Risk Perception and Communication in International Maritime Shipping in Japan After the Fukushima Daiichi Nuclear Power Plant Disaster

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This paper investigated the contamination-related impact of the Fukushima Daiichi nuclear power plant disaster in Japan on seaport activities and international maritime shipping. Risk perception and risk communication after the disaster were analyzed. The maritime-related newspaper articles published in Japan after this disaster were extensively reviewed. Eleven maritime-related agents, including port managers, governments, shipping companies, port operators, and shippers, were interviewed. These interviews were conducted from June to December 2011. The results of the interviews revealed that the contamination-related impact of the power plant disaster comprised impacts on (*a*) major Japanese ports, including Keihin ports, that were skipped (not called at) by 42 container vessels operated by non-Japanese shipping companies; (*b*) foreign ports and the measurement of radiation of Japanese cargo; and (*c*) actions taken by the Japanese government and port managers. The framework of social amplification of risk communication was used to explain the events observed after the disaster. Use of this framework suggests that the risk communication made by maritime stakeholders successfully reduced the amplification of risk among stakeholders at various levels of information sources, information channels, and stations. A summary of lessons from the study includes the identification of factors that influenced 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.

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 infrastructure, including the major port facilities in Tohoku. Many of these ports were inaccessible for several months (*1*). The severe ground motion and large multiple tsunami waves also significantly damaged the Fukushima Daiichi nuclear power plant. This disaster resulted in the release of considerable amounts of radionuclides into the environment (*2*). Although most radionuclides were carried out into the Pacific Ocean, approximately 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. Meanwhile, the government issued a declaration of safety in the remaining parts of the Tohoku region (Aomori, Iwate, Akita, Miyagi, and Yamagata Prefectures) and the Kanto region (Tochigi, Ibaraki, Saitama, Chiba, Tokyo, and Kanagawa Prefectures). Despite the government's efforts, the Fukushima Daiichi nuclear power plant disaster had a significant impact on seaport activities and maritime shipping to and from the major ports in Japan. The Sendai-Shiogama and Keihin ports (Tokyo, Kawasaki, and Yokohama), which are among the major ports in Japan, are approximately 100 km and 200 km from the power plant, respectively (Figure 1).

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. The contamination-related impacts include the potential risk of radiation to human health, radiation contamination of goods, and the halt in shipping services because of the fear of radiation. Numerous studies and analyses have focused on the earthquake-related impacts (*6–8*); however, few have focused on the contamination-related impacts. As a result, most people are still unfamiliar with and do not understand the mechanisms underlying the complex issues related to nuclear contamination. To elucidate these mechanisms, this paper focuses on risk perception and risk communication, which play key roles in the aftermath of accidents with severe radiological consequences (*9, 10*). Most of the contamination-related impacts were triggered and resolved by the risk perception and risk communication of the actors in the maritime sectors.

The contamination-related impacts of the Fukushima Daiichi nuclear power plant disaster on the seaport activities and international maritime shipping operations for Japan are reported, and the risk perception and risk communication after the disaster are analyzed. The focus is on the risk behaviors and countermeasures taken by actors in the maritime sectors, including shipping companies, the Japanese government, and port managers. The social amplification of risk framework (SARF) is used to analyze risk perception and risk communication. Finally, the implications of better risk communication beyond the maritime shipping field are presented.

The remainder of this paper is organized as follows. The next two sections present the literature review and the approach used for

