ANALYSIS OF TRANSPORT DEMAND MANAGEMENT STRATEGIES FOR MITIGATING ENVIRONMENTAL EMISSION FROM THE URBAN TRANSPORT SYSTEM

Harun al-Rasyid Sorah LUBIS
Research Fellow
Center for Research on Transportation and Communication
Foundation for Research
Institut Teknologi Bandung
Jl. Ganesha 10, Bandung 40132, Indonesia
Fax.: +62 22 2502350
e-mail: halubis@trans.si.itb.ac.id

Muhamad ISNAENI
Research Assistant
Center for Research on Transportation and Communication
Foundation for Research
Institut Teknologi Bandung
Jl. Ganesha 10, Bandung 40132, Indonesia
Fax.: +62 22 2502350
e-mail: isnaeni@trans.si.itb.ac.id

Tatang Hernas SOERAWIDJAJA
Research Fellow
Center for Research on Energy
Foundation for Research
Institut Teknologi Bandung
Jl. Ganesha 10, Bandung 40132, Indonesia
Fax.: + 62-22-2504558
e-mail: ppeitb@bandung.wasantara.net.id

Abstract: Social and economic activities in Indonesia are currently declining as a result of the recent Asian financial crisis. This has brought temporarily blessings towards the current level of environmental impact from urban transport, which previously has been in the alarming position.

This paper reports initial findings of the effectiveness of transport demand management (TDM) measures for mitigating environmental emission from the urban transport system. Jakarta and Bandung, two metropolitan cities in Indonesia, were selected as case studies. The present and possible future energy demand and emission from the transport sector of the two cities will be partly estimated using a road network traffic model. The results of the base and alternative scenarios are presented and the most optimal strategies will be recommended.

In medium term, the most possible solutions to the road environment are by combining some mitigated policy on optimizing the existing transport supply and managing the demand, which in order of effectiveness, these include reducing cars in the road network, promoting public transport, supply management and smart travel behavior.

Key Words: TDM, option mitigation, emission, and energy demand

1. INTRODUCTION

1.1 Typical Urban Transport Problem in Indonesian

Many cities grew and have been agglomerated to metropolitan cities. Nowadays Jakarta, Surabaya, Bandung, and Medan have been categorized as metropolitan cities in term of city area, population, and land-use intensity. Issue related to environmental problems is crucial in setting the strategy for the urban transport planning in the future. In the era of globalization, economic competitiveness of a city will be determined by the efficiency of its urban transport systems. The performance of transport system would become the key factors in shaping the competitiveness and livability of a city in the future.

The management of transport system in those big cities in Indonesia up until now is still managed and regulated at one or two waves behind the changing trend of the current state-of-practice of transport regulation and technology. A piecemeal problem solving with poor institutional planning framework amongst the varying sector policies related to transport industries hamper many strategic changes that have been planned, e.g. declining public transport performance and services, delay on the implementation of road user tax policy, to mention a few. Consequently the prevailing in-efficiency of transport operations, such as the resulting waste of resource, energy, and time and excessive vehicle emission, all are continue to grow.

LPM-ITB (1992) reported that the emission form transport sector contribute about 55.2% to the total air pollution in those four cities (Jakarta, Surabaya, Bandung, and Medan). Lubis et al (2000) estimated that in Greater Bandung Area the contribution of transport system operation about 54.4% to the total air pollution; also wasting the time resource in the amount of Rp. 1.78 billions a day plus energy lost in amount of 21.8 %. This figure is equivalent to 623 billions rupiah or US$ 56.6 millions annually.

The mood of *predict and provide* (road building spirit) strategy in urban transport policies and planning in Indonesia was identified partly as the main cause of these prevailing transport problems; this approach has been widely proven always fail to solve those transport problems comprehensively. Predict and provide strategy tend to lead the transport policies in circumstance that all being driven only by the transport demand and hence policy only as a temporary solution; and by the time the size of the problems will become bigger and bigger.

On the other hand, as unemployment rate increases, as a matter of fact city road network capacity contracted as a result of a road side vendor business penetration to the side walk and the roadway, plus uncoordinated on-street parking management. These have been the toughest problems and sensitive to be resolved socially that many city managers are reluctant to response, only few have a political will to re-act on this.

One of the policy options that had been proven more effective to solve the transport system problems in the urban area is Transport Demand Management (TDM). TDM strategies based on optimizing the existing transport supply and managing the demand e.g. managing the operational scheme of the transport supply, reducing amount of cars in the road network, promoting public transport, car sharing and smart travel behaviors. In the medium term, combination of some mitigated policies of TDM is the most possible solutions to manage the traffic and road network environment impact.

In the policy analysis, the objectives should include the environment measures, such as emission reduction and efficiency of energy utilization. For this requirement, apart from obtaining some mobility indicators (travel speed, travel time, and vehicle composition, etc), other traffic indicators should be further analyzed to obtain the environment indicators of transport process e.g. fuel consumption and vehicle emissions.

Model to obtain the traffic indicators had been well known and established viz. four stages transport model (trip generation, trip distribution, modal split, and assignment). The structure of the model allows us to provide estimated fuel consumption and vehicle emissions based on validated network model.

This paper reports a modeling approach to quantify the impacts of urban traffic on fuel consumption and vehicle emission. Initial findings resulting from the implementation of some TDM measures will be reported. Jakarta and Bandung were selected as the case study; detailed transport statistics for the two cities are given in Table 1.

