Jurnal
Teknologi

Full Paper

Estimation of Exhaust Ship Emission from Marine Traffic In the Straits of Singapore and Batam Waterways Using Automatic Identification System (AIS) Data

Article history
Received
27 April 2015
Received in revised form
15 June 2015
Accepted
25 November 2015

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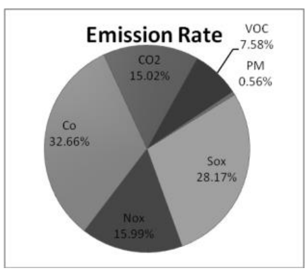
Graphical abstract



Total emission rate in the Strait of Singapore and Batam Waterways on September 27, 2014 at 06.00 – 08.00

Abstract

This study focuses on the Strait of Singapore and Batam Waterways area because it is one of the world's most congested straits used for international shipping. The study aims to estimate exhaust gas emission and the concentration of emission to several areas around the strait. This is accomplished by evaluating the density of shipping lanes in the strait by using the data which obtained by Automatic Identification System (AIS). MEET methodology is used to estimate emissions from ships. There were 1269 total number of ships through the strait on September 27, 2014 at 06.00 am-08.00 am produces total exhaust emission for NOx, CO, CO2, VOC, PM and SOx were about 12595.35 g/second (15.99%), 25725.19 g/second (32.66%), 11832.31 g/second (15.02%), 5973.23 g/second (7.58%), 443.71 g/second, (0.56%), 22185.57 g/second (28.17%), respectively. The ships under the Singapore flag contribute approximately 22.78% of total emissions in the Strait of Singapore and Batam Waterways followed by Panama, Indonesia and Malaysia 14.47%, 3.67%, 1.91%, respectively. Based on the total emission rates hips under Indonesia and Malaysia rank of seventh and eighth respectively.

Keywords: Exhaust ship emissions, Automatic Identification System (AIS), meet methodology, straits of singapore, batam waterways

1.0 INTRODUCTION

Global warming and air pollution have become one of the important issues to the entire world community. About 80% of the international trade and movement of goods carried by ship through the sea [1] cause exhaust emission from marine traffic, which contribute to the global warming and air pollution problems. There are 64.000 cardiopulmonary, lung cancer mortalities and 92% premature death as globally caused by Particulate Matter (PM) from ship traffic [2]

The Straits of Malacca and Singapore are one of the most important shipping channels in the world, connecting the Indian Ocean with the South China Sea and the Pacific Ocean. The Straits remains as one of the world's most congested straits used for international shipping. Approximately over 60,000 vessels pass through the Straits annually [3], the Strait play role in producing of shipping emission and contributed to air pollution.

In previous attempts, some researches of emission using ATMOS (Atmospheric Transport Modeling System) showed that shipping emission of sulfur oxide (SO2) on the Strait of Malacca almost the same in Sumatra, Indonesia (32,000 t SO2 of Strait of Malacca and 52,000 t SO2 per year of Sumatra) and approximately one-quarter of the total emissions in each of Singapore and Malaysia [4-6].

This study focuses on the Strait of Singapore and Batam Waterways area because it is one of the world's most congested straits used for international shipping where located on the border among three countries of Indonesia, Malaysia and Singapore. The objective of this study is to estimate the air pollution such as SOx, Nox, CO, CO_2 and Particulate Matter (PM) resulting from the marine traffic in the Strait of Singapore and Batam Waterways area using Automatic Identification System (AIS) data. Previously, There were several researchs has conduct the same method on their study [8-10]

AIS data are used as an initial data (raw data), it can identify Maritime Mobil Service Identity (MMSI) of ship, ship speed, initial position and type of ship. The such data isused to evaluate the traffic density of the Strait of Singapore and Batam Waterways area. The initial data will combine with ship database to obtain gross tonnage (GT) of the ship for emission estimation consideration.

