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Risk Perception and Communication at Maritime Transportation to and from Japan after the Fukushima Daiichi Nuclear Power Plant Disaster

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Abstract. This paper reports the contamination-related impact of the Fukushima Daiichi nuclear power plant disaster on seaport activities and international maritime transportation. It then analyzes the risk perception and risk communication after the disaster. First, the maritime-related newspaper articles published in Japan after the disaster were extensively reviewed. Next, 11 maritime-related actors, including port managers, governments, shipping companies, port operators, and shippers, were interviewed. The interviews were conducted from June to December, 2011. The results of these interviews revealed that the contamination-related impact of the power plant disaster included impacts on 42 skipping ports of container vessels operated by non-Japanese shipping companies in Keihin Ports, on radiation measurements of Japanese cargo at foreign ports, and on actions taken by the Japanese government and port managers. Then, the events observed after the disaster are explained along with the framework of social amplification of risk communication. They suggest that the risk communication made by maritime stakeholders successfully reduced the amplification of risk among stakeholders at the various levels of information sources, information channels, and stations. Finally, the lessons from the study are summarized, including the identification of factors influencing the amplification of risk, quick responses and appropriate countermeasures by authorities and port managers, and the introduction of systematic radiation measurement under the international agreement.

Keywords. maritime transportation, Fukushima Daiichi nuclear power plant disaster, risk perception, risk communication, skipping port, radiation measurement

INTRODUCTION

On March 11, 2011, a devastating earthquake shook the Tohoku Region in Japan. The 9.0 magnitude earthquake that was followed by a deadly tsunami destroyed maritime transportation infrastructure, including the major port facilities in the Tohoku Region. Many of these ports were inaccessible for months (*1*). At the same time, the severe ground motion and large multiple tsunami waves significantly damaged the Fukushima Daiichi nuclear power plant. This resulted in the release of huge amounts of radionuclides into the environment (*2*). Although most of the radionuclides were carried out into the Pacific Ocean, it is still estimated that about 10% to 20% of the total radionuclides emitted from the power plant were deposited over land in northeastern Japan (*3*, *4*). In response, the Japanese government set up a 20-km restricted zone and “planned evacuation areas” out of the restricted zone in Fukushima Prefecture. The government also announced the safety in the remaining parts of the Tohoku and Kanto regions. Despite the government’s efforts, the Fukushima Daiichi nuclear power plant disaster had a significant impact on seaport activities and maritime transportation to and from the major ports in Japan. The Sendai and Keihin ports are nearly 100 km and 200 km away from the power plant, respectively (refer to the map of Japan in **FIGURE 1**). The Keihin Port is one of the major ports in Japan. This port is located near Tokyo, where the Tokyo, Kawasaki, and Yokohama ports are also present. The Tohoku region includes Aomori, Iwate, Akita, Miyagi, Yamagata and Fukushima Prefectures, and the Kanto region includes Tochigi, Ibaraki, Saitama, Chiba, Tokyo and Kanagawa Prefectures.

The impacts can be divided into two categories: earthquake and tsunami-related impacts and contamination-related impacts. The earthquake and tsunami-related impacts include the physical destruction of facilities and the damage caused by the tsunami, whereas the contamination-related impacts include the potential risk of radiation on human health, radiation contamination of goods, and the halt in service because of the fear of radiation. A number of studies and analyses have focused on the earthquake-related impacts (*6*–*8*), but few have focused on the contamination-related impacts. The mechanisms underlying the complex nuclear contamination-related issues have remained unfamiliar and incomprehensible to most lay people. In order to clarify those mechanisms, we have focused on risk perception and risk communication, which play key roles in

