Reduction of CO, NOx and SO2 emissions from the transfer of private vehicles to public transportation: a case study of Surabaya

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Abstract. Surabaya as the center of economic activities in eastern Indonesia suffers significant growth of vehicles annually. This increase has tremendous impact towards the environment, including air pollution, mainly comes from private vehicle users. Therefore, users of private vehicles should be limited in order maintain air quality. The use of this private vehicle can be limited by offering them adequate public transportation. This study aims to investigate the reduction of pollutants, namely CO, NO2, and SO2 emissions, which is obtained from the shift of private vehicles to public transportation, in this case, buses and paratransit. Results show that there are 77% of private vehicle users who are willing to shift to public transportation if the facilities of these modes are significantly improved. The reduction of CO, NOx, and SO2 every year reach up to 385,264.894 tons of CO/year; 12,292.303 tons NOx/year, and 365.689 tons SO2/year, respectively. However, due to the limited number of buses and paratransit, the public transportation may accommodate as many as 10% from the private vehicle users. This shows immediate action from the government is required not only to improve the quality but also quantity of public transport modes.

Keywords: emission reduction, air pollutants, public transportation

1. Introduction
Transportation has been the main problem causing air pollution in Western Europe and North America. Emissions from land, air and sea transport are the causes of acid deposition, stratospheric ozone depletion and climate change. Emissions from vehicles cause concerns about urban air quality, human health, and tropospheric ozone production. However, emissions from traffic have now been reduced in European countries with the help of the latest technology. On the other hand, in developing countries there are still many private vehicle users which cause high air pollution [1]. Pollutants coming from transport, namely carbon monoxide (CO) and nitrogen dioxide (NO2), have shown significant increase annually.

CO is the result of incomplete combustion of fossil fuels and thus emitted from motorized vehicles, and biomass combustion, especially burning of plant waste. Despite CO can be used to identify atmospheric pollution from regional transportation [2], it has impact on climate change and human
health. The large variation in emission factors causes uncertainty in CO\textsubscript{2} and CO inventories, especially in developing countries [3].

In Central Java, Semarang is currently a center of economic development in the industrial, commercial, service and education sectors. The impact of this development is air pollution. This air pollution then causes acid rain in Semarang due to excessive SO\textsubscript{2}. In addition, SO\textsubscript{2} emissions generated from such stationary sources and transportation had increased of 1.1 - 1.9% [4]. Cars with diesel fuels exclude NOx emissions compared to other fueled vehicles. More than 10,000 premature deaths from PM\textsubscript{2.5} in adults over 30 years old in Norway and Switzerland in 2013 can also caused by NOx emissions from diesel-fueled cars. These deaths can be reduced by almost 50% when diesel usage can be reduced [5]. In Ireland, land vehicles are a major supplier of NOx emissions and greenhouse gas emissions. Nearly 50% of total NOx emissions are generated from vehicles (2009). Reducing emissions from transportation activities is currently being done. This emission reduction is carried out by carrying out various actions and policies. If the purchase of diesel fuel vehicles continues to increase, the NOx emissions produced will increase by 24% by 2020 [6].

Public vehicles and cycling and walking are ways that can be used as an alternative to travel in addition to using a private vehicle. The existence of good service and frequency from public transport is an important point that must be provided. By using public services such as accessibility to attract public vehicles to use public transportation. Points needed to access public facilities, public facilities and security in mobility [7].

The problem of the lack of public transportation causes high car ownership in Malaysia. When the number of private vehicles increases, it can cause congestion problems that are quite severe. The congestion can have an impact on wasted time on the road and high pollution caused by the large number of private vehicles. From this, with the increase in public transportation, it is expected to reduce congestion [8].

Surabaya is a city which from year to year has an increasing economic growth. This also resulted in increased use of motor vehicles by the people of Indonesia. Human activity is also increasingly high lately causing high mobility as well. Congestion becomes unavoidable as human activity increases. These activities require a mode of transportation to support the smoothness of humans in facilitating its activities. Given the high emission from transportation sector in Surabaya City, it is necessary to analyze the emission change from transportation sector by transfer from private vehicle to public transportation.

Effort to cut fuel subsidies could have an impact on improving mass transportation infrastructure. The increase can be done in the form of repair and addition of fleet for public transportation. The existence of the policy of transport mode transportation from private vehicles to public transportation can also overcome congestion and reduce CO\textsubscript{2} emissions, especially in metropolitan cities such as Jakarta, Surabaya, Bandung and other cities in Indonesia. This mass transportation policy is also part of the implementation of mitigation of greenhouse gas emissions from the transportation sector [9].

