Monitoring the Environmental Impact from Ship Emissions Using AIS, GIS, and Fuzzy Logic

Wu-Hsun Chung*, Sheng-Long Kao, Chao-Wei Chen, Hsiao-Cheng Chang

Abstract: Due to growing environmental concerns, the measuring, monitoring, and reducing carbon emissions in a port is a critical issue. This paper applied Automatic Identification Systems (AIS), Geographic Information System (GIS), and fuzzy logic to develop an environmental impact indicator for monitoring the influence of ship emissions on the vicinity of a port. A case study of the Port of Keelung in Taiwan was used to demonstrate the proposed method.

Keywords: Carbon footprint, Green port, Automatic Identification System (AIS), Geographic Information System (GIS), Fuzzy logic

1. Introduction

The development of globalization in recent decades has resulted in massive international trade and logistics. Maritime transportation is the major transportation mode in international trade and logistics (Coyle et al. 2012). A port plays a pivot role in maritime transportation. It is not only a hub of ships and freight, but also a hub of ship emissions. Due to growing environmental concerns, the desire for green port also increases. How to effectively measure, monitor, and reduce the environmental influence of operational activities in a port is a challenge for port administration. Ship emissions are one of major pollution sources in the area of a port. This paper proposes a method to effectively estimate and monitor the environmental impact from ship emissions in the area of a port.

2. Method

The proposed method applied multiple tools, Automatic Identification System (AIS), Ship Traffic Emissions Assessment Model (STEAM), Geographic Information System (GIS), and fuzzy logic, to indicate the environmental impact of ship emissions on a port and visualize the resulting information on GIS. As shown in Figure 1, after receiving ship AIS data and ship basic information, STEAM can estimate ship emissions. In addition, the ship-to-port distance can be also calculated based on the AIS data. Next, fuzzy logic aggregates the information of the distance, the ship emissions and environment sensitivity zone to calculate the environmental impact caused by ship emissions. These steps are detailed as follows.

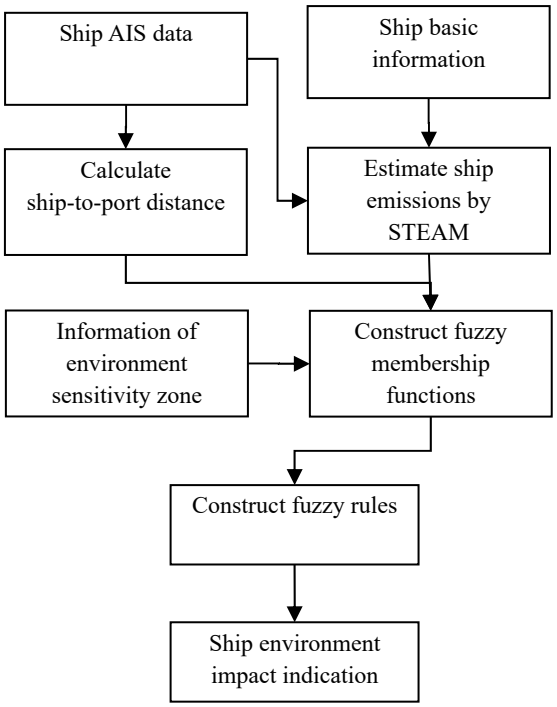

Figure 1. Workflow of the proposed method

The AIS data in the paper were collected by the AIS base stations around the Port of Keelung in June 2015 including arriving, departing, and berthing container ships. The study area here is the zone within 20 nautical miles (NM) around the center of the Port of Keelung as indicated in Figure 2. The zone was mapped in a grid with 500-meter grid intervals.

Figure 2. The map of the port of Keelung

2.1. Automatic Identification System (AIS)

AIS is a ship tracking system which combines global positioning system (GPS) and very high frequency (VHF). It has been widely used on ships at sea and enables ships to exchange various navigational information (e.g., ship name, ship type, position, course, speed, draft, etc.) with other nearby ships at sea or base stations on land. Traditionally, the main function of the AIS is ship collision avoidance and maritime safety.