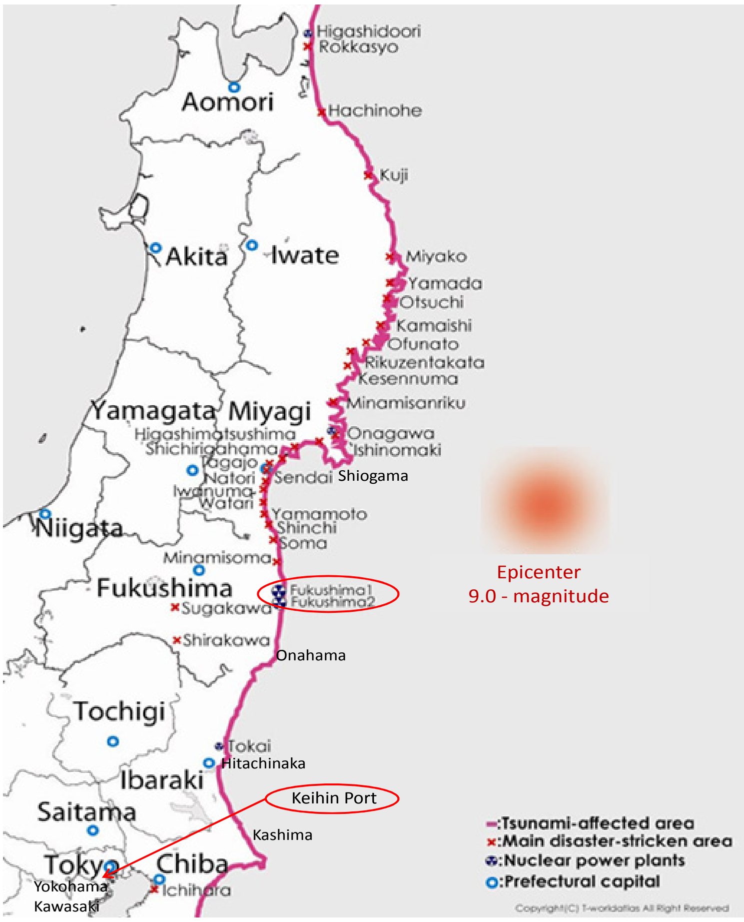

FIGURE 1: Map of Kanto and Tohoku Region in Japan

Source: Japan International Cooperation Agency (JICA) (*5*) the aftermath of the accidents with severe radiological consequences (9, 10). Indeed, most of the contamination-related impacts were triggered and resolved by the risk perception and risk communication of maritime transportation actors.

This paper aims to report the contamination-related impacts of the Fukushima Daiichi nuclear power plant disaster on the seaport activities and international maritime transportation to and from Japan. It then aims to analyze the risk perception and risk communication after the disaster. The paper focuses on risk behaviors and countermeasures taken by maritime transportation actors, including shipping companies, Japanese government, and port managers. Risk perception and risk communication are analyzed with the social amplification of risk framework. Finally, implications of better risk communication beyond the maritime transportation field are presented.

This paper is organized as follows: motivations and goals are described in the introduction. The next part details the literature review and this study's approach. The results from the review of maritime newspapers and from the interviews with stakeholders are reported from the viewpoint of contamination-related impacts. Then, the analyses on risk perception and risk communication are presented. Finally, the policy implications and further research issues are summarized.

LITERATURE REVIEW

Contamination-related impacts are influenced by the risk perception and risk communication of maritime stakeholders. Risk perception is defined as the processing of physical signals and/or information about potentially harmful events or activities and the formation of a judgment about the seriousness, likelihood, and acceptability of the respective event or activity. Risk communication is defined as an interactive process of the exchange of information and opinion among individuals, groups, and institutions (11–13).

Risk perception is commonly used in reference to natural and man-made hazards, which are studied mainly in the contexts of psychology, sociology, and technical sciences (11). Social amplification of risk framework (SARF) suggested by Kasperson et al. (14) is an integrative framework for explaining risk perceptions as well as social responses to risks. SARF suggests that social and economic impacts of an event are determined by a combination of the direct physical consequences and the interaction of psychological, social, institutional, and cultural processes (15–17). Social interactions can both intensify and attenuate perceptions or risk. In this framework, risk information is communicated through "amplification stations," which can be individual, group, and institutional, according to their perceptions. Consequently, risk behavior is influenced and the behavioral patterns, in turn, generate secondary consequences that extend far beyond the immediate impacts. Several empirical applications have been conducted using this framework (18–22).

Risk communication was originally developed as a means of investigating how expert assessments could be communicated with the public most effectively to bridge the gap between public perceptions and expert judgment (11). This paper focuses on nuclear risk communication. Nuclear risk includes naturally occurring radiation, nuclear-related technology applied in the medical field, nuclear waste, and nuclear power (23). Perceived nuclear risk is typically different among lay people and experts (9, 10, 24, 25). Usually, naturally occurring radiation and nuclear-applied technology that is practiced in the medical field (such as x-rays) are perceived as having lower risk and higher benefits than nuclear waste and nuclear power. The image of nuclear waste and nuclear power among lay people is, generally, negative, because the perception originates from nuclear war weapons, which have invisible contaminations with uncontrollable consequences. Thus, risk communication is a significant issue in the case of utilizing nuclear power and nuclear waste. Slovic (23) shows that the acceptance of risk is conditioned by the following four factors: trust in the managers of the technology, appreciation for the direct personal benefits of the technology, knowledge, and whether the risk is of natural origin. Some risk communication strategies have been introduced, such as nuclear knowledge diffusion to lay people and comparison between the radiation levels of particular exposures with background value. So far, it has been pointed out that the aftermath of the Fukushima Daiichi nuclear power plant disaster has caused difficulties in nuclear risk communication including rebuilding the trust and confidence of Japan (26–28). This requires more sophisticated risk communication strategies (29, 30).

