

IMPROVEMENT OF PUBLIC TRANSPORT TO MINIMIZE AIR POLLUTION IN URBAN SPRAWL

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* Corresponding Author, Received: 15 Dec. 2018, Revised: 17 Jan. 2019, Accepted: 08 Feb. 2019

ABSTRACT: The phenomenon of urban sprawl has been a big issue in big cities of Indonesia since the beginning of the 20th century which has effects on increasing traffic congestion, demand for mobility and air pollution. Air pollution from transportation emission especially in urban areas produces most of the air pollutants and reduces air quality on road corridor. The present study examines the effects due to the improvement of public transport, monorail system in order to minimize air pollution concentration and cost. Air pollution is exhausted from an increase in traffic volume with rising mobility from suburban. Current research is insufficient to reveal the effects of urban sprawl on the cost build-up of air pollution parameters. This study examines to what extent an improvement of the monorail system is able to increase accessibility, reduce air pollution as well as air pollution cost due to housing development in the suburbs of Surabaya City, Indonesia. Comparative analysis was conducted to assess the influences of the design of the monorail system and existing public transport on differences in air pollution cost. The results show that the design of the monorail system has a significant effect on the reduction of air pollution concentration and cost compared to the existing condition. Another result revealed the change of air quality on different road corridor. The reduction of light vehicles due to the design of monorail shows better accessibility and air quality of residents in the western regions of Surabaya City as a case study area in the morning peak hour.

Keywords: Urban sprawl, Air quality, Emission parameter, Monorail system, Transport mode choice.

1. INTRODUCTION

Urban development with the phenomenon of urban sprawl occurs in many cities the world-wide. This phenomenon influences living condition due to the change of the complex pattern of land use, transportation pattern, and socio-economic development. Urban sprawl is a pattern of land use in an urban area that illustrates low levels of some dimensions such as density, continuity, concentration, compactness, centrality, diversity and proximity [1]. Duncan [2] informed that urban sprawl characteristics are a rapid expansion of residential area at the outskirts of the town, causing a spatial mismatch of jobs and residential dwellings, further producing an imbalance in transport system with high dependence on the automobile. The increase of personal mobility and automobile dependence, associated with health hazards such as air pollution, vehicles accidents, and pedestrian injuries and fatalities are some effects of urban sprawl [3].

A strategy to take into consideration of sustainable transport, including improvement of public transport, the legislative system, fuel quality, traffic management, vehicle condition, health effects, and public participation, were held in reviewing transport issues in Georgia [4]. The

impacts of improvement of transport technology in the reduction of vehicles pollution could be integrated by “intelligent” transport management system. The integrated system was designed by assessing the real-time traffic-related air pollution in Beijing [5]. Recommendations for further research are to understand the mechanisms leading to air pollution impacts from transport emissions, to reduce the uncertainty in our ability to quantify the relationships between all emissions and all impacts, especially for NO₂ and particles.

Transport strategies based on travel behaviors were intended to change mode choice, as well as influencing energy consumption and pollution emission. Coefficients of energy consumption and emissions were influenced by different sizes and ages of engines [6;7]. These studies designed an integrated model for cars and motorcycles by assessing choice behavior related to ownership, type, and usage. They recommended the reduction of air pollution by manipulating the variables, such as reducing ownership and user costs and improving transit services. Other study informed that the vehicle fleet was the largest single source of global air pollution. The fastest growing source of carbon dioxide emissions was exhausted from road traffic, having huge environmental problems with US\$93 billion worth of damage to health and

environmental quality each year in the US [8].

Transport demand management (TDM) as one of the transport strategies in order to reduce air pollution from motor vehicles has been conducted in some studies. Environmental inequality occurred in Leeds, the UK [9]. This condition was reduced by an analysis of transport strategies with natural fleet renewal and road-user charges. Another transport strategy has been conducted by two demand management measures, i.e. road pricing and the vehicle quota scheme (VQS), revealed as effective instrumental in controlling both congestion and automobile ownership [10].

