TRANSNAV the International Journal on Marine Navigation and Safety of Sea Transportation
http://www.transnav.eu
Volume 15
Number 3
September 2021
DOI: 10.12716/1001.15.03.15

Distribution of the International Marine Traffic Air Pollutant Emissions in the Port of Split

L. Mihanović[1], B. Lalić[2], K. Bratić[2] & L. Stazić[2]
[1] *Croatian Military Academy "Dr Franjo Tuđman", Zagreb, Croatia*
[2] *University of Split, Split, Croatia*

ABSTRACT: The paper describes the initial part of the research into the impact of the Port of Split marine traffic on the environment and the city. The Port of Split is situated in the middle of the Adriatic Sea and it is one of busiest marine traffic regions in the Mediterranean. The Port consists of six geographically separated basins, two of them for smaller vessels, other four for the international marine traffic. The paper presents type and size of vessels in basins, engine size, stay in Port and finally quantity of the international marine traffic air pollutant emission per each basin. The distribution of the international marine traffic and its air pollutant emission pinpoint exactly main sources of the emissions in the area around the city and its dependency on various factors linked to the vessels, showing that the city is encircled by with multiple pollution sources.

1 INTRODUCTION

The research described in the paper is the initial part of the research into the impact of Port of Split marine traffic on the environment and the city. The research is similar to other researches [4, 6] trying to determine best and most effective means to reduce overall pollution. "The Port of Split is one of busiest marine traffic regions in the Adriatic Sea and third largest port in the Mediterranean" [2, 9]. The Port of Split consists of several geographically separated units or basins situated at different locations around the city [8] (Figure 1).

Four of the basins are designated for the international marine traffic:

- Gradska luka basin, or City harbour basin is part of the Port of Split situated near the centre of the city. There are 27 berths for various ship size with maximal draught of 10.5 meters [8].
- Vranjic-Solin basin, is situated at the, 4 kilometres north from centre of the city. It is called also "Sjeverna luka" (Northern harbour). There are 8 berths with maximal draught of 10.3 meters [8].
- Kaštela B basin is situated at the northern part of the Kaštela Bay, at the place called Kaštel Sućurac. There are 5 berths for ships with draught of 6.8 to 8.5 meters [8].
- Kaštela C basin is situated at the north eastern part of the Kaštela Bay, at the place called Sv Kajo. There are 8 berths for ships with draught of 4.0 to 10.5 meters [8].

As the article is considering the international marine traffic air pollutant emission distribution, only above listed four basins will be analysed in the article. Kaštela basins A and D are not included in this analysis due to their predestined purpose for national traffic.

Figure 1. Port of Split basins

There is also limit of the size of vessels in this analysis. To exclude numerous smaller vessels like fishing boats and yachts, all vessels smaller than 500 GT are removed from this inventory.

2 THE METHODOLOGY

The Port of Split international marine traffic air pollutant emission is the sum of emissions per basins, given in the Equation 1:

$$E_{Total} = E_{Gradska\ luka} + E_{Vranjic-Solin} + E_{Kastela\ B} + E_{Kastela\ C} \quad (1)$$

where:
E - Emission

Air pollutant emission calculation used in this paper is using the ship engines' power [11] and is recommended by the EMEP/EEA (2009) air pollutant emission inventory guidebook [3]. That method is called a full bottom-up model because "emission evaluation is bottom up, and the geographical characterization of emissions is bottom-up'' [5, 12]. To enable this model, extensive data about ship and ship movement in the port has been collected, obtaining the information from the Split port authority [6] and Port of Split [10].

Air pollutant emission is calculated separately for each basin, for manoeuvring and for whole period on berth (so called hotelling). Manoeuvring to and from the berth is calculated separately in order to quantify the air pollutant emission according to the activity of the vessel. Manoeuvring air pollutant emission is calculated according to equation [11]:

$$E_{maneuvering} = \frac{D}{v} \cdot \left[\left(ME \cdot LF_{ME} \cdot EF \right) + \left(AE \cdot LF_{AE} \right) \cdot EF \right] \quad (2)$$

where:
D – Distance travelled (NM),
v – Average ship speed (knots),
ME – Main engine power (kW),
LF_{ME} – Main engine load factor (%),
AE – Auxiliary engine power (kW),
LF_{AE} – Auxiliary engines load factor (%),
EF – Emission factor, vary on the type of fuel and the engine speed (g/kWh).

