Journal of
Marine Science and Engineering

MDPI

Article

Fine Dust and Sustainable Supply Chain Management in Port Operations: Focus on the Major Cargo Handled at the Dry Bulk Port

Jeho Hwang and Sihyun Kim *

Department of Logistics, Korea Maritime and Ocean University, Busan 49112, Korea; jeho9288@kmou.ac.kr
* Correspondence: sihyunkim@kmou.ac.kr

Received: 29 June 2020; Accepted: 16 July 2020; Published: 17 July 2020



Abstract: Local residents living adjacent to ports are directly affected by the fine dust generated from the port operations. There is a need to prepare detailed measures according to cargo type given the high correlation between the types of dust-producing cargo primarily managed at ports and local industries. This study attempts to establish the attributes of the cargo handled at ports and the relationship between supply chains built for local key industries and the air quality of the local community. It aims to ascertain which cargo needs managing preemptively at the local level, based on the major cargo types handled in a port. A correlation analysis and Granger causality test were performed to investigate the causality between the factor of cargo and fine dust concentrations. The results in this study indicate the necessity for intensive management of scrap metal cargo among the major cargo handled at the target port, which confirms the large effect of management on fine dust reduction, as well as on reduction efficiency. The results suggest requirements to expand the regulations on the emissions of supply chains by cargo type, not by industry type. Additionally, it is required to minimize the blind spots of management and form an eco-friendly supply chain by introducing green technology. The preparation of emission control measures is also necessary. The findings provide useful insights for the sustainable operations of the local supply chain around the target port and will help the strategic agenda for future improvement.

Keywords: port operations; fine dust; local supply chain; time series modeling; cross-correlation; Granger causality; Busan Gamcheon Port

1. Introduction

Ports create the foundations of supply chains in various fields, such as the logistics, trade, and manufacturing industries, and greatly contribute to national and regional economic growth. However, the functions of ports have recently expanded into the environmental sector, as air pollution arising from ports has become an issue. Thus, it has become mandatory for ports to implement measures to reduce the hazards of air pollution such as NO_X (Nitrogen Oxide), SO_X (Sulphur dioxide), VOC_S (Volatile Organic Compounds), CO (Carbon Monoxide), and PM (Particulate Matter) to maintain sustainability, not only in the economic field for short-term performance but also in the environmental field over the long term.

In particular, the International Maritime Organization (IMO) has been working on continuous countermeasures to reduce the air pollutants emitted from ships since 1997 and has sought to improve the air quality around port areas by designating Emission Control Areas since 2015. However, since the chief target managed by the IMO's regulations of air pollutant emissions is ships, the IMO has adopted an approach to improve air quality around port areas by decreasing the quantity of emissions generated from ships. The primary air pollutants regulated by IMO2020 are thus NO_X and SO_X, and those

regulated by IMO2030 are NO_X, SO_X, and CO_2. Compared to other air pollutants floating in the atmosphere, relatively less particulate matter (PM) resides in the atmosphere and creates secondary aerosols through organic chemical responses with other pollutants, as well as the primary pollutants. Specifically, most PM and components such as NO_X, SO_X, and VOC_S combine with each other and directly affect the human body and environment [1].

The World Health Organization first established guidelines on $PM_{2.5}$ and PM_{10} emissions in 1987, and its affiliated organization, the International Agency for Research on Cancer (IARC), designated them as class one carcinogens [2,3]. The fine dust concentrations in port cities are extremely influential on ship operations, but air pollutions emitted from ports and port-based local industries affect the health of the residents in the vicinity. Moreover, it is vital to manage the air quality in the port industry, including ship operations, to improve the air quality in coastal cities [4].

The industrial supply chains handling bulk cargo in particular are usually built near bulk ports, and the quantity and distribution of emitted air pollutants are based on various factors such as the cargo's characteristics, industrial activities, and weather conditions in the area. That is, from the local perspective, it is necessary to have an approach to prepare regulations against the emissions from ships and ports, as well as nearby supply chains, to visibly regulate the PM emitted from the supply chains of bulk cargo.

According to Figure 1, Busan Port, the primary port in South Korea, was designated as one of the top 10 ports emitting ultra-fine particles along with the ports in Qingdao, Tianjin, Shanghai, Guangzhou, Ningbo, Shenzhen, Hongkong, Singapore, and Dubai. South Korea has recognized the severity of air pollutant emissions in port areas and has implemented improvement policies since January 2020 by designating low-speed sailing sea areas, expediting eco-friendly ship purchases, strengthening criteria on air pollutant emissions for unloading equipment, regulating scattering dust, and introducing eco-friendly unloading equipment and Alternative Maritime Power (AMP) [5].

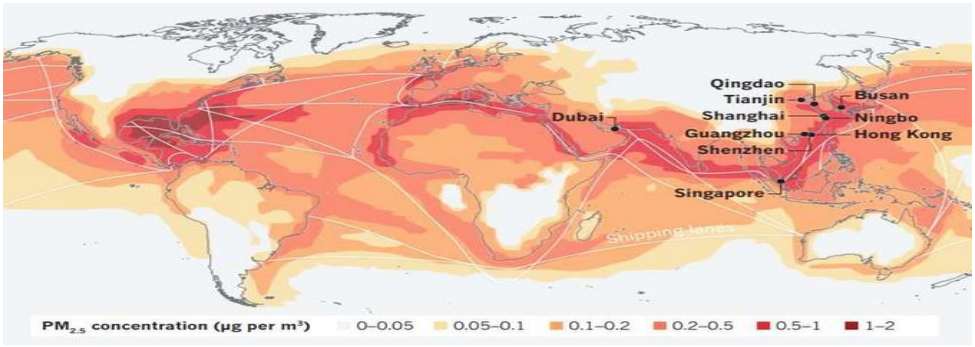


Figure 1. Distribution of the top 10 ports emitting ultra-fine dust worldwide (Wan et al., 2016:275).

