ON A FUZZY APPLICATION OF THE PARTICULATE MATTERS ESTIMATION

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Abstract. The Bosphorus (Istanbul Strait) that connects the continents of Europe and Asia is too complex due to geographical conditions and have a continuously increasing maritime traffic. The length of the Bosphorus which connect the Black Sea and the Marmara Sea is 29.9 km. The number of ships (Tanker, general Cargo and bulk carrier) passing through the Istanbul strait was recorded as 42553 in 2016 and these transit ships cause more than half of the amount total ship emissions in the Bosphorus. The aim of this study is to estimate the PM amounts emitted from transit vessels passing through the Bosphorus by using fuzzy inference system in MATLAB. Total emissions from ships are expressed by surfaces allowing the analysis of the data according to the gross tonnage and the types of ships.

1. Introduction

PM stands for particulate matter which a mixture of solid particles and liquid droplets found in the air. Some particles are large or dark enough to be seen with the naked eye. Others are so small they can only be seen using an electron microscope. Particulate matters can be made up of hundreds of different chemicals and are in many sizes and shapes. These are emitted directly from some sources, such as power plants, industrie, automobiles and ships. Particulate matter are inhalable particles that get into the air with harmful affects (it was taken the web site of EPA: https://www.epa.gov/pm-pollution) see e.g. [8, 20]. Maritime traffic plays an important role as a significant source of the total air pollution. The exhaust emission causes the environmental problems such as acid rains, climate changes and affects human health as premature death, various lung impacts see e.g. [11, 22]. Many researchers have been studied on the estimation of the ship emission in different regions of the world (see e.g. [9, 10, 19, 23, 30]). Capaldo et al.(1999) studied on the effect of ship emissions on Sulphur cycling and radiative climate furcing over ocean see e.g. [4]. Skjolsvik et al. (2000) studied on green house gas emissions from ships in [25]. Bilgili et al (see e.g. [1, 2, 3]) estimated emissions occurred during operation phase of a ship, they developed some formulas by

Received: September 2017; Revised: December 2017; Accepted: September 2018

Key words and phrases: Particulate matter, Ship, Fuzzy, Surface.

This paper is the extended version of presented paper in "13th Algebraic Hyperstructures and Applications Conference (AHA2017)" which was held during 24-27 July 2017 at Yildiz Technical University, Istanbul, Turkey.

using the relationship between characteristic dimensions of ship and emission methods. The emissions are investigated within the perspective of ship life cycle. Also emission estimating studies were made for Tokyo Bay Area, NE Atlantic region, Tyrrhenian Sea, Turkish Straits, sea of Marmara; Dannish Ports by Onagawa [21], Carlton [5] , Trozzi and Vaccaro [27, 28], Keskin and Vardar [17], Alper [18] and Saxea and Larsena [24]. On the other hand, Corbett and Fischbeck [6], Corbett and Koehler [7], Endresen [12]were estimated globally annual emissions. In recent years some researcher were studied about emission estimation by using fuzzy modeling. Ovun and Uzunsoy [16] were predicted the exhaust emissions values of a spark ignition engine fuelled with gasolinewater macro emulsions, which contains isopropanol using a neuro fuzzy method. Huang et al. see e.g. [13, 14, 15] introduced the identification of fuzzy inference systems based on the multi objective opposition-based space search algorithm (MOSSA) and information granulation (IG) and an NOx emission process that is modeled by using the data of gas turbine power plants. Sohret et al. [29] and Yazar et al. [26] introduced their studies about estimating of aircraft engines exhaust gas emissions. The aim of this study is to estimate the Particle Matters Emission from transit ships passing through the Bosphorus by using fuzzy inference system. The effect of the cruising speed and gross tonnage changes were taken into account in the model. The results are given as surfaces.

