*Journal of Korea Port Economic Association*
Vol.39, No.3, 2023, pp.47-60.
https://doi.org/10.38121/kpea.2023.9.39.3.47

# A Study on Estimating Ship's Emission in the Port Area of Mokpo Port

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# 목포항 항만구역 내 선박 배기가스 배출량 산정에 대한 연구

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## Abstract

A thorough inventory of ship emissions, particularly ship's emission of in-port area is necessary to identify significant sources of exhaust gases such as NOx, SOx, PM, and $CO_2$ and trends in emission levels over time, and reduce their serious effects on the environment and human health. Therefore, the goal of this study is to assess the volume of emissions from ships in Mokpo port, which serves as a gateway to the southwest coast of Korea, using a bottom-up methodology and data from the automatic identification system (AIS) and the Korean Port Management Information System (Port-MIS). In this work, an analysis of ship movement utilizing AIS data and an actual set of data on ship specification were gathered. By examining ship movement using AIS data, We also proposed a new approach for identifying cruising/maneuvering mode. Finally, the results were classified by ship operating mode, by exhaust gas, by ship type, and by berth, which provides a thorough and in-depth analysis of the air pollution caused by ships in Mokpo port.

*Key words : Ship emissions; Bottom-up method; Mokpo port; Port MIS; Automatic identification system*

▷ 논문접수: 2023. 08. 16. ▷ 심사완료: 2023. 09. 24. ▷ 게재확정: 2023. 09. 30.

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## Ⅰ. Introduction

Gases known as greenhouse gases (GHGs) are those that retain heat in the atmosphere. Carbon dioxide ($CO_2$) is the main greenhouse gas released when fossil fuels (coal, natural gas, and oil) are used for energy and transportation, accounting for 79% of global GHG emissions in 2021. Shipping, while essential for trade, contributes significantly to the emissions that cause climate change. Global shipping is responsible for roughly 3% of global $CO_2$, emitting approximately a billion tons of $CO_2$ per year, on average from 2007 to 2015 (IMO, 2015). The sun's heat is trapped by $CO_2$, which results in higher average and severe temperatures, altered rainfall patterns, melting permafrost, and an increase in dangerous weather.

Beside greenhouse gases, there are 450 distinct airborne pollutants that the combustion of ship engines is said to generate (Bilgili & Celebi, 2016). Among these, sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter (PM) are regarded to be the principal air pollutants that are created by ships. On a global scale, commercial ships burn fuel for energy and the marine shipping industry's share of total emissions is 13% of SOx per year and 20% of NOx per year (IMO, 2015). Breathing air with a high concentration of SOx and NOx can irritate airways in the human respiratory system. Numerous studies have demonstrated a strong link between ship emissions in coastal areas and local community health, which may result in, among other things, asthma, respiratory and cardiovascular disorders, lung cancer, and early mortality (Lamas et al., 2013; Sofiev et al., 2018). Ship-related health impacts include about 400,000 premature deaths from lung cancer and cardiovascular disease and about 14 million childhood asthma cases annually worldwide (Sofiev et al., 2018). PM, on the other hand, describes an airborne combination of solid particles and liquid droplets. Dust, grime, soot, and smoke are a few examples of particles that may be seen by human eyes. Some require an electron microscope to be detected, while others are much smaller. Inhalable particles having a diameter of normally 10 micrometers or less are known as PM10, while fine inhalable particles with a diameter of typically 2.5 micrometers or less are known as PM2.5. This has been connected to a number of detrimental outcomes for heart and lung health, including cancer (Martuzzi et al., 2006; Sofiev et al., 2018). In Europe, East Asia, and South Asia's coastal regions, it is speculated that PM emissions from shipping operations are the primary cause of the 60,000 cardiopulmonary and lung cancer fatalities that occur each year (Chen et al., 2017; Corbett et al., 2007; Sofiev et al., 2018).