However, since the regulations on air pollutant emissions tend to focus on container ports, rather than dusty bulk ports, the regulations against air pollutants emitted from bulk ports are relatively immature. Although the regulations on both container and bulk ports have to be implemented in a balanced manner, the maturity of air quality management policy remains lower than that of other countries where advanced ports are located.

Unlike other air pollutants that can be described under a single definition, PM is a term defining extensive air pollutants formed from secondary aerosols created by a secondary chemical response, wherein the primary aerosol and other air pollutants react, and the other pollutants affect PM emissions. Therefore, the regulations against PM have to be more effective and intensive than those for other pollutants in the atmospheric environment field, and advanced studies on cargo that largely emit PM must be implemented based on the characteristics of the local industries near Gamcheon Port. However, the studies evaluating the effect of bulk cargo characteristics and supply chain operations on the local community's air quality in the center of the port remain limited. Furthermore, although studies dealing with port areas and the atmospheric environment have been conducted multilaterally,

their subjects are biased toward the effects of ship operations on air quality at the port, as well as the effects of geographical and climatic factors on air quality in the area adjacent to the port. Thus, the objective of this study is to determine what cargo must be predominantly dealt with to reduce the concentration of fine dust in nearby areas by elucidating the relationship between supply chain operations for each cargo at the port and the PM concentrations in the adjacent area.

2. Literature Review

2.1. Definition of Fine Dust

PM is a harmful airborne substance and the generic term for particles suspended in the air. The diameter range of PM is 0.001–100 μm, and PM is divided into total suspended particles (TSP), whose diameters are less than 50 μm; PM_{10}, whose diameters are less than 10 μm; and $PM_{2.5}$, whose diameters are less than 2.5 μm. Further, secondary aerosols are formed by combining with carbons, ions, and metals through chemical reactions between the primary aerosol and other air pollutants directly emitted from the agent [6].

Figure 2 provides a graph showing the total amount of air pollutant emissions in Busan Metropolitan City in 2016. In total, 49,468 tons of NO_X were emitted, followed by 40,899 tons of VOC, 23,388 tons of CO, 10,777 tons of SO_X, 6903 tons of PM_{10}, 2544 tons of $PM_{2.5}$, and 1744 tons of NH_3, with PM accounting for a low portion, approximately 7%. Although the portion of PM is small, its effects on the weather conditions, ocean, internal waters, soil acidification and acid rain, and atmospheric environment, as well as health, inflict serious damage since PM contain hazardous substances on its surface, such as heavy metals and gases.

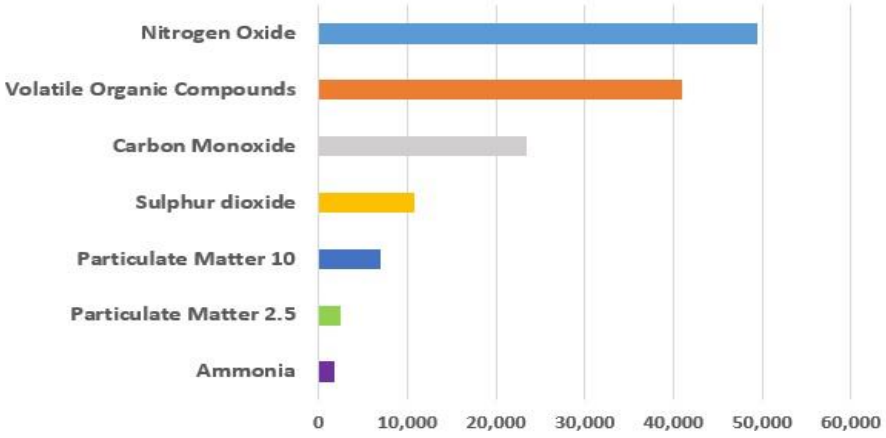


Figure 2. Air pollutant emission quantity in Busan Metropolitan City 2016, (unit: Tons).

Also, exposure to highly concentrated PM directly affects the incidence of diseases and death [7]. Figure 3 shows diseases that are caused by PM affecting the lungs and respiratory organs, brain and central nervous system, heart and blood vessels, and inducing premature delivery [8]. In particular, PM with a 1–5 μm diameter can infiltrate into the alveoli, and that with a diameter 0.5 μm or smaller can accumulate continually in the alveoli [9].

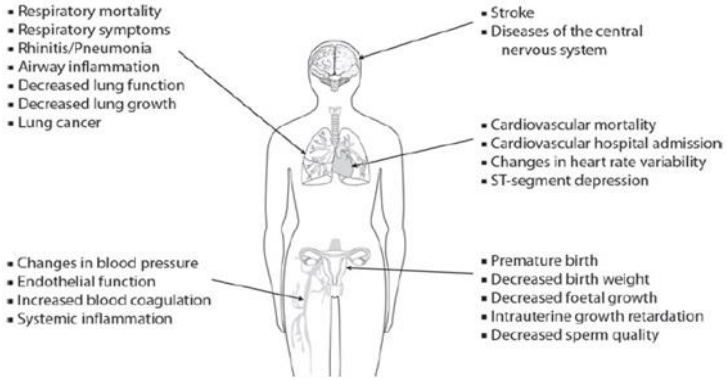


Figure 3. Diseases of the human body caused by PM (Adapted from Rückerl et al., 2011, with permission from Taylor & Francis, 2020).