This paper highlights the risk perception and risk communication of maritime transportation stakeholders in reaction to the Fukushima Daiichi nuclear power plant disaster. Drabek (31) pointed out that the risk perceptions associated with nuclear energy is fairly different from tornados, floods, and other kinds of man-made hazards. Although most previous studies have assumed hypothetical cases about nuclear risk, this study deals with the real situation observed under nuclear risk. In addition, risk perception and risk communication in the field of transportation has been merely studied. Thus, a timely report of contamination-related impacts and the fact-based analysis of risk perception and risk communication will contribute to the comprehensive understanding of risk perception and risk communication, particularly in maritime transportation.

DATA COLLECTION

This paper first reviewed the literature related to the impacts of the earthquake and the subsequent Fukushima Daiichi nuclear power plant disaster as well as the risk communication at Keihin Port and at the ports in the Tohoku region. The literature review covered articles in the four major Japanese maritime newspapers issued from March 11, 2011, to the end of June 2011. These newspapers are: Maritime Daily News, The Japan Maritime Daily, Nikkan Kaijitsushin, and Daily Kaiji Press. The reason for reviewing only Japanese newspapers is that the articles in those newspapers contain more local information than those in international mass media sources. The articles reporting on risk communication were searched for the following keywords: "skipping-port," "stigma," "radiation," "the Great Tohoku Earthquake," "disaster," "response," and "countermeasure." The articles in each newspaper were also reviewed by focusing mainly on recoveries in the ports in the Tohoku region from March 11, 2011, to the end of November 2011, with the same keywords as those used in the literature reviews for Keihin Port.

Next, we conducted interviews with maritime actors in Japan. The interviewees included the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in Japan, which is in charge of governing ports and maritime transportation in Japan; shipping companies; port managers; and shippers. The interviewed organizations are listed in **TABLE 1**. The sources of the data and descriptions shown in the remaining part of this paper are taken from the articles in the above-mentioned newspapers and/or from the results of the interviews with the maritime actors.

TABLE 1: A List of Interviewed Maritime Actors

Organizations	Dates	Places	Types
MLIT, Kanto Regional Bureau	June 9, 2011	Yokohama No.2 Joint Government Office Building	Government
Port & Harbor Bureau, City of Yokohama	June 11, 2011	Industry and Trade Center Building, Yokohama	Port manager
Mitsui O.S.K. Lines, Ltd. (MOL)	Sept. 30, 2011	MOL Tokyo Office	Japanese shipping company
NYK Container Line	Sept. 30, 2011	NYK Container Line Tokyo Office	Japanese shipping company
Cosco Container Lines Japan Co., Ltd.	Oct. 3, 2011	Cosco Container Lines Japan Tokyo Office	Chinese shipping company
Hapag-Lloyd (Japan)	Nov. 4, 2011	Hapag-Lloyd Japan Tokyo Office	German shipping company
MLIT, Tohoku Regional Bureau	Dec. 21, 2011	Tohoku Regional Bureau Office Building	Government
Port & Harbor Bureau, Miyagi Prefecture	Dec. 21, 2011	Miyagi Prefecture, Sendai-Shiogama Port Bureau	Port manager
Shiogamako UNSO Co., Ltd.	Dec. 21, 2011	Shiogamako UNSO Office	Port operator
Sanriku Unyu Co., Ltd.	Dec. 21, 2011	Sanriku Unyu Office	Port operator
Shima Co., Ltd.	Dec. 22, 2011	Shima Office	Shipper

CONTAMINATION-RELATED IMPACTS

General Impact on Foreign Countries

After the Fukushima-Daiichi nuclear power plant disaster, many foreign countries expressed concerns, given the dire situation. Some foreign embassies in Tokyo shortened their working hours, stopped their services, or even shifted the functions of the embassy to the Kansai region, which is more than 500 km away from the affected nuclear plant (*32*). They also issued warnings about the dangers of radioactive contamination to the foreign residents in Japan. For example, the French government advised its nationals to leave Tokyo on March 13, 2011, owing to the threats posed by the nuclear power plant, which was 220 km north of the Japanese capital (*33*). Concerns on radioactive contamination lasted long after the nuclear disaster calmed down, particularly in relation to the safety of food and drinking water. Major newspapers in the United States and China had also expressed deep concerns on food contamination (*34)*. At the same time, foreign tourists to Japan sharply declined after the disaster. The Japan Tourism Agency (*35*) reported that the number of foreign tourists decreased by 62.5% in April 2011 compared to the same month last year.