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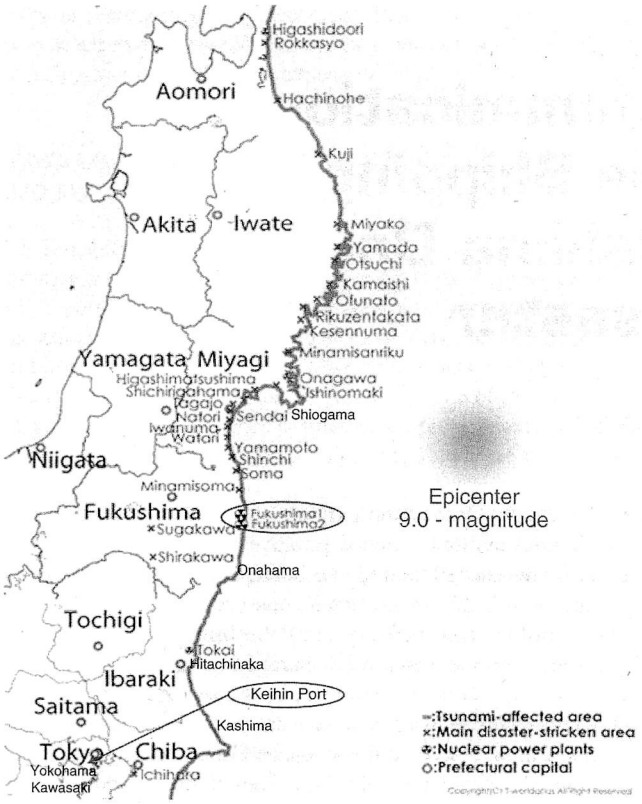

FIGURE 1 Kanto and Tohoku Regions of Japan (5).

conducting this study, respectively. The following section discusses the results obtained from the review of maritime newspapers and the interviews with stakeholders from the perspective of contamination-related impacts. Subsequently, a section is dedicated to discussing the risk perception and risk communication. The final section of this study summarizes the policy implications and some research issues that offer potential for further study.

LITERATURE REVIEW

Contamination-related impacts are influenced by the risk perceptions and risk communications of maritime stakeholders. Risk perception is the process of physical signals or information about potentially harmful events or activities and the formation of judgments about the seriousness, likelihood, and acceptability of the respective events or activities. Risk communication is as an interactive process of the exchange of information and opinions among individuals, groups, and institutions (*11, 12; 13,* p. 21).

Risk perception is commonly used in reference to natural and human-made hazards, which are studied mainly in the contexts of psychology, sociology, and technical sciences (*11*). SARF, as suggested by Kasperson et al. (*14*), is an integrative framework for explaining risk perceptions and 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 with SARF (*18–22*).

Risk communication was originally developed for investigating how expert assessments could be communicated to 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*). Typically, nuclear risk is perceived differently by lay people and experts (*9, 10, 24, 25*). Usually, naturally occurring radiation and nuclear-applied technology that is used in the medical field (such as X-rays) are perceived to have lower risk and higher benefits than nuclear waste and nuclear power. Lay people generally perceive nuclear waste and nuclear power negatively, because these perceptions originate with nuclear war weapons, associated with invisible contamination that has uncontrollable consequences. Thus, risk communication is a significant issue in the use of nuclear power and nuclear waste. Slovic showed that the acceptance of risk is conditioned by the following four factors: trust in the people managing the technology, appreciation for the direct personal benefits of the technology, knowledge, and whether the risk is of natural origin (*23*). Some risk communication strategies have been introduced, such as dissemination of nuclear knowledge to lay people and comparison between the radiation levels of particular exposures with background value. Thus far, these strategies have indicated 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 lay people in Japan (*26–28*), which requires more sophisticated risk communication strategies (*29, 30*).

This paper highlights the risk perception and risk communication of maritime shipping stakeholders in their reaction to the Fukushima Daiichi nuclear power plant disaster. Drabek indicated that the risk perceptions associated with nuclear energy are different from those associated with tornados, floods, and other human-made hazards (*31*). Although most previous studies have discussed hypothetical nuclear risk, this study deals with a real, observed situation of nuclear risk. In addition, risk perception and risk communication in the field of transportation have been little studied. Thus, a timely report of contamination-related impacts and the fact-based analysis of risk perception and risk communication will contribute to a comprehensive understanding of risk perception and risk communication, particularly in maritime shipping.

DATA COLLECTION

A literature review of the impacts of the earthquake and the subsequent Fukushima Daiichi nuclear power plant disaster covered articles in the following four major Japanese maritime newspapers issued from March 11 to the end of June 2011: *Maritime Daily News,* the *Japan Maritime Daily, Nikkan Kaijitsushin,* and *Daily Kaiji Press.* Only Japanese newspapers were reviewed because the articles in those newspapers contained 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 with a focus on the port recoveries in the Tohoku region from March 11 to the end of November 2011; the same keywords were used as those in the literature review for Keihin ports.