Table 1. Jakarta and Bandung Transport Statistics (1999)

Statistics	City	
	Jakarta	Bandung
Population in 1999, Projected (000)	11,327	2,530
Population growth (%pa)	4.1	1.1
Per capita income (Rp. 000)	8,881	3,424
Area (Ha)	65,570	17,750
Total area (Ha)	66,029	16,729
Agr./Estate/Open (Ha)	18,910	4,632
Population/area –total (People/Ha)	173	143
Road length (km)		
Primer arterial	276	31
Secondary arterial	377	9
Primary collector	43	22
Secondary collector	992	65
Local	4,659	776
Roads total a/c LT	6,347	902
Roads total a/c Bappenas.	5,061	738
Road meters/person	0.5	0.20
Sidewalks, Main road with meters		
roads	401	112
%roads	6.3%	12.4%
Junctions with traffic light		
Available	514	153
Working	514	107
Needed	65	12
Registered number of vehicles		
Motorcycle	1,775,153	182,483
Car, Jeep, Kijang	1,251,581	1,246,693
Truck	334,730	38,128
Bus	26,284	6,847
Total motorised	3,387,748	352,151
Cycle (recorded)	n.a	n.a
Becak, Dokar	4,146	6,100
Tour/extra Urban Bus	6,790	1,327
Urban public transport vehicles, with average seat numbers		
Large bus, 50 seats	3,539	147
Med bus, 24 seats	4,939	6
Small bus, 14 seats	6,423	5,367(city);6500 (res.)
Micro bus, 10 seats	4,593	
Total buses	19,494	5,520
Total bus seats	431,338	82,632
Bus population in 1996, (000)	1.94	2.25
Seats population in 1996, (000)	43.0	33.8
Public transport route		
Large bus	374	14
Med bus	123	2
Small bus	134	38
Total buses	631	54

The scenarios are developed for a time span of 25 years, from 1995, which is taken as the base year, until the year 2020. A road network traffic model, SATURN (Simulation and Assignment of Traffic in Urban Transport Network), (Van Vliet, 1994) is used for the TDM option experiments. The results of the base and alternative scenarios are discussed and the most optimal strategies will be recommended.

2. MODELING APPROACH

Figure 1 shows the main structure of modeling approach used in this research. Fuel consumption and vehicle emission are the main outputs to be estimated under various alternative scenarios. Traffic related indicators such as link flows, speeds and times, hence in network-wide level could be reproduced from the traffic assignment model. Assuming an average fuel consumption and emission factor reflected the current traffic in the cities, total system energy demand and emission can be provided.

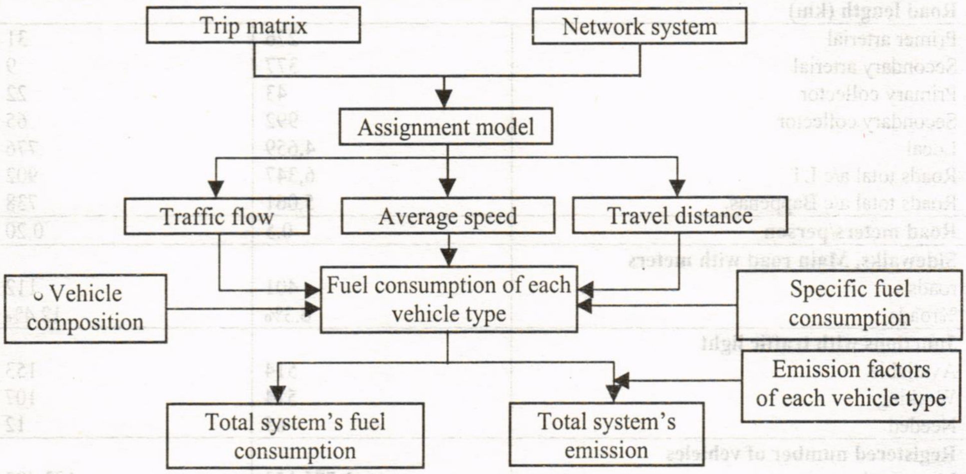


Figure 1. Main Structure of Modeling Approach

First of all, inputs data related to trip matrix as the demand side and road network database as the supply side of transport system in the base year case have to be provided, as well as the trip matrices and network databases for alternative scenarios that are tested. Estimation method to obtain trip matrices was adapted, such as maximum entropy matrix estimation (ME2), we refer to Willumsen (1982) for more detailed explanation on this.

Assignment process was conducted using SATURN (Van Vliet, 1994) with input data that had been adapted to the characteristic of road network and traffic in Indonesia. In this research assignment is used only for private car, while public transport route was treated fixed.

2.1 Traffic Assignment Model

Assignment model used to allocate the content of trip matrix to the road network according to the assumption used to represent route choice behavior of road users. Several factors could influence the route choice behavior. Outram and Thompson (1978) stated that travel distance and travel time was the most realistic combination to represent the factor that influence drivers in choosing their routes.

2.1.1 Speed Flow Relationship

Measurement of travel distance and travel time derive from speed-flow relationship curve; in Indonesian Highway Capacity Manual (IHCM, 1997) the speed-flow relationship expressed by Single Regime model below:

$$V = FV^*[1-(D/Dj)^{l-1}]^{1/(l-m)} \quad (1)$$

$$D_o/D_j = [(1-m)/(l-m)]^{1/(l-m)} \quad (2)$$

Where FV represent the link free-flow speed (km/h). Then, D represents the vehicle density (pcu/h) that expresses in degree of volume per capacity; and further D_o and D_j express the vehicle density at capacity and when total traffic jam occurs. Then, l and m are constants, road geometric dependent, obtained from empirical calibration.

SATURN provides a form of speed-flow relationship that could be adapted to mimic the IHCM specification. The SATURN's model represents by a mathematical relationship below:

$$t = a\,V^n + t_o \text{ for } V < C \quad (3)$$

$$t = a\,C^n + t_o + b\,(V - C)/C \text{ for } V > C \quad (4)$$

Where C (pcu/h) represents the link capacity; t_o (sec.) and t (sec.) respectively represents the travel time at free-flow condition and travel time at traffic volume on this link is V (pcu/h). In the equation above a, b, and n are constants; where n should be estimated as the model driver, whereas b and a will self estimated by SATURN that depend on the flow degree in each link.

