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Modeling for the allocation of oil spill recovery capacity considering environmental and economic factors

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ABSTRACT

This study presents a regional oil spill risk assessment and capacities for marine oil spill response in Korea. The risk assessment of oil spill is carried out using both causal factors and environmental/economic factors. The weight of each parameter is calculated using the Analytic Hierarchy Process (AHP). Final regional risk degrees of oil spill are estimated by combining the degree and weight of each existing parameter. From these estimated risk levels, oil recovery capacities were determined with reference to the recovery target of 7500 kl specified in existing standards. The estimates were deemed feasible, and provided a more balanced distribution of resources than existing capacities set according to current standards.

1. Introduction

With the rapid growth of industrial activity over the past few decades, the risk of pollution to water, air, land environment, plants, animals, and humans has become inevitable (Davies and Hope, 2015; Poch et al., 2004). In general, the increased transportation of oil via sea tankers brings tremendous benefits to various regions (Verma et al., 2013), but it also exacerbates the probability of large-scale marine pollution accidents (Lee and Oh, 2014). Oil spills usually have an enormous impact on marine and coastal environments (Liu and Wirtz, 2009), resulting in losses to the fishery and tourism industries and negatively affecting recreational and environmental values (Alvarez et al., 2014; Carson et al., 2003; Helle et al., 2015; Loureiro and Loomis, 2013; Loureiro et al., 2009); even small-scale oil spill accidents may cause huge losses (Cirer-Costa, 2015; Kirby et al., 2014). For this reason, various policies should be established to prevent marine oil spill accidents, and various effective countermeasures should be established to minimize damage in events of accidents. In particular, countermeasures to be taken in the event of an accident should be optimized in accordance with geographical characteristics. For example, various situations can be considered in advance according to various geographical characteristics, such as archipelagos, shallow areas, and high-density transport areas. With such considerations, a customized response model that can efficiently cope with the situations should be established.

The Republic of Korea, which is a peninsula, underwent a period of rapid economic development, known as ‘The miracle on the Han River’ (Heo, 2012). After liberation from the Japanese, the Korean economy has shifted from light industry to heavy industry (Heo, 2012), and energy consumption to support economic activities has also been steadily increasing (Corporation, 2017). As a result, marine transportation of crude oil and chemical products has increased significantly (Almansoori, 2014; Koo et al., 2015; Lee and Oh, 2014; Young-Gyun Ahn and Park, 2017). Moreover, Korea is characterized by a diverse and complex marine environment with many coastal islands, complex coastlines, shallow waters of the South Sea and West Sea, and deep waters of the East Sea. Owing to these economic and geographical characteristics, Korea has already experienced many marine pollution accidents (Kang and Kang, 2003). Therefore, if a resource allocation model for marine pollution accidents targeting Korea is developed, the model is expected to become a standard that is universally applicable and efficient for developing countries and many other countries around the world with coastal environments similar to the complex coastal environment of Korea.

Previously, a response model for Korea was established taking into account the experience of many large oil spill accidents. Examples include the oil tankers *Sea Prince* in 1995 and *Hebei Spirit* in 2007, which gained wide interest and emphasized the importance of preparation and response to large-scale oil spill accidents (Lee and Jung, 2013). Alerted by these large-scale marine pollution accidents, Korea introduced the concept of ‘National Recovery Capacity’ to respond effectively to marine pollution accidents and acquired and maintained sufficient response equipment prepared for future catastrophic spills (Corporation, 2011). Korea has set regional recovery capacities to efficiently utilize limited resources (Corporation, 2011). However, one shortcoming is that the current standard for regional oil recovery capacity takes into

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consideration only causal factors (Corporation, 2011), and not environmental or economic factors. Therefore, the standard should be reconfigured to reflect environmental and economic factors with emphasis on the importance of the environment and economy (Cho and Kim, 2015).

Therefore, this study considered environmental and economic factors in addition to the existing factors in setting the present regional oil recovery capacities, to determine the degree of risk for each region. In this manner, a more advanced model for Korea with the most complex marine environments was developed, thereby providing an efficient and universal model with improved capability for marine pollution control.

In this study, seven evaluation items were set into two categories to investigate the current statistical status: accident probability and post-accident sensitivity. The Analytic Hierarchy Process (AHP) is the most widely used multi-criteria decision-making technique for handling problems (Dong and Cooper, 2016; Wallenius et al., 2008). The AHP approach is frequently used to determine the importance levels of hazards (Aminbakhsh et al., 2013; Kokangül et al., 2017; Padma and Balasubramanie, 2007). The AHP allows decision makers to view decision issues in a systematic manner that takes into account all relevant decision parameters (Dong and Cooper, 2016). Therefore, as a suitable decision-making method, the AHP was used to set the weights of the items in this study.