Over the years, there were many study efforts in emission's estimations fields. A estimation of emission and energy use evaluation ever conducted in North American on 172,000 ship voyages to and from North American ports using Ship Traffic, Energy, and Environment Model (STEEM) [2]. Transport Emissions and Energy Consumption Methodology (MEET Methodology) ever been used to estimate Nox and PM10 emission from marine traffic in the Italian harbor of Ravenna by considering the number of ships in the harbor. The study also evaluated the contribution of emission to air quality by using ADMS-URBAN model, Atmospheric Dispersion Modelling System (ADMS) is a dispersion model of pollutants released into the atmosphere from industrial, domestic and traffic sources in urban areas [11]. In the Belgian area of the North Sea, estimated of atmospheric emissions ever conducted from international shipping (carbon dioxide, sulfur dioxide and nitrogen oxides) for a one year period [2]. Estimation of emission as globally ever conducted by using a different approach of Top-down and Bottom-up approaches to calculate the fuel consumption and to estimate shipping and route specific emissions based on ship movements, ship attributes, and ship emission factors [13]. A three-dimensional Eulerian chemistry transport model ever been used to evaluate the impact of ship emission in coastal areas of the North Sea under conditions of the year 2000 [14]. In Asian water, The RAINS-ASIA project methodology has been used to estimate sulfur dioxide from international shipping in major ports by considering the number of ships from 12 different ports in Asia waters. The approach for deposition of this sulfur was calculated using the ATMOS model of atmospheric transport and deposition. The result of the study for The Straits of Malacca areas, showed that land areas most heavily affected are those bordering the Strait of Malacca, where portions of Sumatra, peninsular Malaysia, and Singapore have contributions from shipping in excess of 10% of total sulfur deposition. Emissions within the Strait of Malacca, measured from the northwestern tip of Sumatra (4S"N latitude, 93.5"E longitude) to Singapore, are estimated to be 39,400 t SO2 per year [4]. It can be compared to other researches also conducted in the Strait of Malacca. It showed that shipping emission of sulfur oxide (SO_2) on the Strait of Malacca almost the same in Sumatra, Indonesia (32,000 t SO2 of Strait of Malacca and 52,000 t SO2 per year of Sumatra) and approximately one-quarter of the total emissions in each of Singapore and Malaysia [5-6].

Initially, Automatic Identification System (AIS) has been used to comply security regulations since September 11, 2001, functioning as traffic management, collision avoidance, and other safety applications. However, today, Automatic Identification System (AIS) be able used to estimate ships emissions. A modeling system for maritime traffic exhaust emissions of NOx, SOx, and CO_2 has been proposed for Baltic Sea area based on data obtained from AIS receivers. The approach for estimating emission of by using ship Traffic, Energy, and Environment Model (STEEM) [7]. The method has been extended in 2011 for ship emission of particulate matter (PM) and carbon monoxide (CO) and presented Ship Traffic Emissions Assessment Model (STEAM2) as a method for estimation of ship emissions [8].

The use of combination AIS and Geographic Information System (GIS) conducted to spatially analyze the emissions of marine vessels [9]. However, AIS doesn't provide completeness of ship information such as main engine power, auxiliary engine power, and gross tonnage. Therefore, additional of ship information is needed from ship database as Lloyd's Register. The study propose for estimated the emission of NOx, CO, non-methane volatile organic compounds (NMVOC), SO2, NH3, PM less than or equal to 10 μm (PM10), PM less than or equal to 2.5 μm (PM2.5), and several significant hazardous air pollutants for Texas State waters for ship that recorded in years of 2007 by using Swedish Methodology for Environmental Data's (SMED) [9]. In Indonesia, estimation of emission ever conducted in the Strait of Madura [10] and Strai of Malacca & Singapore [15] using standard European (MEET) methodology for estimation of ship emission level NOx, SOx, particulate matter (PM), CO and CO2 by using Automatic Identification System (AIS) receiver to obtain ship data.

2.0 METHODOLOGY

The methodology of the study indicates stages of the working process of the study. The study framework started from an investigation of AIS raw data to be several databases such as information relating to ship speed and locations (longitude & latitude), MMSI number of ships, ship departure and arrival speeds, types and names of ship, etc. could be obtained. Ship data of Gross Tonnage (GT) that could not be obtained from AIS receivers were extracted from free ship databases, such as *marinetraffic.com*, *maritime-connector.com*, *equasis.org* and *vesseltracker.com*. For evaluating ship operational modes, such as maneuvering, hotelling and cruising needs ship speed characteristics which obtained from AIS databases. Figure 1 shown overall framework of the study.