2.1.2 Traffic Assignment Technique

Some traffic assignment techniques can be used to allocate the trip matrix to each link in the network. The models are ranging from a simple method to a complex method that involving the iteration procedure. Equilibrium assignment model is recommended to be used for road network that has a high congestion level like Jakarta and Bandung, e.g. Lubis (1992).

Equilibrium assignment based on Wardrop-Equilibrium Principle (Wardrop, 1952) that assume: "*under equilibrium condition, traffic arranges its self in congested networks in such a way that no individual trip maker can reduce his path costs by switching routes*".

Beckmann (1956) proposed a formulation to solve the equilibrium problems by minimizing an objective function, $Z(v)$, below:

$$Min\ Z(v) \equiv \sum_a \int_o^{Va} c_a(v)dv \quad (5)$$

subject to $Tpij \geq 0$ and $\sum_{Pij} Tpij = Tij$

Whereas v_a and c_a are link flow and cost at link a. Then T_{pij} is the trips from i to j that pass the p route and T_{ij} as the total trip from i to j.

Solving algorithm for the Beckmann's formulation developed by Frank-Wolfe (1956) based on convex combination method. The Frank-Wolfe algorithm adopted by SATURN that used in the assignment procedure of this research. Further discussion about Frank-Wolfe Algorithm could be found in Sheffi (1985).

2.2 Vehicle Composition

Traffic flow from the transport model should be grouped on to type of vehicles. Vehicle composition ideally categorised by type of fuel and cylinder capacity (cc), but in practice, it was almost impossible to gather data up this level of detail from the field survey. Secondary data from vehicle registration can not be used directly, because vehicle utilisation rate should be firstly provided.

In this research, vehicle composition was derived from observation of traffic counts in several road links in the study areas. Unfortunately, in a standard traffic counts survey, categories of vehicle only carried out by the level of traffic disturbance level; hence information about type of fuel used by the vehicle and their cylinder capacity can not be obtained.

The most probable solution to this problem is by using traffic counts data to obtain vehicle composition by traffic disturbance type; and the result of this composition is classified into types of fuel and cylinder capacity using the vehicle registration data. The problem is simpler in public transport, because routing system was fix and the operation frequency in an hour could be estimated from the vehicle fleet.

2.3 Fuel Consumption Model

The fuel consumption model have to represent the corelation between fuel consumption and average speed, becuase one of main indicators of TDM performance is the increasing of total transport system's travel speed and reduction of the fuel utilization. Average speed model was the most suitable model for fuel consumption estimation in network-wide basis as well as for long term analysis, because travel speed on any year during the horizon year can be reproduced using the traffic model.

Fuel consumption vs operational speed model that used in this research was adopted from the recomendation of PT Jasa Marga (Indonesia Highway Corporation) study that conducted by LAPI-ITB in 1996. The PT Jasa Marga model formulation written as:

$$\textit{Fuel Consumption} = \textit{basic fuel}\ (1 \pm (kk + kl + kr)) \quad (6)$$

Where the *basic fuel* is the value of basic fuel consumption in litre/1,000 km, *kk* is correction factor for slope, *kl* correction factor for traffic condition, and *kr* is correction factor for roughness. Basic fuel consumption for each vehicle category given as follows:

$$\textit{Basic fuel category I} = 0.0284\ V^2 - 3.0644\ V + 141.68 \quad (7)$$
$$\textit{Basic fuel category II A} = 2.26533 * \textit{basic fuel category I} \quad (8)$$
$$\textit{Basic fuel category II B} = 2.90805 * \textit{basic fuel category I} \quad (9)$$

Vehicle Category I including passenger cars (sedan, jeep, pick up, and minibus), ¾ truck, and medium bus. Vehicle Category II A including (big) truck and bus with 2 axles, and Vehicle Category II B including (big) truck and bus with 3 axles or more. Correction factor for each variable considered presented in Table 2.

Table 2. Basic Fuel Consumption Correction Factors

Correction factor	Explanation	Condition	Value
Correction for negative-slope's (*kk*)	g = *gradient*	g<-5%	- 0.337
		-5%≤ g < 0%	- 0.158
Correction for positive-slope's (*kk*)	g = *gradient*	0% ≤ g < 5%	0.400
		g ≥ 5%	0.820
Correction for traffic condition (*kl*)	v/c = *volume per capacity ratio*	0 ≤ v/c < 0,6	0.050
		0,6 ≤ v/c < 0,8	0.185
		v/c ≥ 0,8	0.253
Correction for roughness (*kr*)	r = *roughness*	r< 3 m/km	0.035
		r≥ 3 m/km	0.085

Source: PT Jasa Marga and LAPI-ITB (1996)

2.4 Vehicle Emission Model

Several models could be used to obtain the vehicle emission, but since the fuel consumption had been estimated, hence the use of emission factors is preferable. In general, the estimation method used in this research to obtain total emission of vehicle operation estimated by multiplying the total fuel consumption of each vehicle category with its specific emission factor.

Since there are several emission factors estimated from various studies, comparison of calculation result on each emission factors used should be taken as a reference point. The reference points are the study results conducted on the base year or initial forecasting point. The emission factor with less calculation discrepancy are chosen where others emission factor with other pollutants were taken also as consideration.

In this study, the emission factors were chosen mostly from the revised of IPCC (1996) and the study that conducted by Forsch. JGH. in 1991. Whereas, the reference point taken from studies conducted in several cities of Indonesia by LPM-ITB for BAPEDAL in 1992. Emission factors used in this research presented in Table 3.