The phenomenon of urban sprawl has occurred in most Indonesian cities since the beginning of the 20th century. This phenomenon was identified by a pattern of urban development with increasing settlement growth in the suburbs. The phenomenon also occurs in the city of Surabaya as a case study area, are characterized by an estimated 38% of the population lives in the suburbs [11]; most of them commute every day to work in the central urban area. This condition has significant consequences for mobility, increasing traffic congestion due to growing the numbers of motorcycles and private cars. Current mode choice by residents in the city of Surabaya: private car (30%), motorcycle (62%), and other vehicle types (8%, mostly minibusses). This condition results in a significant increase of time, cost and productivity losses, and an increase in air pollution. A transport strategy by improving public transport is expected to change modal split from private vehicles to public transport, to reduce the amount of air pollution from motorized vehicles, as well to lessen air pollution cost imposed to road users. Currently, private vehicles are a substantial source of environmental pollution and traffic congestion in urban areas.

Insufficient studies consider on the improvement of public transport related minimizing the impacts of the phenomenon of urban sprawl and opportunity to reduce air pollution concentration and cost. Therefore, this research has attention on the improvement of public transport, i.e. monorail system related to impact assessment, particularly air pollution concentration in the existing condition and the condition with a design of the monorail system. Assessment of air pollution cost imposed on road users will be conducted in this research as a consequence from the expansion of housing development in the western regions of the city of Surabaya.

This research is based on an extensive survey to estimate the mode choice of residents due to the design of the monorail system. The effectiveness of the design of monorail system in order to minimize the phenomenon of urban

sprawl and to assist in policy making with regard to addressing air pollution as part of the control of urban sprawl are the goals of the research.

The structures of this paper are as follows: data collection and methodology are elaborated in Section "Methods" consisting of background information on the existing public transport and improvement of public transport in the city of Surabaya. Section "Results" details a simulation analysis of transport, measurement of air pollution values, procedure to assess the change of transport modal split and air pollution cost and concentration. This section discusses the estimation of emission parameters and compares the impacts of each emission parameter as well as air pollution cost for each parameter. Section "Conclusions and recommendations" presents conclusions and recommendations for further research.

2. METHODS

The case study area is Surabaya City, the second biggest city in Indonesia and the capital city of East Java Province, comprising 31 districts and 163 villages (Fig.1) with the total area of 327 km² and population of 2,765,908 [11]. The population density in 2011 was estimated more than 11,000 people per km². A major problem related to settlement development occurs in the central urban area. The problem is several informal settlement areas are built, having a high density (45% built-up area). This situation is contrary to suburban, low density.

Primary data was collected for each village (called *desa*) within the urbanized area of Surabaya City by distributing questionnaires to 163 villages (approximately 554 respondents). The questions consisted of three parts: socio-economic background, trip characteristic, transport mode choice. Other data i.e. traffic counting, speed study, and road geometric inventory also were investigated on the several road-sections of Surabaya City (31 roads). Vehicle emission values were determined based on traffic volume and speed. Secondary data was collected from the Department of the Environment.

The existing public transport network comprises minibus/paratransit and busses. There are 68 available paratransit routes and 22 bus routes. The Local Government has planned to improve transport infrastructures such as monorail and tram system as seen in Fig.2. Monorail accommodates the passengers in the western and eastern regions. This research will assess the effect of monorail operation on the decrease of air pollution concentration and cost.