2.2. Fine Dust and Atmospheric Environment

Several studies are being conducted on the atmospheric environment and the spatial and temporal characteristics of PM and its harmful effects on the human body. The weather conditions in coastal areas are affected by the atmospheric circulation between the sea and land breeze based on the interactions between the atmosphere, land and sea, and their geographical and seasonal characteristics. In addition, wind speed and direction, temperature, and humidity are the leading causes for the diffusion of air pollutants into the air [10]. The distribution and concentrations of PM are largely influenced by wind direction, humidity, precipitation, surface pressure, and ground surface temperature, and the concentrations illustrate the variability of each year and season in response to the changes in atmospheric patterns [11]. PM concentrations are strongly affected by ground surface heat and humidity in the atmosphere [12]. The concentration change of $PM_{2.5}$ can be interpreted as 50% through temperature, humidity, and precipitation. Moreover, concentrations of static $PM_{2.5}$ are higher than those of circulating $PM_{2.5}$ by approximately 2.5 $\mu g/m^3$ on average [13]. PM concentrations are affected by various factors, but a specific standardization of all these factors is limited, as these limits are not specifically stipulated. However, the results of advanced studies on the relationship between the atmospheric environment and PM indicate that a PM concentration change is greatly affected by climate change.

2.3. Bulk Port and Fine Dust

Studies on the effect of the amount of the PM emitted from ports on the PM concentrations in local communities have been conducted. One study on the Port of Valencia located in Valencia, Spain, utilized a Classic Source Apportionment Methodology PCA (Principal Component Analysis) and CMB (Chemical Mass Balance) based on the data of air quality collected from four air quality observatories in the port to ascertain the primary tasks that emit PM by monitoring the changes in PM concentrations. This study also illustrated that PM concentrations, on a daily basis, have noticeable differences according to the type of work performed in the port and are largely affected by wind direction. The scattering dust in clinker and petroleum storage yards particularly influenced PM_{10} concentrations by 23%–53% and 12%–32% in a port that was under construction due to expansion [14].

Considering the geographical wind direction of dust, metals, and metalloids emitted from Townsville, the numerical value of arsenic, cadmium, lead, and nickel from six observatories in Northern Queensland was collected over 5 days using the sampling method of ASTM E1728-10 (a standard protocol for surface dust lead measurement). In that study, it was shown that the operations of Townsville ports significantly affect the measured values of dust, metals, and metalloids in the adjacent areas [15].

3. Methodology

3.1. Research Method

This study aimed to determine the primary cargo types of supply chains, according to cargo type in the adjacent areas around the target port, that have a high influence on fine dust concentrations over one month. Based on the advanced research in 2.2, it was found that the concentrations of TSP, $PM_{2.5}$, and PM_{10} are highly affected by meteorological factors (wind direction, temperature, humidity, and atmospheric pressure) and are seasonal in response to patterns of atmospheric circulations. This method was carried out in 4 steps. In step 1, a correlation analysis was conducted between the bulk cargo throughput primarily handled in Gamcheon Port, and the PM concentrations were extracted by seasonal factors through the X11 method from the time series data of PM (TSP, $PM_{2.5}$, PM_{10}) over time. The X11 method, which is a filter based method of seasonal adjustment, was invented by the US Census Bureau and Statistics Canada. X11 is used to estimate and remove seasonal and irregular components that happen repeatedly in a regular pattern in time series data. It is also used to provide a more accurate result through time series analysis [16].

Equation (1). Pearson Correlation Coefficient Equation:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \sum_{i=1}^{n}(y_i - \overline{y})^2}}. \quad (1)$$

The Pearson Correlation Coefficient (described as in Equation (1)) is used to ascertain the level and direction of relations between two coefficients showing a linear relation in a normal distribution [17]. The variables of Equation (1) are as follows; x—value of independent variables, $\overline{x}$—mean of independent variables, y—value of dependent variables, $\overline{y}$—mean of dependent variables, and n—pairs of numbers x and y. However, the causality relationship cannot be proven by correlation only because correlation is only one of the premises. In other words, correlation is a necessary condition for causality relationships. In step 2, stationarity tests was conducted on the time series data derived from step 1 using the Augmented Dickey–Fuller (ADF) and KPSS ((Kwiatkowski–Phillips–Schmidt–Shin) tests, which are complementary to each other. As the time series data lacks stability, there is a risk that a false statistical result could emerge.

In step 3, ARIMA models were fitted for the derived independent variables. The output time series data were constructed by applying the operator of independent variables, the ARIMA operator, to the ARIMA models of the dependent variables. Time series models are classified into autoregressive (AR), moving average (MA), autoregressive moving average (ARMA), and autoregressive integrated moving average (ARIMA) models. Residuals (ϵ), which are components of the models, signify the estimated value representing the difference between the real and estimated values from the fitted models. White noise is defined as a time series without autocorrelation between the residuals (ϵ).

In step 4, the time series data were pre-whitened and then assessed to ensure they represent white noise via a cross-correlation graph. Then, a Granger causality test was conducted to determine whether statistical causality is present in the time series data of the primary cargo types that emit fine dust. Due to the autocorrelation in time series data, the process to remove autocorrelation in the data before ascertaining cross-correlation could lead to false cross-correlation, which is called pre-whitening [18]. The pre-whitening procedure in the ARIMA model proceeds by choosing a proper model, selecting a proper parameter value based on the estimated function, and then evaluating the model.

