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Ketut Buda Artana
Institut Teknologi Sepuluh Nopember

Emmy Pratiwi
Institut Teknologi Sepuluh Nopember

Trika Pitana
Institut Teknologi Sepuluh Nopember

Mohammad Danil Arifin
Universitas Darma Persada

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ENHANCEMENT ON METHODOLOGY FOR ESTIMATING EMISSION DISTRIBUTION AT MADURA STRAIT BY INTEGRATING AUTOMATIC IDENTIFICATION SYSTEM (AIS) AND GEOGRAPHIC IDENTIFICATION SYSTEM (GIS)

Ketut Buda ARTANA*, **Emmy PRATIWI *, Bagus DINARIYANA***, **Trika PITANA***, **Agoes A. MASROERI***, **Made ARIANA***, **Mohammad D. ARIFIN****

*Dept. of Marine. Eng., Institut Teknologi Sepuluh Nopember,
Campus ITS Sukolilo Surabaya, 62111, Indonesia
** Dept. of Marine. Eng., Darma Persada University,
Jalan Raden Inten II No. 1 Pondok Kelapa Duren Sawit JakartaTimur DKI Jakarta, Indonesia

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1. INTRODUCTION

Madura Strait is one of the area in Indonesia having the most marine traffic density. This strait is the only access to several major ports in Indonesia, such Port of Tanjung Perak, Port of Gresik, and the new and under construction port of Teluk Lamong, as well as several berthing facilities of industries at the surroundings (see Fig. 1). Port of Tanjung Perak Surabaya – Indonesia, is one of the biggest and busiest ports in Indonesia. Currently, not less than 27.000 shil calls to be served by port annually and it is expected to double in 2030 (Artana, 2012). Increasing amount of ships in the Madura strait will produce more emission.

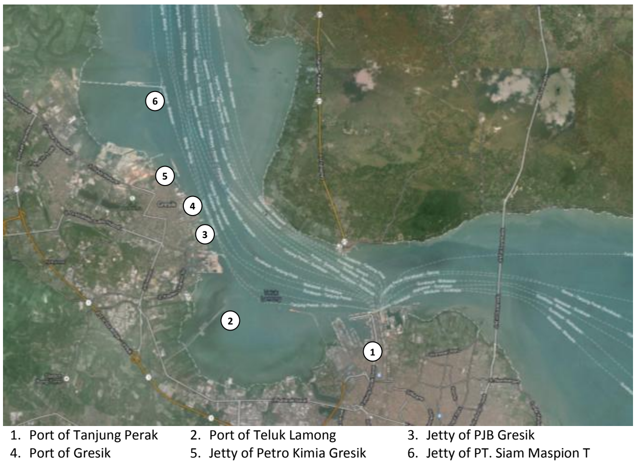

Figure 1. Port of Madura Strait

Main purpose of this study is to seek the possibility of further enhancing the methodology in examining the distribution of emissions from ships operating in the area and to determine the effect of ship emissions on health in the Madura Strait area (Pitana, et al). Exhaust emissions from the ships can cause health and environmental problems. Kinds of air pollutants contained in exhaust gas emissions such nitrogen oxides (NOx), carbon monoxide (CO) and sulfur oxides (SOx). Traffic data obtained from the Automatic Identification System (AIS) installed in ITS Surabaya is used to calculate the estimated amount of emission by applying methodology provided by Trozzi et al. The data from the Automatic Identification System (AIS) is further integrated with the Geographic Identification System (GIS) software as well as the shipping database.

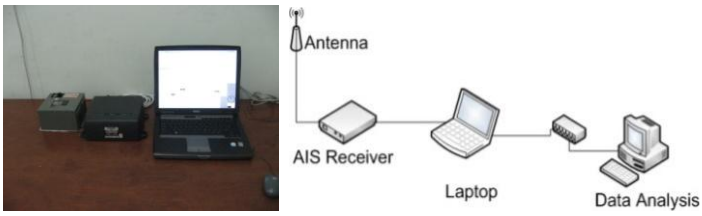

Figure 2. Instalation of AIS in ITS Surabaya

2. PREVIOUS RESEARCH METHODOLOGY

2.1 Automatic Identification System

The Automatic Identification System (AIS) is an automatic tracking system used on ships and by Vessel traffic services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships and AIS Base stations. AIS gives several input data such as MMSI number, speed of ground, position of ship and ship type. AIS is used to enable vessels to “see” each other more clearly in all conditions, collision avoidance system, aid navigation, search and rescue, and maritime security. AIS needs a AIS transceiver and transponder. It uses a VHF frequency and GPS receiver. AIS provides information that can be displayed on a screen or an ECDIS.