2. **Maritime Traffic in the Bosphorus**

As can be seen from Figure 1 (it was taken from http://www.bosphorusstrait.com/the-bosporus-strait/map-of-bosphorus/) the Bosphorus (Istanbul Strait) that connects the continents of Europe and Asia is too complex due to geographical conditions and have a continuously increasing maritime traffic. The length of the Bosphorus which connect the Black Sea and the Marmara Sea is 29.9 km and the width ranges between 700 and 1500 meters. Since more than 50000 transit ships pass through each year from the Bosphorus the maritime traffic is an important air pollution source for Istanbul.

3. **Objectives and Method**

The main objective of this study is to estimate PM amounts from transit ships passing though the Bosphorus. The amounts of PM from ships were calculated by using the methodologies which explained in studies of Trozzi and Voccaro (see [27, 28]) and Kilic (see [18]. Amounts of emissions were calculated by the following equation;

$$E_i = t \cdot P \cdot (EF)_i \cdot [EngineLoad], \tag{1}$$

where i is the pollutant type, t is time, P is engine power in kilowatts (kW), $(EF)_i$ is emission factors of pollutant i, $[Engineload]$ is the percentage of full power of the engine. The gross tonnages and engine powers are presented according to the ship types in Table 1 (see [18]).

The number of ships (Tanker, general cargo and bulk carrier) passing through the Istanbul strait was recorded as 42553 in 2016 and the number of ships according

to ship types are given on Table (2) ,(it was taken from the web-site of DTGM (2016): $https://atlantis.udhb.gov.tr/istatistik/\ gemi_gecis.aspx$ of DTGM).

In Table (1), main and auxiliary engine powers are given in six categories depending on gross tonnages of ships. The numbers of ships in each category are unknown. It is seen in Table (2) that three different types of ships are grouped in three categories according to their gross tonnages. For this particular study, three groups of ships are divided into two separate subgroups for handling together tonnage of the ships and the engine powers. The subgroups can be seen in Table (3). The emission factors for each type of ship are presented in Table (4) (see [18]).

It can be assumed that the engine runs 80 % load of the power of engine (Engine load is 0.8) and 4 generators work during the cruising time and run 75% load of the power of auxiliary engine. The cruising times which are dependant on the weather conditions and the traffic conditions are between $t_{min} = 1.54$ hours and $t_{max} = 2.42$ hours. In order to include the engine powers between the minimum and the maximum power values which are listed in table (2) equation (1) has been modified as the following form:

$$t_{min} \cdot P_{kl} \cdot (EF)_i \cdot [Engineload] \leq E_i \leq t_{max} \cdot P_{kl} \cdot (EF)_i \cdot [Engineload], \quad (2)$$

k: type of ship (n=1, 2, 3; 1:Tanker, 2: Cargo Ship, 3: Bulk Carrier)

l: number of group on Table (3)

The calculated amounts of E_i for one ship by (2) according to gross tonnages and emission factors values which are seen on table (3) and table (4) listed on the table (5) and the minimum values of E_{PM} are for t_{min} and maximum values of E_i are for t_{max} .



FIGURE 1. Maritime Traffic in Bosphorus

Engine Power (kW)						
Ship Types	**< 500 grt**	**500-999 grt**	**1000-4999 grt**	**5000-9999 grt**	**10000-49999 grt**	**> 50000 grt**
Bulk Carier	550	750	2700	5000	8800	17000
Cargo Ships	810	1181	3366	7516	13932	31471
Tanker	751	1003	2160	4854	10376	15997
Auxiliary Engine Power (kW)						
Ship Types	**< 500 grt**	**500-999 grt**	**1000-4999 grt**	**5000-9999 grt**	**10000-49999 grt**	**> 50000 grt**
Bulk Carier	20	40	175	300	380	500
Cargo Ships	56	96	241	615	1396	1914
Tanker	52	65	153	300	425	761

