ON A FUZZY APPLICATION OF THE PARTICULATE MATTERS ESTIMATION

F. KANBAY AND N. VARDAR

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...

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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, Tyrrenian Sea, Turkish Straits, sea of Marmara; Danish 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 Koecher [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-bosphorus-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 through the Bosphorus. The amounts of PM from ships were calculated by using the methodologies which explained in studies of Trozzi and Vaccaro (see [27, 28]) and Kilic (see [18]). Amounts of emissions were calculated by the following equation;

\[ E_i = t \cdot P \cdot (EF)_i \cdot [EngineLoad], \]

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 $t_{\text{min}} = 1.54$ hours and $t_{\text{max}} = 2.42$ 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:

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

$k$: 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 $t_{\text{min}}$ and maximum values of $E_i$ are for $t_{\text{max}}$.

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{figure1.png}
\caption{Maritime Traffic in Bosphorus}
\end{figure}
### Engine Power (kW)

<table>
<thead>
<tr>
<th>Ship Types</th>
<th>&lt; 500</th>
<th>500-999</th>
<th>1000-4999</th>
<th>5000-9999</th>
<th>10000-49999</th>
<th>&gt; 50000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Carrier</td>
<td>550</td>
<td>750</td>
<td>2700</td>
<td>5000</td>
<td>8800</td>
<td>17000</td>
</tr>
<tr>
<td>Cargo Ships</td>
<td>810</td>
<td>1181</td>
<td>3366</td>
<td>7616</td>
<td>13932</td>
<td>31471</td>
</tr>
<tr>
<td>Tanker</td>
<td>751</td>
<td>1003</td>
<td>2160</td>
<td>3854</td>
<td>10376</td>
<td>15997</td>
</tr>
</tbody>
</table>

### Auxiliary Engine Power (kW)

<table>
<thead>
<tr>
<th>Ship Types</th>
<th>&lt; 500</th>
<th>500-999</th>
<th>1000-4999</th>
<th>5000-9999</th>
<th>10000-49999</th>
<th>&gt; 50000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Carrier</td>
<td>20</td>
<td>40</td>
<td>175</td>
<td>300</td>
<td>380</td>
<td>500</td>
</tr>
<tr>
<td>Cargo Ships</td>
<td>56</td>
<td>96</td>
<td>241</td>
<td>615</td>
<td>1396</td>
<td>1914</td>
</tr>
<tr>
<td>Tanker</td>
<td>52</td>
<td>65</td>
<td>153</td>
<td>300</td>
<td>125</td>
<td>761</td>
</tr>
</tbody>
</table>

### Table 1. Ship Types and Engine Power

<table>
<thead>
<tr>
<th>Ship Types</th>
<th>&lt; 999grt</th>
<th>1000-9999grt</th>
<th>&gt; 9999grt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessels</td>
<td>(Group1)</td>
<td>(Group2)</td>
<td>(Group3)</td>
</tr>
<tr>
<td>Tanker</td>
<td>110</td>
<td>7964</td>
<td>807</td>
</tr>
<tr>
<td>Cargo Ships</td>
<td>320</td>
<td>23177</td>
<td>2354</td>
</tr>
<tr>
<td>Bulk Carier</td>
<td>92</td>
<td>7017</td>
<td>712</td>
</tr>
</tbody>
</table>