Main engine and auxiliary engines load factors are taken from the methodology recommendations [3, 11], as well as emission factors. Both papers [3, 11] are recommending same factors which vary upon engine size, type of fuel, type of engine, engine manufacturing year,…. Manoeuvring distances for the Port of Split are calculated as a distance between pilot boarding station (cca 0.5 Nm in front of Gradska luka) and basins. Manoeuvring distances for the Port of Split are given in the Table 1:

Table 1. Manoeuvring in Port of Split [based on [9]]

Berthing point	Manoeuvring distance
Gradska luka basin	0.5 Nm
Vranjic-Solin basin	6.93 Nm
Kaštela B basin	5.67 Nm
Kaštela C basin	6.52 Nm

Following the recommendation of the International Regulations for Preventing Collisions at Sea [1], the manoeuvring speed in the Port of Split and approach is reduced to 6-8 knots [7]. During stay in the port ships are emitting the following air pollutant emission:

$$E_{hotelling} = T \cdot \left[AE \cdot LF_{AE} \cdot EF \right] \quad (3)$$

where:
T – Average time at berth (h).

3 STATISTICS OF ARRIVALS PER BASINS

Gradska luka is passenger port and only passenger ships are visiting Gradska luka basin. Table 2 shows total number of arrivals of cruise ships in 2017 and 2018; value in brackets is giving the percentage of overall arrivals in the Port of Split in that year.

Table 2. International cruise vessels in the Port of Split

Gradska luka basin		
	2017	2018
Cruise ships	232	247
Percentage of all arrivals (%)	29.97	32.58%
Average time in port [h]	15.91	15.52
Average engine size [kW]	14980	19970

Table 3 is presenting data of cargo ships in the international marine traffic, sorted according to basins. All tables have fields with average time in port and average engine size which will be used later in discussion.

Table 3. International cargo marine traffic in the Port of Split

Basin:	Vranjic-Solin		Kaštela C		Kaštela B	
Ship type	2017	2018	2017	2018	2017	2018
Bulk Carrier	97	80	12	10	221	172
Tanker	nil	nil	115	122	nil	1
Container	39	40	nil	nil	1	nil
General/other	20	52	23	6	14	28
Total	156	172	150	138	236	201
Percentage of all arrivals	20.16%	22.69%	19.38%	18.21%	30.49%	26.52%
Average time in port [h]	54.66	47.10	29.21	25.46	36.89	44.03
Average engine size [kW]	3486	3663	1816	1729	1243	1141

4 AIR POLLUTANT EMISSION IN 2017 AND 2018

The calculation of manoeuvring air pollutant emissions is performed according to Equations 2 and 3, using average manoeuvring speed of 8 knots, while the manoeuvring distance (d) is changed according to data given in Table 1.

Table 4. Air pollutants in Port of Split in 2017 [9]

Tons	Manoeuvring			In port		
	SOx	PM	NOx	SOx	PM	NOx
Gradska luka	0.65	0.63	18.07	10.09	9.84	283.45
Kaštela B	0.04	0.04	1.21	0.32	0.31	9.74
Kaštela C	0.03	0.03	0.95	0.36	0.35	9.83
Vranjic-Solin	0.06	0.06	1.82	0.44	0.43	13.60
Total	0.78	0.76	22.05	11.21	10.93	316.62

When all emissions are added together, total air pollutant emission of the international marine traffic in 2017 in the Port of Split was:
- SOx – 11.99 ton,
- PM – 11.69 ton,
- NOx – 338.67 ton.

Table 5. Air pollutants in Port of Split in 2018

Tons	Maneuvering			In port		
	SOx	PM	NOx	SOx	PM	NOx
Gradska luka	0.91	0.89	25.04	13.36	13.03	365.73
Kaštela B	0.03	0.03	0.99	0.29	0.29	8.86
Kaštela C	0.03	0.03	0.81	0.30	0.29	8.17
Vranjic-Solin	0.05	0.05	1.65	0.47	0.46	13.78
Total	1.02	1.00	28.49	14.42	14.07	396.54

Total air pollutant emission of the international marine traffic in 2018 in the Port of Split was:
- SOx – 15.44 ton,
- PM – 15.07 ton,
- NOx – 425.03 ton.

5 AIR POLLUTANT EMISSION DISTRIBUTION

Distribution of the NOx air pollution emission is presented in Figures 2 and 3, respectively for each year separately. Other pollutants share for each basin is very similar to the presented NOx air pollution distribution.