Equation (2), cross-correlation coefficient:

$$r_{xy}(\diagup) = \frac{\sum_{i=1}^{n}(x_t - \overline{x})(y_{t\pm k} - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_t - \overline{x})^2 (y_t - \overline{y})^2}}, \text{ where } \diagup = 0, \pm 1, \pm 2, \pm 3, \ldots \quad (2)$$

The correlation between consecutive observed values in a time series classified by the range of time difference is known as cross-correlation; the cross-correlation coefficient is described by Equation (2), which indicates the correlation between two time series' estimated values, X_t and Y_{t+k}, classified by the time difference unit, k. The construction of Equation (2) is the same as Equation (1), except for the time difference, k. To test the Granger causality, it is necessary to ensure that the time series data indicate white noise by cross-correlation (Equation (2)). The time difference, t ± k, is added to the equation to draw the coefficient of variables X and Y, whose ordering relationship is determined by k's negative or positive value that brings $r_{xy}(\nearrow)$ to its maximum. In other words, if k < 0, X is preceded by Y; if K = 0, X and Y are together; and if k > 0, X is followed by Y. That is, Y_{t+k} can be calculated by X_t with the time difference of k.

Equation (3), Granger causality:

$$\begin{array}{rcl} Y_{it} & = & \gamma + \sum_{i=1}^{k} \alpha_i X_{t-i} + \sum_{j=1}^{k} \beta_j Y_{t-j} + \varepsilon_{1t} \\ X_{it} & = & \delta + \sum_{i=1}^{k} \lambda_i X_{t-i} + \sum_{j=1}^{k} \sigma_j Y_{t-j} + \varepsilon_{2t}. \end{array} \quad (3)$$

The Granger causality test is a technique used to define the causality of dependent (Y) and independent variables (X) in the linear regression model. When the past time series data (X) and (Y) are predicted linearly from two time series data, there is said to be causality if the resulting value, predicted linearly with only Y, is significant (and vice versa) in the formula described in Equation (3) [19]. In other words, if the condition of $\sum_{i=1}^{k} \alpha_i \neq 0$ is satisfied under the assumption of uncorrelated white noise for the error terms (ε_{1t}, ε_{2t}), the variable X is determined to be causal for variable Y, and vice versa. In the formula, γ and δ represent the intercept coefficients, and α, β, λ, and σ represent the slope coefficients. The Granger causality test determines whether the variable affects not only the time difference k but also its lag. This study derives the type of cargo emitting fine dust based on a correlation analysis between the bulk cargo primarily handled by Gamcheon Port and fine dust concentrations and also investigates the causality between the derived cargo types and fine dust concentrations.

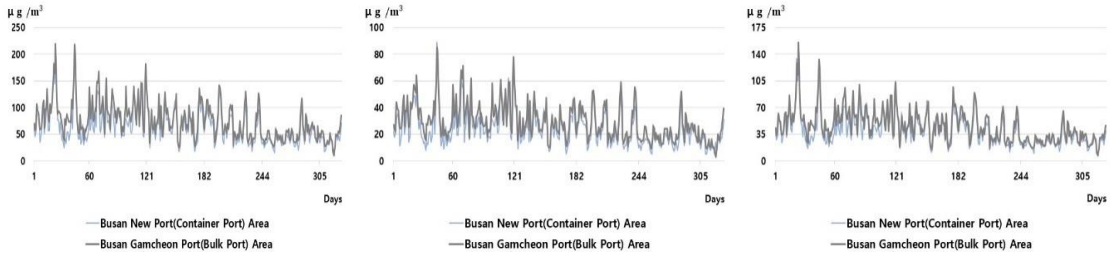
3.2. Target Port

The target port in this study is Gamcheon Port in Busan, South Korea. The port's primary bulk cargo, including scrap metal, sand and cement, are chiefly processed in the west ports from pier 5 to 7, as shown in Figure 4. In total, 103,647 tons of scrap metal were processed in 2016, 118,119 tons in 2017, and 78,552 tons in 2018, representing a ratio of 46.5% in 2016, 78% in 2017, and 86.5% in 2018 compared to the amount of scrap metal managed in the ports that comprise the Port of Busan. A total of 683,328 tons of sand cargo was processed in 2016, 865,454 tons in 2017, and 562,648 tons in 2018, with a ratio of 34.1% in 2016, 54.1% in 2017, and 51.1% in 2018 compared to the amount of sand processed in the other ports of the Port of Busan. Furthermore, for cement cargo, 1,774,236 tons, 2,201,750 tons, and 1,909,674 tons were processed from 2016 to 2018, respectively, and approximately 100% of such cargo imported to the Port of Busan were handled in Gamcheon Port. Figure 4 illustrates the distribution of factories near Gamcheon Port. The supply chains located in Gamcheon Port and its adjacent areas are YK Steel (B), which handles scrap metal; Ssangyong Cement Industrial (C) and Sampyo Cement (D), which handle sand and cement cargo; and Tongyang Aggregate (E), which manages sand cargo. The concentration data used in this research for TSP, $PM_{2.5}$, and PM_{10} were measured from the air quality observatory (A) located at a radius of 2.9 km from the west port of Gamcheon Port.



Figure 4. Industrial Factory Distribution near Gamcheon Port.

Figure 5 provides graphs comparing the concentration data of TSP, $PM_{2.5}$, and PM_{10} collected by an air quality observatory located in Busan New Port (container port) and Gamcheon Port (bulk port), from 7 November 2018, when $PM_{2.5}$ began to be measured at Busan New Port, to 30 September 2019 (328 days in total). Compared to Busan New Port, higher concentrations of TSP were found for 298 days, $PM_{2.5}$ for 307 days, and PM_{10} for 301 days in Gamcheon Port. Thus, the industrial activities derived from bulk ports are responsible for air pollution in the adjacent areas. Therefore, PM and oxide dust are produced in a relatively large volume compared to container ports due to their dusty nature and processing of heavy cargo.



TSP $PM_{2.5}$ PM_{10}

Figure 5. Comparison of PM Concentrations between Busan New Port and Gamcheon Port.