Impact on Shipping Services

Reportedly, 42 international container vessels skipped the Keihin Port from April 1, 2011, to May 15, 2011 (Source: Interview with the Kanto Regional Development Bureau, MLIT). All the vessels that skipped Keihin Port were operated by non-Japanese shipping companies (as shown in **TABLE 2)**. Foreign shipping companies, particularly European companies, responded sensitively to the release of radioactive materials. Most foreign shipping companies called at the ports in the Kansai and Nagoya regions (more than 400 km away from the Fukushima Daiichi nuclear power plant) after skipping Keihin Port. In these cases, the international cargo to and from the Tokyo Metropolitan Area was transported by a domestic feeder service or land transportation service. Some of the foreign shipping companies even canceled all shipping services to and from Japan from March 11, 2011, to May 2011. Note that no instance of port skipping was seen at Keihin Port because of the radiation since June 2011. On the other hand, the situation at the ports of the Tohoku region differs from that at Keihin Port. Immediately after the disaster, both Japanese and non-Japanese shipping companies skipped ports in the Tohoku region because of the earthquake-related damage to the quay walls and loading/unloading machines. The Japanese shipping companies restarted their services after the port facilities were partly operational, while the non-Japanese shipping companies kept skipping some ports of the Tohoku region including Sendai Port even after the port facilities were operational. At least ten international vessels skipped Sendai Port from April 1, 2011, to May 20, 2011 (*36*). These cases include one where a shipping company refused to call at Sendai Port although the shipper had requested a coal-shipping vessel. The port-skipping vessels changed their routes to other ones such as the route to Keihin Port, ports in the Kansai region, and ports along the Japan Sea (Source: Interview with a port operator). Note that the ports in the Tohoku region mainly handle irregular shipments rather than regular shipments. Thus, the shippers in the Tohoku region who require irregular shipment services had no choice but to charter domestic vessels from another port located along the Japan Sea to Sendai Port. This led to a critical increase in maritime shipping costs for them. In September 2011, one of the Korean shipping companies restarted its transportation service connecting Sendai Port with foreign ports, making them the first to do so after the earthquake (*37*). However, the other Korean shipping company that offered the same service before the disaster had not restarted its service as of December 2011 (Source: Interview with Tohoku Regional Bureau, MLIT). The insufficient international shipping services to and from Sendai Port led to the substitution of shipping services through the use of neighboring ports. For example, three regular international container services at Hachinohe Port were quickly operational in the Tohoku region as of May 19, 2011. In addition, many vessels changed their sailing routes by taking detours that were more than 100 km away from the Fukushima Daiichi nuclear power plant to and from the ports in the Tohoku region and in the north Kanto region (Source: Interview with Tohoku Regional Bureau, MLIT).

TABLE 2: Major Responses to the Disaster by Non-Japanese Shipping Companies

Date	Responses to the disaster
March 11, 2011	Date of the earthquake.
March 14, 2011	APL (Singapore) temporarily suspends booking to and from Japan*[1]. Business hours reduced in Tokyo office to 9:30–16:00 (until March 18).
March 16, 2011	● Hamburg Sud (Germany) begins to skip Keihin Port. ● 60% of the staff of the CMA/CGM (France) from the Tokyo office work from home. Cancelation of the issuance of a bill of landing (B/L) on March 16. Limited service on March 17. Limited booking service in Keihin Port shipment.
March 17, 2011	● Hapag-Lloyd (Germany) starts to skip Keihin Port. Staff stays indoors from March 17 to March 18. ● The Yokohama Port manager visits shipping companies directly.
March 18, 2011	MLIT starts to post radiation-related information on its website.
March 21, 2011	SJJ (China) cancels calling Keihin Port from Shanghai on March 21 and March 25. They skip Keihin Port and reduce calling on March 28.
March 22, 2011	The Yokohama Port manager begins to offer radiation-related information.
March 23, 2011	● China Shipping (China) skips Tokyo Port and continues calling at Yokohama Port. ● Pacific Atlantic Express (PAX) service by Grand Alliance (Hapag-Lloyd, NYK, and OOCL) skips the Tokyo and Nagoya ports. .
March 28, 2011	● Hamburg Sued (Germany) resumes calling at Keihin Port. ● Sino Trans (China) skips Keihin Port and reduces calling. ● HASCO (China) skips Keihin Port or reduces calling on March 28, 2011.
March 30, 2011	Pacific Atlantic Express/Northwest Express (PAX/NWX) service by Grand Alliance resumes calling at Nagoya Port on March 30 and at Tokyo Port on April 7.
April 1, 2011	China Shipping (China) resumes Japan-China route in Tokyo Port on April 1; other

	routes canceled or reduced on March 28.
Other responses during March	● COSCOS (China) executive at Tokyo local office persuades the crews. Communication is initiated between the headquarters in China and Tokyo. ● MSC (Switzerland) temporarily suspends booking to and from Japan*2. ● YML (Taiwan) has limited booking service to and from Japan*3.