2.2. Ship Traffic Emissions Assessment Model (STEAM)

In recent years, the function of the AIS has been extended to the area of environment. Using AIS data and ship basic information as input, various models have been developed to calculate and assess carbon emissions of ships (Perez et al. 2009; Jalkanen et al. 2009; Miola and Ciuffo 2010; Jalkanen et al. 2012; Ng et al. 2013; Tichavska and Tovar 2014). For instance, Jalkanen et al. (2009) presented STEAM to estimate exhaust emissions of marine traffic in the Baltic Sea area.

2.3. Geographic Information System (GIS)

Geographic Information System (GIS) is a system used to create, analyze, manage, and present many kinds of geographic data on a map. It has been widely applied in different fields including traffic navigation, real estate, national defense, natural resources, etc. In the paper, GIS is used to visualize the ship emissions and resulting information. The GIS software used in the research is ArcMap 10.

2.4. Fuzzy Logic

Fuzziness is a common concept to describe some properties which cannot be precisely defined in daily life, such as hot and cold, short and high. Fuzzy logic introduced by Zadeh (1965) is a form of many-valued logic. The truth values of its variables are any real number between 0 and 1, which is considered to be “fuzzy”. This study exploited ship AIS data and applied fuzzy logic to integrate three fuzzy inputs, “ship emissions”, “ship-to-port distance”, and “environment sensitivity zone”, to output an environment indicator to show the environmental impact of ship emissions on a port as shown in Figure 3 and Table 1. The ship emissions were estimated by STEAM. The environment sensitivity zone means the area full of many environmentally fragile sites, like fishpond, aquaculture farm, coastal protected area, etc. as shown in Figure 4. The fuzzy membership functions for the input and output were set as triangle because of its popularity in general applications.

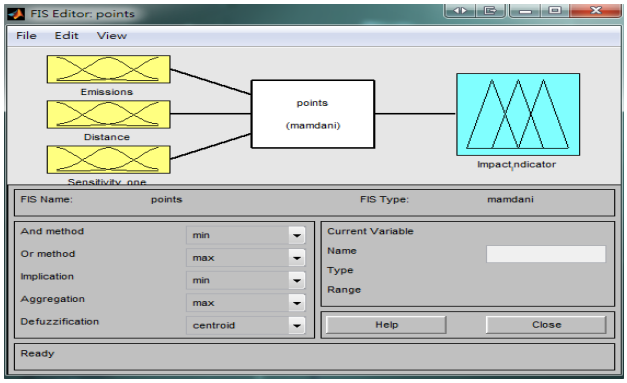

Figure 3. Fuzzy input and output shown on MATLAB

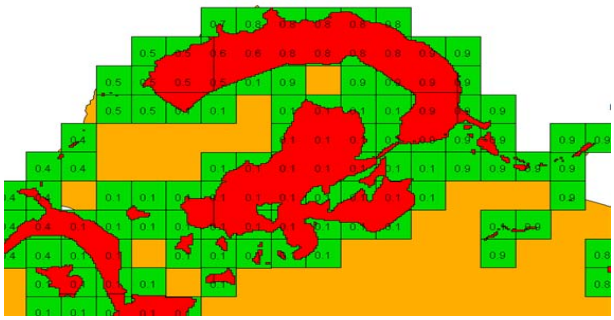

Figure 4. Environment sensitivity zone (Kao and Ko, 2005)

Once the fuzzy input and output are defined and the fuzzy membership functions are formed, we collected experts' opinions to determine the fuzzy rules for the input-and-output relationship as shown in Figure 5.