3.3. Data Collection

Time series data of the bulk cargo throughput collected from the big data system of Busan Port Authority and those of the fine dust concentrations estimated by the air quality observatory near Gamcheon Port and collected by Busan Metropolitan City's Environment Information System were used in this research. For the PM data, a data set was created by converting the daily data to monthly mean data since it is possible to collect the bulk cargo throughput of Gamcheon Port on a monthly basis. The collection period for the time series data of cargo throughput ranged from January 2001 to September 2019 for Arima Modeling. The collection period for the time series data of fine dust ranged from January 2016, when $PM_{2.5}$ began to be measured at Busan Gamcheon Port, to May 2020. The PM was categorized into TSP, $PM_{2.5}$, and PM_{10} by diameter to perform specific analyses, and the statistical software used was R Studio.

4. Results of the Empirical Analysis

4.1. Correlation Analysis and Time Series Stabilization

To ascertain the relationship between the bulk cargo primarily managed in Gamcheon Port and fine dust concentrations, a correlation analysis between those variables was first conducted. Table 1 provides a graph displaying the correlation analysis results. The correlation coefficients of the scrap metal throughput calculated at a 1% significance level were 0.40 (TSP) and 0.32 ($PM_{2.5}$); 0.43 (PM_{10}) was calculated at a 5% level. The sand throughput at a1% significance level was 0.31 (PM_{10}), with 0.29 (TSP) and 0.23 ($PM_{2.5}$) at a 10% level. However, a meaningful correlation with the adjacent area's fine dust concentrations was not observed for cement throughput. Thus, the cargo type whose causality was analyzed was determined via the throughput of scrap metal and sand. Other sources that could contribute to dust concentrations include scattering dust around the street caused by exhaust from vehicles, the abrasion of tires, and construction sites, residential, and commercial areas. In the following section, a causality test will be conducted on the fine dust concentrations from sand and scrap metal derived in this analysis.

Table 1. Correlation between the primary cargo throughput and fine dust concentrations.

Types	TSP	PM2.5	PM10
Scrap Metal	0.3998865 ***	0.316925 **	0.4304194 **
Sand	0.2914414 *	0.2335745 *	0.3121511 ***
Cement	0.00004999	0.02634775	−0.01558108

***, **, *: Null hypothesis is rejected at each of the 1%, 5%, 10% significance levels.

The prerequisite to perform a cross-correlation analysis and Granger causality test is to secure the normality of the time series data. ADF and KPSS tests were performed to confirm the normality of the time series data. The scrape throughput and the sand throughput thus secured stationarity via single log transformations and differentiation. If the transformation process is necessary for the time series data of the independent variable X (cargo) while securing stationarity, the data of Y (fine dust), which represent the dependent variable, require the same transformation process. Table 2 demonstrates the statistical value of stationarity of the time series data of scrap metal and sand throughput. In addition, Table 3 describes the statistical value of the stationarity of the fine dust concentration (Y) time series data in response to the scrap metal and sand throughput.

Table 2. The stationarity process of scrap metal and sand throughput time series data.

Test		ADF Test	KPSS Test
Category	Changes	Dickey-Fuller	KPSS Level
Scrap Metal Throughput	Before	−2.4436	0.58083 ***
	After	−5.8228 ***	0.025888 *
Sand Throughput	Before	−2.8341	0.37883 **
	After	−6.5395 ***	0.37883 *

***, **, *: The null hypothesis is rejected at 1%, 5%, and 10% significance levels.

Table 3. The stationarity process of metal and sand throughput PM concentration data.

Test		ADF Test	KPSS Test
Category	**Changes**	**Dickey-Fuller**	**KPSS Level**
TSP	Before	−3.9007 **	1.0491 ***
	After	−6.1381 ***	0.026704 *
$PM_{2.5}$	Before	−4.3047 ***	0.91546 ***
	After	−6.6286 ***	0.023881 *
PM_{10}	Before	−3.7875 **	1.0291 ***
	After	−5.8615 ***	0.028707 *

***, **, *: The null hypothesis is rejected at 1%, 5%, and 10% significance levels.

4.2. Cross-Correlation Analysis

Next, we set the ARIMA model of the scrap metal time series data as ARIMA (3,1,0), whose optimal value is described in Table 4. When the Ljung-Box test was implemented for the drawn residuals, Q* = 4.3673, df = 7, and p-value = 0.7366, signifying that their autocorrelations represent white noise. The sand throughput also shows ARIMA(1,1,1), whose optimal value is described in Table 4. After implementing the Ljung-Box test for the sand throughput, Q* = 6.9356, df = 8, and p-value = 0.5436, which signifies that the residual autocorrelations represent white noise.

Table 4. Error measures for the ARIMA model.

Model	ME	RMSE	MAE	MPE	MAPE	MASE
ARIMA(3,1,0)	0.009389019	0.4733851	0.3697988	−0.1222482	4.084577	0.6979161
ARIMA(1,1,1)	−0.01245689	0.3489491	0.2404142	−0.2166252	2.31866	0.9296629

The results of the fitted ARIMA model for each cargo are summarized in Figures 6 and 7. The standardized residuals did not show clusters of variation. They also showed no significant autocorrelation between the residuals. In addition, the p-value of the Jung-Box statistics provided a value above the dotted lines representing the confidence bands.