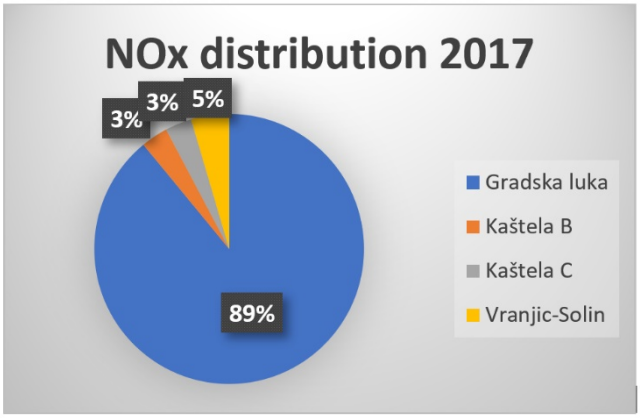

Figure 2. Distribution of NOx emissions in 2017

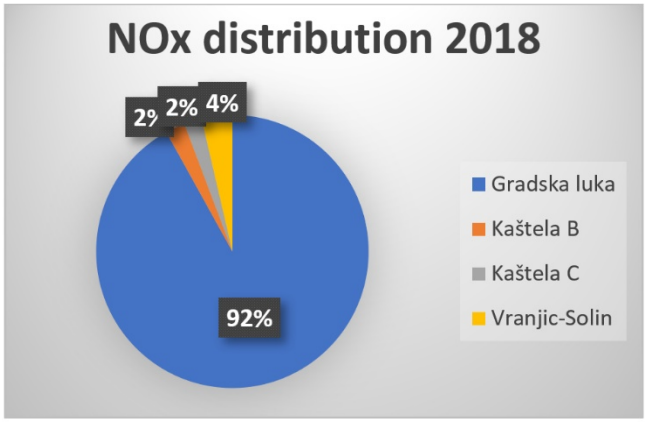

Figure 3. Distribution of NOx emissions in 2018

From Figures 2 and 3 it is visible that overall air pollutant emission distribution changed from 2017 to 2018. Gradska luka basin, as a berthing port for cruise vessels increased its share of the pollution to from 89% to 92%. All other basins decreased their share of the air pollutant emission despite the fact that there was a slight increase of the overall air pollutant emission in the Vranjic-Solin basin.

6 DISCUSSION

Results presented in Tables 4 and 5 show significant increase of over 25% of the overall air pollutant emissions in the period of one year. Tables 2 and 3 give the reason of this increase. Although overall international marine traffic in 2018 in the Port of Split slightly decreased, from 774 to 758 arrivals (the decrease of 2%), there was an increase of the arrivals of cruise vessels, as it is visible on the Figure 4. Cruise traffic share of arrivals raised 2.5% to close to one third of all international marine arrivals in 2018.

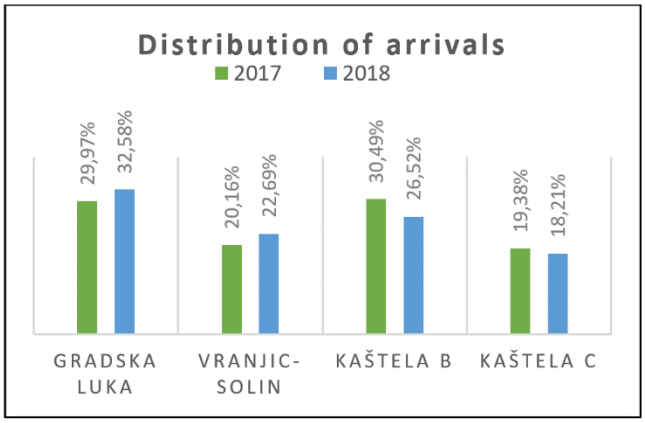

Figure 4. Arrivals in Port of Split

Average time in port is compared on the Figure 5 and shows that values changed, but the overall change is not significant.

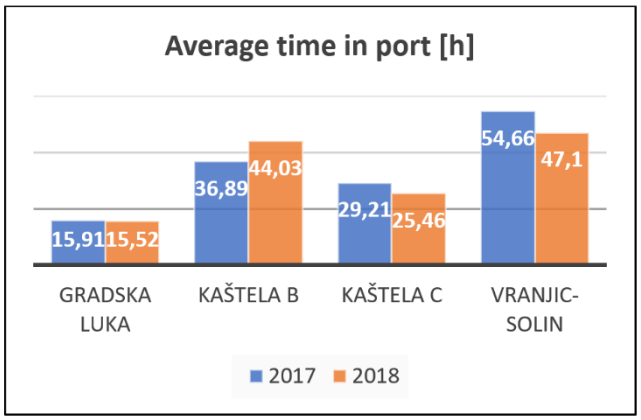

Figure 5. Average time in port [h]

The last analysed parameter give the real reason for the increase of the overall air pollutant emission of the international marine traffic in the 2018. As it is visible on the Figure 6, the average size of cruise vessels engines increased significantly from around 15000 kW to close to 20000 kW.

