Estimation of Exhaust Emissions of Marine Traffic Using Automatic Identification System Data (Case Study: Madura Strait Area, Indonesia)

Trika Pitana[1], Eiichi Kobayashi[2], Nobukazu Wakabayashi[2]
[1] Institut Teknologi Sepuluh Nopember, Surabaya
[2] Graduate School of Maritime Sciences, Kobe University

***Abstract*- The Madura Strait area is one of the busiest marine traffic regions in Indonesia. Many ships arrive, depart and travel through that area, thus influencing the air quality of the port environment. Furthermore, the Indonesian government has not yet ratified Marine Pollution (MARPOL) 73/78 Annex VI regarding the prevention of air pollution from ships and the absence of restricting regulations could have an influence on the level of air pollution. In this study, an Automatic Identification System (AIS) receiver is used to obtain ship data. AIS recognizes a vessel's Maritime Mobil Maritime Identify (MMSI), speed of ship, initial position of ship and ship type. This data is used to evaluate the marine traffic density in the Madura Strait area. Information from ship databases and AIS data are combined for retrieving gross tonnage (GT) information, which is then used to estimate the ship's air pollution emissions. Air pollution estimates also consider the ship's operation modes such as berthing, maneuvering and hotelling. The basic aims of this study are to evaluate marine traffic contributions to the nitrogen oxides (NO_x), sulfur oxides (SO_x), particulate matter (PM), carbon monoxide (CO) and carbon dioxide (CO_2) levels in the Madura Strait area, and to evaluate the possibility of using AIS data when estimating air pollution levels. The emission quantities of NO_x, SO_x, PM, CO (as indicators of air pollution) and CO_2 (as a greenhouse gas) are shown in this paper. The process for estimating emissions using AIS is a potential decision-making tool when considering issues such as the effects of ship emissions on health is also evaluated.**

I. INTRODUCTION

Air pollution and global warming are considered very important issues. Exhaust emissions from marine transportation engines are known to cause environmental and health problems. Nitrogen oxides (NO_x), carbon monoxide (CO), hydrocarbons (HC) and sulfur dioxide (SO_2) are considered air pollutants that cause environmental damage. For instance, NO_x is a precursor to N_2O, which is believed to damage the ozone layer and aggravate the greenhouse effect. CO_2 is a common exhaust emission that is believed to contribute to global warming.

Furthermore, the Indonesian government has not yet ratified MARPOL 73/78 Annex VI [12]. This situation also contributes negative impacts on the environment and further investigations into the necessity of ratifying MARPOL 73/78 should be considered.

This study focuses on the Madura Strait area because it is the second largest marine traffic region in Indonesia. In addition to domestic shipping, there are also numerous foreign vessels transiting this area. Consequently, air pollution levels are high, which aggravates other environmental problems. The objective of this study is to estimate the air pollution conditions resulting from the shipping in the Madura Strait area using Automatic Identification System (AIS) data. Additionally, the possibility of using AIS data for other purposes is also evaluated. In order to achieve these objectives, this paper is presented in several sections. First, a literature review, showing how AIS data could be used to estimate air pollution, is presented. Second, a research methodology describing how to estimate air pollution is described. Third, an analysis of AIS data showing traffic density and ship numbers (by type) are shown for emission estimation consideration. Fourth, a method for calculating emission estimations by considering gross tonnage (GT), ship types and ship operational modes is explained. Finally, the estimated emission levels of NO_x, SO_x, particulate matter (PM), CO and CO_2 concentrations are discussed.

II. LITERATURE REVIEW

Over the years, numerous research efforts into worldwide emission estimations have been conducted. Wang et al. [8] evaluated the energy use and emissions of North American shipping by developing the Ship Traffic, Energy, and Environment Model (STEEM). Their approach, which is designed for quantifying and geographically presenting inter-port vessel traffic and emission levels, uses Geographic Information System (GIS) information for spatial emission analysis. Lucialli et al. [5] evaluated the damage to air quality resulting from maritime traffic in the Italian harbor of Ravenna. They estimated NO_2 and PM by considering the number of ships in the harbor. The Methodology for

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Calculating Transport Emissions and Energy Consumption (MEET Methodology), which is adopted from Trozzi et al. [6][13][14], was used for air pollution estimates. Meyer et al. [2] estimated the atmospheric emissions of CO_2, SO_2 and NO_x from international merchant shipping in the Belgian portion of the North Sea over a one year period.