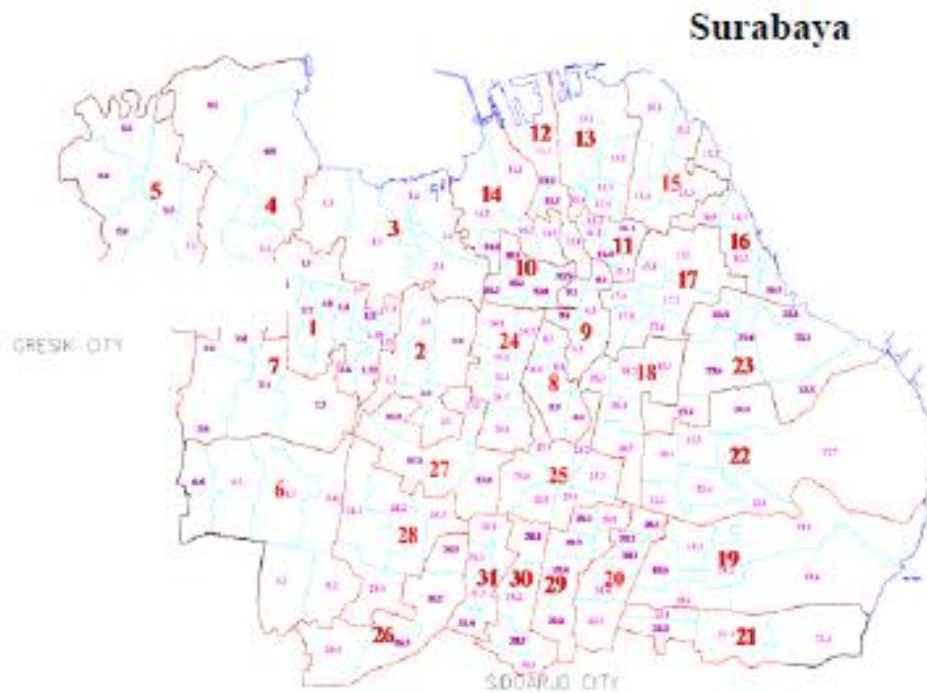


Fig.1 The study area (Surabaya City), located in East Java Province, Indonesia

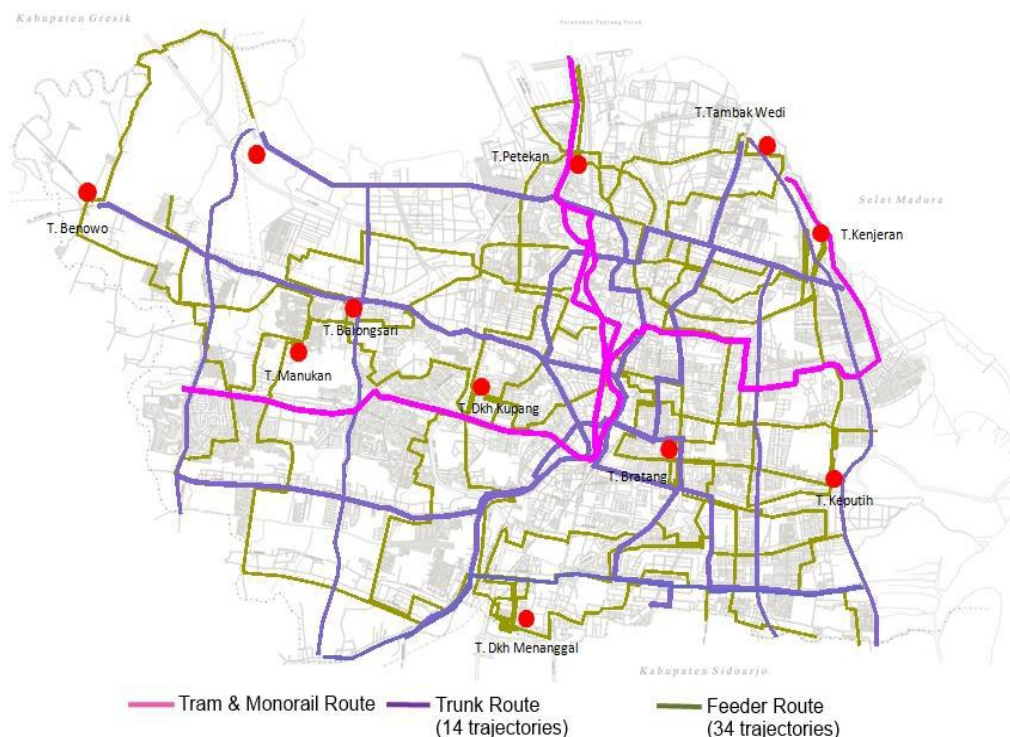


Fig. 2 The monorail routes

Fig. 3 informs the research framework, consisting of the background condition of the public transport system, further plan of public transport development, the expectation in order to reduce the use of private vehicles and air pollution and to increase the benefits received from the improvement of public transport.