In recent years, significant measures and regulations have been devised and put into place to limit emissions from ocean-going vessels and reduce their adverse impacts. These regulations are generally designed to encourage the use of ships' engines with less polluting and greener fuel. Additionally, some restrictions try to encourage the adoption of machinery and engines that are more energy-efficient while restricting ship speed within the approved area. One of the recently applied regulations, the Energy Efficiency Existing Ship Index (EEXI), became compulsory from this year, 2023. Ships of 400 gross tonnage or more involved in international voyages are required to comply with the EEXI as a technological measure to minimize their greenhouse gas emissions, as stated by the International Maritime Organization (IMO). The Korean government has been stepping up its attempts to improve the country's air quality through 10-year comprehensive projects. The 0.1% sulfur restriction has been implemented starting in January 2022 for all vessels entering the ECAs, which include five major port areas: Busan, Ulsan, Pyeongtaek-Dangjin, Incheon, and Yeosu-Gwangyang. Shipping businesses must plan a variety of countermeasures to achieve such goals, including restricting engine output, installing energy-saving equipment, and employing environmentally friendly alternative fuels to operate current ships in compliance with regulations. Additionally, according to the research community, a complete and trustworthy evaluation of the ship's exhaust emissions is required to estimate a high-resolution inventory, understand its quantitative effects, and implement efficient countermeasures. There is no doubting that many scholars in Korea have recently been interested in the subject of estimating ship emissions, but they have largely focused on the two big ports of Incheon and Busan, ignoring other smaller but no less significant ports. Moreover, it is challenging to compare and evaluate results due to the lack of a consistent approach for estimating emissions and the uncertainties of data sources imported from overseas that have varied geographical and temporal scopes.

In this study, the amount of emissions emitted from ships operating in Mokpo port in Korea was estimated. The authors seek to propose a new approach of identifying cruising/maneuvering mode by assessing ship movement using AIS data in addition to offering a real database on the specs of all ships working in the port area. Other researchers may take into account this approach and apply it to each port based on its own area characteristics rather than just applying defaulted values. The local port operators and government organizations may find these trustworthy data helpful in their decision-making about air quality control.

The rest of the paper is developed as follows. Section 2 begins by summarizing earlier research on emissions from ships before outlining the need for more study for this work. Following an introduction of the study area, methodology, and data utilized in this study to estimate shipping emissions in Section 3, Section 4 presents the findings from the case study of Mokpo port. The final section offers the study's findings and recommendations for further research.

## II. Literature review

The estimate of ship emissions has been the subject of several prior research. There are two major methodologies that are often used to calculate ship emission inventories: top-down approach and bottom-up approach.

In the top-down approach, exhausted ship emissions are estimated using statistically marine fuel sales and fuel-related emission parameters, instead of using data on traffic (Nunes et al., 2017). This approach is used to calculate coastal and global emission inventories when it is hard to create an accurate statistical database on movement information. This approach is recommended for a low level of traffic data availability situation. For example, a ship type and size dependent estimate of emissions volume was undertaken in 2004, using information from more than 32,000 global port arrival and departure ship data and input data for 15 ship types and 7 size categories (Dalsoren et al., 2009). Nevertheless, it was demonstrated that there is a large gap between banker fuel sales data and the actual fuel utilized by the world's fleets (Corbett, 2003). The major causes of this discrepancy can be the practice of offshore fiddling or the unreliable fuel data in a number of nations (Psaraftis & Kontovas, 2009).

In contrast to the top-down approach, the bottom-up approach which is now used by more studies requires a higher level of input parameters, including specifics about ship specifications (such as ship type, engine characteristics, fuel type), as well as operational records of the ship (such as travel distances, speed, ship tracking, and activity time). It is widely accepted that the bottom-up strategy is more accurate than the top-down approach since it requires vast and in-depth input data. In general, to calculate emissions from ships, the input data came from several different sources. A ship's identity information, such as name, IMO registry number, ship type, gross tonnage, and deadweight tonnage, as well as its physical attributes and engine characteristics, can be accessed from either public or commercial data sources. The engine power and designed speed of ships were approximated using regression models or default values in several studies due to the absence of a database, which is erroneous compared to the actual facts. The problem of missing ship data was solved by using simple linear regression analyses by ship type between ship tonnage and main engine from the sample to estimate the main engine power (Chang et al., 2013; Chen et al., 2017; Lee et al., 2020; Sun et al., 2018). However, understanding the importance of input data affecting the accuracy of calculation results and in order to provide trustworthy and reliable inputs, in this study, a real detailed database of ship specifications was created by combining both data from Port-MIS and Marine Traffic website.