Table 3. Emission Factor Value (grams/litre) for Each Type of Vehicle

No	Vehicle type	CO		NO_x		HC		SO_2		SPM	
		Gasoline	Solar	Gasoline	Solar	Gasoline	Solar	Gasoline	Solar	Gasoline	Solar
1	Passenger car										
a	< 1600 cc	195.05	53.05	57.02	10.46	18.51	4.07	-	4.90	-	-
b	> 1600 cc	152.75	0	44.66	8.19	14.50	3.19	-	3.84	-	-
2	Jeep/St. Wagon/ Ambulans										
a	< 1600 cc	318.78	44.16	70.38	12.28	30.26	4.23	-	5.64	-	-
b	> 1600 cc	248.40	39.90	54.84	11.10	23.58	3.83	-	5.10	-	-
3	Pick-Up										
a	< 1600 cc	347.76	42.03	76.78	11.69	33.01	4.03	-	5.37	-	-
b	> 1600 cc	372.60	45.75	82.26	12.73	35.37	4.39	-	5.85	-	-
5	Truck	N/A	14.81	N/A	63.13	N/A	9.32	N/A	5.02	N/A	2.12
6	Minibus										
a	Private	389.16	48.94	85.92	13.62	36.94	4.69	-	6.26	-	-
b	Public	322.92	38.30	71.29	10.66	30.65	3.67	-	4.90	-	-
7	Microbus	N/A	13.62	N/A	55.12	N/A	8.32	N/A	4.56	N/A	1.96
8	Bus	N/A	10.28	N/A	41.60	N/A	6.28	N/A	3.44	N/A	1.48

Source: Center for Research on Energy ITB, 1999

3. TDM STRATEGIES AND SCENARIOS DEVELOPMENT

3.1. TDM options for Jakarta

TDM strategis development for Jakarta are based on 6 action plans, i.e. Jakarta Mass Transit System (JMTS) (Halcrow Fox, 1996), Jakarta Outer Ring Road (JORR) Toll Road System (Directorate General of Highway, 1995), Jakarta Urban Arterial Road Development (Pacific Consultants International, 1995), Bus-way Corridors Development (Directorate of Traffic and Road Transport, 1996), Land Use Master Plan (Local Government of DKI Jakarta, 1995), and Traffic Management by parking policy on the city center road. These options might be combined as shown in Table 4, each of which will be called scenario. BAU scenario developed under assumption that the trend of economic activities would grow under market mechanism and the local government continued their usual business on road development.

Table 4. Scenarios and TDM Strategies for Jakarta

Scenarios	TDM Strategies					
	JMTS	JORR Toll Road	Arterial Road	Bus-Way	Land Use	Traffic Management
Scenario 1: Do-nothing	-	-	-	-	-	-
Scenario 2: Business as usual (BAU)	-	-	✓	-	-	-
Scenario 3: Land use	-	-	✓	-	✓	-
Scenario 4: Traffic management	-	-	✓	-	✓	✓
Scenario 5: Road development	-	✓	✓	-	✓	-
Scenario 6: Mass rapid transit (MRT)	✓	-	✓	✓	✓	-
Scenario 7: All Scenarios	✓	✓	✓	✓	✓	✓

Annotation: (✓) included (-) not included

3.2. TDM Options for Bandung

Strategies for Bandung have been based on 5 action plans, i.e. Mass Rapid Transit (MRT) Plan (M+R International and Associates, 1995), Inner Toll Road Plan (Pacific Consultants International, 1995), Arterial Road Development (Center for Research ITB, 1997), Land Use Plan (Center for Research ITB, 1997), and Traffic Management by parking restriction on the city center road. Some possiblescenarios are listed in Table 5. BAU scenario developed under assumption that the trend of economic activities would grow under market mechanism and the local government continued their usual business on road development.

Table 5. Scenarios and TDM Strategies for Bandung

Scenarios	TDM Strategies				
	MRT	Inner Toll Road	Arterial Road	Land Use	Traffic Management
Scenario 1: Do-nothing	-	-	-	-	-
Scenario 2: Business as usual (BAU)	-	-	✓	-	-
Scenario 3: Land use	-	-	✓	✓	-
Scenario 4: Traffic management	-	-	✓	✓	✓
Scenario 5: Road development	-	✓	✓	✓	-
Scenario 6: Mass rapid transit (MRT)	✓	-	✓	✓	-
Scenario 7: All Scenarios	✓	✓	✓	✓	✓

Annotation: (✓) included (-) not included

4. SIMULATION RESULT AND ANALYSIS

4.1 Simulation Result and Analysis for Jakarta Case

4.1.1 Traffic Indicators

Traffic indicators resulting from simulation for all scenarios developed for Jakarta are presented in Figure 2 to Figure 5.

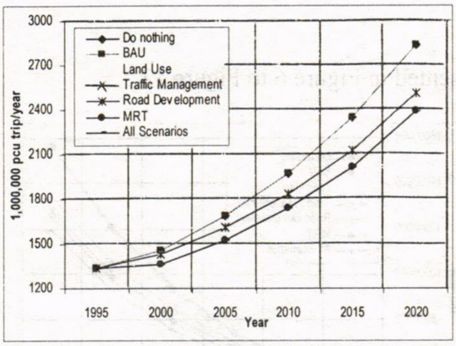


Figure 2. Total Trip Demand (Jakarta Case)

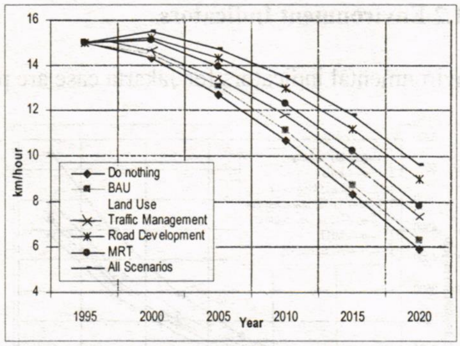


Figure 3. Average Travel Speed at Peak Hour Period (Jakarta Case)

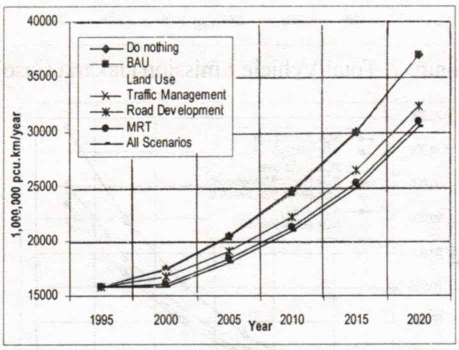


Figure 4. Total Travel Distance (Jakarta Case)