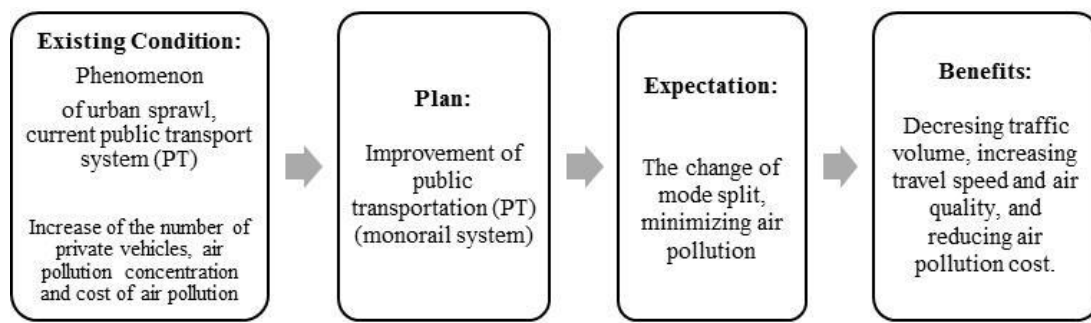


Fig. 3 The research framework

2.1 Planning Monorail System

The existing public transport comprises minibuses (paratransit) with 68 routes and buses in 22 available routes (minibus accommodates 8–12 passengers, while bus has 50–55 seats). The frequency of minibuses and buses are approximately 20–25 veh./h and 5–6 veh./h respectively. Each region of the city is served by approximately 26 minibus routes, except the southern regions of the city, which is accommodated by 10 minibus routes. The current performance of public transport and monorail systems planned, such as capacity, quality, and efficiency were investigated by an onboard survey.

A monorail system is planned in order to decrease the amount of traffic congestion and to provide the alternative option for public transport which is safe, comfortable and scheduled [12]. The properties of the proposed monorail system are: a ticket price of approximately \$0.82, stop spacing of 0.5–2 km, seat capacity of 177 seats. The plan of the monorail system is expected to encourage the users of cars and motorcycles to shift their transport mode.

2.2 Assessment of Emission Load

The assessment of emission load was conducted in two conditions, i.e. the current public transport condition and the design of the monorail system.

The analysis of the motorized vehicle emissions was classified based on vehicle types and air pollutant parameters. Subsequently, the values of a pollutant can be calculated based on traffic volume and traffic composition [13], as follows:

$$\text{Air pollutant (gr)} = \text{traffic flow of each vehicle class (veh.)} \times \text{emission value for each parameter for each type of vehicles (g/veh.mile)} \times \text{road length mile} \quad (1)$$

Unit emission loads (g/veh. km) are various for different modes and different speeds. Relevant

emission parameters are CO, CO₂, NO_x, SO_x, and HC. The average vehicle occupancy is 3 passengers, 8 passengers, 30 passengers, 55 passengers, 2 passengers, and 2 passengers for automobiles/ private cars, minibuses, medium buses, large buses, trucks, and motorcycles accommodate respectively. The standard value of motorized vehicle emissions is shown in Table 1.

Table 1. The standard value of motorized vehicle emissions in Peak Hours (gr/pass. mile)

Mode	HC	CO	NO _x	SO _x
Automobile	2.42	18.13	1.47	0.05
Car Pool	0.88	6.55	0.53	0.02
Diesel Bus (medium or large bus, truck)	0.06	0.81	0.36	0.05

Source:[13] .