2. Methods
The research was carried out by collecting primary and secondary data. The method to be used in primary data collection is a survey in the form of direct interviews using questionnaires to the public and related stakeholders. The survey was conducted to collect information regarding the number of vehicle users who are interested in switching to public transportation. The study was conducted to analyze the percentage of the number of vehicle users in the city of Surabaya who have an interest in switching from private vehicles to public transportation. The survey method used is by distributing questionnaires to all respondents with a random sample method, then the respondent fills in the answers and the questionnaire maker will collect and record the answers. All questionnaires that have been completed and returned are then processed. The purpose of this stage is to simplify and tabulate data. Whereas in calculating the amount of CO, NOx and SO\textsubscript{2} emissions before the transfer of transportation mode is calculated by the formula for the amount of emissions based on the Minister of Environment Regulation No. 12 of 2010 with the Tier 2 method, as follows:
\[ E = \sum_{b=1}^{n,m} (VKT_{b,c} \times EF_{b,c} \times 10^{-6}) \] 

Where \( E \) is the total CO, NO\(_x\), or SO\(_2\) emissions examined (ton/year), and \( EF \) represents the emissions factor (g/km). Emissions factors are based on categories of vehicles and fuels, according to the regulation where index \( b \) is category vehicle (e.g., sedan, bus, truck) using fuel type \( c \) (e.g., solar, gasoline). The following is the EF of each vehicle:

| Table 1. Emission Factor of each vehicle |
|----------------------------------------|
| Category          | CO (g/km) | NO\(_x\) (g/km) | SO\(_2\) (g/km) |
| Motorcycle        | 14        | 0.29             | 0.008            |
| Car (Gasoline)    | 40        | 2                | 0.026            |
| Car (Solar)       | 2.8       | 3.5              | 0.44             |

Source: Minister of Environment Regulation No. 12 of 2010 with the Tier 2 method

Total VKT (Vehicle Km Traveled) was calculated from the average VKT for motorcycles, gasoline-fueled cars, and solar-fueled cars based on calculation on fuel consumption per year and fuel economy obtained from all respondents. We then averaged overall VKT.

Reduction of pollutants will succeed if it has sufficient support from people. We conduct survey to capture factors that may affect them to shift to bus, paratransit, and monorail-tram. We provide them in total eleven (11) external (e.g., congestion, more stress if driving using private vehicle) and internal variables (e.g., air conditioner). Each user may select more than one (1) option for each public transport mode.

3. Results and Discussion

3.1. Emissions (CO, NO\(_x\), SO\(_2\)) Reduction

As other cities in developing countries, vehicle ownership is dominated by motorcycle. In Surabaya the number of motorcycle reaches 2,081,449 units. The number of cars (gasoline) as many as 372,080 units and the number of cars (solar) as much as 38,780 units. Given the VKT for motorcycle, gasoline and diesel car which are 12,204.6 km/year, 9,646 km/year, and 10,453.99 km/year, respectively, we can calculate emission by using formula (1) and emission factor in accordance with Table 1. The emission of CO, NO\(_x\) and SO\(_2\) emission of motorcycle, car (gasoline), and car (solar) are shown in the Table 2 below:

| Table 2. Initial emissions from private vehicles (ton/year) |
|-----------------------------------------------------------|
| Emission | Motorcycle | Car (gasoline) | Car (diesel) | Total          |
|----------|------------|----------------|--------------|----------------|
| CO       | 355,645.535| 143,563.347    | 1,135.136    | 500,344.018    |
| NO\(_x\) | 7,366.943  | 7,178.167      | 1,418.92     | 15,964.03      |
| SO\(_2\) | 203.226    | 93.316         | 178.379      | 474.921        |

From the interview, it was found that 77% of motorcycle, car (gasoline) and car (diesel) users were willing to shift to public transportation if public transportation (bus, paratransit and monorail-tram) improves. There were at least 77% of respondents stated their interest to shift. Based on initial emission and potential shift from private vehicle users, the reduction of CO, NO\(_x\) and SO\(_2\) would be 385,264.894; 12,292.303; and 365,689 tons/year, respectively. The numbers are big and significant that they won’t allow us to overlook how importance this shift is.
Figure 1. Percentage of private vehicle users who are willing to shift to public transportation if improvements are made.