The International Maritime Organization's (IMO) International Convention for the Safety of Life at Sea (SOLAS) requires AIS to be fitted aboard international voyaging ships with gross tonnage (GT) of 300 or more, and all passenger ships regardless of size. It is estimated that more than 40,000 ships carried AIS class A equipment In 2007, the new Class B AIS standard was introduced which enabled a new generation of low cost AIS transceivers.

The application of AIS has been moving to a more advance application such as accident investigation, binary messages, computing and networking, AIS data on the internet, range limitations and space-based tracking, and others. This, consequently, opens a broader chance in R&D perspectives.

Figure 3. AIS type A

Figure 4. Automatic Identification System (AIS) and retrieved data

2.2 Geographic Information System (GIS)

A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. With these features, GIS can be arranged to display ship's position, tracking, and other important information obtained from AIS.

Ariana (2012) has developed an interface to combine AIS and GIS, in which dynamic position of ships in terms of its longitude and latitude is displayed in the forms of geographically referenced information. Further to that, GIS platform was then used to display the emission distribution by means of SURFER, a full-function 3D visualization, contouring and surface modeling package that runs under Microsoft Windows, than can be used for contour mapping of the distributed emission as shown in Figure 5.

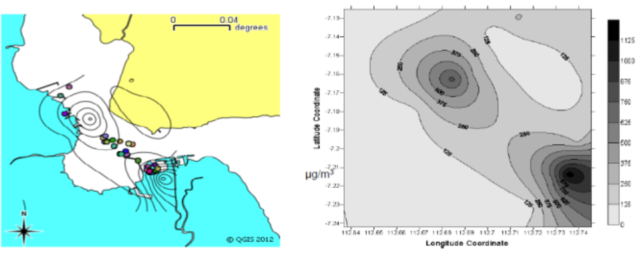

Figure 5. NOx Emission (Plume Model)

2.3 Estimate of Emission Distribution of Ships

Previous research carried out by the author has implemented emission calculation method provided by MEET project (methodologies for estimating air pollutant emissions from transport-Trozzy, 2002). For the application of the methodology are needed an estimate of the number of working days for each class of ships equipped with engines type and using fuel.

Three different operation conditions of ships are considered here, those are: maneuvering phases, hotelling phase, and cruising phase.

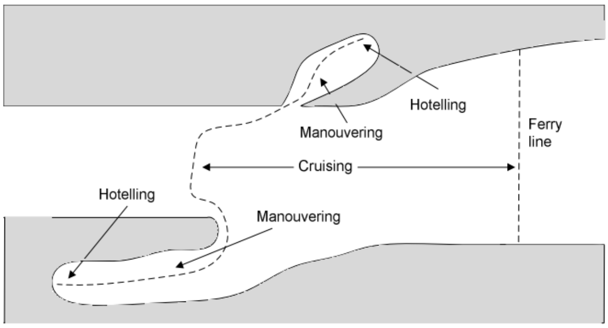

Figure 6. Vessel movement characteristic

Maneuvering is defined as vessel movement when approaching port and leaving the port or can be also defined as a condition when there is significant vessel speed reduction in a short period (Pitana,et al, 2011). Hotelling is a condition when vessel is berthing and when vessel speed is zero, whilst cruising is a condition when vessel is moving in a constant speed at Service Continuous Rating (SCR). When mode of operation of the vessel is known, then fuel consumption can be calculated according to its operation mode.

The emissions produced by ship's main engine are obtained as:

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

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

Where i is pollutant, j is fuel type, k is ship class for use in consumption classification, l is engines type class for use in emission factors characterization, m is operating mode, E_i is total emissions of pollutant I, E_{ijklm} is total emissions of pollutant i from use of fuel j on ship class k with engines type l in operating mode m, and $S_{jkm}(GT)$ is daily consumption of fuel j in ship class k in mode m as a function of gross tonnage, t_{jklm} is days in navigation of ships of class k with engines type l using fuel j in operating mode m and finally the F_{ijlm} is average emission factors of pollutant i from fuel j in engines type l in mode m (for SOx, taking into account average sulfur content of fuel).