Numerous researchers have used AIS data to evaluate air pollution or emissions. Jalkanen et al. [4] purposed a modeling system for maritime traffic exhaust emissions based on data obtained from AIS receivers. Perez et al. [3] used a combination of GIS and AIS data to spatially analyze the emissions of marine vessels. They describe how AIS data could be used to estimate emission levels. However, several types of information that are useful for emission estimates are not available in AIS data. These include main engine power, auxiliary engine power, and gross tonnage. Therefore, the use of ship databases, such as Lloyd's Register, is needed to provide such additional information [7][3]. By considering the abovementioned research efforts, the possibility of using AIS data, as well as combinations of ship database, GIS and AIS information, provide potential ways of estimating maritime emissions and clarifying their resulting air pollution levels.

III. METHODOLOGY

As shown in Figure 1, the research framework started from an investigation of AIS data obtained by GIS in the Indonesian Madura Strait area. From this investigation, information relating to ship departure and arrival speeds, types and names, ships locus, etc. could be obtained. Ship data that could not be obtained from AIS receivers were extracted from free ship databases, such as Equasis, the World Shipping Register, and the International Telecommunication Union (ITU) [9][10][11]. In order to evaluate ship traffic patterns, AIS data is input into the ArcGIS software suite. Ship traffic patterns are useful when evaluating ship operational modes, such as maneuvering, hotelling and cruising. The assessment of ship operational modes is necessary for determining their emission factors, which are used when creating evaluations [6][13][14].

A. Overview of AIS and Installation

The actual vessel data were obtained from the AIS receiver installed at the Marine Engineering Department, Faculty of Marine Technology, ITS, Surabaya, Indonesia. The equipment consisted of a Furuno FA-30 AIS receiver that was used to collect data; a personal computer (PC) and an RS-232C serial connection that was used to connect the AIS and the PC, as shown in Figures 2(a) and (b). The data collected by the AIS was simultaneously stored and updated in a hard disk on the PC. Once recorded, such data could be utilized by other laboratories on the ITS campus via the local area network.

Currently, AIS can recognize ships of more than 300 GT on international voyages and ships of more than 500 GT on domestic routes. Both static and dynamic ship data can be obtained [1]. The dynamic information is updated every 2 to 10 seconds depending on the vessel speed [1].

The static information consists of the vessel's maritime mobile service identity (MMSI), vessel name, vessel call sign, ship length, draft, beam, IMO number, ship type, and antenna position. The dynamic information consists of longitude, latitude, time, course, rate of turn, speed over ground (SOG), navigation information, destination and cargo type. AIS data used in this paper are longitude, latitude, SOG, ship type, ship length and course. From this AIS data, it is possible to determine the traffic density and ship tracking patterns of vessels in the Madura Strait area.

B. Analysis of AIS data

Traffic density analysis is very important when evaluating the number of vessels passing in and out of the Madura Strait area. Air pollution emissions are influenced by the traffic density, ship types and ship operational modes. From the emissions point of view, operational modes considered are the maneuvering phase, hotelling phase and cruising phase [6][13][14].