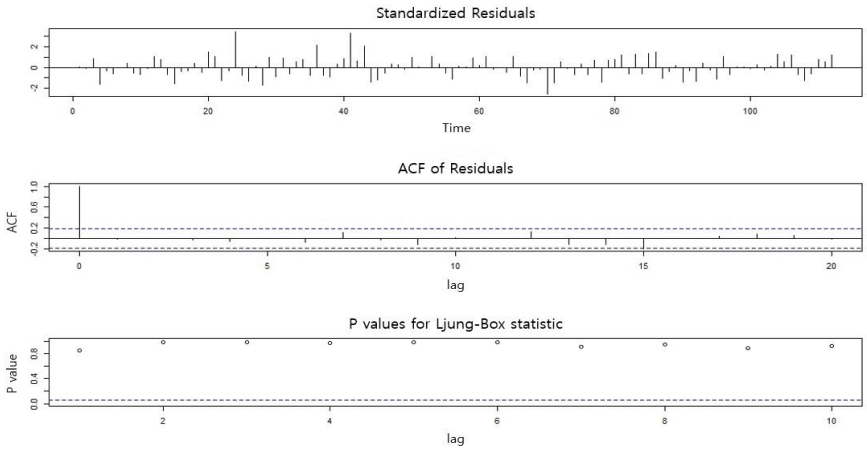


Figure 6. Fitted model for scrap throughput.

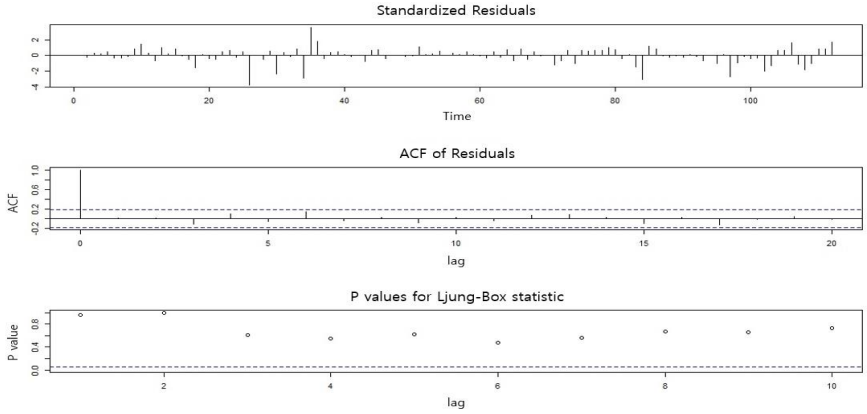
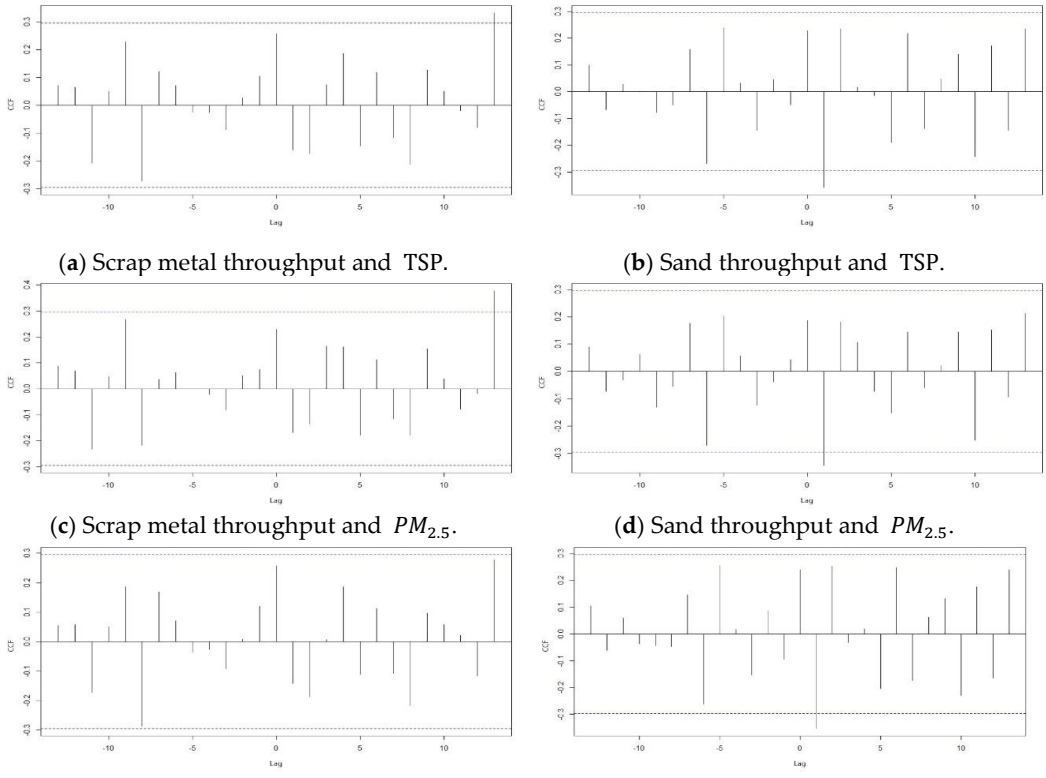


Figure 7. Fitted model for sand throughput.

Next, after the cross-correlations between the fitted ARIMA models of scrap metal and sand throughputs and PM(TSP, $PM_{2.5}$, and PM_{10}), the concentration models set symmetrically were analyzed, and the cross-correlations between variables after pre-whitening were analyzed again. Consequently, the PM data were filtered using each fitted model of the main cargo to find differences between the observed values of PM and the estimated values of PM based on the fitted main cargo models. The results of the cross-correlations for each case after pre-whitening show white noise, which is represented by the dotted line (ccsl) in Figure 8.



(**a**) Scrap metal throughput and TSP. (**b**) Sand throughput and TSP.

(**c**) Scrap metal throughput and $PM_{2.5}$. (**d**) Sand throughput and $PM_{2.5}$.

(**e**) Scrap metal throughput and PM_{10}. (**f**) Sand throughput and PM_{10}.

Figure 8. Cross-correlations after pre-whitening between the main cargo and fine dust concentrations.

