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Air Quality Modelling Study Due to Traffic Activities

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Abstract:

One of the impacts of traffic activity is air pollution. The size or level of the pollutants that are produced from traffic activity is very dependent on the characteristics of the operation of the traffic system and the format of the city itself. Air pollution prediction modelling due to traffic is carried out to find a prediction model that is the most suitable and look for an alternative way of treatment that can be taken to reduce the level of air pollution due to traffic.Alternative road network development by constructing inner-city freeway and removing parking can reduce air pollution due to traffic activities.

Keywords **—Air traffic prediction modelling, traffic activities, road network system.**

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I. INTRODUCTION

The road traffic sector is the largest source of air pollution in urban areas. The main pollutant that is produced from vehicle exhaust emission is Carbon dioxide (CO_2), Nitrogen Oxide (NO_x), Carbon monoxide (CO), Hydrocarbon (HC), Sulfur oxides (SO_x), and Lead (Pb). A low-speed vehicle will produce more exhaust emissions. Pollutants that are produced from these low-speed vehicles can reach three times the normal speed vehicle [1].

The city's economic growth will have an impact on the increase of industrial activities which will also contribute to the decrease of the air quality [2][3]. Air pollution is caused by human activities such as the burning of fuels (coal, oil, gas), forest burning, mining, metallurgy, etc. and natural activities like volcanic activity [4][5].

In Europe, road transportation sector accounts for total annual emissions by 40% for NO_x, 23% for CO, 13% for primary PM2.5, 9% for primary PM10, and 11% for VOC_s. Shares rise to 23% for total PM10 and 28% for O_3 precursors if emissions from precursors of secondary aerosol and O_3 are also considered [6].

There have been many efforts done to reduce air pollution caused by motorized vehicles in many developed countries such as improving the technology of the vehicle engine, changing to better fuels, and others. On the other hand, traffic management measures can reduce up to 20% [7]. This research was conducted to predict the air pollution that is produced from traffic activities and to look for alternatives that can be taken to reduce air pollution due to traffic activities.

Currently, more than 70% of pollutant source in Indonesia comes from motorized vehicles, especially in big cities in Indonesia [8]. In the city of Bandung, 93,5% of air pollution comes from the transportation sector [7]. One of the causes of pollution is caused by the increase in transportation activity in the city of Bandung through the massive growth of motorized vehicles which is reaching 11% per year, with indications of higher traffic density which is dominated by 98% private vehicles and only 2% public transportation [9].

II. LITERATURE REVIEW

Transportation activities cause a decrease in environmental quality.One of the pollution comes from motorized vehicle. The main pollutants that isproduced from the exhaust emissions are NO_x (Nitrogen Oxide), CO (Carbon Monoxide), HC (Hydro Carbon), SO_2 (Sulfur Dioxide), SPM (Suspended Particulate Matter), dan Pb(Lead) [10].

The modelling was carried out by using a multi-linear regression model [11].

$$y = a_0 + a_1x_1 + a_2x_2 + \ldots\ldots + a_nx_n + \varepsilon \qquad (1)$$

y = dependent variable
xi = independent variable
ai = coefficient of independent variable
a = constant
= error

The type of pollutant that will be the dependant variable is NO_x, CO, and HC. As for the Independent variable is the numberand the composition of the vehicle: large and public vehicle (LPV), large bus (LB), small bus (SB), Large truck (LT), small truck (ST), motorcycle (MC), and the speed of the vehicle (S).

Furthermore, route selection is carried out to allocate every movement between zones to the various route that is used the most often by someone that is moving from the origin zone I to the destination zone j [12]. The output of this stage is the traffic flow information on each road.