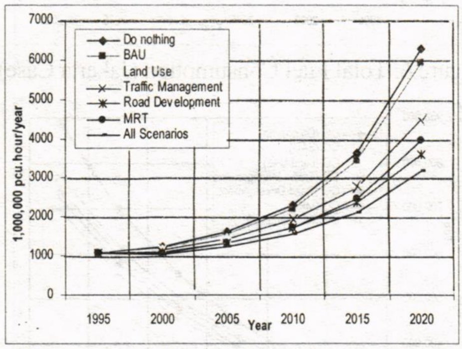


Figure 5. Total Travel Time (Jakarta Case)

As shown in Figure 2, the trip demand growth developed at 3 scenarios, i.e. grow as usual (for Scenario 1 and 2), grow in line with land use pattern (for Scenario 3, 4, and 5) and reduced growth by mass transit (for Scenario 5 and 6). The land use scenario seems presents a bigger reduction of trip demand for road, than the mass transit. The reducing of trip demand by the MRT scenario only about 5% and by the land use scenario reached 12%. However, since the MRT line only operate in one lane between Blok M to Kota, then the implementation of MRT will remain unattractive, unless feeder public transport services are also provided.

Operational feature of each scenario presented in Figure 3 to Figure 5. Average travel speed at peak hour period for Jakarta Case (Figure 3) decreased over the time horizon. Road development option giving highest operational speed increasing (from do-nothing) than the others. Individually, Land Use option provide the highest operational speed increasing about 25%, Road Development 22%, and MRT only about 6%.

Since the travel demand could reduce by the land use arrangement and MRT provision, then the travel distance and travel time also could reduce by those strategies. The statement proved in Figure 4 and Figure 5, where the travel distance and travel time in the road network reduced significantly by these two kind of strategies. For travel distance, Land Use and MRT provide reduction about 12% and 5% respectively. Different feature showed for travel time estimation, where the road development option performed better than MRT. Road development reduced travel times about 19% and MRT only 12%. The result shows that road development programs are highly desirable for Jakarta, because traffic, nowadays, has been operated in over saturated condition, noting that Jakarta only has 0.5 meter road per capita.

4.1.2 Environment Indicators

Environmental indicators for Jakarta case are presented in Figure 6 to Figure 13.

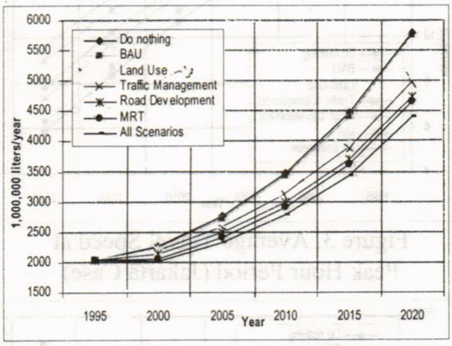


Figure 6. Total Fuel Consumption (Jakarta Case)

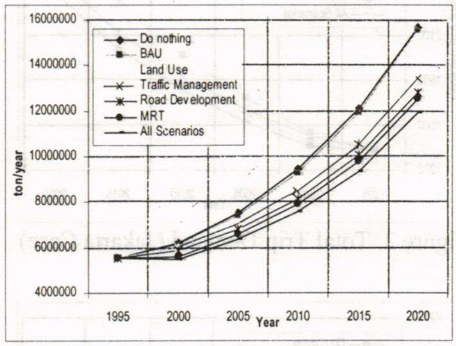


Figure 7. Total Vehicle Emission (Jakarta Case)

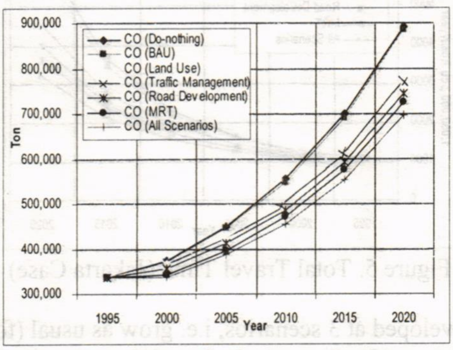


Figure 8. Total CO Emission (Jakarta Case)

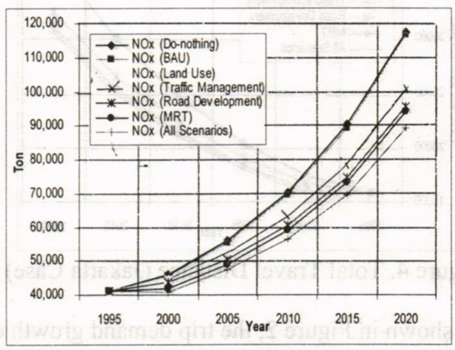


Figure 9. Total NOx Emission (Jakarta Case)

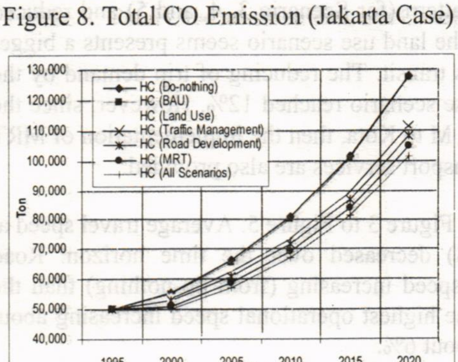


Figure 10. Total HC Emission (Jakarta Case)