Additionally, a vessel tracking system called AIS has recently been widely used in the stream to improve estimations when it comes to data on ship activity in ports, such as ship route, speed, and time in each activity mode, namely cruising, maneuvering, and hoteling. As a result, the ship's actions are more spatially identified and studied, which raises the accuracy of the study of the emission inventory. Although several earlier research to estimate ship emissions inside the port area supported the use of AIS as an input, variations in ship speed and activity modes have not been well documented in those studies. To put it another way, the method for dividing ship's operation modes, namely cruising, maneuvering and hoteling, was not thoroughly explained. In this study, a sample of ships for each ship type in each port, which was extracted from AIS data in Mokpo port, was gathered and analyzed to classify ship operating modes into cruising, maneuvering, and hoteling, which is more precise and accurate. After that, the load factor was calculated for each ship based on ship's speed change in each operational mode instead of using default values from prior studies.

Several domestic studies on ship emissions connected to Korean ports have been undertaken during the past few decades. Chang (2013) employed the bottom-up method to assess the ship GHGs emissions in Incheon port in the duration from 2012 January to October based on the fuel consumption approach. Woo (2021) calculating geographical ship gas emissions in real-time adapting a bottom-up methodology using AIS data from the Busan Port, including the North Port and Gamcheon & Dadaepo Port, known as the largest port in Korea and surrounded by residential, business, and industrial areas. This study demonstrates that approximately 35% of the yearly ship gas emissions of Busan port in 2019 were concentrated in the passageway to North port because ships enter or leave the port at great speeds. Zhao(2019) calculated air pollution produced by ships berthing in the ports of Gwangyang and Ulsan in 2017 by adopting methodologies and default factors from EEA and EPA. With the same method, Zhao(2022) aimed to propose a framework for calculating ship air pollutant emissions by comprehensively considering processes and methods officially used in other countries. A case study focused on the Gwangyang and Yeosu Port, using adaptive data collection and emission-calculation processes. However, the input data was mainly based on the authors assumptions and some default values adopted from previous studies, which leads to some unavoidable uncertainties. Kim(2022) also calculated ship emissions in the ports of Yeosu and Gwangyang during 2019 using activity-based methodology and supplemented by AIS data and Port-MIS data.

A trustworthy in-port ship emission inventory is also crucial to assess and address the present environmental issues and to support effective public regulations for the reduction of air pollution in ports and coastal areas. Following a study of the literature, we discover that there are just a few studies that have been done in Korea that estimate in-port ship emissions. It is undeniable that some studies have already evaluated them, but they have mostly concentrated on major ports, such as Incheon and Busan port, which is insufficient to contribute to a whole emission inventory in Korea, which aids in providing an overview and developing a long-term strategy to enhance the air quality nationwide. Hence, the goal of this study is to assess the volume of emissions generated by ships in Mokpo port, which is well-known as one of the busiest ports in the southwest area of Korea. This will help to address the deficiencies previously mentioned and contribute to the ship emission inventory of Korea.

## III. Research model

### 3.1. Study area

Mokpo port with its favorable natural condition and location has played a pivotal role in the economy of the southwest region. It has a total of 31 berths with a total berth length of 5,149 meters. There are two pilot stations in Mokpo port where pilot captain can embark or disembark: No.1 PS (Gasado - optional) and No.2 PS (Bulmugido - compulsory). Mokpo port has three main berths: Daebul, New Port, and Samhak. Figure 1 illustrates the geographical location of main berths and pilot stations in Mokpo port, as well as the ship routes when ships enter port area.

Located in Goha island in Mokpo City, recently, the Mokpo New Port is becoming an important spot for marine trade that a central axis of Korea, China and Japan intersects with the artery sea route and a place where the traffic map of South Korea starts. The Mokpo New Port that is a base port for the southwest region is the first privately invested port and a multipurpose port and possesses the equipment and personnel for stevedoring to be able to deal with general freight of 5 million ton and 360 thousand TEU of containers per year. It is expected that the port will also contribute significantly to the local and national economies.