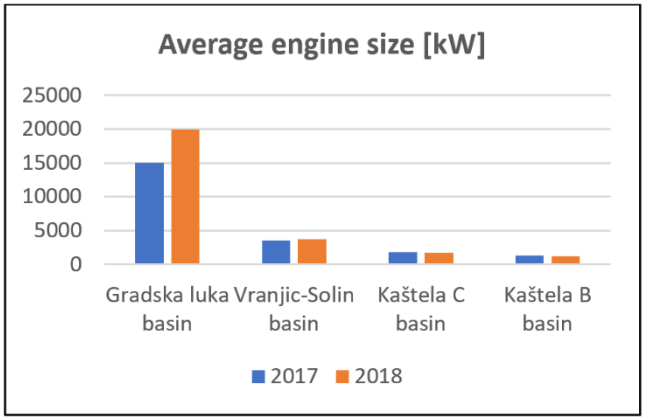

Figure 6. Average engine size [kW] in 2017 and 2018

This reason, together with the increased number of cruise vessels arriving to the Port of Split caused mentioned increase of the air pollutant emission.

7 CONCLUSION

Total air pollutant emission of international marine traffic in Port of Split increased from 2017 to 2018 by more than 25%. At the same time, overall number of arrivals in the international marine traffic decreased by 2% while stay in port changed only slightly, not causing mentioned increase of the air pollutant emission.

That increase is explained in the increase of the number of overall cruise vessels arrivals in 2018, combined with the increase of the ship and engine size (cruise ship engine size increased by 33% in 2018).

Distribution of the air pollutant sources is in line with above presented facts. Due to the much larger engine size (5-10 times larger, depends of the basin) and much larger fuel consumption, majority of the air pollutant emission sources is concentrated in the Gradska luka basin, where 89% of all international marine traffic air pollutant emission was released in 2017. In 2018 that percentage increased tom 92%, followed with the increase off the size of vessels and respectively engines.

REFERENCES

1. COLREGS: International Regulations for Preventing Collisions at Sea, https://www.jag.navy.mil/distrib/instructions/COLREG-1972.pdf, last accessed 2020/09/01.
2. Croatian Technical Encyclopedia: The Port of Split, https://tehnika.lzmk.hr/luka-split/, last accessed 2020/08/27.
3. European Environment Agency: EMEP/EEA air pollutant emission inventory guidebook 2016 : technical guidance to prepare national emission inventories. Publications Office of the European Union, Denmark (2016).
4. Gutierrez-Torre, A., Berral, J.Ll., Buchaca, D., Guevara, M., Soret, A., Carrera, D.: Improving maritime traffic emission estimations on missing data with CRBMs. Engineering Applications of Artificial Intelligence. 94, 103793 (2020). https://doi.org/10.1016/j.engappai.2020.103793.
5. Miola, A., Ciuffo, B.: Estimating air emissions from ships: Meta-analysis of modelling approaches and available data sources. Atmospheric Environment. 45, 13, 2242–2251 (2011). https://doi.org/10.1016/j.atmosenv.2011.01.046.
6. Myszka, A., Kaizer, A.: Analysis of the Vessels' Service Time in the Port of Gdańsk, Based on the Time Registration of Ships Entries and Departures, as a Proposition of Multi-aspect Method of Port Monitoring. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 14, 2, 465–468 (2020). https://doi.org/10.12716/1001.14.02.26.
7. Split Maritime Pilots: https://www.splitpilot.com/copy-of-area, last accessed 2020/09/01.
8. Split Port Authority: Port areas in which the jurisdiction of the Port Authority Split extends, https://portsplit.hr/en/luka-split/lucka-podrucja/, last accessed 2020/08/27.
9. Stazić, L., Radonja, R., Pelić, V., Lalić, B.: The Port of Split international marine traffic emissions inventory. Pomorstvo. 34, 1, 32–39 (2020). https://doi.org/10.31217/p.34.1.4.
10. The Port of Split: http://www.lukasplit.hr/, last accessed 2020/09/01.
11. Trozzi, C.: Emission estimate methodology for maritime navigation. Presented at the 9th International Emissions Inventory Conference , San Antonio, Texas, USA (2010).
12. Wahl, C., Scarbrough, T., Stavrakaki, A., Green, C., Squire, J., Noden, R.: UK Ship Emissions Inventory, Final Report, https://naei.beis.gov.uk/reports/reports?report_id=636, last accessed 2020/09/01.