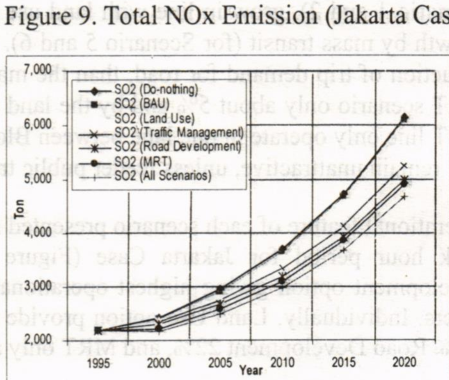
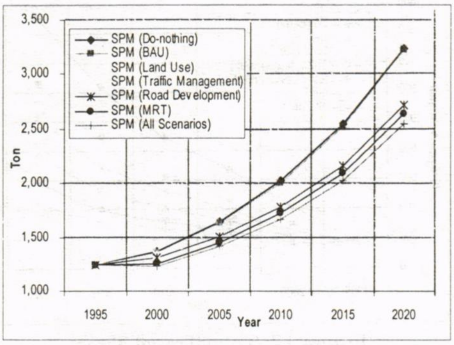


Figure 11. Total SO_2 Emission (Jakarta Case)



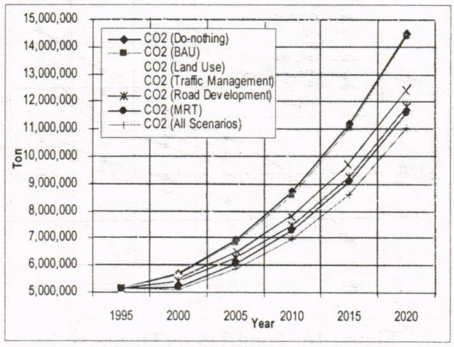


Figure 12. Total SPM Emission (Jakarta Case) Figure 13. Total CO_2 Emission (Jakarta Case)

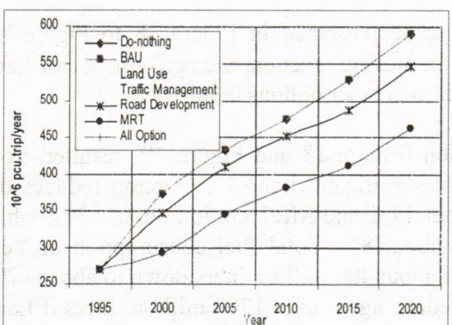
Similarly to the traffic indicators result discussed in previous section, the performance of Land Use Option, Road Development, and MRT Option also perform better than the other option in this case. Reduction of total fuel consumption and emission (Figure 6 and Figure 7) resulted by Land Use Option and MRT Option are the most significant. Land Use Option reduce the total fuel consumption and vehicle emission about 15% and MRT Option about 6%; while Road Development Option give reduction about 4%. Total fuel consumption for do-nothing option in Year 2020 about 5800 million liters, and could reduced about 850 million liters down to about 4950 million liters by Land Use Option, and it could reduce again until 4650 million litters if Land Use and MRT Option implemented simultaneously.

Similar profiles were also obtained for each emission types over the time horizon studied. These are shown in Figure 8, 9, 10, 11, 12 and 13 for CO, NOx, HC, SO_2, SPM and CO_2 respectively. The emissions increase over year, and the Land Use and MRT Option giving less emission than the others. For example, CO emission (as the major of green house gas pollutant) could reduced by Land Use Option about 14% and by MRT Option about 6%.

4.2 Results and Analysis for Bandung Case

4.2.1 Traffic Indicators

Traffic indicators resulting from simulation for all scenarios developed for Bandung are presented in Figure 14 to Figure 17.



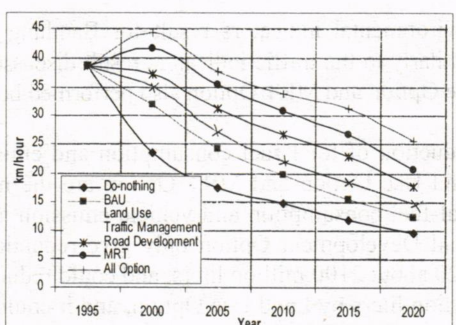


Figure 14. Total Trip Demand (Bandung Case) Figure 15. Average Travel Speed at Peak Hour Period (Bandung Case)

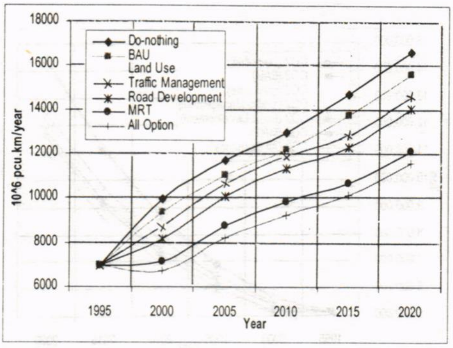


Figure 16. Total Travel Distance (Bandung Case)

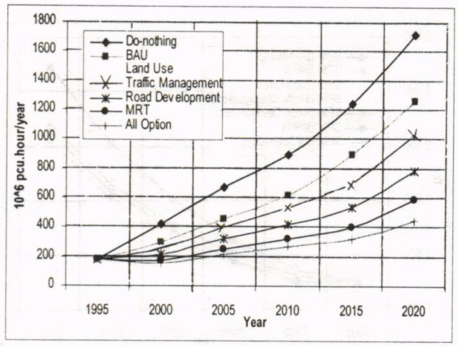


Figure 17. Total Travel Time (Bandung Case)

As shown in Figure 14, the trip demand growth also developed at 3 scenarios, i.e. grow as usual (for Scenario 1 and 2), grow in line with land use pattern (for Scenario 3, 4, and 5) and reduced growth by mass transit (for Scenario 5 and 6). However, the mass transit operation obtained the most attracted scenario that could reduce the trip demand for road. The reducing of trip demand by the MRT scenario about 15% and by the land use scenario about 7%.

Operational feature of each scenario presented in Figure 15 to Figure 17. Average travel speed at peak hour period for Bandung Case (Figure 16) decreased over time horizon. MRT option giving highest operational speed increasing (from do-nothing) than the others. Individually, Land Use option provide the highest operational speed increasing about 48%, MRT about 45%, and Road Development only 25%. It is interesting to note that the road improvement program will not give better performance since the travel demand growth were not restricted.