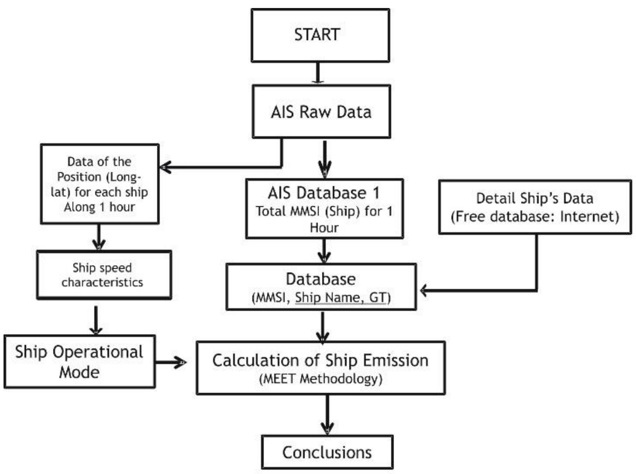


Figure 1 Framework of the study

2.1 Overview Of AIS Installation and Decode

In this research, AIS data obtained from an AIS receiver installed in Politeknik Negeri Batam as shown in the Figure 2. The AIS receivers report ASCII data packets as a byte stream over USB lines, using the NMEA 0183 data formats. In normal operation, an AIS transceiver will broadcast a position report (type 1, 2, or 3) every 2 to 10 seconds depending on the vessel's speed while underway, and every 3 minutes while the vessel is at anchor and stationary [16]. The following sentence show example of AIVDM sentence type 1 which is received by AIS:

!AIVDM,1,1,,A,18I0eb000v7JnOF0eR3CARTV0dA9,0*47

The field 1 !AIVDM is the name of the sentence, the last 2 characters are the checksum. To get the ship information, extracted the data of field 6th from AIVDM sentence, **(18I0eb000v7JnOF0eR3CARTV0dA9)**, translated to binary data and separated based on ITU-R M.1371 as shown on table 1.

Figure 2 AIS Installation in Politeknik Negeri Batam

Table 1 Common Navigation Block (Types 1, 2 and 3: Position Report Class A)

Field	Length	Description
0-5	6	Message Type
6-7	2	Repeat Indicator
8-37	30	MMSI
38-41	4	Navigation Status
42-49	8	Rate of Turn (ROT)
50-59	10	Speed Over Ground (SOG)
60-60	1	Position Accuracy
61-88	28	Longitude
89-115	27	Latitude
116-127	12	Course Over Ground (COG)
128-136	9	True Heading (HDG)
137-142	6	Time Stamp
143-144	2	Maneuver Indicator
145-147	3	Spare
148-148	1	RAIM flag
149-167	19	Radio status

Automatic identification systems (AIS) are designed to be capable of providing information about the ship to other ships and to coastal authorities automatically for ship 300 gross tonnage and above engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size [17].

2.2 Analysis Of AIS Data

To identify the ship traffic in the Strait of Singapore and Batam Waterways, a program of the MySQL Database Management is used to obtains required data for the purposes of emissions calculation and the distribution assessment. Air pollution and 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 [18]. Figure 3 and 4 shows the traffic density data recorded on September 27, 2014 in term of average number of ships per hour and per two hour, respectively.

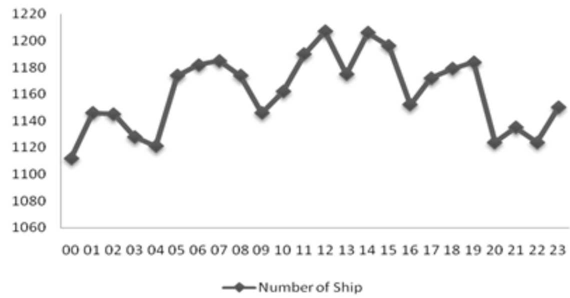
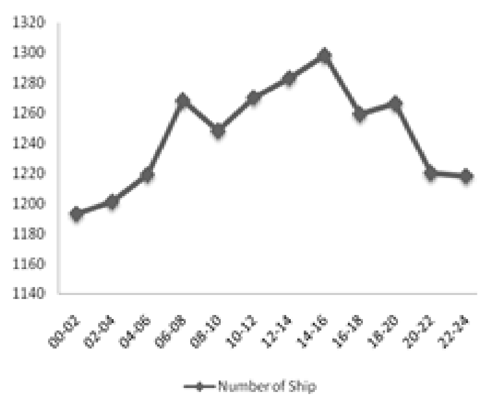