4.3. Granger Causality Analysis

The granger causality test was implemented for the main cargo throughput and fine dust (TSP, $PM_{2.5}$, and PM_{10}) using the pre-whitened data. At the first lag, the causality of the scrap metal emitting

fine dust was shown as statistically significant at a 5% significance level (TSP, $PM_{2.5}$, PM_{10}), as shown in Table 5. That is, the local supply chains of scrap metal processed in Gamcheon Port affect the fine dust concentrations in the adjacent areas within lag 1 (1 month). However, the sand throughput did not show causality with fine dust (see Table 6). Conversely, the fine dust (TSP, $PM_{2.5}$, and PM_{10}) did not show causality with the main cargo.

Table 5. Granger causality of scrap metal throughput and fine dust.

Null		Lag (1)	Lag (2)	Lag (3)
Scrape Metal Throughput ≥ TSP	F-statistic	5.0945	1.1053	0.9979
	p-Value	0.02999 **	0.3427	0.4068
Scrape Metal Throughput ≥ $PM_{2.5}$	F-statistic	4.4118	1.0219	0.1025
	p-Value	0.04238 **	0.3704	0.958
Scrape Metal Throughput ≥ PM_{10}	F-statistic	4.1909	1.3966	0.8938
	p-Value	0.04725 **	0.2602	0.4543

**: The null hypothesis is rejected at 5% and 10% significance levels.

Table 6. Granger causality of sand and fine dust.

Null		Lag (1)	Lag (2)	Lag (3)
Sand Throughput ≥ TSP	F-statistic	0.3483	0.7875	0.1749
	p-Value	0.5584	0.4625	0.9127
Sand Metal Throughput ≥ $PM_{2.5}$	F-statistic	0.0036	0.0655	0.0738
	p-Value	0.9527	0.9367	0.9736
Sand Throughput ≥ PM_{10}	F-statistic	0.1991	1.0879	0.6669
	p-Value	0.6579	0.3474	0.5782

5. Discussions and Conclusions

After analyzing the causality of local supply chains and fine dust concentrations in adjacent areas along with the primary bulk cargo (scrap metal, sand, and cement) managed in Busan Gamcheon Port, we determined a causality between scrap metal and fine dust concentrations in the local unit up to a radius of 2.9 km. However, sand and cement cargo did not show any causality. Thus, if scrap metal were appointed as the core management cargo and local supply chains were intensively managed, the effect on lowering fine dust concentrations in the adjacent areas would be to be great.

In the process of unloading and transporting sand and cement cargo from Gamcheon Port to nearby factories, dedicated equipment is used, such as semi-open conveyor belts and underground ducts. However, for handling scrape metal, the basic equipment necessary at construction sites is used, such as excavators and dump trucks. Due to the form of scrape, there is a limit to the use of dedicated equipment to handle it, and factories have not yet developed effective measurements to reduce fine dust emissions in its processing phase.

As a result, integrated management is necessary for ports and front back industries to respond to pollution, improve resident health, and develop a sustainable local economy. Problems that arise from fine dust reduction measures need to be supplemented by countermeasures made at the national and local levels to contribute to air quality improvements. From the perspective of local supply chains, for industries and cities to achieve sustainable development, an eco-friendly industrial structure must be arranged through integrated approaches in economy, society, and the environment.

5.1. Political Recommendations

Industrial activities vary around port areas according to the types of bulk cargo and the port facilities. However, the industrial activities in supply chains that manage bulk cargo are universally similar. Advanced bulk ports have built a system to measure the fine dust concentrations used in operations at ports and the adjacent areas. These systems can also monitor in real time to ascertain the

extent of specific industrial activities on fine dust concentrations. However, for Busan Gamcheon Port, an air quality observatory has not yet been developed, and emissions are investigated instead by air quality measurement vehicles twice a year.

It may be difficult to prepare and implement integrated measurements to solve the fine dust emission problems in a short time at the local level due to the interests of the corporations that make up the supply chains. Thus, it is necessary to introduce a real-time air quality monitoring system in Gamcheon Port and its adjacent areas, and it is meaningful to develop an approach to prepare communal regulations against fine dust emissions by regulating each cargo in the supply chains [20]. In the future, we expect to minimize the blind spots of existing management and prepare countermeasures that will help local industry mechanisms operate efficiently and sustainably.

5.2. Technical Recommendations

Due to the characteristics of the scrap metal cargo and industry, residents living in areas adjacent to bulk ports are directly affected by the fine dust created by factories operating periodical and local industries located around ports. Despite the various efforts of Gamcheon Port and enterprises in the supply chain to reduce the amount of fine dust emissions created during operations, such as watering and using wet cleaners and dry vehicles, it is difficult to reduce the fine dust emissions created from industrial activities, such as unloading, loading, transporting, storage, and manufacturing, thus minimizing the effects of any reduction measures.

However, the dry fog system, a technique that carries out a high pressure procedure on hydrogen and sprays water through high pressurization as a fine fog into the air, can remove fine and standard dust in the fine fog process to absorb dust particles [21]. Unlike existing chemical spray systems for removal, the dry fog system is designed to prevent fine dust particles intruding from workplace surroundings, including bulk cargo, and is appropriate for managing hygroscopic cargo and cargo that can be damaged when exposed to moisture, including coal, coke, copper, and cement. This system also makes it possible to reduce the fine dust particles generated from hoppers and dump pockets that were unable to be controlled previously and can be attached to the hatch deck beams in bulk carriers. The Everglades Port in the United States serves as an example of operating a dry fog system in a bulk port and has achieved a visible outcome by reducing its fine dust emissions drastically using this system [22,23].

Moreover, dry fog systems are principally operated in the ferrous and nonferrous metal manufacturing industries both at home and abroad. The companies using this system in Korea include Hyundai Hysco, Korea Zinc Company, and Sungchang Board. This system has not been introduced yet in the ports of Gwangyang, Incheon, Pyeogtaek/Dangjin, Donghae, and Busan, where bulk cargo has to be managed. The introduction of a dry fog system to the bulk cargo based-supply chains dramatically reduce the fine dust emissions in local units; thus, it could be possible to resolve conflicts between Gamcheon Port and the residents of the area. In addition, future work might consider ports in other regions that underpin operational management.