Since the travel demand could reduce by the land use arrangement and MRT provision, then the travel distance and travel time also could reduce by those strategies. The statement proved in Figure 16 and Figure 17, where the travel distance and travel time in the road network reduced significantly by these two kind of strategies. Land Use option giving 16% reducing and MRT giving 24%. Road wise policies only give slight improvement, Road Development option only reduce 8% of total travel time and travel distance in road network, and traffic management only 1%. The traffic management option seems worst, but this option needs less cost.

4.2.2 Environmental Indicators for Bandung

Environmental indicators result for Bandung case ae presented in Figure 18 to Figure 25. Similarly to the traffic indicators result discussed in previous section, the performance of Land Use Option and MRT Option also performed better than other options in this case.

Reduction of total fuel consumption and emission (Figure 18 and Figure 19) resulted from Land Use Option and MRT Option are the most significant. Land Use Option reduces the total fuel consumption and vehicle emission about 17% and MRT Option about 23%; while Road Development Option only give reduction about 8%. Total fuel consumption in Year 2020 about 2100 million liters, and could reduced about 400 million liters down to about 1700 million liters by Land Use Option, and it could reduce again until 1200 million litters if Land Use and MRT Option implemented simultaneously.

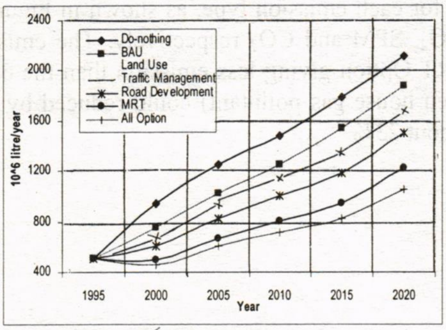


Figure 18. Total Fuel Consumption (Bandung Case)

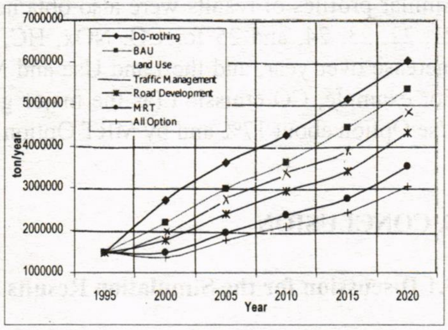


Figure 19. Total Vehicle Emission (Bandung Case)

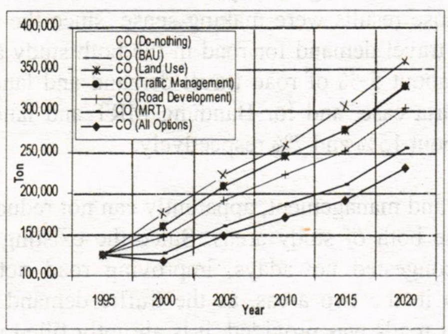


Figure 20. Total CO Emission (Bandung Case)

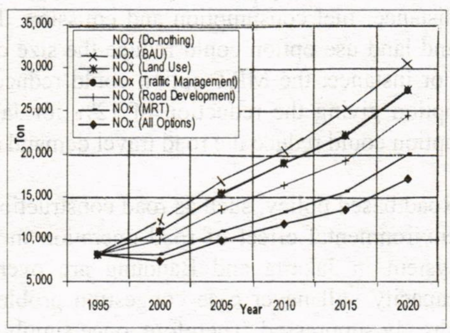


Figure 21. Total NOx Emission (Bandung Case)

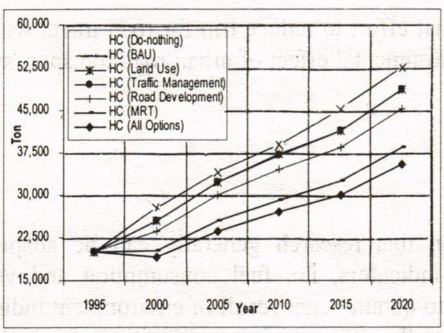


Figure 22. Total HC Emission (Bandung Case)

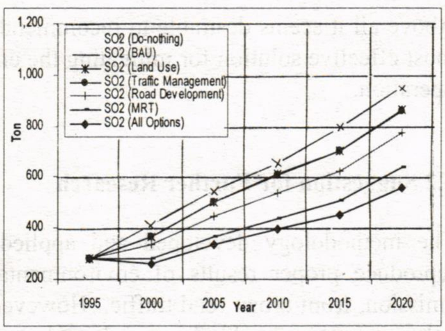


Figure 23. Total SO_2 Emission (Bandung Case)

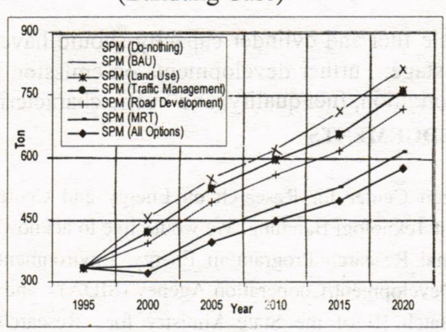


Figure 24. Total SPM Emission (Bandung Case)

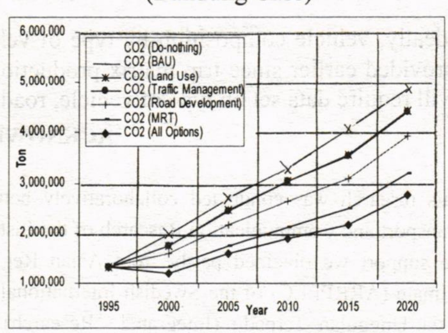


Figure 25. Total CO_2 Emission (Bandung Case)

Similar profiles of results were also obtained for each emission type, as shown in Figure 20, 21, 22, 23, 24, and 25 for CO, NOx, HC, SO_2, SPM and CO_2 respectively. The emissions increase over year, and the Land Use and MRT Option giving less emission than the others. For example, CO emission (as the major green house gas pollutant) could reduced by Land Use Option about 17% and by MRT Option about 23%.