The number of motorcycle users is 2,081,449 people. Car users (gasoline) are 372,080 people. Users of cars (diesel) are 38,780 people. So that the total number of private vehicle users is 2,492,309 people. If public transportation is improved, 77% of the public will shift to public transportation, in this case bus, paratransit and Monorail-tram. Private vehicle users who shift to public vehicles amounted to 1,919,078 people in total. In the following scenario, we calculate whether the current unit of public transport that consist of bus and paratransit is sufficient to accommodate all these users. Otherwise, the remaining users who cannot be accommodated by public transport will remain using their private vehicle, which means the total reduction will reduce. In addition, we also measure emission that come from paratransits and buses. The emission calculation of Monorail-tram is excluded since we use assumption that the system will use electricity, thus no emission will be generated.

Surabaya served by 426 city bus fleets with capacity of 50 people and by 5,253 paratransit fleets with capacity of 12 people [10]. The headway is 10 minutes. The operating time of the bus and angkot is 17 hours (1,020 minutes), starting at 05.00-22.00. We use these data to estimate the number of private vehicles that can be accommodated by public transport with current units.

3.1.1. Paratransit.
There are 5,253 fleets and a total of 67 routes so each route served by 78 fleets. The headway for paratransit is 10 minutes and the operating time is 17 hours, therefore are 102 trips per day. Each paratransit fleet makes 2 trips per day and in one trip we assume each paratransit can carry as many as 30 people, in total with up and down passengers, around 60 passengers carry by fleet everyday. In total, paratransit can carry as many as 315,180 people daily. If it is assumed that 50% of the number are already permanent users whom have been using paratransit everyday, so the number of private vehicle users who shift to public vehicles that can be accommodated is as many as 157,590 people.

3.1.2. Bus.
There are 426 and a total of 19 routes, each route served by 22 fleets. The headway for this bus is 10 minutes and the operating time is 17 hours. So there are 102 trips per day. Each paratransit fleet can do 5 trips per day and in one trip can carry as many as 30 people. Thus, every day one fleet can carry 150 people. The total of bus can carry as many as 63,900 people daily. It is assumed that 50% are permanent users of bus, so the number of private vehicle users who shift to public vehicles that can be accommodated is as many as 31,950 people.

Private vehicle users who can be transported by paratransit and bus are 189,540 (10%) of the total private vehicle users who will shift to public transportation. This is small portion of whole users which potentially shift to public modes. In this case, additional fleets of buses and paratransit are needed with improved facilities and systems.
3.2. Factors that Affect People Choose Public Transport

Public transportation in urban areas has an important role in the economic sector because it supports community activities. Public transportation is chosen by the middle to lower class. The existence of a good, planned, and coordinated public transportation system can improve effectiveness and efficiency in urban transportation systems. Things that can do to improve public transportation services is by reforming public transportation [11]. At this time, most of Surabaya residents still use private vehicles as their daily transportation. This can be seen from the large number of motorcycles and cars in Surabaya. The improvement of public transportation is expected to provide reliable and affordable services for all people. In addition, in the long run, public transportation is also expected to reduce the lifestyle of people who currently still use private vehicles. The existence of this public transportation has a purpose to provide good and feasible services to the community. This good and feasible service means that the service is comfortable, safe, affordable, and fast. To determine the choice of this type of transportation there are number of considerations, such as travel destinations, distance and travel time, costs and comfort [12]. The existence of public transportation can also reduce traffic volume. This can happen because transportation is more flexible and can accommodate more people. The cost of using public transportation can be lower than using a private vehicle because the cost is charged to more people [13]. There are factors that can influence people to shift to public transportation. These factors include traffic congestion, parking costs at destination, parking availability at destination, petrol cost, unfamiliarity routes, stress of driving, more practical, more affordable, certainty of schedule, more comfortable, there is air conditioning.

3.2.1. Bus.

Problems regarding public transportation, especially buses are currently a matter of comfort. In Surabaya, there are still many city buses that are not feasible to operate. Not as good as the bus can be seen from the rigid passenger seat, there are no AC, and when in the rain the bus also leaked [14]. The number of bus shortages at this time causes people to be reluctant to shift using buses. However, if there are improvements of bus facilities, there were 52 people from overall respondents chose the bus as public transportation to be used.