### Table 2. Number of Ships Passed Bosphorus

<table>
<thead>
<tr>
<th>Ship Types</th>
<th>&lt; 999grt</th>
<th>1000-9999grt</th>
<th>&gt; 9999grt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgroup</td>
<td>(P1)</td>
<td>(P2)</td>
<td>(P3)</td>
</tr>
<tr>
<td>Tanker</td>
<td>110</td>
<td>7964</td>
<td>807</td>
</tr>
<tr>
<td>Cargo Ships</td>
<td>320</td>
<td>23177</td>
<td>2354</td>
</tr>
<tr>
<td>Bulk Carier</td>
<td>92</td>
<td>7017</td>
<td>712</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Ship Types</th>
<th>&lt; 500</th>
<th>500-999</th>
<th>1000-4999</th>
<th>5000-9999</th>
<th>10000-49999</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgroup</td>
<td>(P1)</td>
<td>(P2)</td>
<td>(P3)</td>
<td>(P4)</td>
<td>(P5)</td>
</tr>
<tr>
<td>Tanker</td>
<td>52</td>
<td>54</td>
<td>56</td>
<td>58</td>
<td>60</td>
</tr>
<tr>
<td>Cargo Ships</td>
<td>52</td>
<td>54</td>
<td>56</td>
<td>58</td>
<td>60</td>
</tr>
<tr>
<td>Bulk Carier</td>
<td>52</td>
<td>54</td>
<td>56</td>
<td>58</td>
<td>60</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Ship Types</th>
<th>(EF)_{NOX}</th>
<th>(EF)_{SO2}</th>
<th>(EF)_{CO2}</th>
<th>(EF)_{HC}</th>
<th>(EF)_{PM}</th>
<th>(EF)_{SFC}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Carrier</td>
<td>17.7</td>
<td>10.6</td>
<td>627</td>
<td>0.59</td>
<td>1.61</td>
<td>197</td>
</tr>
<tr>
<td>Cargo Ships</td>
<td>14.9</td>
<td>11.2</td>
<td>672</td>
<td>0.50</td>
<td>1.15</td>
<td>211</td>
</tr>
<tr>
<td>Tanker</td>
<td>14.00</td>
<td>11.5</td>
<td>699</td>
<td>0.47</td>
<td>1.27</td>
<td>221</td>
</tr>
</tbody>
</table>
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 ($< 999 grt$):

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

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

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

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

\[
A_3 = [(\alpha_3)_{ij}]_{3 \times 4} = \begin{bmatrix}
0.0187 & 0.0294 & 0.0294 & 0.0463 \\
0.0271 & 0.0426 & 0.0547 & 0.0860 \\
0.0200 & 0.0031 & 0.0037 & 0.0058 \\
\end{bmatrix}.
\] (5)

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

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

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

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

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

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

<table>
<thead>
<tr>
<th>Ship Types</th>
<th>$&lt; 500$ grt Subgroup 1-1</th>
<th>$&lt; 500-999$ grt Subgroup 1-2</th>
<th>$1000-4999$ grt Subgroup 2-1</th>
<th>$5000-9999$ grt Subgroup 2-2</th>
<th>$10000-49999$ grt Subgroup 3-1</th>
<th>$&gt; 50000$ grt Subgroup 3-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanker</td>
<td>Min. 0.0014 Max. 0.0023</td>
<td>Min. 0.0019 Max. 0.0030</td>
<td>Min. 0.0042 Max. 0.0067</td>
<td>Min. 0.0095 Max. 0.0146</td>
<td>Min. 0.0187 Max. 0.0284</td>
<td>Min. 0.0294 Max. 0.0463</td>
</tr>
<tr>
<td>Cargo Ships</td>
<td>Min. 0.0014 Max. 0.0022</td>
<td>Min. 0.0017 Max. 0.0034</td>
<td>Min. 0.0060 Max. 0.0119</td>
<td>Min. 0.0165 Max. 0.0218</td>
<td>Min. 0.0271 Max. 0.0547</td>
<td>Min. 0.0600 Max. 0.0860</td>
</tr>
<tr>
<td>Bulk Carrier</td>
<td>Min. 0.0012 Max. 0.0019</td>
<td>Min. 0.0017 Max. 0.0028</td>
<td>Min. 0.0066 Max. 0.0104</td>
<td>Min. 0.0101 Max. 0.019</td>
<td>Min. 0.020 Max. 0.031</td>
<td>Min. 0.037 Max. 0.058</td>
</tr>
</tbody>
</table>