TABLE 1 Interviewed Maritime Actors

Organization	Date	Place	Type
Kanto Regional Development Bureau, MLIT	June 9, 2011	Yokohama No. 2 Joint Government Office Building	Central government
Port and Harbor Bureau, City of Yokohama	June 11, 2011	Industry and Trade Center Building, Yokohama	Port manager (local government)
Mitsui OSK Lines, Ltd. (MOL)	September 30, 2011	MOL Tokyo Office	Shipping company (Japan)
NYK Container Line	September 30, 2011	NYK Container Line Tokyo Office	Shipping company (Japan)
COSCO Container Lines Japan Co., Ltd.	October 3, 2011	COSCO Container Lines Japan Tokyo Office	Shipping company (China)
Hapag-Lloyd (Japan) KK	November 4, 2011	Hapag-Lloyd Japan Tokyo Office	Shipping company (Germany)
Tohoku Regional Development Bureau, MLIT	December 21, 2011	Tohoku Regional Development Bureau Office Building	Central government
Port and Harbor Bureau, Miyagi Prefecture	December 21, 2011	Miyagi prefecture, Sendai-Shiogama Port Bureau	Port manager (local government)
Shiogamako Unso Co., Ltd.	December 21, 2011	Shiogamako Unso Office	Port operator
Sanriku Unyu Co., Ltd.	December 21, 2011	Sanriku Unyu Office	Port operator
Shima Co., Ltd.	December 22, 2011	Shima Office	Shipper

NOTE: OSK = Osaka Shosen Kaisha; Co. Ltd. = company limited; KK = Kabushiki Kaisha (Japanese for company limited).

Interviews were conducted with maritime agents in Japan. The interviewees included shipping companies, port managers, shippers, and the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT), which governs ports and maritime shipping in Japan. The interviewed organizations are listed in Table 1. The data and descriptions in the remainder of this paper were obtained from articles in the four reviewed newspapers or are based on the results of the interviews with maritime actors.

CONTAMINATION-RELATED IMPACTS

General Impact on Other Countries

After the Fukushima Daiichi nuclear power plant disaster in Japan, many other countries expressed their concerns about the situation. Some foreign embassies in Tokyo shortened working hours, stopped services, or began conducting operations from the Kansai region, which is more than 500 km from the affected nuclear plant (*32*). They also issued warnings to foreign residents in Japan about the dangers of radioactive contamination. For example, the French government advised its nationals to leave Tokyo on March 13, 2011, because of threats posed by the nuclear power plant, which is 220 km north of the Japanese capital (*33*). Concerns about radioactive contamination lasted long after the nuclear disaster, particularly in relation to the safety of food and drinking water. Articles in major newspapers in the United States and China expressed deep concern about food contamination (*34*). The number of foreign tourists to Japan declined sharply after the disaster. The Japan Tourism Agency reported that the number of foreign tourists had decreased by 62.5% in April 2011 compared with April 2010 (*35*).

Impact on Shipping Services

According to an interview at the Kanto Regional Development Bureau of MLIT, 42 international container vessels skipped Keihin ports from April 1 to May 15, 2011. All the vessels that skipped Keihin ports were operated by non-Japanese shipping companies (as shown in Table 2). Foreign shipping companies, particularly European companies, responded cautiously to the release of radioactive materials. Most foreign shipping companies called at the ports in the Kansai and Nagoya regions (which are more than 400 km from the Fukushima Daiichi nuclear power plant) after skipping Keihin ports. 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 foreign shipping companies canceled all shipping services to and from Japan from March 11 to May 2011. No instance of port skipping because of radiation has been seen at Keihin ports since June 2011. The situation at the ports of the Tohoku region, however, differs from that at Keihin ports. Immediately after the disaster, both Japanese and non-Japanese shipping companies skipped ports in the Tohoku region because of earthquake-related damage to the quay walls and the loading and unloading machines. Japanese shipping companies restarted their service to ports in the Tohoku region after the port facilities were partially operational; however, the non-Japanese shipping companies continued to skip some ports of the Tohoku region, including the port of Sendai-Shiogama, after the port facilities were operational. At least 10 international vessels skipped the port of Sendai-Shiogama between April 1 and May 20, 2011 (*36*). This number includes one case in which a shipping company refused to call at the port of Sendai-Shiogama, although the shipper had requested a coal-shipping vessel. According to an interview with a port operator, the port-skipping vessels changed their routes to other routes, such as those to Keihin ports, Hanshin ports (located in the Kansai region), and ports along the Sea of Japan. Ports in the Tohoku region handle mainly irregular shipments rather than regular shipments. Thus, the shippers in the Tohoku region who required tramp services had no choice but to charter domestic vessels from another port located along the Sea of Japan to the port of Sendai-Shiogama, which resulted in a substantial increase in the maritime shipping costs. In September 2011, one of the Korean shipping companies, Namsung Shipping, restarted its transportation service connecting the port of Sendai-Shiogama with foreign ports, making that company the first to do so after the earthquake (*37*). However, according to an interview with officials at the Tohoku Regional Bureau of MLIT, the other Korean shipping company that offered the same service before the disaster had not restarted its service as of December 2011. Insufficient international