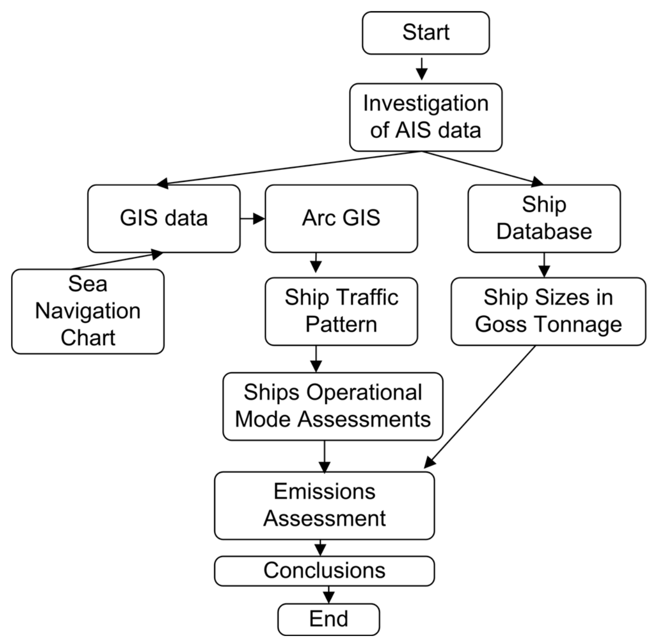
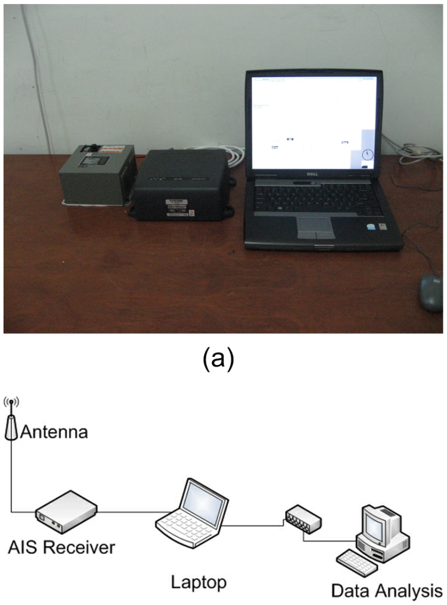


Figure 1. Framework of assessment



(b)

Figure 2. (a) AIS Installation (b) outline of the AIS Installation in the ITS Marine Engineering Department

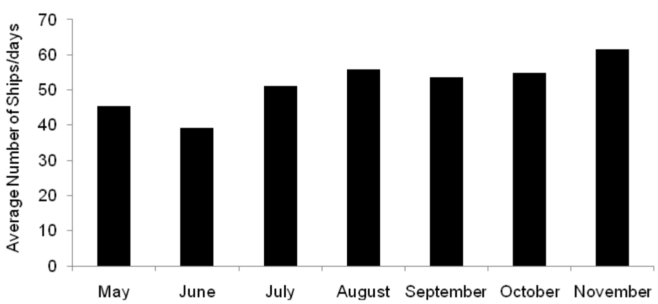


Figure 3. Average numbers of ships per day during 2008

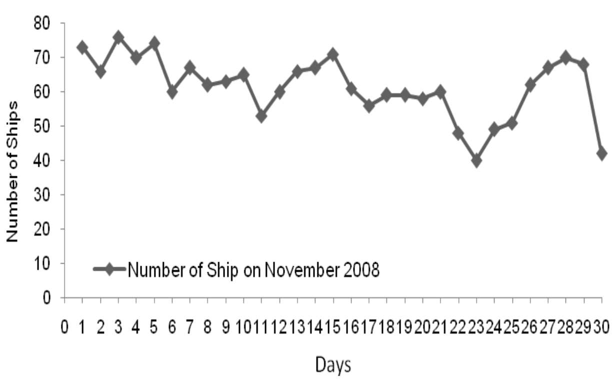


Figure 4. Number of ships recorded during November 2008

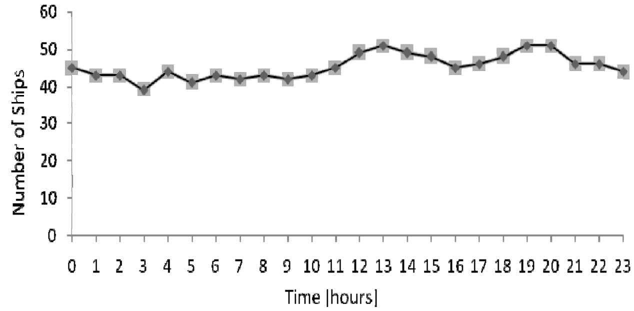
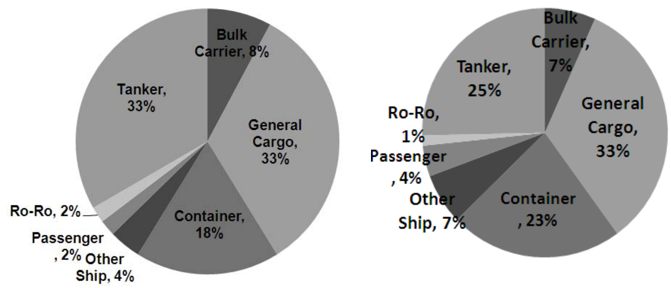


Figure 5. Number of ships recorded on November 3, 2008



(a) (b)

Figure 6. (a) Percentage of ship distribution at 13.00 (b) on November 3, 2008

Figure 3 shows the traffic density data recorded from May 2008 to November 2008 in terms of average number of ships per day. For example, there were about 50 ships per day during July 2008 while the densest traffic period was recorded in November 2008, which showed about 60 ships per day.