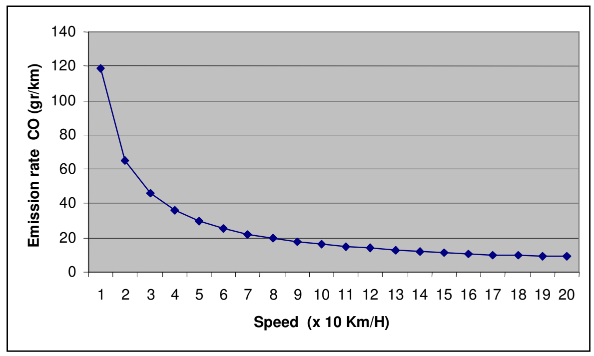
The selection modelling process uses a computer-based simulation program SATURN (Simulation and Assignment of Traffic to Urban Road Networks) that is developed at the Institute for Transport Studies – University of Leeds. The SATURN input consists of a network model and an Origin-Destination Matrix (MAT). Network modelling is done by compiling basic network data whose format has been determined in the SATURN program [13].

III. RESULTS

The city of Bandung is currently experiencing transportation problems that are quite concerning. Trafficjam in a rush hour like morning or afternoon on the roads in the city of Bandung has now become a common phenomen on that must be faced by the people of Bandung. One of the main causes of trafficjams in the city of Bandung is that there are too many vehicles that are operating on the road network and the capacity of the road network in Bandung is also very limited. This will have an impact on the increase in air pollution.

A. Air Pollution Prediction Modelling

Theresultofthemeasurement shows thatthespeedofthevehicleaffectstheamountoffuelsthatisused and theperfectionof combustión whichwillaffectsthelevelofemissionsproduced.



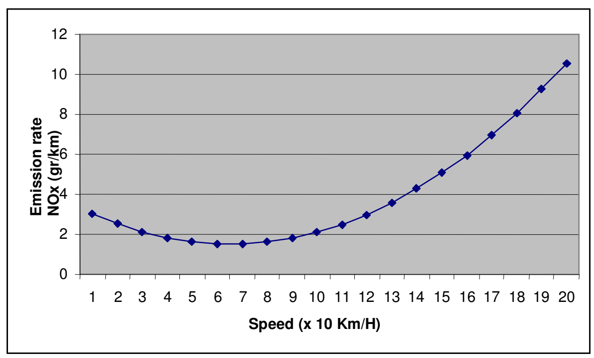


Fig 1. Relationship between Exhaust Emission Rate and Speed

Generally, the number of exhauste missoons will decrease if the speed increases, and at a certain point will increaseag a in.Furthermore, modelling of air pollutants due to traffic is carried out which is divided into three groups, namely:

- Emission model for the open area (EMOA)
  This emission model is for roads in urban areas where air movement is free to move because it is not blocked by buildings on either side of the

road.The result of multiple linear regression processing are as follows:

a. NO_x = 0,0001734 + 0,0000268 **LPV** + 0,0000405 **LB** + 0,0000356 **SB**+ 0,0000417 **LT** + 0,0000376 **ST** + 0,0000021 **MC** - 0,0000006 **S**

b. CO =0,0656347 + 0,0005849**LPV** + 0,0000881**LB** + 0,0001823**SB** + 0,0001018**LT** + 0,0001988**ST** + 0,0004701**MC**- 0,0003784**S**

c. HC= 0,0002574 + 0,0005117 **LPV** + 0,0001830 **LB** + 0,0001783 **SB** + 0,0002354 **LT** + 0,0002499 **ST** + 0,0002162 **MC** - 0,0000618**S**

Mean, standard deviation,and R square for Emission model for the open areacan be seen in Table I

TABLE I.

LINER REGRESSION PARAMETER (EMOA)

	Exhaust gas emission		
	NO_x	**CO**	**HC**
Mean	0,0682	2,93	1,4471
Standard Deviation	0,0315	1,0677	0,3789
R square	56,4%	73,3%	55.2%
F test	11,363	31,128	4,974

- Emission model for closed area(EMCA)
  This emission model is for roads in urban areas where air movement is not free to move because it is blocked by buildings on either side of the road. The result of multiple linear regression processing are as follows:

a. NO_x = 0,0134 + 0,000129 **LPV** + 0,000196 **LB** + 0,000166 **SB** + 0,000224 **LT** + 0,000172 **ST** + 0,000002 **MC** - 0,000133**S**

b. CO = 0,905109 + 0,003575 **LPV** + 0,001344 **LB** + 0,001450 **SB** + 0,001747 **LT** + 0,001206 **ST** + 0,002348 **MC**- 0,005307 **S**

c. HC = 0,003058 + 0,000844 **LPV** + 0,000127 **LB** + 0,000319 **SB** + 0,000131 **LT** + 0,000324 **ST** + 0,000321 **MC** - 0,006754 **S**

Mean, standard deviation,and R square for Emission model for the open areacan be seen in Table II

TABLE II.