TABLE 1. Ship Types and Engine Power

The Total Number of Ships				
Ship Types	**< 999grt (Group1)**	**1000-9999grt (Group2)**	**> 9999grt (Group3)**	**Total Number of Vessels**
Tanker	110	7964	807	8881
Cargo Ships	320	23177	2354	25851
Bulk Carier	92	7017	712	7821

TABLE 2. Number of Ships Passed Bosphorus

Engine Power (kW)						
	< 999grt (Group1)		**1000-9999grt (Group2)**		**> 9999grt (Group3)**	
Ship Types	**< 500 grt Subgroup 1-1**	**500-999 grt Subgroup 1-2**	**1000-4999 grt Subgroup 2-1**	**5000-9999 grt Subgroup 2-2**	**10000-49999 grt Subgroup 3-1**	**> 50000 grt Subgroup 3-2**
Tanker	$751 \leq P_{11} \leq 1003$		$2160 \leq P_{12} \leq 4854$		$10376 \leq P_{13} \leq 15997$	
Cargo Ships	$810 \leq P_{21} \leq 1181$		$3366 \leq P_{22} \leq 7516$		$13932 \leq P_{23} \leq 31471$	
Bulk Carier	$550 \leq P_{31} \leq 750$		$2700 \leq P_{32} \leq 5000$		$8800 \leq P_{33} \leq 17000$	
Auxiliary Engine Power (kW)						
Ship Types	**< 500 grt Subgroup 1-1**	**500-999 grt Subgroup 1-2**	**1000-4999 grt Subgroup 2-1**	**5000-9999 grt Subgroup 2-2**	**10000-49999 grt Subgroup 3-1**	**> 50000 grt Subgroup 3-2**
Tanker	$52 \leq p_{11} \leq 65$		$153 \leq p_{12} \leq 300$		$425 \leq p_{13} \leq 761$	
Cargo Ships	$56 \leq p_{21} \leq 65$		$241 \leq p_{22} \leq 615$		$1396 \leq p_{23} \leq 1914$	
Bulk Carier	$20 \leq p_{31} \leq 40$		$175 \leq p_{32} \leq 300$		$380 \leq p_{33} \leq 500$	

TABLE 3. The Ship Types and Engine Power (P : Main Engine Power, p: Auxiliary Engine Power)

Emmision Factors						
Ship Types	$(EF)_{NOX}$	$(EF)_{SO2}$	$(EF)_{CO2}$	$(EF)_{HC}$	$(EF)_{PM}$	$(EF)_{SFC}$
Bulk Carier	17.7	10.6	627	0.59	1.61	197
Cargo Ships	14.9	11.2	672	0.50	1.15	211
Tanker	14.00	11.5	699	0.47	1.27	221

TABLE 4. Emission Factors According to Ship Type and the Pollutant (g / kWh)

By using the number of ships given on table (2), for the four different E_{PM} values of each three main groups on table (5), the level of total E_{PM} values of each three main groups are calculated as the following form: Let A_m , B_m , S be seven matrixes. Here $m = 1, 2, 3$ express the number of group.

$m = 1 for (< 999 grt)$:

$$A_1 = [(\alpha_1)_{ij}]_{3\times 4} = \begin{bmatrix} 0.0014 & 0.0019 & 0.0023 & 0.0030 \\ 0.0014 & 0.0021 & 0.0022 & 0.0034 \\ 0.0012 & 0.0017 & 0.0019 & 0.0028 \end{bmatrix}. \tag{3}$$

$m = 2, for (1000 - 9999 grt)$:

$$A_2 = [(\alpha_2)_{ij}]_{3\times 4} = \begin{bmatrix} 0.0042 & 0.0067 & 0.0093 & 0.0146 \\ 0.0060 & 0.0095 & 0.0139 & 0.0218 \\ 0.0066 & 0.0104 & 0.0120 & 0.0190 \end{bmatrix}. \tag{4}$$