5. CONCLUSION

5.1 Discussion for the Simulation Results

The simulation results for Jakarta and Bandung shows that the MRT provision and land use control options give a higher performance on reducing the system's travel time, travel distance, fuel consumption and emission. Those results were making sense, since the MRT and land use option could reduce the size of travel demand for road in the both study areas. For instance, the MRT option could reduce about 5 % of road travel demand and land use option giving the reduction of 12% for Jakarta case, and for Bandung MRT and land use option could reduce the road travel demand about 15% and 7% respectively.

Road based policy, such as road construction and management, apparently can not reduce the environmental effect of road operation in the both of study areas. Since the existing road system in Jakarta and Bandung are over-congested nowadays, improving road network capacity will never ease congestion problem in the two areas, as the traffic demand were already suppressed. Therefore, once supply of roads was provided, it is abruptly filled up by the existing suppressed demand.

Above all it seems desirable to recommend that effort to reduce trip for road travel were the most effective solution for mitigating the environmental effect of urban road transport system operation.

5.2 Suggestion for Further Research

The methodology developed and applied in this research generally can be adapted to reproduce proper results of environmental indicators, i.e. fuel consumption and vehicle emission, from urban road traffic. However, to obtain better result of environment indicators enhancements should be conducted especially in vehicle composition method and development of emission factor that appropriates for a specific study case.

Ideally, vehicle composition by type of vehicle fuel and cylinder capacity should have been provided earlier since trip matrix production stage. Further developments on emission factor will require data set on type of vehicle, road condition, fuel quality, and traffic characteristic.

ACKNOWLEDGEMENTS

This research was conducted collaboratively between Center for Research on Energy and Center for Transport and Communication Research of the Institut Teknologi Bandung. We would like to acknowledge the support we obtained partly from Asian Regional Research Program in Energy, Environment and Climate (ARRPEEC) of the Swedish International Development Cooperation Agency (SIDA) and from Riset Unggulan Terpadu (Integrated Research) Batch III of the State Ministry for Research and Technology, the Government of Indonesia.

REFERENCES

Beckmann, M.J, McGuire C.B., and Winsten C.B. (1956) **Studies in Economics of Transportation**. Yale University Press, New Haven.

Center for Research ITB (1997) Integrated Transportation System Study for Bandung Municipality Area, **Final Report**, Bandung.

Center for Research on Energy ITB (1999) Analyses of Technical Options for Mitigating Environmental Emissions from the Urban Transport System in Selected Asian Countries: Indonesian Case, **Second Progress Report,** November 1999, Bandung.

Directorate General of Highway (1995) Jakarta Outer Ring Road (JORR) Toll Road System Feasibility Study, **Final Report**, Jakarta.

Directorate General of Highways (1997) **Indonesian Highway Capacity Manual**, Jakarta

Directorate of Traffic and Road Transportation (1996) The Feasibility Study of Pasar Minggu and Pramuka-Pemuda Bus-Way Corridors, **Final Report**, Jakarta.

Forsch. JGH (1991) **Environmental Impacts of Energy Strategies for Indonesia: Assessment of the Emission Coefficients of the Traffic Sector in Java**, BPPT & Forsch. JGH, Jakarta.

Frank, M and Wolfe P. (1956) An Algorithm for Quadratic Programming. **Naval Research Logistics Quarterly 3 (1-2)**, pp. *43-53.*

Halcrow Fox (1996) Jakarta Mass Rapid Transit Study, **Final Report**, Jakarta.

Lembaga Afiliasi dan Penerapan Industri (LAPI-ITB) in collaboration with PT. Jasa Marga (1996) **Final Report of Vehicle Operating Cost Estimation Study**, Bandung.

Lembaga Pengabdian Kepada Masyarakat (LPM-ITB) in collaboration with BAPEDAL (1992) **Report of Status of Air Quality in Medan, Jakarta, Bandung, Semarang, and Surabaya**, Bandung.

Local Government of DKI Jakarta (1995) **General Planning of DKI Jakarta Land Use 1995-2000**, Jakarta.

Lubis H.A.S, Isnaeni M., and Frazila R.B. (2000) Preparing A Competitive Greater Bandung in 21st Century Through Transport Improvement and Business Networking, **Proceeding of One Day Seminar Toward Integrated Transport System in Bandung and Surrounding Area**, Civil Engineering Department of Unjani-FSTPT- Regional Government of Bandung Regency, 6 May 2000.

Lubis, H.A.S (1992) Choice of An Appropriate Assignment Model, **Journal of Civil Engineering**, Institute Technology of Bandung, Indonesia.

M+R International and Associates (1995) Urban and Sub Urban Railway Transport System for The Bandung Metropolitan Area, **Final Report**, Bandung.

Outram, V.E. and Thompson, E. (1978) Driver Route Choice-Behavioural and Motivational Studies. **Proceedings 5th PTRC Summer Annual Meeting**, University of Warwick, July 1977, Warwick.

Pacific Consultants International (1995) The Feasibility Study on Urban Arterial Road System Development Project in Jakarta Metropolitan Area, **Final Report**, Jakarta.

PT. Seecons and Associate (1995) The Feasibility Study of Bandung Inner Toll Road, **Final Report**, Bandung.

Sheffi, Y. (1985). Urban Transportation Networks, Prentice Hall, Inc., Englewood Cliffs, New Jersey

Van Vliet, D (1994) **SATURN: A User's Manual – Universal Version (Date of Last Update 24 July 1994)**, Leeds.

Wardrop, J.G. (1952). Some Theoretical Aspects of Road Traffic Research, **Proceedings Institution of Civil Engineers II(1)**, pp. 325-378.

Willumsen, L.G. (1982) Estimation of trip matrices from volume counts; validation of a model under congested conditions. **Proceedings 10th PTRC Summer Annual Meeting**, University of Warwick, July 1982, England