2.3 Air Pollution Cost

Air pollution cost is calculated by comparing the existing condition and design of the monorail system condition. According to [14], air pollution cost for the urban road is calculated by using the following:

$$\text{Air pollution cost (\$)} = \text{air pollution cost constant (\$/veh. mile)} \times \text{peak hour traffic volume (veh.)} \times \text{road length (mile)} \quad (2)$$

The air pollution cost constant is shown in Table 2.

Table 2 Air pollution cost content (\\$/veh. mile)

HC	CO	NO _x	SO _x
7.20	12	0.60 – 8.40	0.01 – 0.36

Source: [13].

Note: the value will convert from USD into IDR

3. RESULTS

This section explains the assessment of modal split on existing condition and improvement of the public transport situation, emission parameter concentration and cost imposed on road users.

3.1 Modal Split

The change of modal split for each vehicle class based on the existing condition and design of the monorail system condition is conducted by comparative analysis. Three cases are simulated by OmniTRANS model, comprising an estimation of transport model parameters for each condition and emission parameters. The simulation model has been done in previous research [15].

The following the results of previous research [15] as follows:

- The design of monorail systems (C3) encourages the use of public transport up to 37% from the current trend.
- The number of cyclists in C3 also increases six times compared to the current trend 2030. This finding means that this case can influence the load of traffic flow and air quality on the road corridors.

The C3 should be carried out with sufficient PT in order to take over the users from other modes. The increase of passengers in the monorail system reduces the use of private motorized vehicles, is expected to decline emission parameters.

3.2 Value of Air Pollution Parameter

Three cases are proposed in order to understand the reduction of traffic volume because some private vehicle users change to use the monorail system.

Loads of emissions based on specific weighted emission parameters regarding air quality for the city of Surabaya roads are required. The weighted emission parameters refer to air quality data containing the weighted emission values per vehicle kilometer (gr/veh.-km) and depend on average speed standard of each vehicle class for each road type (motorway, urban, and rural). The weighted parameters, such as CO, NO_x, SO_x, and HC are estimated. The values were analyzed for the current base 2010 according to [14], the procedure for determining air pollutants at a micro level due to traffic, as explained as follows:

$$qCO = 867.92 \cdot U_v^{-0.8648} \quad (3)$$

$$qNO_x = 0.0005 \cdot U_v^2 - 0.0656 \cdot U_v + 3.6586 \quad (4)$$

where U_v is average speed standard for each vehicle class for each road type in km/hr.

Improvement of the PT system with the design of monorail system (C3) has an effect on decreasing the load of private vehicles (cars and motorcycles), as reflected in 30% (cars) and 50% (motorcycles) reducing CO emission compared to C2 as explained in Table 3.

Table 3 Weight emission for CO for each case

Transport mode	Concentration of CO		
	Case		
	(C1) Current Base	(C2) Current trend	(C3) Monorail system
Cars	22.8	65.3	21.2
Motorcycles	53.4	124	60.3
PT	84.3	45.1	20
Total (all vehicles)	160.5	234.4	101.5

The emission load for each parameter has been computed by simulation of the OmniTRANS model, based on the simulated flows on the transport network, for various cases, as explained in the next section.

3.3 Emission Parameter for Different Road Corridor

From the analysis, the operation of monorail in the western part of Surabaya areas can reduce the air pollutant concentration. A great benefit for the community due to an increase in air quality and air pollution cost is obtained. Emission parameter and cost is determined on different road corridor, i.e. Lontar St. with residential areas and Sungkono St. as business areas. A significant difference in emission concentration and cost is described in Table 4. The value of air pollutant can be analyzed using the Equation (1) and Table 1. Lontar St. and Sungkono St. are both 2.3 km length (1.43 miles).

From the analysis, it can be concluded that monorail operation can reduce the amount of CO pollutant due to the decrease of the user of a motorized vehicle on the roads and increase of monorail user.