$m = 3, for (> 9999 grt)$:

$$A_3 = [(\alpha_3)_{ij}]_{3\times 4} = \begin{bmatrix} 0.0187 & 0.0294 & 0.0294 & 0.0463 \\ 0.0271 & 0.0426 & 0.0547 & 0.0860 \\ 0.020 & 0.0031 & 0.0037 & 0.0058 \end{bmatrix}. \tag{5}$$

$$S = [s_{ij}]_{3\times 3} = \begin{bmatrix} 110 & 7964 & 807 \\ 320 & 23177 & 2354 \\ 92 & 7017 & 712 \end{bmatrix}. \tag{6}$$

$$B_m = [(\beta_m)_{ij}]_{3\times 4} = [s_{im} \cdot (\alpha_m)_{ij}]_{3\times 4}. \tag{7}$$

$m = 1 for (< 999 grt)$:

$$B_1 = [(\beta_1)_{ij}]_{3\times 4} = \begin{bmatrix} 0.154 & 0.253 & 0.209 & 0.330 \\ 0.448 & 0.704 & 0.672 & 1.088 \\ 0.110 & 0.174 & 0.156 & 0.257 \end{bmatrix}. \tag{8}$$

$m = 2, for (1000 - 9999 grt)$:

$$B_2 = [(\beta_2)_{ij}]_{3\times 4} = \begin{bmatrix} 33.4 & 53.35 & 74.06 & 116.27 \\ 139.062 & 220.18 & 322.16 & 505.25 \\ 46.31 & 72.97 & 84.20 & 133.32 \end{bmatrix}. \tag{9}$$

E_{PM} **Ton Year**						
	< 999grt (Group1)		**1000-9999grt (Group2)**		**> 9999grt (Group3)**	
Ship Types	**< 500 grt Subgroup 1-1**	**500-999 grt Subgroup 1-2**	**1000-4999 grt Subgroup 2-1**	**5000-9999 grt Subgroup 2-2**	**10000-49999 grt Subgroup 3-1**	**> 50000 grt Subgroup 3-2**
Tanker	Min. 0.0014 Max. 0.0023	Min. 0.0019 Max. 0.0030	Min. 0.0042 Max. 0.0067	Min. 0.0093 Max.0.0146	Min.0.0187 Max.0.0294	Min. 0.0294 Max. 0.0463
Cargo Ships	Min. 0.0014 Max. 0.0022	Min. 0.0021 Max. 0.0034	Min. 0.0060 Max. 0.0095	Min. 0.0139 Max. 0.0218	Min. 0.0271 Max. 0.0426	Min. 0.0547 Max. 0.0860
Bulk Carier	Min. 0.0012 Max. 0.0019	Min. 0.0017 Max. 0.0028	Min. 0.0066 Max. 0.0104	Min. 0.012 Max. 0.019	Min. 0.020 Max. 0.031	Min. 0.037 Max. 0.058

TABLE 5. E_{PM} According to Ship Types and Their Gross Tonnage for One Ship

$m = 3, for(> 9999grt)$:

$$B_3 = [(\beta_3)_{ij}]_{3\times 4} = \begin{bmatrix} 15.09 & 23.72 & 23.72 & 37.36 \\ 63.79 & 100.28 & 128.76 & 202.44 \\ 14.24 & 22.07 & 26.34 & 41.29 \end{bmatrix}. \tag{10}$$

i : ship type ($i = 1$ tanker, $i = 2$ Cargo ship, $i = 3$ Bulk Carier)
j :PM values ($j = 1$ min, $j = 2$ med1, $j = 3$ med2, $j = 4$ max)(From Table(5))
m : the number of group

4. **Results**

The results given by the equations (8), (9), (10) of the equation (7) are illustrated on Table (6).

