A Way Toward Low-Carbon Shipping: Improving Port Operations Planning using Machine Learning

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Abstract

Despite being the most carbon-efficient way of transportation, shipping is an important contributor to air pollution especially in coastal areas. The sector's impact on the environment still need mitigation, through different measures undertaken so far. Operational optimization of ports and ships is a step in shipping progress towards reducing the pollution. The main purpose of this research is to reduce the degree of error and uncertainty of some operational parameters using Machine Learning models, and provide port managers with accurate information to assist them in their decision-making process. Therefore, they will be able to manage ships speed and port times for a better monitoring of ships emissions during sea voyage and port stay.

1 Shipping and climate change:

Over 80% of international trade by volume is carried by ships, and relatively speaking, they are the most fuel-efficient means of transportation in terms of g CO_2/ton-km [1]. However, the sector has a significant carbon footprint as a whole, especially international shipping accounting for 2.02% of global CO_2 emissions in 2018 [2]. No particular economies are directly held liable for this emissions source, that being so, the International Maritime Organization (IMO) takes the lead to reduce shipping emissions. IMO is the specialized agency of the United Nations which is responsible for the technical regulation of maritime transport, in particular the prevention and control of pollution engendered by ships. By taking actions to mitigate climate change, IMO supports the UN Sustainable Development Goal 13, and contribute to the global fight against climate change.

IMO has just released the final report of Greenhouse Gas (GHG) study [2], stating that shipping share of global CO_2 emissions increased from 2.76% in 2012 to 2.89% in 2018. Total maritime transport GHG emissions increased by 9.6% from 977 million tons in 2012 to 1076 million tons in 2018. However, IMO's ongoing efforts toward low-carbon shipping were reflected by 10% lower emissions level in 2018 compared to 2008, although seaborne trade increased by 40% in the same period. Despite further efficiency gains, the study forecasts that 2050 shipping emissions will increase by up

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to 50% over 2018 levels, as a result of the high prediction in transport demand. Furthermore, shipping is still responsible of important emissions of other relevant substances. Annual global contribution is estimated to be 13% in Sulfur Oxides (SO_x) as most marine fuels has high sulfur content, and 15% in Nitrogen Oxides (NO_x) [3]. Shipping emissions have a significant impact on human health and were responsible for approximately 400 000 premature deaths from lung cancer and cardiovascular diseases and 14 million childhood asthma cases annually; measures such as adopting low sulfur fuel in shipping would save 266 300 lives from premature death in 2020 [4]. For instance, between 14 500 and 37 500 premature deaths were caused by shipping in East Asia during 2013 [5]. The health impact of ship emissions is particularly concentrated in dense coastal areas, as most of ships emissions are generated during routine operations such as in-port activities, with approximately 70% of ships emissions happening within 400 km of coastlines [6, 7].

In order to minimize maritime pollution, the IMO developed the International Convention for the Prevention of Pollution from Ships called MARPOL [8], with requirements regarding dumping, oil and air pollution. With the purpose of further minimizing airborne emissions from ships, a number of regulations have been defined under MARPOL. The actions include the introduction of Emission Control Areas to reduce air pollutants in specific regions and the use of low sulfur fuel oil to become effective from 01 January 2020 [9]. Two major actions were added in 2011 about energy efficiency of ships [10]. The first is the Energy Efficiency Design Index (EEDI), a mandatory technical measure for new ships, and the second is the Ship Energy Efficiency Plan (SEEMP) which is an operational measure to monitor ships energy efficiency. The SEEMP is based on a wide range of measures to increase energy efficiency either from ship design or operations. One of the operational measures is voyage optimization, including all the actions for optimizing ship operations considering logistics, scheduling, and contractual constraints, and this measure can itself achieve 1 to 10% savings in CO2 emissions [11]. Voyage optimization includes just-in-time arrivals policy, which aim is to make ships reach their port destination at a revised arrival time when delays are detected at port. The implementation of just-in-time arrivals require a commitment from all stakeholders to improve the ship-shore relationship, as well as an amenable operation model. IMO is pushing for the adoption of just-in-time ships operations through its public-private partnership initiative the GIoMEEP Global Industry Alliance [12], which focuses on measures to overcome operational and contractual barriers.

The importance of just-in-time sailing is shown by the results of a study commissioned by the Port of Rotterdam Authority and the TNO research institute (Netherlands Organization for Applied Scientific Research) [13]. According to the study, keeping ships updated accurately about berthing times enable them to adjust their speed and lower their gas emissions. Moreover, further reduction is feasible through shortening waiting time at the port area. The study found that for the Port of Rotterdam, adopting just-in-time arrivals could help avoiding 4% or 134 000 tons of CO_2 emissions every year from containerships activity. For the waiting times, the study found that shortening the waiting time of bulkers by 12 hours could reduce the emissions by 35% or 188 000 tons of CO_2. In another evaluation, for a particular voyage, the application of just-in-time measure led to 23% less fuel consumption compared to usual practice [14]. However, the implementation of this measure may be difficult, as it depends on many uncertain parameters. This implementation requires updating arriving ships with their estimated time of berthing. Also, the time spent by previous ships must be determined with precision. To do that, cooperation is needed between different actors in order to control the time needed for different tasks executed at berth.