The emission itself calculated based on power in order to supply the ship's propulsion power, lighting, heating, refrigeration, ventilation, etc. To implement the method, this research also combines the AIS and GIS data with shipping database in which principal dimension of the ship is obtained its main engine and auxiliary engine power. The equations used to calculate the emission is shown in Table 1. The emission factor produced by the ships is shown in Table 2.

Table 1. Ship classes and fuel consumption factor

Ship class	Fuel consumption (ton/day) as function of Gross Tonnage (GT)
Solid Bulk	C_{jk} = 20.1860 + 0.00049 × GT
Liquid Bulk	C_{jk} = 14.6850 + 0.00079 × GT
General Cargo	C_{jk} = 9.8197 + 0.00143 × GT
Container	C_{jk} = 8.0552 + 0.00235 × GT
Ro-Ro Cargo	C_{jk} = 12.8340 + 0.00156 × GT
Passenger	C_{jk} = 16.9040 + 0.00198 × GT
High Speed	C_{jk} = 39.4830 + 0.00972 × GT
Inland Cargo	C_{jk} = 9.8197 + 0.00143 × GT
Sail Ship	C_{jk} = 0.4268 + 0.00100 × GT
Tugs	C_{jk} = 5.6511 + 0.01048 × GT
Fishing	C_{jk} = 1.9387 + 0.00448 × GT
Other Ships	C_{jk} = 9.7126 + 0.00091 × GT

Table 2. Emission factor (kg emission/ton fuel)

	Engine / Fuel	NO_x	CO	CO_2	VOC	PM	SO_x
Cruising	SSD/BFO	87	7.4	3200	2.4	1.2	60
	MSD/BFO	57	7.4	3200	2.4	1.2	60
	HSD/MDO	70	9	3200	3	1.5	20
Maneuvering	SSD/BFO	78	28	3200	3.6	1.2	60
	MSD/BFO	51	28	3200	3.6	1.2	60
	HSD/MDO	63	34	3200	4.5	1.5	20
Hotelling	SSD/BFO	35	99	3200	23.1	1.2	60
	MSD/BFO	23	99	3200	23.1	1.2	60
	HSD/MDO	28	120	3200	28.9	1.5	20

SSD = Slow Speed Diesel Engine BFO = Bunker Fuel Oil
MSD = Medium Speed Diesel Engine MDO = Marine Diesel Oil
HSD = High Speed Diesel Engine PM = Particulate Matter
VOC = Volatile Organic Compound

On the other hand, the emission obtained from the auxiliary engine is obtained by implementing the following formula.

$$f = 0.2 \; x \; O \; x \; L \tag{3}$$

Where f is the ship's fuel consumption (kg/ship/hr), O is rated output (PS/engine) and L is load factor (cruising: 30%, hotelling (tanker): 60%, hotelling (other ship): 40% and maneuvering: 50%).

2.4 Gaussian Plume and Gaussian Puff Model

Currently, there are five types of air pollution dispersion models widely used to model the emission dispersion of gas. In some cases, the combination between different model (hybrids type) have also been investigated by researchers. The models are Box model (assumes the airshed i.e., a given volume of atmospheric air in a geographical region, is in the shape of a box) (Atkins, 2008), Gaussian model (the most commonly used model type - assumes that the air pollutant dispersion has a Gaussian distribution) (Bosanquet, 1936), Lagrangian model (mathematically follows pollution plume parcels as a random walk process) (JRC, 1988), Eulerian model (similar to a Lagrangian model in that it also tracks the movement of a large number of pollution plume parcels as they move from their initial location) (JRC, 1988), and Dense gas model (simulate the dispersion of dense gas pollution plumes i.e., pollution plumes that are heavier than air).