LINER REGRESSION PARAMETER (EMCA)

	Exhaust gas emission		
	NO_x	**CO**	**HC**
Mean	0,28	19,87	2,64
Standard Deviation	0,056	1,044	0,347
R square	63,1%	55,2%	64,6%

- Emission model environmental road (EMER)
  This emission model is for roads in residential areas where air movement is not free to move because it is blocked by buildings on either side of the road. The result of multiple linear regression processing are as follows:

a. NO_x = 0,0131049 + 0,0000795 **LPV** +0,0001141 **SB** + 0,0001057 **ST** +0,0000015 **MC**

b. CO = 1,237390 + 0,0010674 **LPV** + 0,0002416 **SB** + 0,0003213 **ST** +0,0008630 **MC**

c. HC = 0,032980 + 0,0000308 **LPV** + 0,0000116 **SB** + 0,0000143 **ST** +0,0000118 **MC**

Mean, standard deviation,and R square for Emission model for the open areacan be seen in Table III

TABLE III

LINER REGRESSION PARAMETER (EMER)

	Exhaust gas emission		
	NO_x	**CO**	**HC**
Mean	0,0276	1,6697	0,1058
Standard Deviation	0,0166	0,4628	0,0637
R square	59,3%	62,3%	62,5%
F test	660,279	47,735	39587

B. Development of Road Network Database and Zone System

The data of the traffic that collected to obtain the data about the pattern and the size of trips in the study area by the reference to the Study on Implementation / Stages of Toll Road Network [14]. The development of a road condition network databaseincludes identifying the existing condition of the road network regarding the width and length of the road, geometry, speed at the condition of vehicle volume = 0 (*free flow speed*), the capacity of the road segments, along with its codification system (*node and centroid numbering or codification*). The level of resolution of the road network used is up to the function of the secondary collector road. The use of this level of resolution aims to accommodate the desire of the driver to determine the best route.

Furthermore, this road network data base is formed by SATURN format which is used as a simulation device in this study. The road network configuration modeled for this study is presented in Figure 2

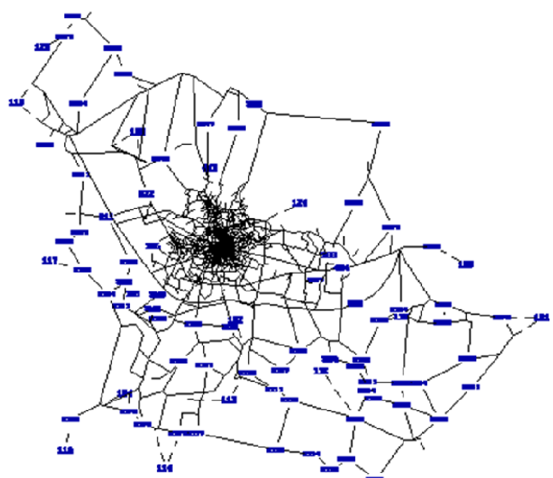


Fig 2. Bandung City Road Network Model

The area that is determined as the study area is all area that is considered to be affected by the inner-city highway plan in the city of. This study area is divided into several travel zones. For the modelling above, it is represented by 1 (one) centre zone (Centroid), which is connected to the road network through the centroid connector. In the road network modelling, there are 2 terms of traffic zones, namely:

a. External Zone, namely the traffic zones outside the cordon line.
b. Internal Zone, namely the traffic zones inside the cordon line.
c. The division of zones is taken based on the division of administrative area up to the sub-district and/or village level that is in the regency and city of Bandung according to the location of the zone. For the internal zone, the smallest aggregation zone is the village, while for the external zone the smallest aggregation is a combination of several village or sub-districts.