Notes: *1Hitachinaka, Kashima, Ishinomaki, Ofunato, Sendai-Shiogama, Onahama, and Hachinohe Ports
*2Sendai, Hachinohe, Ofunato, Hitachinaka, and Kashima Ports
*3Hachinohe, Sendai, and Onahama Ports

On the other hand, most of the Japanese shipping companies maintained their shipping services to and from Japan even after the disaster. They requested their foreign employees not to skip Keihin Port and ports in the Tohoku region. Although some of the foreign crews had fears of radiation exposure, they accepted these requests from their employers. Some non-Japanese shipping companies also maintained their services after the disaster. One of the actions taken by these companies was a voluntary-based radiation measurement, which was done according to the MLIT's guidelines. For example, APL introduced its original radiation measurements at an early stage after the nuclear disaster (*38*). Note that APL followed the MLIT's guidelines.

Radiation Measurement of Japanese Cargo at Foreign Ports

Port managers in foreign countries became cautious about the cargo exported from Japan after the Fukushima Daiichi nuclear power plant disaster. For example, it was reported that on March 29, 2011, a vessel of Mitsui O.S.K. Line (MOL) departing from Japan was refused permission to call at its arrival port in Xiamen, China, immediately after the nuclear disaster (*39*). The vessel returned to Japan and was not allowed to call at China again until April 5, 2011. The total amount of loss from this refusal reached more than 100 million JPY (Source: Interview with MOL). Note that the exchange rate for 1 US dollar was equivalent to about 80 JPY as of April, 2011. Cargos exported from Japan were also examined randomly/completely at major foreign ports to measure the radiation level of the surfaces and/or contents of containers. It is also reported that, on May 16, 2011, containers exported from Japan were opened for content radiation measurements at Saint Petersburg Port, Russia (*40*).

The situation was even worse for food exports. For example, in the European Union, items from 12 prefectures, including Tokyo, were required to attach radiation attestations; others were required to provide certificates of origin; sample tests were required for all shipments for more than one year (*41*). As of October 2012, most of the countries have simplified the process of their radiation measurements but still require sample-based radiation measurements at the ports. These examinations led to the increase of cost in loading and unloading activities of cargos exported from Japan.

Actions Taken by the Japanese Government

Under the condition that little information about the radiation contamination was available just after the nuclear disaster, particularly after the hydrogen explosions at Fukushima Daiichi nuclear power plant, the headquarters of many foreign shipping companies requested their local agents in Japan for reports on the latest information. The Japan Foreign Steamship Association (JFSA) responded to the inquiries from the local agents of the foreign shipping companies during the early stage. JFSA then strongly requested that the Japanese government issue a statement announcing that "Tokyo/Yokohama is decontaminated," to the public, including the international society. Then, MLIT started posting and updating information on the latest results of radiation measurements on their official website on March 17, 2011. In addition, the first Yokohama Port communication meeting, organized by MLIT, was held on April 1, 2011. The main aim was to share information among stakeholders and to discuss the necessary actions required to improve port activities. It was a closed meeting with about 150 participants from major foreign shipping companies. The second Yokohama Port communication conference was held on April 25, 2011 in response to the request of relevant stakeholders. Furthermore, MLIT introduced a guideline on radiation measurement at seaports on April 22, 2011 (*42*). This guideline indicated the measurement method, the contents of attestation document, indicative criteria, and the actions to be taken if the measured dose rate exceeded the given criteria. They requested the port managers to monitor the radiation level of cargo at the departure ports in Japan by following the MLIT guidelines. If the container cargo was safe, then the attestation would be issued officially by MLIT. If the radiation level of a cargo container was higher than the given criteria for decontamination, the cargo would be immediately decontaminated. If the radiation level of a cargo container and even that of decontaminated container cargos was higher than the given criteria, they would be isolated in a specified area. The guidelines also required the port managers to measure the radiation level in the atmosphere and the seawater inside the ports. The guidelines showed that all these efforts made by shipping companies, port managers, and the Japanese government had to be explained abroad through the local Embassy of Japan to help foreign governments make the best use of the attestations and data.