Table 4 explains that CO is the major component of the motorized vehicle emission. Thus, motorcycle gives the largest contribution to air pollution, followed by automobile. The amount of air pollution is influenced by the characteristics of the vehicle engine.

The air pollution costs imposed to users on each street can be calculated after the value of air pollutant on Lontar St. and Sungkono St. were identified, using the Equation (2), and converted into IDR (1 USD = 13,500 IDR). The results of air pollution cost are explained in Table 5.

From the results of the change of mode split, the traffic volume reduction can be obtained as informed in previous research [15], thus the air pollutant reduction with three scenarios can be calculated using Equation 1, as seen in Table 6.

Table 4 The value of emission parameter on Lontar St.(gr) and Sungkono St

Vehicle Type	Traffic Vol. (veh./h)	HC	CO	NO _x	SO ₂
Automobile	2,787	9,639	72,213	5,855	199
Car Pool	264	332	2,471	200	8
Diesel Bus ^{*)}	108	9	125	56	8
Motorcycle	6,638	47,434	113,841		
Total	9,689	57,414	188,650	6,111	215
Automobile	4,108	42,623	319,323	25,891	881
Car Pool	78	1,177	8,762	709	27
Diesel Bus ^{*)}	18	5	74	33	5
Motorcycle	9,607	137,299	329,518	-	-
Total	13,811	181,104	657,677	26,633	913

Table 5 Prediction of air pollution cost on Lontar St. and Sungkono St. (IDR)

Vehicle Type	Traffic Vol. (veh./h)	HC	CO	NO _x	SO ₂
Automobile	2,787	92,821,262	154,702,104	58,013,289	2,449,450
Car Pool	264	2,198,135	3,663,559	1,373,835	58,006
Diesel Bus ^{*)}	108	3,896,695	6,494,491	2,435,434	102,829
Motorcycle	6,638	331,618,697	552,697,829	207,261,686	8,751,049
Total	9,689				1,428,538,351
Automobile	4,108	410,451,825	684,086,376	256,532,391	10,831,368
Car Pool	78	7,793,389	12,988,982	4,870,868	205,659
Diesel Bus ^{*)}	18	1,798,474	2,997,457	1,124,046	47,460
Motorcycle	9,607	959,885,756	1,599,809,594	599,928,598	25,330,319
Total	13,811				4,578,682,562

Table 6. Prediction of Air Pollution on Lontar St. and Sungkono St. with Monorail Operation (gr)

Scenario	Mode	Peak Hour (Average of Morning, Noon and Afternoon)							
		Lontar St.				Sungkono St.			
		HC	CO	NO _x	SO _x	HC	CO	NO _x	SO _x
I	Automobile	1,570	11,763	954	33	8007	59,983	4,864	165
	Car Pool	42	311	25	1	221	1,659	134	4
	Diesel Bus	221	1,658	134	5	266	1,995	162	6
	Motorcycle	7,191	53,877	4,369	149	21,524	161,25	13,074	445
II	Automobile	4,628	34,668	2,811	95	23,581	176,66	14,324	487
	Car Pool	194	1,451	118	4	983	7,359	597	20
	Diesel Bus	230	1,727	140	5	355	2,660	215	7
	Motorcycle	10,247	76,765	6,224	212	30,673	229,79	18,632	634
III	Automobile	6,637	49,722	4,032	137	33,814	253,33	20,540	699
	Car Pool	443	3,317	269	9	2,380	17,827	1,445	49
	Diesel Bus	248	1857	150	5	522	3,912	317	11
	Motorcycle	13,124	98,322	7,972	271	39,282	294,29	23,862	812

Three scenarios of monorail systems with the change of ticket price are set in order to know the different concentration of air pollution parameter for each vehicle type. The first scenario is a condition with monorail ticket 2,500 IDR less cheap than the existing public transport. The second scenario is a condition which is monorail ticket similar to the existing public transport. The third scenario is done by monorail ticket 2,500 IDR more expensive than the existing public transport.