These statistical status and weights were unified into one value, which indicated the final regional degree of risk. Based on the final regional degree of risk values, new regional oil recovery capacities are suggested for each region. The plausibility of the proposed targets was evaluated by simulating the mobilization of oil cleanup equipment for a large-scale oil spill accident. The results showed that the proposed method is viable.

The remainder of this paper is organized as follows: Section 2 reviews the current criteria for the oil recovery capacity of the Republic of Korea, Section 3 describes the study method, Section 4 presents and discusses results of setting the proposed regional oil recovery capacities, and Section 5 summarizes the main conclusions of this study.

2. Review of current criteria

2.1. Criteria for Korean national oil recovery capacity

Korea's national recovery capacity assumes that a maximum of 60,000 tons of oil would be spilled in a marine accident involving an oil tanker of 300,000 DWT (deadweight tons) capacity, which is the maximum size of vessels that enter and depart from Korean waters since the Sea Prince incident. In a spill, it is assumed that 20,000 tons (one third of the spilled oil) would evaporate, another one third would be deposited in the ocean, and the goal is to recover and treat the remaining one third from the sea. However, following the Hebei Spirit accident, the existing term 'national recovery capacity' was revised to 'oil recovery capacity'. As the calculation method changed, the maximum volume of a virtual oil spill was reduced to 45,000 kl, with corresponding oil recovery capacity on water reduced to 15,000 kl. Formulas for calculating valid recovery capacities of oil skimmers, numbers of oil booms required for oil recovery, and the capacity of temporary storage tanks have been included and form the current standard for oil recovery capacity from water (Corporation, 2011).

2.2. Criteria for calculating regional oil recovery capacity

2.2.1. Regional categorization

The study areas were categorized into three metropolitan areas, Ulsan, Yeosu, and Daesan, based on the distribution of coast guards and the locations of Korea Marine Environment Management Corporation branch offices as shown in Table 1. The central and neighboring sectors of each area were grouped together to form one area (Corporation, 2011) (Fig. 1).

Table 1
Division of areas and regions.

Area	Region
Ulsan	Donghae·Sokcho, Pohang, Ulsan, Busan, Tongyeong·Masan
Yeosu	Yeosu, Wando, Mokpo, Jeju·Seogwipo
Daesan	Gunsan, Taean·Daesan, Pyeongtaek, Incheon

2.2.2. Virtual maximum spill per region

The virtual maximum volume of an oil spill in each area is 45,000 kl, of which the quantity to be cleaned up from the water is 15,000 kl. When a maximum oil spill occurs in a certain area, cleanup equipment is deployed from other areas for the cleanup operation according to the deployment system. The target was set to ensure 50% (7500 kl) oil recovery in a given area attributable to the deployment system (Corporation, 2011).

2.2.3. Regional volume of oil recovery from water

In order to calculate regional targets for volume of oil recovery, the regions grouped within each of the large areas were categorized as center (where a maximum pollution incident can occur) or periphery. In principle, oil skimmers (which are capable of recovering the total volume of a maximum oil spill event within the corresponding area) were primarily deployed in the peripheries, and the remaining equipment was deployed to the centers. The specified volumes of regional oil recovery on water according to this principle are shown in Table 2 (Corporation, 2011). These required quantities are the current regional targets for recovery of oil from water.

2.2.4. Problem in setting current regional oil recovery capacities from water

The current regional capacity for recovery of oil from water was set according to the size of ships entering and leaving Korean waters, and based on past marine pollution incidents, without considering the unique characteristics of each region. Therefore, the present criteria consider only the causal aspect of accidents. However, it is also necessary to consider environmental and economic aspects, which may be affected following a pollution event.

3. Study method

3.1. Determining items for setting oil recovery capacity

Items in the standards for deployment of recovery resources were determined based on marine pollution risk factors and ESI. These were categorized largely into accident probability factors and post-accident sensitivity factors. The former includes volume of oil transport, distribution of industrial facilities (oil storage facilities), entry and departure of ships, and past oil spill accidents. The latter includes aquaculture distribution, sea of high environmental significance, and amenities (beaches) (Fig. 2).

3.2. Calculating regional risk and setting oil recovery capacity on water

Regional statistical data were analyzed for the 7 items previously suggested (volume of oil transport, distribution of industrial facilities (oil storage facilities), entry and departure of vessels, past oil spill accidents, aquaculture distribution, environmentally special sea, and amenities) based on statistical data obtained from Statistics Korea, Korea Coast Guard, Korea Marine Environment Management, the Korea Tourism Organization, and the Marine Environmental Management Act. These data were used for calculating the degree of risk for each item in each region.

The Analytic Hierarchy Process (AHP) is one of the techniques developed to support Multiple-Criteria Decision Making (MCDM) for cases involving multiple alternatives and assessment criteria (Demir and