Furthermore, theOrigin-Destination Matrix isusedwhichisreadyto be chargedtotheroadnetwork so thatthepatternoftheroadisgenerated in the data processingprocess. Topredictthe future MAT, theFurnessmethodisused[12]. Theassumptionisthatthedistributionpattern in thestudyarea and its future influencing factor will be similar tothecurrentpattern and influencingfactors. Thus, theamountoftraveldemandthatisdistributedfrom a zonewill be more determinedbytheamountoftripgeneration and attractionproducedbyeachzone in thestudyarea.

C. Alternative Proposals for Pollution Rediction

The results of the prediction model that have been obtained, will be tested to analysis alternative ways to reduce air pollution in the city of Bandung.

There is two ways to reduce the level of air pollution, namely by reducing the number of vehicles and increasing the speed of the vehicle to a certain extent. However, in this study, it will be tested by increasing the speed. The speed increase is done by adding the road network and increasing the road network capacity. The main objective of this alternative is to improve the performance of the road network.

The performance of this road network will be characterized by increasing speed and reducing the number of vehicles passing. All of this will affect the size of air pollution that is produced. The load analysis on the road network with the help of the SATURN program package. The simulation result of the road network performance based on the above scenario will result in the current magnitude (emp/hr) and speed (Km/hr) at every sub-road segment. The data that is used is the result of a traffic survey at the time of emission measurement.

Alternative development to reduce air pollution from traffic activities to be analysis are:

1. *Do Nothing*,Means there is no intervention at all on the changes in the traffic system. Traffic will develop as it is without any meaningful regulation.

   The calculation results can be seen in Table IV.

TABLE IV.

DO-NOTHING CONDITION EMISSION LEVELS

No	Emission/ Type/ Category	Length of the road	
		Km	%
1	NO_x		
	Normal	217,47	61,02
	High	138,95	38,98
	Total	356,42	100,00
2	CO		
	Normal	353,18	99,09
	High	3,24	0,91
	Total	356,42	100,00
3	HC		
	Normal	30,15	8,46
	High	326,27	91,54
	Total	356,42	100,00

Based on the results of the calculation of pollution prediction, it was found that in most of the road segments (38,98 % or 138,95 km) in the city of Bandung the NO_x value was above the set threshold of 0,05 ppm. As for CO, almost all roads segment (99,09 % or 353,18 km) are still below the standard limit or less than 20 ppm. As for HC, almost every segment (91,54 % or 325,27 km) of the road have an HC level far above the quality standard or higher than 0,24 ppm

2. Freeway contructions. The operation of the freeway refers to the study of impementation strategy/stages of freeway network development.

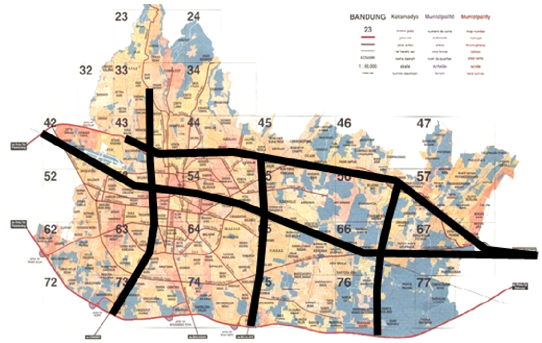


Fig3. Freeway development program plan within the Bandung city

In this scenario, it is assumed that every freeway network within the city of Bandung is operating properly. Every driver that will pass the freeway will be charged a tariff which is one component of the total cost of the trip. The conversion of the applicable toll rates into units of time is based on the assumption of the time value of the drivers used in the SATURN program. Furthermore, the time that is obtained will be added to the (fixed time) for the involved road segment of the freeway.

The development of the number of vehicles is left as the existing tendency. From the simulation, it can be seen that some of the traffic flows move to the freeway network resulting in the speed on the non-freeway network will also mostly increase.

The result of the calculation of the emission levels can be seen in Table V.

TABLEV.