The Gaussian model is the most commonly used model for estimating air pollution dispersion. It assumes that the air pollutant dispersion has a Gaussian (or normal) distribution. Gaussian models are most often for predicting the dispersion of continuous, buoyant air pollution plumes originating from ground-level or elevated. sources. When it is required to use the model for predicting the dispersion of non-continuous air pollution plumes, the Gaussian puff models is preferable

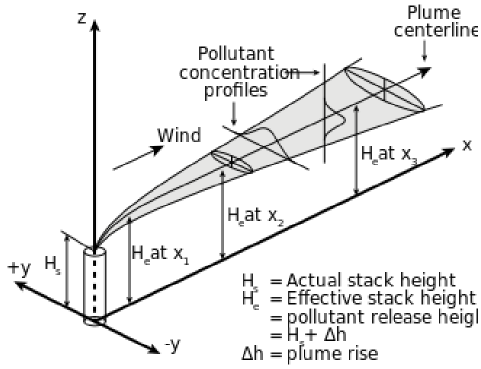

Figure 7. Gaussian model for air pollution dispersion (Altwicker, 2000)

A number of assumptions are typically used for Gaussian modeling. First, the analysis assumes a steady state system (i.e., a source continuously emits at a constant strength; the wind speed, direction, and diffusion characteristics of the plume remain steady; and no chemical transformations take place in the plume). Second, diffusion in the x direction is ignored although transport in this direction is accounted for by wind speed. Third, the plume is reflected up at the ground rather than being deposited. Fourth, the model applies to an inert gas and an ideal aerosol (Altwicker, 2000). In this research, emitted gases are represented by an idealized plume coming from the top of ship funnel (exhaust gas) of some height and diameter. One of the primary calculations is the effective funnel height.

As the exhaust gases are produced in main and auxiliary engine, the hot plume will be thrust upward some distance above the top of the funnel. We need to be able to calculate this vertical displacement, which depends on the funnel gas exit velocity and temperature, and the temperature of the surrounding air.

Once the plume has reached its effective height, dispersion will begin in three dimensions. Dispersion in the downwind direction is a function of the mean wind speed blowing across the plume. Dispersion in the cross-wind direction and in the vertical direction will be governed by the Gaussian plume equations of lateral dispersion. Lateral dispersion depends on a value known as the atmospheric condition, which is a measure of the relative stability of the surrounding air. The model assumes that dispersion in these two dimensions will take the form of a normal Gaussian curve, with the maximum concentration in the center of the plume.

The standard algorithm used in plume studies is the Gaussian plume model, developed in 1932. It is then further developed by (Bracken, et al., 2007 ; Pingjian, et al, 2006;

Altwicker, 2000). The algorithm is as follows:

$$C\ (x,y,z,He) = \frac{Q}{2\pi\sigma_y\sigma_z u_s} \times e^{\left(\frac{-y^2}{2\sigma_y^2}\right)} \times \{e^{\left(\frac{-(z-He)^2}{2\sigma_z^2}\right)} + e^{\left(\frac{-(z-He)^2}{2\sigma_z^2}\right)} \quad (4)$$

where:

1. C(x,y,z) is the concentration of the emission (in micrograms per cubic meter) at any point x meters downwind of the source, y meters laterally from the centerline of the plume, and z meters above ground level.
2. Q is the quantity or mass of the emission (in grams) per unit of time (seconds)
3. u is the wind speed (in meters per second)
4. H is the height of the source above ground level (in meters)
5. σ_y and σ_z are the standard deviations of a statistically normal plume in the lateral and vertical dimensions, respectively

Furthermore, the stability of the atmosphere depends on the temperature difference between an air parcel and the air surrounding it. Therefore, different levels of stability can occur based on how large or small the temperature difference is between the air parcel and the surrounding air. The atmosphere can be stable, conditionally stable, neutral, conditionally unstable, or unstable. Pasquill developed a method for classifying atmospheric conditions which was later modified by Gifford (1975), resulting in six stability classes, labeled A through F. The method was based on the amount of incoming solar radiation, cloud cover, and urface wind speed as shown in Table 3. Classes E and F indicate stable air in which stratification strongly dampens mechanical turbulence, typically with strong winds in a constant wind direction. Class D stability is neutral, with moderate winds and even mixing properties. Classes A, B, and C represent unstable conditions which indicate various levels of extensive mixing (Altwicker, 2000).