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

Date	Responses to Disaster
March 11, 2011	Date of earthquake.
March 14, 2011	American President Lines Limited (Singapore) temporarily suspended booking to and from Japan.[a] Business hours were reduced in Tokyo offices to 9:30–16:00 (until March 18).
March 16, 2011	Hamburg Sud (Germany) began to skip Keihin ports. 60% of staff of CMA-CGM (France) from Tokyo office worked from home. Cancellation of issuance of bills of lading (B/L) on March 16. Limited service on March 17. Limited booking of shipments to and from Keihin ports.
March 17, 2011	Hapag-Lloyd (Germany) began to skip Keihin ports. Staff stayed indoors March 17 and March 18. Managers of Yokohama Port visited shipping companies directly.
March 18, 2011	MLIT started to post radiation-related information on its website.
March 21, 2011	Jin Jiang Shipping (China) canceled calling at Keihin ports from Shanghai on March 21 and March 25. It skipped or reduced calling at Keihin ports on March 28.
March 22, 2011	Managers of Yokohama Port began to offer radiation-related information.
March 23, 2011	China Shipping (China) skipped Tokyo Port and continued calling at Yokohama Port. Pacific Atlantic Express service operated by Grand Alliance (Hapag-Lloyd, NYK, and OOCL) skipped the Tokyo and Nagoya ports.
March 28, 2011	Hamburg Sud (Germany) resumed calling at Keihin ports. Sinotrans (China) skipped Keihin ports and reduced calling. HASCO (China) skipped or reduced calling at Keihin ports on March 28, 2011.
March 30, 2011	Pacific Atlantic Express–Northwest Express service operated by Grand Alliance resumed calling at Nagoya Port on March 30 and at Tokyo Port on April 7.
April 1, 2011	China Shipping (China) resumed the Japan–China route in Tokyo Port on April 1; calling at other routes canceled or reduced on March 28.
Other responses during March 2011	COSCO (China) executive at Tokyo local office persuaded crews to call at Keihin ports. Communication was initiated between headquarters in China and Tokyo. MSC (Switzerland) temporarily suspended booking to and from Japan.[b] YML (Taiwan) limited booking service to and from Japan.[c]

[a]Hitachinaka, Kashima, Ishinomaki, Ofunato, Sendai-Shiogama, Onahama, and Hachinohe ports.
[b]Sendai, Hachinohe, Ofunato, Hitachinaka, and Kashima ports.
[c]Hachinohe, Sendai-Shiogama, and Onahama ports.

shipping services to and from the port of Sendai-Shiogama led to the substitution of shipping services through the use of neighboring ports. For example, three regular international container services at Hachinohe port in the Tohoku region were quickly restarted on May 19, 2011. In addition, many vessels sailing to and from the ports in the Tohoku region and in the north Kanto region changed their sailing routes by taking detours to maintain a distance of more than 100 km from the Fukushima Daiichi nuclear power plant, according to an interview with officials at the Tohoku Regional Bureau of MLIT.