From the survey results (Figure 2) the most influencing factor for choosing buses as their daily transportation is traffic congestion (85%) and petrol cost (85%). Congestion occurs every day and it causes a lot of harm to the community such as the amount of time wasted on the streets and wasteful fuel. In addition, congestion can cause stress and emotion so that it affects work productivity. Congestion can also cause high air pollution because the engine cannot operate to the maximum which causes combustion to last longer. Long burning produces carbon dioxide. These two external factors also imply that the more congested the road is and the more expensive the fuel is, the more likely people will shift to bus.

Other factors that also affected were more practical (77%), more affordable (73%), parking availability at destination (73%), and parking cost at destination (71%). The “practical” variable is quite a lot chosen because it is possible because the bus stop is closer to the place of residence so that it is easier to reach. Besides that, more affordable prices are quite important because public transportation is indeed to facilitate all people. The factors of parking availability at destination and parking cost at destination are also quite widely chosen because currently the parking lot is often full because of the large number of people who use private vehicles and also now parking rates continue to increase.

3.2.2. Paratransit.

There are various problems related to social issues in the community regarding paratransit. Poor services such as lack of certainty of schedule, non-permanent tariffs and quite a lot of criminal cases that occur in paratransit. In addition, paratransit, which likes to stop too long to wait for passengers to make the impact of congestion increase. The frequency of paratransit that suddenly stops to pick up passengers and cut roads suddenly also unsettles the public. With the improvement in service by paratransit the survey results stated that there are 59 people who choose to use paratransit as daily transportation. The
reason they use paratransit is due to more practical (78%). Besides that, it is also due to traffic congestion (66%), petrol cost (66%), and more affordable (64%). Same as the factors that influence people choosing a bus, more practical factors and traffic congestion are still included in many factors that are chosen to use paratransit compared to private vehicles if there is improvement. Paratransit does not have a special bus stop such as a bus so that stops can be more flexible. Besides that, the factor of congestion and fuel prices that influence each other because the more traffic is, the more energy is wasted. In addition, affordable prices also influence the selection of paratransit because with affordable paratransit prices, people can save on other expenses, for example, the cost of fuel. The survey results can be seen in Figure 2.

3.2.3. Monorail-Tram.

Other public transportation chosen by the community is the monorail tram. The survey results can be seen in Figure 2. From Figure 2 it can be seen that the traffic congestion factor dominates the selection of Tram Monorail as public transportation chosen by the community (88%). Another factor influencing the selection of tram monorail as public transportation is the certainty of schedule (71%) and is more practical (70%). Certainty of schedule factors are chosen because using a monorail tram is considered more scheduled and the duration of the trip can also be estimated compared to using a bus or paratransit whose travel time and arrival time cannot be ascertained.

The factor that most affected the community shifted from private vehicles to public transportation was congestion traffic because indeed congestion traffic gives a lot of harm to society and the environment, such as wasting a lot of time on the road causing stress and increasing air pollution. Other factors that also influence are factors more practical, more affordable, certainty of schedule, parking cost, and parking availability at destination.

4. Conclusions

The large number of private vehicles in Surabaya which include motorbikes, gasoline cars, and diesel cars cause significant air pollution. Today people prefer to use private vehicles as daily transportation because public transportation is currently considered less comfortable. However, if there are improvements in public transportation, majority of respondents are willing to shift using public transportation, which will lead to a significant reduction of CO, NOx and SO$_2$ emission in urban.

The factors that influence people choosing to use public transportation (bus, paratransit and monorel-tram) are externals and internals. One external variable such as traffic congestion may force users to shift, that is if a certain degree of congestion level has been reached, a level that has not been reached.
for the time being. With current road capacity limitation which unable to accommodate the growth of vehicle ownership, soon the level will be reached and users will have no choice except to shift. Internal variables affect people’s choice to shift. Practicality and affordable cost will attract people to change mode. Practical and more affordable factors are also quite influential because the low cost of public transportation can reduce expenditure on fuel costs and more practical factors chosen because it is possible that the location of bus stops and paratransit is easily accessible because it is close to the place of residence. In addition to these factors, there are also certainty of schedule, parking cost and parking availability factors at destination which also affect the selection of public transportation (buses, paratransit, and monorel-tram).

Despite that there are several variables are more dominant than the others, the results show that if actions to improve facilities of public transport as well as applying and constructing better technology such as monorail-tram, the shift of private vehicle users will definitely take place successfully.

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