Operational optimization is an important element in the maritime decarbonization challenge. Adopting new technologies and green fuels with high expenditure can have a huge impact on shipping global carbon footprint, but would also take too much time to implement. Achieving short-term performance is otherwise possible, by adopting efficient operations at the port and ship levels. In this context, we want to take a further step in the effort to reduce emissions from maritime transport, by improving port operations planning and scheduling using Machine Learning. This application will help in implementing just-in-time arrivals to respond to air quality issues experienced in coastal areas. Adopting such approach not only supports the attainment of the UN Sustainable Development Goal 13 related to climate action, but also Goal 12 of responsible consumption and production, both at the port and the ship levels.

Our application will focus first on a North African port located in Morocco, but will be extended subsequently to include other ports. Morocco is one of the most committed countries to fight against climate change. Ranked third after Sweden and Denmark according to the Climate Change Performance Index 2020, Morocco has recently invested vastly in renewable energies [15]. On another note, with 60% of the population and 90% of the industry located along coastlines [16], an effort for reducing shipping emissions in coastal areas will be more than welcome. Our work will contribute to reduce harmful emissions to air from ships, the measures are expected to have a significant beneficial impact on the atmospheric environment and on health, particularly for communities living nearby the port area (2 million people). Our work will also establish a methodology for assessing the emissions generated by ships under the just-in-time policy.

2 Improving port operations planning and scheduling using Machine Learning:

Ports are considered as complex systems in which many actors interact to achieve the objective of loading and unloading ships. Optimization models and Machine Learning have been successfully used to improve port operations efficiency and reduce emissions, through applications using real-time data from the landside and the seaside [17]. Port terminals rely on optimization models to manage their operations, but they are still affected by many disruptions, in particular, the uncertainty related to service time and ships arrival time [18]. To improve operations management and planning models, Machine Learning can be used to help monitoring operational parameters [19]. Therefore, to assist the implementation of just-in-time arrivals, we propose a supporting system to improve port operations planning and scheduling, that would be easily adaptable to any port. This system will forecast ships arrival time and berth productivity in order to provide reliable planning and optimize ship's speed accordingly. We also suggest monitoring ships emissions and emphasize avoided emissions as an impact of the application of just-in-time arrivals. We will use two maritime data sources, Automatic Identification System (AIS) data and port operations data. AIS is a vessel tracking system that provides regular updates on a vessel's movement and other relevant ship voyage. Data is available and can be obtained from governmental and open source providers as well as private and commercial sources [20]. Information about port operations will be provided by port terminal operators and port authorities. The data include historical details of port calls, berth schedules and times spent by ships at port. The work presented here comprise three modules that will assist terminal operations planning:

- **Ships arrival time prediction**: from a dynamic perspective, we will provide real-time prediction of ships arrival time, thus updating the prediction when needed for a thorough monitoring of the operations. The proposed framework is based on Deep Learning models as they are a promising tool for the prediction of arrival times. We will combine ships trajectory data from AIS and weather conditions to improve the prediction. The challenge would be to find a generic solution dealing with different types of ships and trajectories.
- **Berth productivity estimation**: operations at berth are affected by several factors leading to variations in loading and unloading rates or berth productivity. Disruptions can come from weather conditions such as wind and tides, human strikes, machine breakdowns and many others. Being able to forecast berth productivity will reduce the variation of time spent at berth and provide a better visibility on future operations. We want to work on a system based on historical operational data with capability of learning from past events to provide good estimate of berth productivity. Our system will be based on data from terminal operators and Machine Learning models. For that, we will use data about past berth schedules and operations records, these documents may vary from port to port, but they contain more or less the same information. Berth schedules are usually a graphic document similar to Gantt charts, representing ships at quays with estimated time of arrival, berthing and departure, number of cranes, berth number and ship length. Operations reports are documents where details about each port call are recorded. This report contains information about ships, handled cargo, tonnage, operations suspension and related causes.
- **Emissions monitoring**: We will set up a suitable port related performance indicator of energy efficiency that will reflect ships emissions changes as a result of the application of just-in time arrivals. Activity based emissions inventory will be performed as per Canada's National Marine Emissions Inventory Tool [21] approach. This method is based on ships trajectory data from AIS and Coast Guard information system, associated to engine and vessel details to provide accurate estimation of emissions. The proposed indicator will characterize the port-related activity as a responsive tool reflecting daily practices performance.