Most Japanese shipping companies continued providing shipping services to and from Japan after the disaster. They asked their foreign employees not to skip Keihin ports and ports in the Tohoku region. Although some of the foreign crews feared radiation exposure, they accepted these requests from their employers. Some non-Japanese shipping companies also continued providing their services after the disaster. One of the actions taken by these companies was a voluntary radiation measurement. For example, APL introduced its original radiation measurements at an early stage after the nuclear disaster, but their measurements were conducted according to the MLIT guidelines after these were introduced (*38*).

Radiation Measurement of Japanese Cargo at Foreign Ports

Port managers in foreign countries became cautious about cargo exported from Japan after the Fukushima Daiichi nuclear power plant disaster. For example, it was reported that on March 29, 2011, a Mitsui OSK Lines vessel departing from Japan was refused entry into the port of Xiamen, China (*39*). The vessel returned to Japan and was not permitted to call at China again until April 5, 2011. The total amount of loss from this refusal reached more than ¥100 million, according to an interview with a representative of Mitsui OSK Lines (¥89 = $1.00 in April 2011). Cargo exported from Japan was also examined randomly or completely at major foreign ports so radiation levels of the surfaces or contents of containers could be measured. On May 16, 2011, containers exported from Japan were opened for content radiation measurements at the port of Saint Petersburg, Russia (*40*).

The situation was worse for food exports. For example, within the European Union, items from 12 prefectures, including Tokyo, were required to have radiation attestations attached. Other items were required to have certificates of origin; sample tests were required for all shipments for more than 1 year after the earthquake (*41*). As of October 2012, most countries had simplified their process of radiation measurement; however, they still require sample-based radiation measurements at the ports. These examinations increased the cost of loading and unloading activities of cargo exported from Japan.

Actions Taken by Japanese Government

Because little information about 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 reports on the latest information from their local agents in Japan. The Japan Foreign Steamship Association responded to the inquiries from these local agents of the foreign shipping companies during the early stages. Subsequently, the association strongly requested that the Japanese government issue a statement to announce to the public, including the international community, that the Tokyo and Yokohama area had been decontaminated. MLIT started posting and updating information about the latest results of radiation measurements on its official website from March 17, 2011, onward. In addition, the first communication meeting at the port of Yokohama, organized by MLIT, was held on April 1, 2011. The main goal for this communication meeting was to share information among stakeholders and to discuss the actions needed to improve port activities. This was a closed meeting with approximately 150 participants from major foreign shipping companies. The second communication meeting was held on April 25, 2011, in response to a request by 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 the certificate, criteria for the decontamination and report, and the actions to be taken if the measured dose rate exceeded the given criteria. MLIT requested that the port managers monitor the radiation level of cargo at the departure ports in Japan by following the guidelines. If the container cargo was safe, the certificate would be issued by MLIT. If the radiation level of a cargo container was higher than the given criteria for decontamination, the cargo had to be immediately decontaminated. If the radiation level of a cargo container and even that of decontaminated cargo containers was higher than the given criteria for report, the containers 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 were to be explained abroad through the local embassies of Japan to allow foreign governments to make the best use of the certificates and data.

Actions Taken by Port Managers

The port managers took several actions to address the fears of port users. For example, the manager of the port of Yokohama sent messages to the shipping companies attesting to the safety of the port, according to an interview with a Yokohama city government representative. The port manager also implemented the radiation measurements based on the MLIT guidelines at the port of Yokohama and announced its results. 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 a time line of monthly measured containers, contaminated containers, and certificate-issued containers at the port of Yokohama from April 2011 to June 2012. Certificate-issued containers are the containers whose safety has been proved with certificates received from the Japanese government according to the MLIT guidelines. Data for