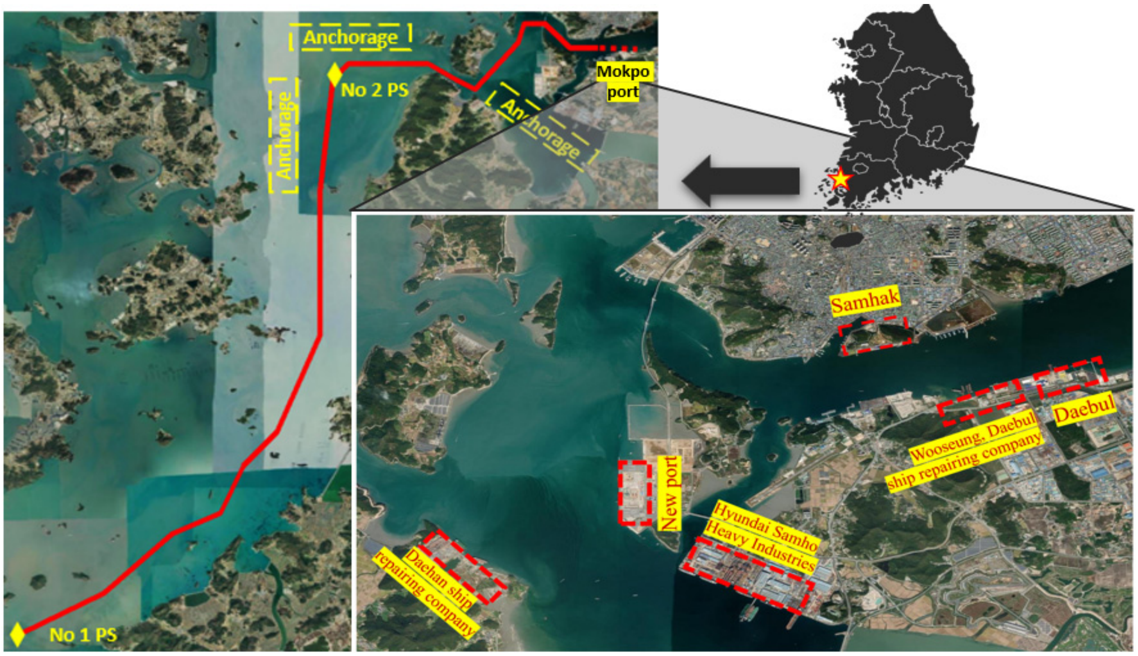


Figure 1. Location of main berths and pilot stations in Mokpo port

According to data collected from the Port-MIS website, cargo volume transported by ocean-going vessels in Mokpo port during 2019 to 2022 were 7,757 thousand tons, 6,093 thousand tons, 7,794 thousand tons and 6,761 thousand tons, respectively. Mokpo port recorded a total number of ship calls of about 717 calls per year on average for 4 years, with an average annual growth rate of 2.3% during the whole period. From 2019 to 2022, Mokpo new port attracted all number of calls of car carrier and container ship, serving about 327 car carriers and 25 container ships per year. Meanwhile, piers in Daebul port mainly handle cargo from bulk carriers and general cargo ships, 32 and 112 calls on average, respectively.

### 3.2. Methodology

The study covered all ocean-going vessel activities inside the port boundary, which is defined as the area from pilot station point (where the harbor pilot gets on board) to berthing/anchoring point, to estimate the amount of in-port air emissions from ship. The ship emissions are estimated in three general modes, namely cruising, maneuvering, and hoteling. In this study, the bottom-up method with high calculation accuracy was used to estimate ship emissions. The calculation formula of pollutant emissions from a single ship is as follows (EPA, 2009):

$$E_{Cruising} = \left(\frac{D}{V}\right) \times (ME \times LF_{ME} \times EF + AE \times LF_{AE} \times EF)$$
$$E_{Maneuvering} = T_{maneuvering} \times (ME \times LF_{ME} \times EF + AE \times LF_{AE} \times EF)$$
$$E_{Hoteling} = T_{hoteling} \times (AE \times LF_{AE} \times EF)$$

where ME is main engine power (kW), AE is auxiliary engine power (kW), V is ship's speed (knots), D is distance of cruising (nautical miles), T is time of maneuvering and hoteling (hours), $LF_{ME}$ is load factor of main engine (%), $LF_{AE}$ is load factor of auxiliary engine (%) and EF is emission factor (g/kWh). Figure 2 below presents the data analysis process for ship emission calculation.

Firstly, the information on ship specifications, including the vessel name, vessel type, engine type, main engine power (ME), weight tonnage (GT), and maximum designed speed (MS), was gathered from the Korean port management information system (Port-MIS) and the Marine Traffic website in order to satisfy the need for a comprehensive and reliable input database. The database of ship specifications of 12,457 vessels operating in major ports in Korea collected by the author, including over 700 calls of ocean-going vessels arriving to and departing from Mokpo port per year.

