from the infrastructure investment, including the economic measures and financial measures, is required. Ultimately, the city dwellers and public entities can greatly enjoy the benefits from the alleviation of the congestion problems and resulting wasteful energy use as efficient transport system would be the fundamental element for the socio-economic activities of city dwellers.