EMISSION LEVELS OF INNER-CITY FREEWAY CONSTRUCTION

No	Emission/ Type/ Category	Length of the road	
		Km	%
1	NO_x		
	Normal	245,69	68,93
	High	110,73	31,07
	Total	356.42	100,00
2	CO		
	Normal	356,42	100,00
	High	0,00	0,00
	Total	356,42	100,00
3	HC		
	Normal	50,66	14,21
	High	305,76	85,79
	Total	356,42	100,00

Based on the calculation result of pollution prediction, it can be concluded that more than half (31,07 % or 110,73 km) of road segment in the city of Bandung the level of NO_x is above the set threshold of 0,05 ppm. For CO every road segment is still at the quality standard limit or less 20 ppm. As for HC, almost every segment (85,79 % or 305,76 km) of the road has an HC level far above the quality standard or more than 0.24 ppm. However, from the results obtained, compared to the do-nothing condition, the existence of the freeway can reduce the level of pollution.

3. Traffic Management, namely parking arrangement on the body of the road forVCR (*volume capacity ratio*) >0,8.
   This alternative is done by eliminating the side barrier that is caused by parking, street vendors, and others on road segment with VCR>0,8. The removal of the side barrier causes the road capacity to increase from before.
   The calculation result can be seen in Table VI.

TABLEVI

ON-STREET PARKING REMOVAL

No	Emission/ Type/ Category	Length of the road	
		Km	%
1	NO_x		
	Normal	222,04	62,30
	High	134,38	37,70
	Total	356,42	100,00
2	CO		
	Normal	355,92	99,86
	High	0,50	0,14
	Total	356,42	100,00
3	HC		
	Normal	36,93	10.36
	High	319,49	89.64
	Total	356,42	100.00

The simulation result shows that there is a change in traffic flow that brings effects on the speed of vehicles on a certain road segment. Most of the changes happened in the downtown area, as for those on the outskirts and the centre of the city the change were relatively less.

From the simulation results of network performance, by using the air pollution estimation model, the following conclusion is drawn; almost half (37,7 % or 134,38 km) of the road sections in the city of Bandung have the NO_x value above the set threshold of 0,05 ppm. For CO almost every road sections (99,86 or 355,92 km) are still at the quality standard limit or less than 20 ppm. As for HC, almost every road sections (89,64 % or 319,49 km) have an HC level above the quality standard or more than 0,24 ppm.

4. Combination of freeway operations and parking arrangements.
   An alternative by combining the construction of a freeway and the removal of On-street parking on the roads with VCR > 0,8
   The calculation can result can be seen in table VII.

TABLEVII.

COMBINATION OFFREEWAY OPERATION AND PARKINGARRANGEMENTS

No	Emission/ Type/ Category	Length of the road	
		Km	%
1	NO_x		
	Normal	250,16	70,19
	High	106,26	29,81
	Total	356,42	100,00
2	CO		
	Normal	356,42	100,00
	High	0,00	0,00
	Total	356,42	100,00
3	HC		
	Normal	61,67	17,30
	High	294,75	82,70
	Total	356,42	100,00

The simulation results show that some of the traffic flows move to the freeway network so that the speed at the non-freeway network mostly will also increase. However, the road segments that are close to the freeway access will get an increase in traffic volume.

From the simulation results of the network performance, by using an air pollution estimation model, the following conclusions are drawn; more than a quarter (29,81 % or 106,26 km) of the road segments in the city of Bandung have the NO_x level above the set threshold 0,05 ppm. For CO, all roads are still at the quality standard or less than 20 ppm. As for HC almost all (82,7 % or 294,75 km) of the road segments have the level of HC far above the quality standard or more than 24 ppm.

The recapitulation of the average predicted emission levels in the city of Bandung can be seen in Table VIII

TABLE VIII

AVERAGE EMISSION LEVELS ON THE ROAD SIDE IN THE CITY OF BANDUNG

No	Alternative	Emission type		
		NO_x	CO	HC
1	Do nothing1)	0.053	2,324	1,030
2	Freeway constructionl2)	0,045	1,971	0,854
3	No parking on the street with VCR> 0,83	0,052	2,270	1,016
4	Freeway + No parking on the street with VCR> 0,84)	0,043	1,919	0,834

IV. RESULTS AND DISCUSSION

Based on the evaluation results, it can be explained that construction of freeway and removing parking can reduce air pollution caused by traffic activities. The parking exemption scenario does not provide a significant improvement to air pollution.

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