Actions Taken by Port Managers

The port managers also took several actions to address the fears of port users. For example, the Yokohama Port manager sent messages to the shipping companies attesting to the safety of Yokohama Port (Source: Interview with Yokohama City Government). The port manager also implemented the radiation measurements on the basis of the MLIT's guidelines at Yokohama Port and announced its results. It should be noted that the Yokohama City government had been implementing the radiation measurement even before the nuclear disaster. This enabled individuals to compare the measured radiation level with the ordinary level. **FIGURE 2** shows the timeline of monthly measured containers, contaminated containers, and attestation-issued containers at Yokohama Port from April 2011 to June 2012. Attestation-issued containers are defined as the containers that have proved their safety by receiving attestations from the Japanese government according to the MLIT's guidelines. Note that the data regarding the number of attestation-issued containers is not available after July 2011.

A similar radiation measurement was also introduced at Sendai Port in October 2011. It was introduced at a later date at Sendai Port than at Yokohama Port, because the first international container vessel after the disaster called at Sendai Port on September 30, 2011. Two terminal operators at Sendai Port have implemented the measurements by hiring additional radiation measurement inspectors. The radiation dose levels of air, seawater, and the sampled containers have also been measured and released on the website.

DISCUSSION

The SARF proposed by Kasperson et al. (*14*) is applied to this case. **FIGURE 3** shows the conceptual framework of SARF. This framework structurally describes the linkage of technical assessment of risk with psychological, sociological, and cultural perspectives of risk perception and risk-related behavior. It also interprets hazard interaction with psychological, social, institutional, and cultural processes in ways that may amplify or attenuate public responses to the risk or risk event. The information system may amplify risk events in two ways: through direct personal experience with a risk object, or through receipt of information about the

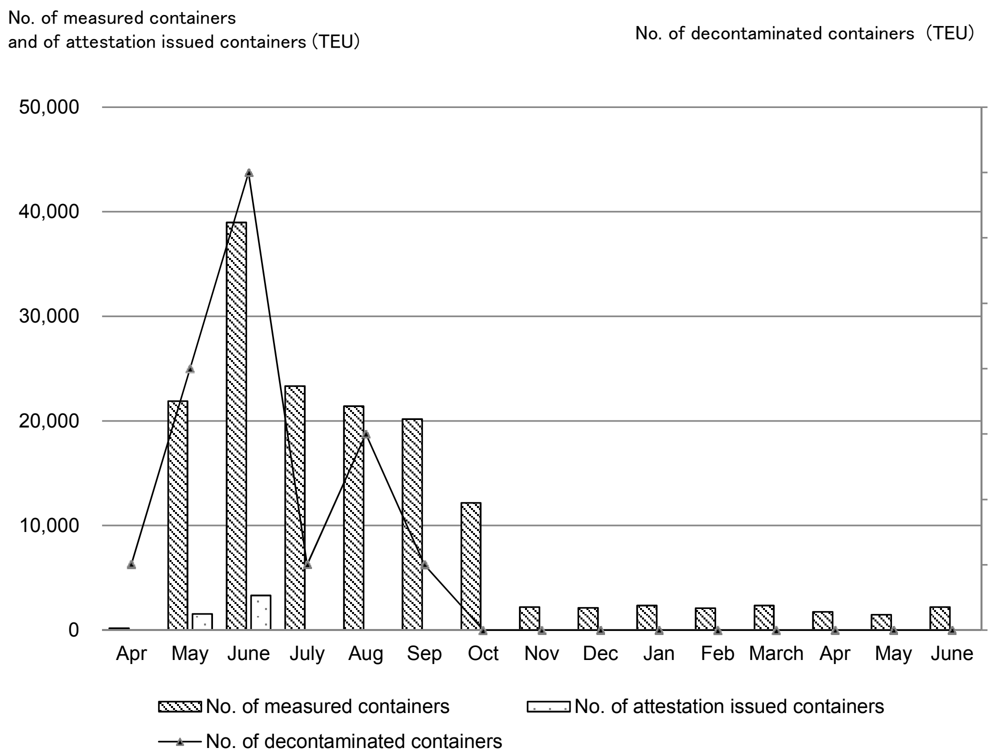

FIGURE 2: Timeline of Monthly Radiation Measurements at Yokohama Port from April 2011 to June 2012
Source: Interview and website of Yokohama Port manager