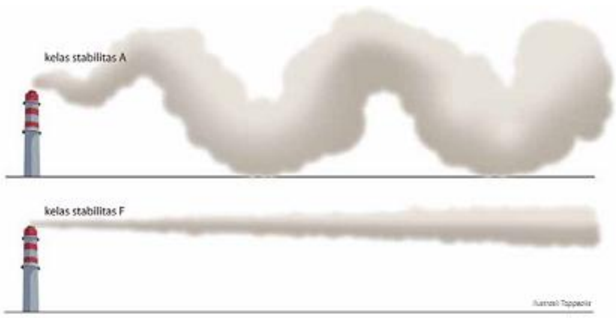

Figure 8. Class of Atmosphere Stability

Table 3. Pasquill-Gifford stability classes

Surface wind speed At 10m (m/sec)	Day			Night	
	Incoming solar radiation			Thinly Overcast	Clear
	Strong	Moderate	Slight	Or ≥4/8	or≤3/8
<2	A	A-B	B	D	F
2-3	A-B	B	C	E	E
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

3. IMPROVEMENT METHODOLOGY

Different to a plume model, when it is required to use the model for predicting the dispersion of non-continuous air pollution plumes, the Gaussian puff models is preferable. Puff model releases emissions independent of the source, allowing the puff to respond to the meteorology immediately surrounding it. This also allows puffs to be tracked across multiple sampling periods until it has either completely diluted or has tracked across the entire modeling domain and out of the computational area. The equation form of Puff model is as follows :

$$C_r = \frac{Q\Delta t}{(2\pi)^{1.5}\sigma_x\sigma_y\sigma_z} \exp\left(\frac{-(x_r-Ut)^2}{2\sigma_x^2}\right) exp\left(\frac{-y_r^2}{2\sigma_y^2}\right)\left[exp\left(\frac{-(z_r-H_e)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(z_r+H_e)^2}{2\sigma_x^2}\right)\right] \quad (5)$$

Where C_r is concentration of emission at receptor (g/m3), X_r, Y_r, Z_r is the distance from the origin in x,y,z (m), H_e is height of the funnel on ship's deck, Q is level of emitted gases (g/s), σ_y, σ_z, σ_x is horizontal and vertical plume deviation standard (m), U is wind speed at the highest position on board (m/s), Δt is time different of dispersion and t is time of dispersion.

4. RESULT

In compiling data obtained from AIS, software named MySql Ver 5.0 was used. AIS data with a year duration was stored in MySql server to ease data retrieval with specific characteristic. Data from July 2010 to March 2011 was used, and among them, specific time with heaviest ship density was taken as model. It was found that in October 2010 the average ship density was 104 ships per day, and on October 22nd 2010 was found as the heaviest density with 120 ships on that day. Figure 7 shows that at 17.00-18.00 PM was the time with heaviest ship density.

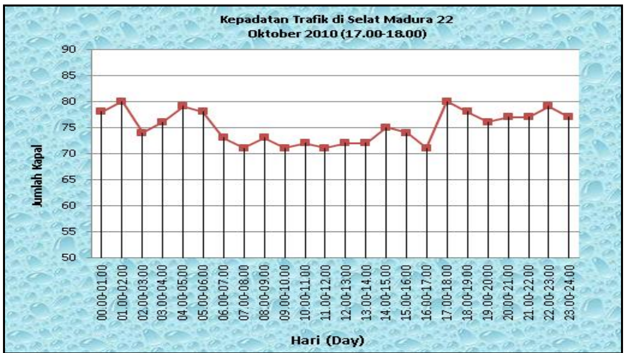

Figure 9. Traffic density on 22nd October 2010 at Madura Strait

By using the emission calculation method developed by Trozzi as explained previously, then it was found the emitted gases produced by ship in 22nd October 2010 is as shown in Table 4 and 5.

After obtaining the amount of the emitted gases, by using the Gaussian plume and puff model, we can compare both of distribution. Figure 10 and 11 is the examples of emission distribution obtained by using plume puff method. Surfer 11, a contouring and 3D surface mapping program that runs under Microsoft Windows was used to visualize the result. This paper only considers the NOx distribution instead of all emission components.