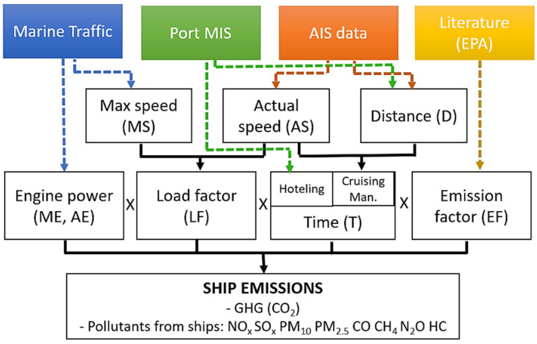


Figure 2. Data analysis process for ship emission calculation

Besides, data on the real-time ship activities were gathered and a set of AIS data in Mokpo port from March 1st to 20th 2015 collected by the authors. For each ship type, a fleet sample of vessels was chosen in order to estimate the average real speed for each ship's operation mode. This information was used to establish routes and analyze actual speed variations as ships move inside port areas from pilot stations to berths. We may derive a broad trend line of speed change when approaching the berth for each ship type by studying the fleet sample. This sample will be used to estimate the typical speed of ships as they approach berths inside the port, identify three main modes, and then apply the findings to all ship fleets in the port. Figure 3 introduces the ship routes and speed changes as an example at the port area for two major ship types operating in Mokpo port: Car carrier and General cargo ship.

As presented in Figure 3a, when car carriers enter Mokpo port from the pilot station, at first, they maintain an average speed of 8.5 knots and do

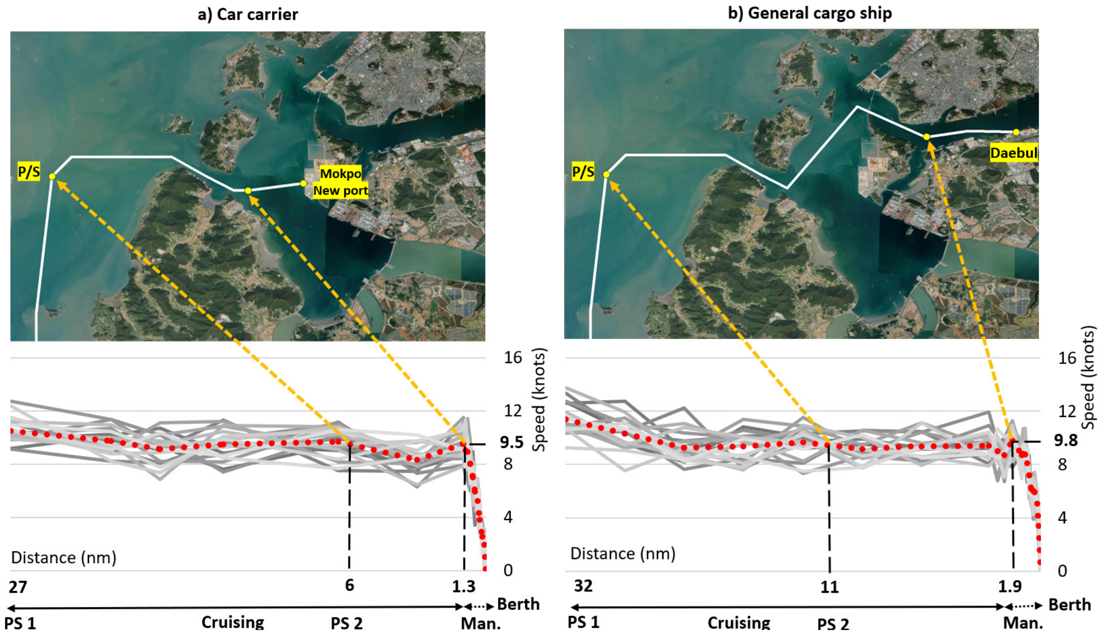


Figure 3. Example of the relation between ship's speed and distance in cruising and maneuvering mode in Mokpo port

not alter significantly. Only from 1.3 nautical miles out from the berth, which is regarded as the maneuvering phase, the speed is lowered remarkably from 9.5 to 0 knots.

Regarding general cargo ships operating in Mokpo port, the maneuvering phase was estimated to be about 1.9 nautical miles from berth with a speed of less than 9.8 knots in Figure 3b. It was estimated that the average cruising speed was 9.6 knots. Table 1 shows the calculated distance, speed, and duration of each ship type in Mokpo port.