Let N and T be two matrixes as the following form:

$$N = [n_{ij}]_{3\times 4} = \begin{bmatrix} 48.68 & 77.32 & 97.98 & 153.96 \\ 203.29 & 321.16 & 451.59 & 708.77 \\ 60.66 & 95.21 & 110.69 & 174.86 \end{bmatrix}. \tag{11}$$

$(N = B_1 + B_2 + B_3)$
$T = \begin{bmatrix} \sum_{k=1}^{3} n_{k1} & \sum_{k=1}^{3} n_{k2} & \sum_{k=1}^{3} n_{k3} & \sum_{k=1}^{3} n_{k4} \end{bmatrix}$
$T = \begin{bmatrix} 312.63 & 493.69 & 660.26 & 1037.59 \end{bmatrix}.$

The amount E_{PM} of the total transit ships passing through the Bosphorus (ton/year)												
Ship Type	**< 999grt (Group1)**				**1000-9999grt (Group2)**				**> 9999grt (Group3)**			
	Min	**Med1**	**Med2**	**Max**	**Min**	**Med1**	**Med2**	**Max**	**Min**	**Med1**	**Med2**	**Max**
Tanker	0.154	0.253	0.209	0.330	33.4	53.35	74.06	116.27	15.09	23.72	23.72	37.36
Cargo Ships	0.448	0.704	0.672	1.088	139.62	220.18	322.16	505.25	63.79	100.28	128.76	202.44
Bulk Carier	0.110	0.174	0.156	0.257	46.31	72.97	84.20	133.32	14.24	22.07	26.34	41.29

TABLE 6. The Amount E_{PM} According to Subgroups

The amount E_{PM} of the total transit ships passing through the Bosphorus E_{PM} (ton/year)				
Ship Type	**Minimum amount**	**Medium 1 amount**	**Medium 2 amount**	**Maximum amount**
Tanker	48.68	77.32	97.98	153.96
Cargo Ships	203.29	321.16	451.59	708.77
Bulk Carier	60.66	95.21	110.69	174.86
Total	**312.63**	**493.69**	**660.26**	**1037.59**

TABLE 7. The Amount E_{PM}

By using the elements of the matrix $T = [t_{ij}]_{1\times 4}$ in (11) the levels of the total E_{PM} are obtained as

$$\begin{aligned} t_{11} \leq (E)_{PM} \leq t_{12} &\Longrightarrow LEVEL - I \\ t_{12} \leq (E)_{PM} \leq t_{13} &\Longrightarrow LEVEL - II \\ t_{13} \leq (E)_{PM} \leq t_{14} &\Longrightarrow LEVEL - III \end{aligned} \tag{12}$$

Results of the equation (12) can be seen graphically in Figure 2.

As mentioned above the gross tonnages and cruising times of the transit ships passing through the Bosphorus are different from each other. For this reason, the particulate matters of these ships are different depending on gross tonnages and cruising times. The diversities of PM are summarized on Table (8).

Tanker Min	Tanker Med	Tanker Max	Cargo Ship Min	Cargo Ship Med	Cargo Ship Max	Bulk Carrier Min	Bulk Carrier Med	Bulk Carrier Max	Total Level
X			X			X			I
X			X				X		I
X			X					X	I
X				X		X			II
X				X			X		II
X				X				X	II
X					X	X			III
X					X		X		III
X					X			X	III
	X		X			X			I
	X		X				X		I
	X		X					X	I
	X			X		X			II
	X			X			X		II
	X			X				X	II
	X				X	X			III
	X				X		X		III
	X				X			X	III
		X	X			X			I
		X	X				X		I
		X	X					X	I
		X		X		X			II
		X		X			X		II
		X		X				X	II
		X			X	X			III
		X			X		X		III
		X			X			X	III