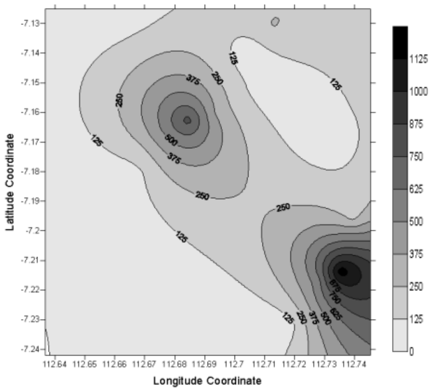

Figure 9. Distribution Emissions NOx (Plume)

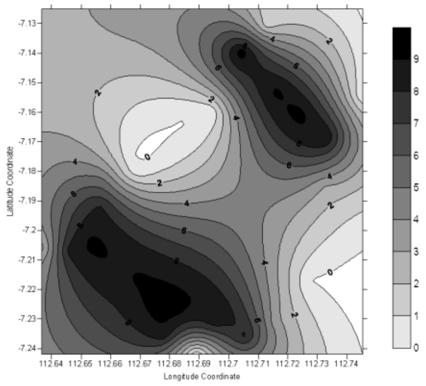

Figure 10. Distribution Emissions NOx (Puff)

Figure 9 shows that to plume model, NOx distribution was concentrated in Gresik and Tanjung Perak Area where port of Surabaya and Port of Gresik is existed. Through this development, puff model results in rather different. Figure 10 shows that NOx distribution mainly concentrated in Madura Strait and tends to move away from the origin. It is understandable considering that puff is a continuous model and provides result in time based, so it is affected by wind direction and time of emission.

Table 4. Estimation NO_x, CO, CO_2, VOC, SO_x and PM (kg/hour) on 22 October, 2010

Flag of Ship	Jumlah	%	NO_x	CO	CO_2	VOC	SO_x	PM
			Kg/hour					
Indonesia	55	71%	422.82	839.08	317.80	195.22	579.66	12.04
Panama	5	6.5%	94.71	145.98	62.31	34.41	116.83	2.34
Antigua and Barbuda	2	2.6%	10.39	29.40	9.50	6.86	17.82	0.36
Liberia	2	2.6%	241.45	42.25	93.14	11.67	174.63	3.49
Marshal Island	2	2.6%	30.51	99.12	29.91	23.41	43.52	1.22
Netherlands	2	2.6%	8.34	23.59	7.62	5.50	14.30	0.29
Norway	2	2.6%	27.18	76.88	24.85	17.94	46.60	0.93
Vietnam	1	1.3%	2.70	7.65	2.47	1.78	4.64	0.09
Cambodia	1	1.3%	28.66	2.44	10.54	0.79	19.77	0.40
Greece	1	1.3%	2.55	7.21	2.33	1.68	4.37	0.09
Hong Kong	1	1.3%	13.76	38.93	12.58	9.08	23.59	0.47
Iran	1	1.3%	0.95	2.69	0.87	0.63	1.63	0.03
South Korea	1	1.3%	11.73	33.19	10.73	7.74	20.11	0.40
St. Kitts and Nevis	1	1.3%	1.12	3.17	1.03	0.74	1.92	0.04
Jumlah	77	100%	896.90	1351.59	585.68	317.46	1069.38	22.18

Table 5. Estimation NO_x, CO, CO_2, VOC, SO_x and PM (kg/hour) on 22 Oktober, 2010

Ship Type	NO_x	CO	CO_2	VOC	SO_x	PM
General	195.91	434.08	155.20	101.62	291.00	5.82
Container	374.74	315.80	194.28	75.39	364.28	7.29
Bulk Carrier	62.97	178.11	57.57	41.56	107.94	2.16
Passenger	23.37	21.90	15.70	5.31	29.43	0.59
Other	50.59	84.12	33.31	19.09	33.68	1.46
Tanker	189.32	317.57	129.62	74.49	243.04	4.86
Jumlah	896.90	1351.59	585.68	317.46	1069.38	22.18

Calpuff View (Leading Interface for Puff Dispersion) shows that emission distribution of Gaussian puff model rather independent to the origin. When plume model involves with a condition with high variability then straight line steady state of a certain distance from the origin is invalid, therefore, for an unsteady state condition, the Puff Model is more precise than plume model. Conclusively, the puff model for a case with several characteristic as below:

1. Unsteady state case
2. There is possibility of interfere of wind and complex topography
3. Non uniform land use pattern
4. Coastal effect is existed
5. Various wind direction

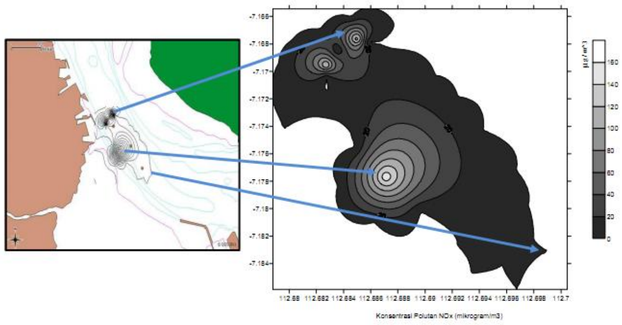

Figure 11. Distribution Emission NOx for MT Lucas.