Table 1. Input and output of fuzzy variables

Input		
Linguistic variables	Definition	Fuzzy value scale
x(Emissions)	The maximal and minimal ship emission in June 2015 (unit: ton)	low(0.0012ton) middle(0.054ton) high(0.107ton)
y(Distance)	The distance between a ship and the center of a port (unit: NM)	close(0NM) middle(10NM) far(20NM)
z(Sensitivity Zone)	The environment & bio sensitivity in an area; from 0 to 10, larger value means more sensitive	low(0) middle(5) high(10)
Output		
Linguistic variables	Definition	Fuzzy value scale
p(Environmental Impact Indicator)	The indicator to represent the strength of the environment impact; larger value means larger impact	high(10) middle(5) low(0)

Figure 5. Fuzzy rules for input and output on MATLAB

3. Results and Discussions

The major ship emissions in June 2015 around the port of Keelung were estimated by STEAM and mapped on GIS. Figure 6 shows the distribution of the ship emissions. The high emission level is marked in red and the low emission level is marked in green. Figure shows us that the ship emission in the central area of the port is most intensified, and the one in the arriving and departing channels is the second.

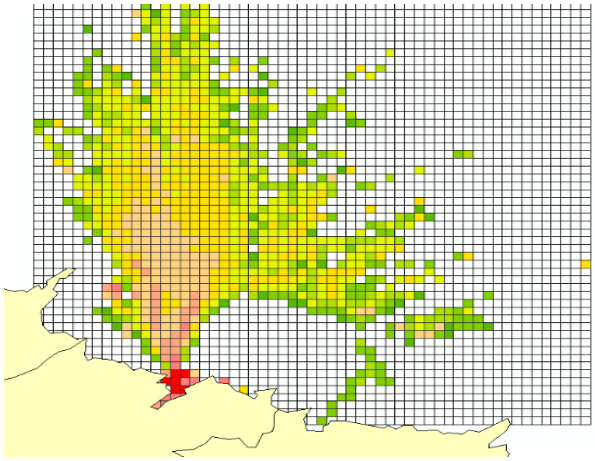

Figure 6. Distribution of ship emissions around the port of Keelung mapped on GIS

The trajectory of five selected ships is mapped as shown in Figure 7. Different ships are marked by different shapes (e.g., square, circle, triangle, etc.). The environment impact is calculated based on the fuzzy logic aforementioned and attached to each trajectory dot. Similarly, the high environment impact level is marked in red and the low environment impact level is marked in green. As observed in Figure 7, the change of ship locations significantly influences the environment impact value and the corresponding color.

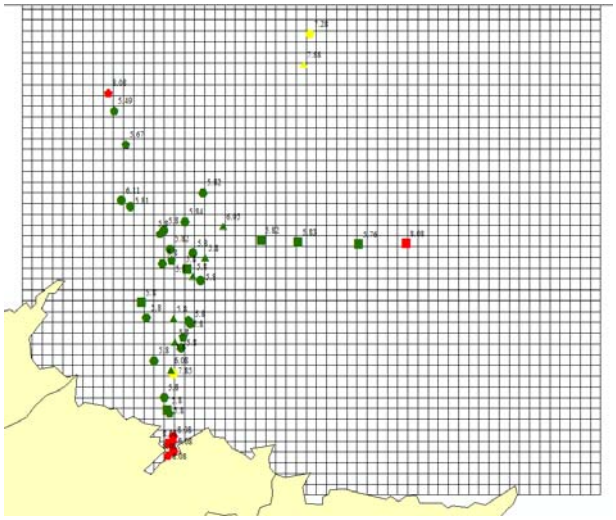

Figure 7. Trajetory of individual ships marked by the environment impact indicator

4. Conclusions and Future Work

This research combines GIS, AIS, and fuzzy theory with port air emissions inventory to construct an effective tool for monitoring the real-time influence of ship emissions on the environment around a port. It can provide useful information for port managers. Because of fuzziness, the proposed method enables itself have more flexibility to adapt to various user environments.

However, some insufficiencies in research remain. For instance, the ship AIS data used in this paper are not complete and contain only one month. More AIS data collection and analysis are required. In addition, the fuzzy membership functions and fuzzy rules is not fully validated. More efforts for this are needed in future work.

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