Author Contributions: J.H. developed the original idea for this study. J.H. was responsible for the data collection. S.K. conducted the data analyses. J.H. and S.K. took part in the formal analysis and validation. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the 4th Educational Training Program for Shipping, Ports, and Logistics by the Ministry of Oceans and Fisheries.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Air Korea. Available online: https://www.keco.or.kr/kr/main/index.do (accessed on 27 March 2020).
2. World Health Organization. *Air Quality Guidelines for Europe*; WHO Regional Office for Europe: Copenhagen, Denmark, 1987.

3. Straif, K.; Cohen, A.; Samet, J. *Air Pollution and Cancer*; International Agency for Research on Cancer (IARC): Lyon, France, 2013.
4. Wan, Z.; Zhu, M.; Chen, S.; Sperling, D. Pollution: Three steps to a green shipping industry. *Nature* **2016**, *530*, 451–466. [CrossRef] [PubMed]
5. Ministry of Government Legislation. Available online: https://www.moleg.go.kr/ (accessed on 3 April 2020).
6. GreenFacts. Available online: https://www.greenfacts.org/en/particulate-matter-pm/level-2/01-presentation.htm (accessed on 6 April 2020).
7. Miller, K.A.; Siscovick, D.S.; Sheppard, L.; Shepherd, K.; Sullivan, J.H.; Anderson, G.L.; Kaufman, J.D. Long-Term Exposure to Air Pollution and Incidence of Cardiovascular Events in Women. *N. Engl. J. Med.* **2007**, *356*, 447–458. [CrossRef]
8. Rückerl, R.; Schneider, A.; Breitner, S.; Cyrys, J.; Peters, A. Health effects of particulate air pollution: A review of epidemiological evidence. *Inhal. Toxicol.* **2011**, *23*, 555–592. [CrossRef] [PubMed]
9. Pope, C.A.; Burnett, R.T.; Thun, M.J.; Calle, E.E.; Krewski, D.; Ito, K.; Thurston, G.D. Lung Cancer, Cardiopulmonary Mortality, and Long-Term Exposure to Fine Particulate Air Pollution. *JAMA Netw.* **2002**, *287*, 1132–1141. [CrossRef] [PubMed]
10. Bachvarova, E.; Spassova, T.; Marinski, J. Air Pollution and Specific Meteorological Conditions at the Adjacent Areas of Sea Ports. *IFAC-PapersOnLine* **2018**, *51*, 378–383. [CrossRef]
11. Park, R.J.; Kim, S.-W. Air quality modeling in East Asia: Present issues and future directions. *Asia-Pac. J. Atmos. Sci.* **2014**, *50*, 105–120.
12. Ebi, K.L.; Mcgregor, G. Climate change, tropospheric ozone andparticulate matter, and health impacts. *Environ. Health Perspect.* **2008**, *116*, 1449–1455. [PubMed]
13. Tai, A.P.K.; Mickley, L.J.; Jacob, D.J. Correlations between fine particulate matter (PM2.5) and meteorological variables in the United States: Implications for the sensitivity of PM2.5 to climate change. *Atmos. Environ.* **2010**, *44*, 3976–3984. [CrossRef]
14. Moreno, N.; Viana, M.; Pandolfi, M.; Alastuey, A.; Querol, X.; Chinchón, S.; Pinto, J.F.; Torres, F.M.; Díez, J.M.; Sáez, J. Determination of direct and fugitive PM emissions in a Mediterranean harbour by means of classic and novel tracer methods. *J. Environ. Manag.* **2009**, *91*, 133–141. [CrossRef] [PubMed]
15. Borrego, C.; Costa, A.; Amorim, J.; Santos, P.; Sardo, J.; Lopes, M.; Miranda, A. Air quality impact due to scrap-metal handling on a sea port: A wind tunnel experiment. *Atmos. Environ.* **2007**, *41*, 6396–6405.
16. Dagum, E.B.; Chiu, K. Derivation and Properties of the X11ARIMA and Census X11 Linear Filters. *J. Off. Stat.* **1996**, *12*, 329–347.
17. Taylor, R. Interpretation of the Correlation Coefficient: A Basic Review. *J. Diagn. Med. Sonogr.* **1990**, *6*, 35–39. [CrossRef]
18. Dean, R.T.; Dunsmuir, W.T.M. Dangers and uses of Cross-Correlation in analyzing time series in perception, performance, movement, and neuroscience: The importance of constructing transfer function autoregressive models. *Behav. Res. Methods* **2015**, *48*, 783–802. [CrossRef] [PubMed]
19. Scholarpedia. Available online: http://www.scholarpedia.org/article/Granger_causality (accessed on 15 April 2020).
20. Jo, J.-H.; Kim, S. Key Performance Indicator Development for Ship-To-Shore Crane Performance Assessment in Container Terminal Operations. *J. Mar. Sci. Eng.* **2020**, *8*, 6. [CrossRef]
21. Wallace, K.A.; Cheung, W.M. Development of a compact excavator mounted dust suppression system. *J. Clean. Prod.* **2013**, *54*, 344–352. [CrossRef]
22. Dust Sollutions, Inc. Available online: https://www.nodust.com/What-s-New-at-DSI/Portable-dry-fog.html (accessed on 30 April 2020).
23. Kang, D.; Kim, S. Conceptual Model Development of Sustainability Practices: The Case of Port Operations for Collaboration and Governance. *Sustainability* **2017**, *9*, 2333. [CrossRef]



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).