Table 5. $E_{PM}$ According to Ship Types and Their Gross Tonnage for One Ship
$m = 3$, for ($> 9999$grt) :

$$B_3 = [(\beta_{3})_{ij}]_{3 \times 4} = \begin{bmatrix}
15.09 & 23.72 & 23.72 & 37.36 \\
63.79 & 100.28 & 128.76 & 202.44 \\
14.24 & 22.07 & 26.34 & 41.29
\end{bmatrix}.$$  \hspace{1cm} (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:

$$N = [n_{ij}]_{3 \times 4} = \begin{bmatrix}
48.68 & 77.32 & 97.98 & 153.96 \\
203.29 & 321.16 & 451.59 & 708.77 \\
60.66 & 95.21 & 110.69 & 174.86
\end{bmatrix}. \hspace{1cm} (11)$$

$N = B_1 + B_2 + B_3$

$$T = \begin{bmatrix}
\sum_{k=1}^{3} n_{k1} & \sum_{k=1}^{3} n_{k2} & \sum_{k=1}^{3} n_{k3} & \sum_{k=1}^{3} n_{k4}
\end{bmatrix}$$

$$T = \begin{bmatrix}
312.63 & 493.69 & 660.26 & 1037.59
\end{bmatrix}.$$

The amount $E_{PM}$ of the total transit ships passing through the Bosphorus

<table>
<thead>
<tr>
<th>Ship Type</th>
<th>$&lt; 999$grt (Group1)</th>
<th>1000-9999grt (Group2)</th>
<th>$&gt; 9999$grt (Group3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Med1</td>
<td>Max</td>
</tr>
<tr>
<td>Tanker</td>
<td>0.154</td>
<td>0.253</td>
<td>0.389</td>
</tr>
<tr>
<td>Cargo Ships</td>
<td>0.448</td>
<td>0.704</td>
<td>1.088</td>
</tr>
<tr>
<td>Bulk Carier</td>
<td>0.110</td>
<td>0.174</td>
<td>0.257</td>
</tr>
</tbody>
</table>

Table 6. The Amount $E_{PM}$ According to Subgroups

The amount $E_{PM}$ of the total transit ships passing through the Bosphorus

<table>
<thead>
<tr>
<th>Ship Type</th>
<th>Minimum amount</th>
<th>Medium 1 amount</th>
<th>Medium 2 amount</th>
<th>Maximum amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanker</td>
<td>48.68</td>
<td>77.32</td>
<td>97.98</td>
<td>153.96</td>
</tr>
<tr>
<td>Cargo Ships</td>
<td>203.29</td>
<td>321.16</td>
<td>451.59</td>
<td>708.77</td>
</tr>
<tr>
<td>Bulk Carier</td>
<td>60.66</td>
<td>95.21</td>
<td>110.69</td>
<td>174.86</td>
</tr>
<tr>
<td>Total</td>
<td>312.63</td>
<td>493.69</td>
<td>660.26</td>
<td>1037.59</td>
</tr>
</tbody>
</table>

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

\[
t_{11} \leq (E)_{PM} \leq t_{12} \implies LEVEL - I \\
t_{12} \leq (E)_{PM} \leq t_{13} \implies LEVEL - II \\
t_{13} \leq (E)_{PM} \leq t_{14} \implies LEVEL - III
\]

(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).

<table>
<thead>
<tr>
<th>Cargo Ship Min</th>
<th>Cargo Ship Med</th>
<th>Cargo Ship Max</th>
<th>Bulk Carrier Min</th>
<th>Bulk Carrier Med</th>
<th>Bulk Carrier Max</th>
<th>Total Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

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

![Figure 2. Total Amount of PM According to Subgroups](image)
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](image)

The variation of PM values for different ship types according to the gross tonnage 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](image)

![Figure 5. PM Level of The Bulk Carrier According to Their Gross Tonnage](image)
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.

REFERENCES


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