Figure 3 Number of ships recorded per-hour on September 27, 2014



Figur e 4 Number of ships recorded per-hour on September 27, 2014

Figure 3 and 4 shows the total number of ships on September 27, 2014. There were about 1852 and 1161 ships recorded during days and average per-hour, respectively on September 27, 2014. The figure 4 show the lowest marine traffic density was recorded at 00.00 to 02.00 by the total number about 1193 ships while the densest occurred at 14.00 to 16.00 by the total number about 1298 ships during the day.

In this research, focus on September 27, 2014 at 06.00 to 08.00. There were recorded about 1269 ships passing through the Strait of Singapore and Batam Waterways. Table 2 shows the total number of ships by type.

Table 2 Total number of ships (by type)

Type	Number of Ship
Solid Bulk (SB)	1
Liquid Bulk /Tanker (LB)	465
Cargo (Container & General Cargo)	275
Passenger (PA)	54
High Speed Ferry (HS)	60
Sail Ship (SS)	8
Tugs (TU)	199
Fishing (FI)	6
Other Ships (OT)	201
Total	**1269**

In addition to the marine traffic density data, it is very important to analyze the ship types as shown in the Figure 5(a) since the ship types influence emission factors.18 Figure 5 (a) and Table 2 shows that the majority of ships recorded at 0600 to 08.00 on September 27 were liquid bulk or tanker, general cargo & container and tugs, followed by high speed ferry, passenger, sail ship and fishing vessel.

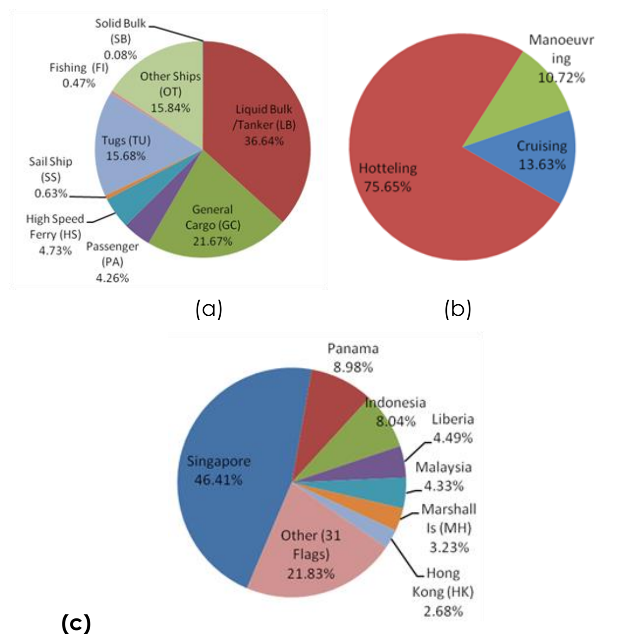


Figure 5 Total number of ships on September 27, 2014 (a) by type (b) by mode operation (c) by flag registered

Figure 5(b) shows the majority of ships by mode operational recorded on that day were hotelling, cruising and maneuvering. Figure 5(c) shows the majority of flag registered ship recorder at 0600 to 0800 on September 27, it can be seen the highest number of ships were by flag of Singapore, Panama, Indonesia, Liberia, Malaysia, Marshall Is, Hong Kong and Other (31 Flags).