Scenario 1 is the condition with monorail ticket is cheaper than the existing modes, the monorail passengers increase, thus the amount of emission

is the lowest concentration. Meanwhile, scenario 3 is the highest emission concentration for each parameter due to less reduction of use of private vehicles. Scenario 3 has the effect on reduction of 26% HC, 23% CO, and 24% NOx. Scenario 2 has impacts on reduction of HC and CO up to 44% and NOx up to 47%. Meanwhile, scenario 1 has significant decreasing HC up to 66%, CO up to 71%, and NOx up to 82%.

The difference of cost due to CO emission between a road with business places and with residential areas in road corridors is approximately 3 billion IDR as seen in Table 7.

Table 7. Prediction of Air Pollution on Lontar St. and Sungkono St. with Monorail Operation (IDR)

Vehicle Type	Peak Hour (Average of Morning, Noon and Afternoon)			
	CO	Total	CO	Total
Private car	106,520,753		542,706,304	
Public transit	1,776,271		9,547,457	
Bus	-	855,111,763	388,559	2,994,659,300
Truck	5,273,305		5,883,898	
Motorcycle	315,954,207		945,697,792	

There was a significant reduction between the existing condition of air pollution cost (with no monorail) and the condition with the monorail. By applying Scenario 3, the community can save about 26% of the air pollution cost, while applying Scenario 2 can save 44%. Scenario 1 can reduce air pollution cost from 5.19 billion IDR to 1.71 billion IDR, or save about 67%. So, it can be concluded that the investment of monorail will be delivered a significant benefit in the savings of air pollution cost as illustrated in Fig. 4.

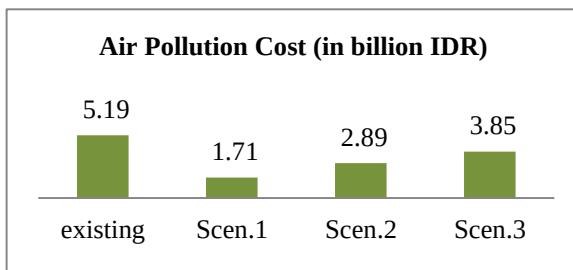


Fig. 4 Total of Air Pollution Cost on Lontar St. and Sungkono St. due to Monorail Operation

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The design of the monorail system is necessary to address the mobility and emission problems in fast-growing urban areas and the associated effects of urban sprawl. Consideration of air quality, i.e. HC, CO, NOx, SOx concentration is an important factor in urban transport planning with analysis of three cases.

From three cases analysis, the case (C3) with improved PT systems, monorail system was characterized by the smallest emissions rates of each parameter. This case (C3) also can reduce the use of private vehicles (cars and motorcycles) which influences on reducing 30-50% of emission parameter compared to the existing public transport (PT).

Three scenarios of monorail ticket prices inform the different concentration of each air pollution parameter. Scenario 1 of monorail operation will reduce emission by 66% (HC), 71% (CO), and 82% (NOx) on both streets. Thus the air pollution cost will decline by 67%. Scenario 2 can decrease 44% for HC and CO and 47% for NOx, and the total air pollution cost of both streets on peak time lessens approximately 44%. Scenario 3

only reduces 26% HC, 23% CO, and 24% NO_x, and the total air pollution cost can be saved 26% for both streets on the peak is saved by 26%.

Road corridors as business places have the highest air pollutant cost. Three billion IDR is CO emission cost due to the difference of road corridors, i.e. business places and with residential areas.

4.2 Recommendations

The further research for air pollutant cost assessment should be conducted in order to estimate the air pollutant suitable with the Indonesian road environment and the change of monorail tariff.

An integration of spatial-transport strategies as well an environmental assessment would provide more sophisticated and long-term advantages when designing improvements in public transport systems related to housing planning. The integrated approach should also be based on residents' preferences as regards the impact of such new developments.

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