### 3.3. Parameters for ship's emission

a) Engine Power

The data on ship parameters, including the ship name, type of ship, type of engine, main engine power, gross tonnage, and design speed, was retrieved from the aforementioned ship database in order to fulfill the need for thorough and trustworthy inputs. It covered all ocean-going vessels operating at Mokpo port from 2019 to 2022. On the other hand, because the manufacturer may or may not offer information on the installed auxiliary engine power, that information was not completely recorded. In order to compensate for the lack of auxiliary engine power data, a calculation based on the given main engine was made using data from a US Environmental Protection Agency study (EPA, 2009). Based on specific ratios for each ship type, the auxiliary engine power is calculated from the main engine power as follows: Bulk (22.2%), Container (22%), General cargo (19.1%), Car carrier (25.9%) (EPA, 2009). Table 2 presents average main and auxiliary engine power by ship type in Mokpo port in this study.

Table 1. Average distance, speed and duration by ship type in Mokpo port

| Ship type | Berth | Cruising | | | Maneuvering | | |
|---|---|---|---|---|---|---|---|
| | | Distance (nm) | Speed (kn) | Duration (min) | Distance (nm) | Speed (kn) | Duration (min) |
| Bulk | Daebul | 30.1 | 9.6 | 186 | 1.9 | 6.5 | 18 |
| Car carrier | New port | 25.7 | 8.5 | 180 | 1.3 | 5.6 | 12 |
| Container | New port | 26.1 | 10.6 | 150 | 0.9 | 5.5 | 12 |
| General cargo | Daebul | 30.1 | 9.6 | 186 | 1.9 | 6.5 | 18 |

Table 2. Summary of ship specifications database in Mokpo port (unit: kW)

| Ship type | Main engine | Aux. engine |
|---|---|---|
| Bulk | 5,942 | 1,319 |
| Car carrier | 13,805 | 1,380 |
| Container | 6,623 | 1,457 |
| General cargo | 3,814 | 728 |

b) Load Factor

An engine's power output as a percentage of its maximum rated power is indicated by the load factor. The Propeller Law, which states that main engine load varies with the cube of ship speed, is used in this study to determine the main engine load factor: LF = (AS/MS)3, where: AS is ship actual speed (in knots) and MS is design maximum speed (in knots) (EPA, 2009). The design maximum speed for Propeller Law formula was obtained from the ship database stated above. Ship speed was identified based on the AIS data in the previous chapter. Table 3 presents the values of main engine's load factor by ship type calculated by Propeller law.

Auxiliary engine load factors depend on type of ship and ship's operation mode. The default values for the auxiliary engine's load factor were frequently used since there was little information available about onboard auxiliary engines as mentioned before. The auxiliary engine load defaults by ship type in three modes used in this study were followed the guidelines by the IMO (2009). During the cruising phase, the ship's movement was supported by the coordination of its main and auxiliary engines, but during the maneuvering phase, the auxiliary engine assumed the majority of the workload since the ship needed to slow down and approach ports or mooring places. Especially, auxiliary engine was the only one working, providing all onboard electricity or certain loading/unloading equipment, while the main engine was deactivated when the vessel was in hoteling mode (IMO, 2009; Sun et al., 2018).

Table 3. Main engine's load factor

| Ship type | Cruising | Maneuvering |
|---|---|---|
| Bulk | 21.5% | 10.2% |
| Car carrier | 17.0% | 10.4% |
| Container | 28.8% | 18.1% |
| General cargo | 21.5% | 10.2% |

c) Operating Time

The operation time includes traveling time in cruising or maneuvering mode or berthing or anchoring time in hoteling mode. Time-in-mode varies according to the location, approach, and turning needs of the vessel at the destination terminal. The operating time in cruising and maneuvering mode was calculated by the ship speed and travel distance between the pilot station and berth for each ship. The distances and speed traveled by ships in different modes were presented in previous for each port. The data for hoteling time of a ship call at port of Mokpo was obtained and calculated from Port-MIS website.