2.3 Emission Assessment Assumption

The calculation of emission is calculated based on the standard European (MEET) methodology which ever been used by other several research [10,18-19]. There are 12 class of ships which considered on the assessment that have gross tonnage in excess of 100 GT. Methodologies for estimating air pollutant emissions from ships used to estimate of consumption and emissions based on present day statistics of ship traffic [18-19]. Fuel consumption of any type of ship are obtained from a linear regression analysis of fuel consumption to gross tonnage as shown in the Table 3. Calculation of emissions rate defined as:

$$E_i = \Sigma_{jklm} \cdot E_{ijklm} \quad (1)$$

$$E_{ijklm} = S_{jkm}(GT) \cdot t_{jklm} \cdot F_{ijlm} \quad (2)$$

Where

i	:	pollutant
j	:	fuel type
k	:	ship class for use in consumption classification
l	:	engine type class for use in emission factors characterization
s	:	reference reduction scenario (low, medium, high)
Ei	:	total emissions of pollutant i
Eijklm	:	total emissions of pollutant i from use of fuel j on ship class k with engines type l in mode operation m
Sjkm(GT)	:	daily consumption of fuel j in ship class k as a function of gross tonnage
Tjklm	:	days in navigation of ships of class k with engines type l using fuel j in mode operational m
Fijlm	:	average emission factors of pollutant i from fuel j in engines type l in mode m

For auxiliary engine (generator) bu using following equation to estimate air pollution and greenhouse gases from ships [18,20]. The equation is defined as:

$$f = P \times L \quad (3)$$

Where:

f : Auxiliary engine fuel consumption
P : Auxiliary engine rated output
L : Load factor

Table 3 Ship class and fuel consumption factors

Ship types(code)	Consumption at full power (t/day) as function of gross tonnage
Solid Bulk (SB)	Cjk = 20.1860 + 0.00049 × GT
Liquid Bulk/Tanker (LB)	Cjk = 14.6850 + 0.00079 × GT
General Cargo (GC)	Cjk = 9.8197 + 0.00143 × GT
Container (CO)	Cjk = 8.0552 + 0.00235 × GT
Ro-Ro Cargo (PC)	Cjk = 12.8340 + 0.00156 × GT
Passenger (PA)	Cjk = 16.9040 + 0.00198 × GT
High Speed Ferry (HS)	Cjk = 39.4830 + 0.00972 × GT
Inland Cargo (IC)	Cjk = 9.8197 + 0.00143 × GT
Sail Ship (SS)	Cjk = 0.4268 + 0.00100 × GT
Tugs (TU)	Cjk = 5.6511 + 0.01048 × GT
Fishing (FI)	Cjk = 1.9387 + 0.00448 × GT
Other Ships (OT)	Cjk = 9.7126 + 0.00091 × GT

In the Table 4, reported the results of the non-linear regression procedure applied to installed main engine power by considering several ship classes as a function of gross tonnage [21]. In this study, the table is used to estimate the power of the main engine. Power of auxiliary engine is calculated by using the vessel ratio of Auxiliary Engines/Main Engines as shown in Table 5, once the power of the main engine is calculated from Table 4. Load factor used for estimates of auxiliary engine fuel, based on Table 6 [21].

Table 4 Installed main engine power as a function of gross tonnage (GT) [21]

Ship categories	2010 World fleet	1997 World fleet	Mediterranean Sea fleet (2006)
Liquid bulk ships	$14.755*GT^{0.6082}$	$29.821*GT^{0.5552}$	$14.602*GT^{0.6278}$
Dry bulk carriers	$35.912*GT^{0.5276}$	$89.571*GT^{0.4446}$	$47.115*GT^{0.504}$
Container	$2.9165*GT^{0.8719}$	$1.3284*GT^{0.9303}$	$1.0839*GT^{0.9617}$
General Cargo	$5.56482*GT^{0.7425}$	$10.539*GT^{0.6760}$	$1.2763*GT^{0.9154}$
Ro Ro Cargo	$164.578*GT^{0.4350}$	$35.93*GT^{0.5885}$	$45.7*GT^{0.5237}$
Passenger	$9.55078*GT^{0.7570}$	$1.39129*GT^{0.9222}$	$42.966*GT^{0.6035}$
Fishing	$9.75891*GT^{0.7527}$	$10.259*GT^{0.6919}$	$24.222*GT^{0.5916}$
Other	$59.049*GT^{0.5485}$	$44.324*GT^{0.5300}$	$183.18*GT^{0.4028}$
Tugs	$54.2171*GT^{0.6420}$	$27.303*GT^{0.7014}$	