Taking November 2008 as the densest period, Figure 4 shows that the peak day for marine traffic density occurred on November 3 while the lowest marine traffic density was recorded on November 23. In this research, we focus on November 3, the densest of marine traffic, as shown Figure 5. On that day, it can be seen that the busiest periods occurred around the hours of 1300, 1900 and 2000. We selected 1300, which showed the highest level of marine traffic. In addition to the marine traffic density data, it is very important to analyze the ship types, as shown in Figures 6(a) and (b) since the ship types influence emission factors [13][14]. Figure 6(a) shows that the majority of ships recorded at 1300 on November 3 were tankers and general cargo ships, followed by container ships, bulk carriers, other ships, passenger vessels and Ro-Ro ships. Figure 6(b) shows that the highest number of ships recorded on November 3 were general cargo ships, followed by tankers, container ships, bulk carriers, other ships, passenger vessels and Ro-Ro ships.

TABLE 1

Ship class and fuel consumption factors

Ship Class	Consumption at full power (tons/day) as a function of gross tonnage (GT)
Solid Bulk	$C_{jk} = 20.1860 + 0.00049 \times GT$
Liquid Bulk	$C_{jk} = 14.6850 + 0.00079 \times GT$
General Cargo	$C_{jk} = 9.8197 + 0.00143 \times GT$
Container	$C_{jk} = 8.0552 + 0.00235 \times GT$
Passenger/Ro-Ro/Cargo	$C_{jk} = 12.8340 + 0.00156 \times GT$
Passenger	$C_{jk} = 16.9040 + 0.00198 \times GT$
High Speed Ferry	$C_{jk} = 39.4830 + 0.00972 \times GT$
Inland Cargo	$C_{jk} = 9.8197 + 0.00143 \times GT$
Sail Ship	$C_{jk} = 0.4268 + 0.00100 \times GT$
Tugs	$C_{jk} = 5.6511 + 0.01048 \times GT$
Fishing	$C_{jk} = 1.9387 + 0.00448 \times GT$
Other Ships	$C_{jk} = 9.7126 + 0.00091 \times GT$

C. *Emission Calculation Assumption*

Emission estimates are based on the standard European (MEET) methodology, which is primarily based on the work of Trozzi et al. [6][13][14]. The estimates considers 12 ship classes that have gross tonnage in excess of 100 GT, using appropriate emission factors, and specific ship parameters such as engine type, time spent in port, fuel consumption and gross tonnage.

Trozzi et al.[13][14] purposed the use of daily engine fuel consumption, as shown in Table 1, and calculated emissions by considering factors such as engine and fuel type. The fuel consumption of each ship type was obtained from linear regression analysis of fuel consumption against gross tonnage as shown in Table 1. Furthermore, emission rates were assumed as shown in the following equation [6][13][14]:

$$\left.\begin{aligned} E_i &= \textstyle\sum_{jklm} E_{ijklm} \\ E_{ijklm} &= S_{jkm}(GT) t_{jklm} F_{ijklm} \end{aligned}\right\} \qquad (1)$$

where:
i: pollutant
j: fuel type
k: ship class for use in emission characterization
l: engine type
m: operating mode of ship
E_i: total emission of pollutant i
E_{ijklm}: total emission of pollutant i from use of fuel j on ship class k with engine type l
F_{ijklm}: average emission factor of pollutant i from fuel j in engine type l in mode m (detailed average emission factor can be referred to [13][14])
$S_{jkm}(GT)$: daily consumption of fuel j in ship class k in mode m as a function of gross tonnage
t_{jklm}: days in navigation of ships of class k with engine type l using fuel j in mode m

In addition, estimates of auxiliary engine fuel usage are created the following basic equation [15]:

$$f = 0.2\ O\ L \qquad (2)$$

where:

f: fuel consumption (kg/ship/hour)
O: rated output (PS/engine)
L: Load factor (cruising: 30%, hotelling (tanker): 60%, hotelling (other ships, excluding tankers): 40% and maneuvering: 50%) [16]