Among all ship categories, bulk carriers had the greatest time in the hoteling phase at 115 hours, followed by general cargo ships with an average operating time at berths of 82 hours. Moreover, while the Container ships spent 18 hours loading/unloading cargo, the car carriers spent only an average time of 12 hours.

d) Emissions Factor

The type and specification of fuel used, the operation mode of ship and engine size, speed, and load are all important aspects that affect emission factors. In activity-based approaches, emission factors are often represented in terms of the mass of the pollutant per unit of engine power or the mass of the pollutant per unit mass of fuel. Because of the high cost and complex technical requirements, the related study has not been to date that estimates local emission factors for ports in Korea. Consequently, in this study, emission factors were reviewed and implemented in accordance with the US Environmental Protection Agency report (EPA, 2009). Compared to earlier studies, this one took into account new standards for marine distillate fuels.

## IV. Results

The results of the emission inventory at Mokpo port are now estimated and presented by ship type, by ship mode, by exhaust gas, and by berth in Table 4. From 2019 to 2022, the total volume of ship emissions released in port area were 10,644 tons, 11,476 tons, 10,796 tons, and 12,720 tons, respectively, with an average of about 11,400 tons emitted over the four years.

Car carriers contributed the most emissions at up to 47% (5,329 tons), followed by general cargo ships with a percentage of 21% (2,388 tons). Container ships and bulk carriers with a percentage of 9% (1,024 tons) and 7% (841 tons). It can be explained that there was 46% of total ship calls recorded during 2019 - 2022 from car carriers.

Additionally, there were three separate modes of ship activity throughout the port period, with each mode emitting a different level of air pollution. Hoteling and cruising modes accounted for the majority of the total emissions, contributing 49% (5,558 tons) and 48% (5,490 tons) respectively, while maneuvering modes contributed just 3%.

Table 4. Result of ship's emissions by type of ship, mode, and exhaust gas in Mokpo port

(unit: tons)

| Category | | 2019 | 2020 | 2021 | 2022 | Average | |
|---|---|---|---|---|---|---|---|
| Ship type | Bulk | 873 | 786 | 691 | 1,013 | 841 | 7% |
| | Container | 594 | 2,030 | 360 | 1,111 | 1,024 | 9% |
| | General cargo | 2,368 | 2,164 | 1,996 | 3,025 | 2,388 | 21% |
| | Car carrier | 5,100 | 5,441 | 5,503 | 5,272 | 5,329 | 47% |
| | Others | 1,769 | 1,055 | 2,247 | 2,299 | 1,837 | 16% |
| Operating mode | Cruising | 5,778 | 4,886 | 5,402 | 5,895 | 5,490 | 48% |
| | Maneuvering | 382 | 324 | 350 | 389 | 361 | 3% |
| | Hoteling | 4,485 | 6,266 | 5,044 | 6,436 | 5,558 | 49% |
| Exhaust gas | $CO_2$ | 10,196 | 10,989 | 10,340 | 12,181 | 10,927 | 96% |
| | Pollutants | 448 | 487 | 456 | 538 | 482 | 4% |
| Total | | 10,644 | 11,476 | 10,796 | 12,720 | 11,409 | 100% |

To understand which exhaust gases dominated Mokpo port from 2019 to 2022, the emissions from the ship were categorized by exhaust gas. On average, ships emitted 10,927 tons of CO2, and 482 tons of other pollutants at port. With 96% of the total volume of ship emissions assessed in this study, CO2 accounted for the highest percentage of emissions. On the other hand, the rest pollutants contributed less amounts compared to CO2: 223 tons of NOx, 191 tons of SOx, 24 tons of PM10, 19 tons of PM2.5, 18 tons of CO, 7 tons of HC, 0.5 tons of N2O and 0.1 tons of CH4. As indicated above, despite their relatively low percentages, NOx, SOx, and PM have been shown to significantly harm human health.

Additionally, based on records of ship emissions at each berth, an investigation of how air pollutants were released in the port area during hoteling mode was carried out. Noticeably, as can be seen in Table 5, New port and Daebul were recorded as two berths where ships emitted the most pollutants to the environment, comprising about 40% of total volume each. However, while New port served up to 66% of total calls, only 26% of total calls were recorded in Daebul pier. Meanwhile, emissions from ships berthing in Samhak area and anchorage were estimated at only 4% and 14%, respectively.