Table 5 Estimated average vessel ratio of Auxiliary Engines / Main Engines by ship type [21]

Ship category	2010 World fleet	Mediterranean Sea fleet (2006)
Liquid bulk ships	0.3	0.35
Dry bulk carriers	0.3	0.39
Container	0.25	0.27
General cargo	0.23	0.35
Ro Ro Cargo	0.24	0.39
Passenger	0.16	0.27
Fishing	0.39	0.47
Others	0.35	0.18
Tugs	0.1	

Table 6 Estimated % load of MCR (Maximum Continuous Rating) of Main and Auxiliary Engine for different ship activity [21]

Phase	% load of MCR Main Engine	% time all Main Engine operating	% load of MCR Auxiliary Engine
Cruise	80	100	30
Manoeuvring	20	100	50
Hotelling (except tankers)	20	5	40
Hotelling (tankers)	20	100	60

2.4 Definitions Of Hotelling, Maneuvering And Cruising

The operational mode of the ship is used to measure emission resulting from ship activities. Mode operational ships of hotelling, maneuvering and cruising are used when estimating fuel consumption and emissions [18-19,21]

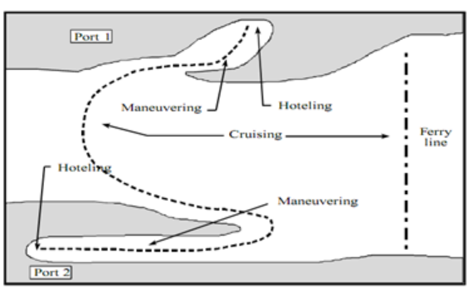


Figure 6 Ship movement characteristics

When the ships spend approaching, docking and departing the harbor called as maneuvering. Hotelling refers to operations taking place while ships are berthed alongside piers, while ships traveling at a constant speed are said to be cruising [10].

4.0 CONCLUSION

In this paper, we demonstrated that it is possible to use AIS data to estimate NOx, SOx, PM, CO and CO2 emissions and distribution of the emission from shipping activities. In additions, the distribution can be seen through amount of concentration of emission in several areas around the ship traffic as an emission source. This study also demonstrated that possibility of calculating the distribution of emission by all mode operational of ships (Manoueuvring, cruising and hoteling), not only one of them.

This study showed the total amount of emission NOx, CO, CO2, VOC, PM and SOx emission were 12595.35 g/second (15.99%), 25725.19 g/second (32.66%), 11832.31 g/second (15.02%), 5973.23 g/second (7.58%), 443.71 g/second, (0.56%), 22185.57 g/second (28.17%), respectively. It also showed that the highest contribution of emission at 06.00 to 08.00 on September 27, 2014 was from liquid bulk (tanker) which contribute 41.80% followed by general cargo & Container which contibute 36.31% of the total emission. Ships under flag registry of Singapore were was contributing 27.79% of the total emission followed by Panama, Liberia, Marshall Is, Hong Kong, Indonesia and Malaysia which contribute 14.47%, 9.68%, 7.44%, 6.01%, 3.67% and 1.91%, respectively.

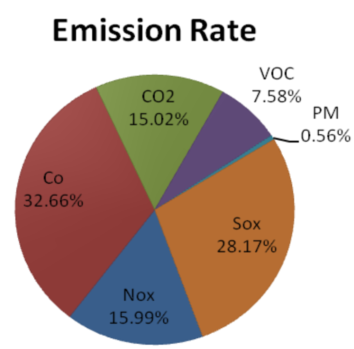


Figure 7 Total ship emission occurred at 06.00 to 08.00 on September 27, 2014 in the Strait of Singapore and Batam Waterways

The Exhaust emission rates which produced through this study may used for evaluating the impact of marine traffic on air quality, the greenhouse effect and could be used when establishing government policy in relation to ratification of international maritime conventions, such as MARPOL 73/78 Annex VI [10].

This study only determines exhaust emission and distribution. The impact of such emissions on human beings was not evaluated. In additions, additional database of ships as complementary AIS Data to get complete data on the ship, in the future research will be necessary.

Acknowledgement

We are grateful for the cooperation of AIS instalation in Politeknik Negeri Batam to Author 4.

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