D. *Definitions of hotelling, maneuvering and cruising*

In order to measure emissions resulting from ship activities, it is first necessary to determine the operational mode. When estimating fuel consumption and emissions, Trozzi et al. [13][14] focused on three operational modes, hotelling, maneuvering and cruising, as shown in Figure 7. Maneuvering is defined as the time ships spend approaching, docking and departing the harbor. Hotelling refers to operations taking place while ships are berthed alongside piers, while ships traveling at a constant speed are said to be cruising. After operational modes are known, fuel consumption is calculated by considering the fraction of maximum fuel consumption of each ship operation modes. It is necessary to consider actual fuel consumption during the different ship operation phases carried out within the port area. Maneuvering, hotelling and cruising are assumed to have default fractions of maximum fuel consumption of 0.4, 0.2 and 0.8 respectively [6][13][14]. The fraction of maximum fuel consumption for passenger ships and tankers in a hotelling phase are 0.32 and 0.2 respectively.

The determination of the cruising, maneuvering and hotelling operational modes in the study area is shown in Figure 8. The figure shows that cruising occurs when the ship velocity is nearly constant, maneuvering conditions are assumed when the ship velocity is changing gradually, and hotelling conditions are assumed when the ship velocity is zero.

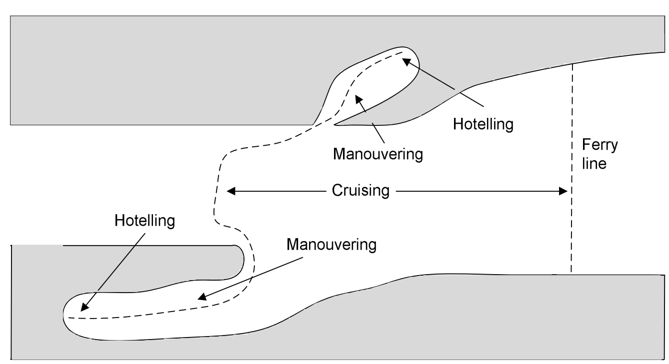


Figure 7. Ship movement characteristics

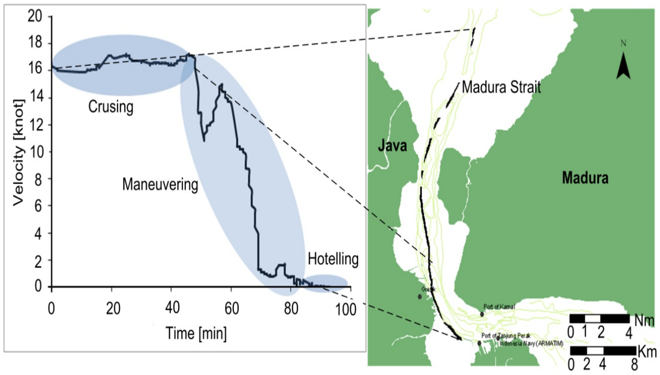


Figure 8. Ship tracking in the Madura Strait area as visualized by GIS

E. Results

The estimation results for NO_x, SO_x, PM, CO and CO_2 emissions from ships ranging in size from 300 GT for international vessels and ships more than 500 GT on domestic routes is shown in Table 2. The results show that NO_x, CO, PM, CO_2 and SO_x concentrations were 22.98, 24.57, 1.00, 1724.44, and 10.78 tons/day respectively. In addition, the highest concentrations of NO_x, CO, PM, CO_2 and SO_x for a single day were emitted by tankers, which contributed 12.76, 15.27, 0.634, 1022.44 and 10.78 tons/day, respectively on November 3, 2008.

It is also possible to estimate exhaust emission by considering the vessel's flag of registry, as shown in Tables 3 and 4. These tables show that the most significant contributions to emissions were from ships registered under the flag of Indonesia. They also show that NO_x, CO, PM, CO_2 and SO_x emissions were 12612.5, 14782.6, 595.7, 922.8 and 6180.9 kg/day respectively, and 713.22, 838.73, 65.08, 173.98 and 1087.40 kg/hr, respectively.