Figure 11 shows the emission concentration in several areas along the Madura Strait obtained by using puff model. It is shown that area around Kamal and Banyu Ujuh in Madura Island has the highest NOx concentration of 0.176 μg/m3, followed by Gili Barat in the second position with 0.132 μg/m3 and then Kalianak and Benowo in third position with 0.11 μg/m3. Kebomas, Gresik, Port of Petrokimia, Lumpur, Kroman, Sukodono and Tlogo Pojok be placed in fourth position with NOx concentration of 0.066 μg/m3.

Table 6. Emission concentration at the shore line area

Area in the shore line	Emission concentration ($\mu r/m^3$)				
	NO_x	SO_x	CO	CO_2	PM
Pelabuhan Semen Gresik	184	377	479	133	3.2
Pelabuhan Petrokimia Gresik	125	280	380	110	5.7
Pelabuhan Tanjung Perak	89.2	213	275	76	4
Petrokimia Gresik	150	279	410	108	5.8
Pelabuhan Gresik	150	315	438	110	6.32
Kemuteran	142	301	420	118	5.5
Tanjung	105	217	310	67	4.3
Gili Barat	90	210	277	66	4
Junganyar	68	115	170	39	2.9
Socah	55	110	156	31	2.3
Pernajuh	72	145	201	53	3
Petaonan	59	130	180	40	2.6
Pasanggrahan	33	150	191	50	3.2
Karanganyar	30	148	168	39	3
Sidorukun	155	281	365	103	6.7
Kebungson	142	314	450	108	6.3
Kroman	152	315	397	105	6.4
Pekelingan	143	310	440	99	6
Tepen	160	315	380	104	6.1
Karangkering	120	246	310	80	4.6
Kalianak	82	160	250	60	3.3
Monokrembangan	90	230	275	74	4.35
Tambak Langon	93	190	250	59	3.7
Tambak Osowilangon	91	201	247	70	4.1
Kedung Cowek	120	210	234	57	4
Kenjeran	53	205	200	50	3
Sukolilo	87	201	170	64	4.6
Tambak Wedi	105	246	330	93	4.5

5. CONCLUDING REMAKS

This paper demonstrates that the use of AIS in combination with GIS and shipping database can be utilized to estimate the emission dispersion produce by ships. Gaussian puff model can be perfectly used to enhance the performance of plume model, in which plume model simulates the emission distribution for steady state condition, while puff model enhances the results in case of unsteady state condition is to be applied.

This kind of research will be even more applicable when it is designed based on real time and dynamical situation so as to enable the result to be used as parameter in examining the quality of air and in controlling the emission concentration due to marine traffic. Though this paper only considers the emission produced by ships, incorporating those of produced by industries will provide a clearer and more sensible results.

Some quantitative findings are obtained from this research:

1. Amount of emitted pollutant in Madura strait due to vessel traffic at the time of study case is:
    a. NO_x : 896.895 kg / hr
    b. SO_x : 1069.376 kg / hr
    c. CO : 1351.586 kg / hr
    d. CO_2 : 585.678 kg / hr
    e. PM : 22.1789 kg / hr
2. The highest concentration of emitted pollutant located at the surrounding of Port of Semen Gresik as below:
    a. NOx : 184,924 µg / m3
    b. SOx : 377,959 µg / m3
    c. CO : 479,086 µg / m3
    d. CO2 : 133,365 µg / m3
    e. PM : 7,634 µg / m3
3. Emitted pollutant such NOx, SOx, CO, CO2 and PM in Madura Strait are not dangerous for environment and human health because the amount of emitted pollutant is under limit according to Indonesian Government Decree No. 5/2010 concerning Pullution Controlling “Baku Mutu Udara Ambien Nasional (BMUAN)”.

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