References

[1] R. Sims, R. Schaeffer, F. Creutzig, X. Cruz-Núñez, M. D'Agosto, D. Dimitriu, M.J. Figueroa Meza, L. Fulton, S. Kobayashi, O. Lah, A. McKinnon, P. Newman, M. Ouyan, J.J. Schauer, D. Sperling, and G. Tiwari, "Transport," in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx, Ed. Cambridge: Cambridge University Press, 2014, ch. 8.

[2] IMO, *Fourth IMO Greenhouse Gas Study 2020: Reduction of GHG emissions from ships*. London: International Maritime Organization (IMO), 2020.

[3] IMO, *Third IMO Greenhouse Gas Study 2014: Safe, secure and efficient shipping on ocean*. London: International Maritime Organization (IMO), 2014.

[4] M. Sofiev, J. J. Winebrake, L. Johansson, E. W. Carr, M. Prank, J. Soares, J. Vira, R. Kouznetsov, J.-P. Jalkanen, and J. J. Corbett, "Cleaner fuels for ships provide public health benefits with climate tradeoffs," *Nature Communications*, vol. 9, p. 406, 2018.

[5] H. Liu, M. Fu, X. Jin, Y. Shang, D. Shindell, G. Faluvegi, C. Shindell, and K. He, "Health and climate impacts of ocean-going vessels in east asia," *Nature Climate Change*, vol. 6, no. 11, pp. 1037–1041, 2016.

[6] S. K. Ng, C. Loh, C. Lin, V. Booth, J. W. Chan, A. C. Yip, Y. Li, and A. K. Lau, "Policy change driven by an AIS-assisted marine emission inventory in hong kong and the pearl river delta," *Atmospheric Environment*, vol. 76, pp. 102–112, 2013.

[7] S. Song, "Ship emissions inventory, social cost and eco-efficiency in Shanghai Yangshan port," *Atmospheric Environment*, vol. 82, pp. 288–297, 2014.

[8] IMO, "Inernational convention for the prevention of pollution from ships MARPOL," http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx, accessed: 2020-09-13.

[9] IMO. Inernational convention for the prevention of pollution from ships MARPOL - Annex VI Prevention of Air Pollution from Ships. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx. Accessed: 2020-09-13.

[10] IMO, "Inernational convention for the prevention of pollution from ships MARPOL - Annex VI - Energy Efficiency Measures," http://www.imo.org/en/OurWork/environment/pollutionprevention/airpollution/pages/technical-and-operational-measures.aspx, accessed: 2020-09-13.

[11] Ø. Buhaug, J. Corbett, Ø. Endresen, V. Eyring, J. Faber, S. Hanayama, D. Lee, D. Lee, H. Lindstad, A. Markowska, A. Mjelde, D. Nelissen, J. Nilsen, C. Pålsson, J. Winebrake, W. Wu, and K. Yoshida, *Second IMO Study 2009*. London: International Maritime Organization (IMO), 2009.

[12] GLoMEEP, "Global maritime energy efficiency partnerships," https://glomeep.imo.org/, accessed: 2020-09-10.

[13] Port of Rotterdam, "'Just-in-time' sailing saves hundreds of thousands of tonnes of CO2," https://www.portofrotterdam.com/en/news-and-press-releases/just-in-time-sailing-saves-hundreds-of-thousands-of-tonnes-of-co2, accessed: 2020-09-12.

[14] Port of Rotterdam, "Desktop just-in-time trial yields positive results in cutting emissions," https://www.portofrotterdam.com/en/news-and-press-releases/desktop-just-in-time-trial-yields-positive-results-in-cutting-emissions, accessed: 2020-09-12.

[15] Climate Change Performance Index 2020, https://www.climate-change-performance-index.org/, accessed: 2020-09-10.

[16] United States Agency for International Development, “Climate risk profile - Morocco,” https://www.climatelinks.org/sites/default/files/asset/document/2016_USAID_Climate%20Risk%20Profile%20-%20Morocco.pdf, accessed: 2020-09-17.

[17] P. Cammin, M. Sarhani, L. Heilig, and S. Voß, “Applications of real-time data to reduce air emissions in maritime ports,” in *International Conference on Human-Computer Interaction*. Springer, 2020, pp. 31–48.

[18] C. Bierwirth and F. Meisel, “A follow-up survey of berth allocation and quay crane scheduling problems in container terminals,” *European Journal of Operational Research*, vol. 244, no. 3, pp. 675–689, 2015.

[19] L. Heilig, R. Stahlbock, and S. Voß, “From digitalization to data-driven decision making in container terminals,” *arXiv preprint arXiv:1904.13251*, 2019.

[20] Marine Index of Open Datasets, “AIS data sources,” https://mods.marin.nl/display/MIOD/AIS+Data+Sources, accessed: 2020-09-10.

[21] Marine Emissions Inventory Tool, https://www.canada.ca/en/environment-climate-change/services/managing-pollution/marine-emissions-inventory-tool.html, accessed: 2020-09-23.