TABLE 2

Estimates of NO_x, SO_x, PM, CO and CO_2 during the densest marine traffic conditions in the Madura Strait area on November 3, 2008

Ship Types	NO_x	CO	PM	CO_2	SO_x
tons/day					
Bulk Carrier	1.29	1.30	0.044	85.26	0.53
Cargo	2.04	3.43	0.099	177.35	1.11
Container	5.03	3.49	0.147	308.84	1.93
Other Ship	0.43	0.12	0.014	25.51	0.16
Passenger	1.37	0.81	0.056	99.04	0.62
Ro-Ro	0.05	0.16	0.004	6.02	0.04
Tanker	12.76	15.27	0.634	1022.43	6.39
Total	22.98	24.57	1.00	1724.44	10.78

TABLE 3

Estimates of NO_x, SO_x, PM, CO and CO_2 based on flag of registry in kg/day on November 3, 2008

Flag of registry	No	%	NO_x	CO	PM	CO_2	SO_x
Kg/day							
Indonesia	47	62.7%	12612.5	14782.6	595.7	922.8	6180.9
Panama	11	14.7%	4719.9	2901.6	151.2	281.3	1932.5
Singapore	4	5.3%	2365.5	2585.6	114.5	163.3	1164.8
China	2	2.7%	654.3	655.2	26.7	41.6	296.6
Marshall Islands	2	2.7%	1292.6	1406.5	53.6	78.5	561.4
Vietnam	2	2.7%	119.6	299.9	7.4	12.4	77.3
Belgium	1	1.3%	58.8	94.4	3.0	5.0	31.4
Germany	1	1.3%	597.5	574.7	19.0	33.4	233.7
Korea	1	1.3%	214.7	346.7	8.9	16.2	101.4
Malaysia	1	1.3%	44.0	48.6	1.8	2.0	21.2
St. Vincent	1	1.3%	131.5	229.9	6.2	11.6	72.6
Thailand	1	1.3%	137.1	254.1	6.8	12.4	77.5
Tuvalu	1	1.3%	36.2	69.9	2.6	4.2	26.5

TABLE 4

Estimation of NO_x, SO_x, PM, CO and CO_2 based on flag of registry in kg/hour at 1300 November 3, 2008

Flag of registry	No	%	NO_x	CO	PM	CO_2	SO_x
Indonesia	31	60.78%	713.22	838.73	65.08	173.98	1087.40
Panama	5	9.80%	179.07	215.22	16.50	44.59	278.67
Singapore	3	5.88%	222.84	171.26	13.50	36.04	225.23
China	2	3.92%	27.24	59.90	4.63	12.39	77.44
Marshall Islands	2	3.92%	54.79	131.80	8.74	23.36	145.98
Vietnam	2	3.92%	5.38	14.20	1.45	3.87	24.19
Germany	1	1.96%	19.35	24.96	2.59	6.96	43.48
Korea	1	1.96%	8.95	14.44	1.48	3.98	24.85
Malaysia	1	1.96%	20.00	2.60	0.52	1.40	8.75
St. Vincent	1	1.96%	5.48	9.58	0.99	2.65	16.58
Thailand	1	1.96%	5.71	10.59	1.09	2.92	18.27
Tuvalu	1	1.96%	1.51	4.82	0.30	0.79	4.96

IV. CONCLUSIONS

In this paper, we demonstrated that it is possible to use AIS data to estimate NO_x, SO_x, PM, CO and CO_2 emissions from shipping activities. The exhaust estimation results could be used for evaluating the impact of marine traffic on air quality and the greenhouse effect. Each ship's NO_x, SO_x, PM, CO and CO_2 emission could be estimated separately. Furthermore, NO_x estimates using AIS data could possibly be used when establishing government policy in relation to ratification of international maritime conventions, such as MARPOL 73/78 Annex VI.

Our study showed that the total amount of NO_x, SO_x, PM, CO and CO_2 were 22.98, 24.57, 1.00, 1724.44, and 10.78 tons/day, respectively. It also showed that the highest contribution of emissions per day was from tankers, which contributed 12.76, 15.27, 0.634, 1022.44 and 10.78 tons/day on November 3, 2008, respectively.

Additionally, we determined that it is also possible to evaluate exhaust emissions by considering the vessel's flag of registry.

Our evaluation only determined exhaust emission concentrations. The impact of such exhaust emissions on human beings was not evaluated. Furthermore, the influence of wind speed and direction on exhaust emissions is significant, and future research regarding those factors will be necessary.

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