Table 5. Ship emissions by berth during hoteling mode

| Name of berth | Emissions volume in hoteling mode | | | Ship call | |
|---|---|---|---|---|---|
| | $CO_2$ (tons) | Pollutants (tons) | % | Number | % |
| New port | 1,755 | 80 | 41 | 440 | 66 |
| Daebul | 1,735 | 79 | 40 | 176 | 26 |
| Samhak | 188 | 9 | 4 | 11 | 2 |
| Anchorage | 610 | 28 | 14 | 40 | 6 |
| Total | 4,288 | 196 | 100 | 667 | 100 |

## V. Conclusions

The study provided a ship emission estimation in Mokpo port from 2019 to 2022 based on a bottom-up approach. The total emission inventory was estimated by ship mode, by exhaust gas, by ship type and by berth, which presents a thorough and in-depth assessment of the air pollution caused by ships at port. It should be noted that a comprehensive and trustworthy database of ship details including the vessel name, vessel type, engine type, main engine power, weight tonnage, and max designed speed was collected by authors and utilized as the input data. Additionally, this research determined load factors for each ship based on the ship's speed, unlike previous studies that used default values from other international studies when addressing load factors for the main engine. Furthermore, a sample of vessels for each ship type was gathered and examined to determine ship operating modes into cruising, maneuvering, and hoteling, which is more detailed and accurate.

In order to control and limit air pollution from ships, characteristics of ship emissions need to be considered, and the regulations should be stricter and focused on some specific cases. Based on calculated results, statistics found that the majority of ship emissions in Mokpo port came from car carriers operating at berths in New port (nearly 50% of total emissions volume). Therefore, it is necessary to strengthen the monitoring and controlling of the emissions emitted from this aforementioned ship type or install shore-based power system at berths in New port to reduce ship emissions while berthing. Also, the results concluded that almost half of the emissions emitted were during the cruising phase when ships slowly approached Mokpo port. It is suggested that by reducing speed, ships can reduce fuel use and, consequently, the emitted volume of $CO_2$ and other air pollutants while considering cost-benefit and assessing effects to all stakeholders. This result of research can be used for shipping and port company's data management of business perspective as well as environmental management in Port of Mokpo.

Although the study tried to overcome shortcomings found in other previous research, it is unavoidable that some limitations remain and need to be improved in future research. This analysis did not consider the environment impact and social cost on controlling ship emissions in the port area. Besides, some average inputs were adapted from some previous studies, which may be not suitable in Korean context, which may be inaccurate owing to the underestimated results. It is suggested that a national data management system on ship specifications is necessary in Korea and an up-to-date research on these important input factors needs to be taken into account. In further works, We will analyze the effect of pollutants of port area using an visualization with meteorological data(wind direction and speed) and social cost calculation from ship's emission.

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# 목포항 항만구역 내 선박 배기가스 배출량 산정에 대한 연구

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## 국문요약

항만구역 내 선박으로부터 배출되는 온실가스, 미세먼지를 포함한 배기가스에 대한 인벤토리 작성과 관리는 선박 배기가스의 주요 배출물질과 시간 경과에 따른 배출량 수준의 추이를 파악하고, 해양환경과 인간 건강에 미치는 부정적 영향을 줄이는 데 필요하다. 따라서 본 연구의 목적은 우리나라 서남권에 있는 국가관리 무역항인 목포항계 내 입출항하는 선박으로부터 배출되는 배기가스를 산정하는데 있다. 이를 위해 선박자동식별장치(AIS)와 해운항만물류정보시스템 (Port-MIS)의 정량적 데이터를 기반으로 선박의 움직임을 분석한 상향식 접근법(Bottom-up 또는 Activity-based)을 이용하였다. 특히 본 연구에서는 최근 4년간(2019~2022년) 목포항 입출항 실적이 있는 선박의 제원, 선종, 재항시간 등의 데이터를 수집하고, AIS 데이터를 이용하여 항만 내 부두 접근 과정을 분석하여 선박 움직임(cruising, maneuvering)을 결정하는 접근 방식을 제시하였다. 주요 연구결과로 최근 4년간 목포항 항만구역 내에서 선박으로부터 배출된 배기가스는 11,409톤이었으며, 자동차전용선이 5,329톤으로 가장 많았고, 정박 중에는 목포 신항 부두에서 1,835톤의 온실가스와 미세먼지가 배출되었다. 이 연구는 목포항의 선박입출항수, 처리 물동량과 더불어 환경적인 측면에서 정보관리를 위한 데이터로 활용될 수 있을 것으로 기대된다.

*주제어 : 선박 배기가스, 상향식 접근법, 목포항, 해운항만물류정보시스템, 선박자동식별장치*