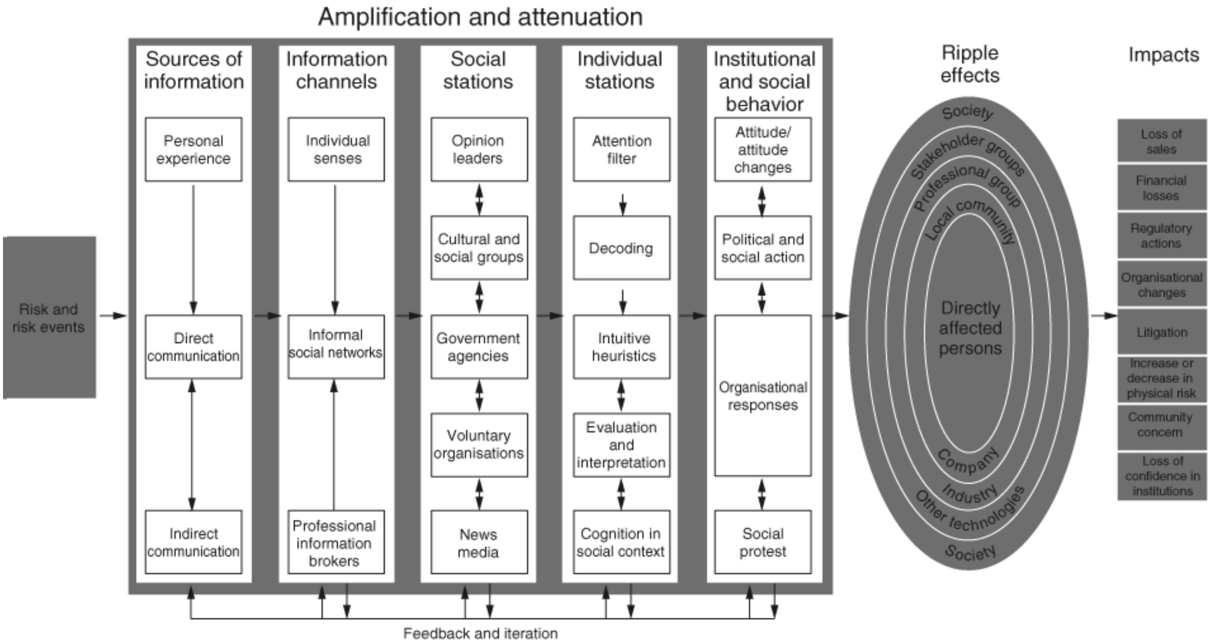

FIGURE 3: Conceptual Framework of Social Amplification of Risk (SARF)

Source: Kasperson et al. (11, 12)

risk object. Note that both ways intensify or weaken signals while filtering multitude signals. These signals are processed by social and/or individual amplification "stations." Social amplification stations generate and transmit information through communication channels. Social amplification of risk will spawn behavioral responses, which, in turn, will result in secondary impacts. Secondary impacts are perceived by social groups and individuals so that another stage of amplification may occur to produce third-order impacts. The impacts thereby may spread or "ripple." Finally, the ripple effects impact society as well.

In our case, the risk event is represented by the Fukushima Daiichi nuclear power plant disaster. After the radiation disaster, information about the disaster was transmitted. Signals of radiation concerns arose through the receipt of information about the radiation disaster. These radiation concerns were processed by social and individual amplification "stations." In this case, the social stations include the headquarters and local offices of shipping companies, labor unions of shipping companies, government organizations, port managers, and news media. Individual stations include individual maritime stakeholders such as the vessel crew, captains, staff of shipping companies, and their family members and friends. The communication channels exist between the social-individual, social-social, and individual-individual stations.

This framework may give us valid explanations about the events observed after the disaster. Two types of explanations could be introduced along with the amplification and attenuation processes (as shown in **FIGURE 3**): 1) explanation for the events observed during a stage; and 2) explanation for the events observed between stages.

First, the events observed during a stage are classified into five categories according to the stages of amplification and attenuation process (as shown in **FIGURE 3**):

- *Sources of information:* Immediately after the disaster, most individuals from non-Japanese shipping companies learned about the risk through indirect communication initiated by other people and/or by the mass media. This is because their direct personal experience was not sufficient enough for them to understand the situation compared with the experience of those who belong to Japanese shipping companies.
- *Information channels:* Individual senses of non-Japanese shipping companies are different from those of Japanese shipping companies mainly owing to different cultural backgrounds. Professional information brokers of non-Japanese shipping companies are mainly non-Japanese agents whereas those of Japanese shipping companies are local agents in Japan. Because of language difficulty, these differences led to dissimilar informal social networks between them.
- *Social stations:* Main communication stations of non-Japanese shipping companies are located outside Japan while those of Japanese shipping companies are located in Japan. This may lead to different understanding of the contexts in decision making between non-Japanese and Japanese shipping companies.
- *Individual stations:* Out-of-Japan individual stations may have biased intuitive heuristics based on the information disseminated through mass media and the opinions of people who experienced the disaster

directly and indirectly. Non-Japanese shipping companies share information among themselves through the Japan Foreign Steamship Association where the behavior of one non-Japanese shipping company has a great impact on that of other non-Japanese shipping companies.