TABLE 8. The Rules of the Estimation According to Gross Tonnage

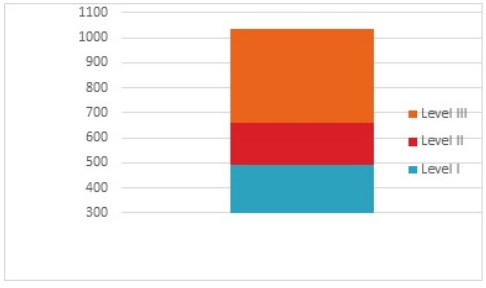


FIGURE 2. Total Amount of PM According to Subgroups

By using Fuzzy Inference System in Mathlab : the rules on Table 8 turn into the following form (in Figure (3)):

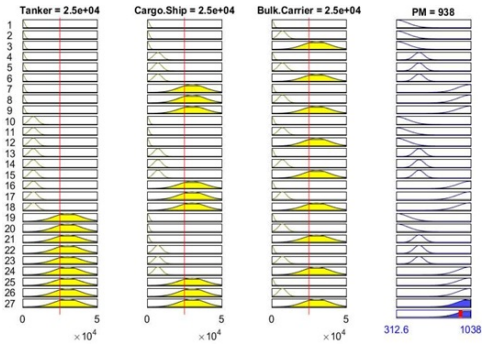


FIGURE 3. The Rule Viewer in Mathlab

The variation of PM values for different ship types according to the grosstonnage of the ships can be seen in Figure (4), (5) and (6). The results are also illustrated by the surfaces in Figure (7), (8) and (9).

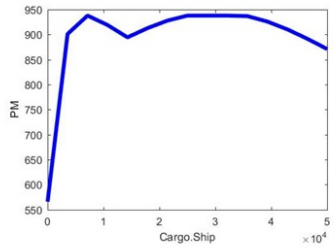


FIGURE 4. PM Level of the Cargo Ships According to Their Gross Tonnage

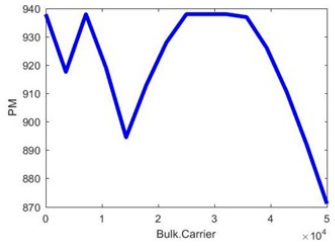


FIGURE 5. PM Level of The Bulk Carrier According to Their Gross Tonnage

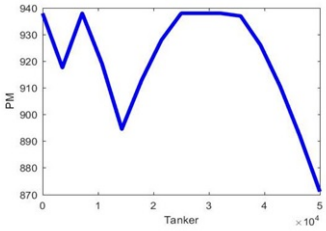


FIGURE 6. PM Level of the Tankers According to Their Gross Tonnage

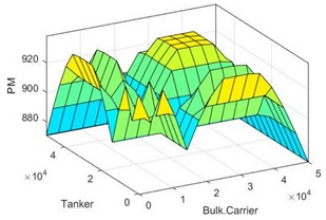


FIGURE 7. The Amount of PM for Tankers and Bulk Carrier According to Their Gross Tonnage

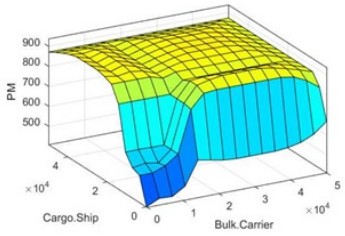


FIGURE 8. The Amount of PM for Cargo Ships and Bulk Carrier According to Their Gross Tonnage

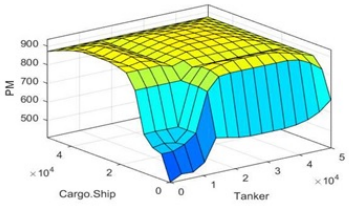


FIGURE 9. The Amount of PM for Tankers and Cargo Ships According to Their Gross Tonnage

5. Conclusions

The Particle Matters (PM) emissions from transit ships passing through the Bosphorus are predicted by using fuzzy inference system. Calculations were made for three different ship types. The effect of the cruising speed and gross tonnage changes of ships were taken into consideration in the model. It is assumed that the engines runs 80% load of maximum power of engine load and that they run at two different cruising times. It seems that the maximum amount of PM occurs from the cargo ships. The results are given as surfaces too.

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