- *Institutional and social behavior:* The radiation measurement was implemented voluntarily by Hapag-Lloyd as its organizational responses. Hapag-Lloyd measured not only the radiation level of the containers and the vessels, but also the radiation level at their container yards in Japanese ports and even at their local offices located in three major cities in Japan. German shipping companies were more concerned about the nuclear disaster than were other shipping companies. German shipping companies have strong labor unions, because of which they have to take care of requests from the unions with regard to safe working conditions.

Next, the events observed between stages are classified into three categories according to the connections between the adjacent steps of amplification and attenuation process (as shown in **FIGURE 3**) as follows:

- *Information channels and social stations:* Some of the non-Japanese shipping companies skipped Keihin Port but restarted calling at these ports after one or two months. This means that the information channels mainly consisted of informal social networks with limited stations immediately after the disaster but then drastically increased as the companies began accessing more stations beyond their original social groups or government agencies to collect the information. The Japanese government and port managers such as the manager at Yokohama Port also began to provide the information in response to requests from maritime transportation actors. They influenced the behaviors of the shipping companies.
- *Social stations and individual stations:* The guidelines for radiation measurement were quickly introduced by the Japanese government and implemented by port managers including Yokohama Port manager. This enabled the non-Japanese shipping companies to evaluate the risk by comparing the observed radiation level with the ordinary radiation level. This means that through the unfiltered information regarding the radiation level, stakeholders were able to assess the risk and appropriate risk communication was realized. This could also reduce exaggerated risk evaluation, inappropriate decoding, and over-reference of the social context.
- *Social/individual stations and institutional/social behavior:* The comparison of observed radioactive levels with those in ordinary cases convinced the decision-makers and social networks that Japanese ports were safe enough to sustain normal business. This also contributed to the discontinuation of further amplification of risk.

CONCLUSIONS

This paper focuses on contamination-related impacts of the Fukushima Daiichi nuclear power plant disaster on seaport activities and international maritime transportation and then analyzes the risk communication and perception after the disaster. Literature review of newspapers and interviews with maritime actors was used for a series of events related to maritime transportation after the disaster. Research revealed that the contamination-related impacts included impacts on shipping services, radiation measurement of Japanese cargo at foreign ports, and actions taken by the Japanese government and port managers. Further, the events observed after the disaster were explained using the framework of social amplification of risk communication.

Lessons and policy implications from this study are:

- Radiation concerns of maritime transportation stakeholders were amplified in different ways and to different degrees. SARF suggests that they are affected by three components: information sources, information channels, and communication stations. Thus, potential factors affecting the amplification of risk among stakeholders should be clearly identified. Then, the effective actions to remove the factors amplifying risk should be assessed for each of the three components.
- Quick responses and appropriate countermeasures by the government and port managers play a key role after a devastating disaster in terms of convincing foreign countries of the safety of the country. Particularly, the provision of objective data works effectively to remove the fear in people and to avoid the social amplification of risks.
- Radiation measurement could be done in a more systematic manner under an international agreement. Port State Control (PSC) inspection may be the most important mechanism to ensure world marine safety, which has been set up by the International Maritime Organization (IMO). It was established to ensure that foreign ships are seaworthy and do not pose pollution risk, to provide a healthy and safe working environment, and to comply with relevant international conventions (*43*, *44*). Better performance could be expected if radiation level is counted as one of the main factors in PSC.

Finally, the issues for further research are summarized as follows. First, our literature review and interviews covered limited maritime stakeholders including the Japanese government, port managers, and shipping companies. Stakeholders such as crews, captains, and ship owners should be included to complete the picture of the social amplification of risk framework. This would result in more comprehensible risk communication plans. Second, this study focuses on nuclear disaster and risk communication. Quantitative analysis could be conducted to estimate the damages caused by the nuclear disaster and social amplification of risks. Giesecke et al. (45) quantified the substantial economic costs that may result from the detonation of a radiological dispersal device in the heart of a major city. The Fukushima Daiichi nuclear power plant disaster is a real example to verify these models. The results, together with elaborated evaluation models/systems, may be applicable to estimate future catastrophic risks in maritime transportation.

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