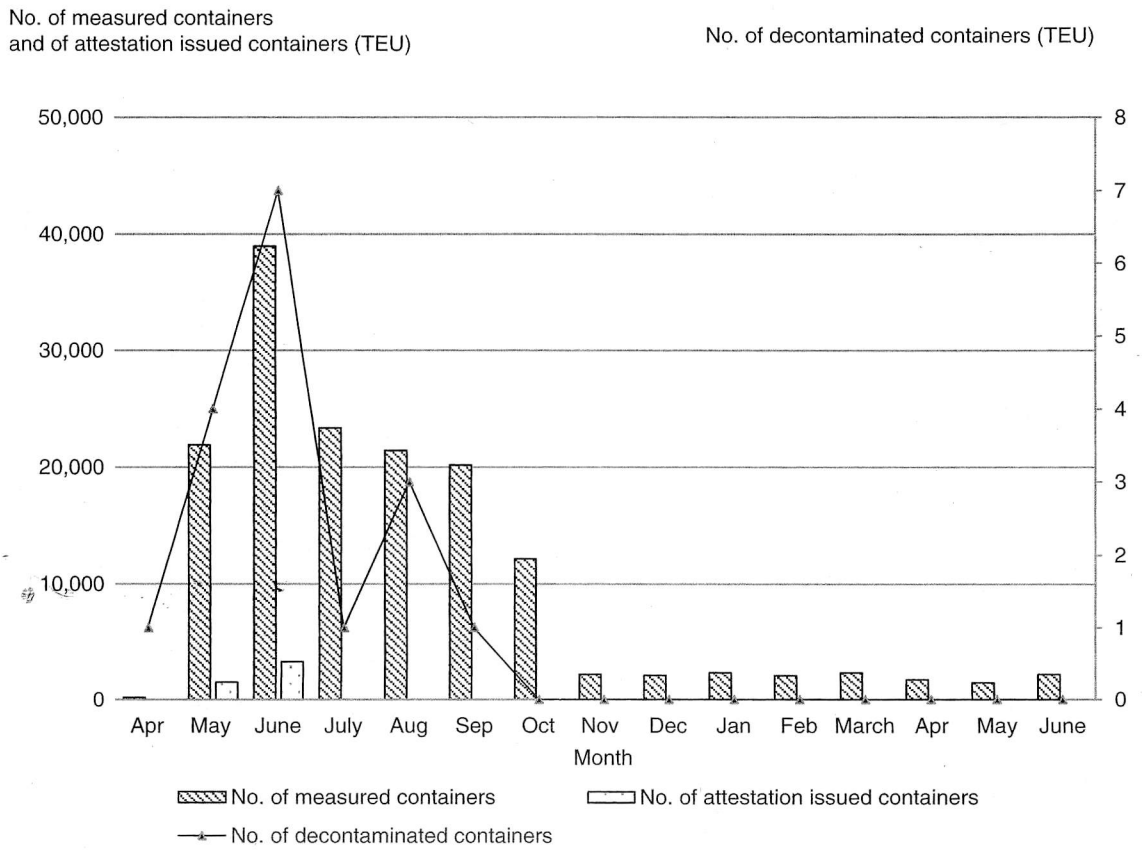

FIGURE 2 Time line of monthly radiation measurements at port of Yokohama from April 2011 to June 2012 (no. = number). (Source: Interview with and website of Yokohama port manager.)

the number of certificate-issued containers are not available for after July 2011.

A similar radiation measurement was introduced at the port of Sendai-Shiogama in October 2011, after being introduced at the port of Yokohama, because the first international container vessel after the disaster called at the port of Sendai-Shiogama on September 30, 2011. Two terminal operators at the port of Sendai-Shiogama implemented the measurements by hiring additional radiation measurement inspectors. The radiation dose levels of air, seawater, and the sampled containers were also measured and released on the website.

DISCUSSION OF RESULTS

The SARF proposed by Kasperson et al. was applied to this case (*14*). Figure 3 shows the conceptual framework of a 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. The framework 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 the receipt of information regarding the risk object. Both ways intensify or weaken signals while filtering many signals. These signals are processed by social 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. These third-order impacts may spread or ripple, and these ripple effects affect society.

The risk event in this case is represented by the Fukushima Daiichi nuclear power plant disaster. After the radiation disaster, information about it was transmitted. Signals of radiation concerns arose through the receipt of information about the 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, staffs of shipping companies, and their family members and friends. The communication channels exist between social and individual stations, social and social stations, and individual and individual stations.

This framework gives valid explanations for the events observed after the disaster. Two types of explanations are introduced along with the amplification and attenuation processes (as shown in Figure 3): explanation for the events observed during a stage and 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 processes (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 or by the mass media. This difference in communication was the result of insufficient direct personal experience for understanding the situation compared with the experience of those who were affiliated with the Japanese shipping companies.

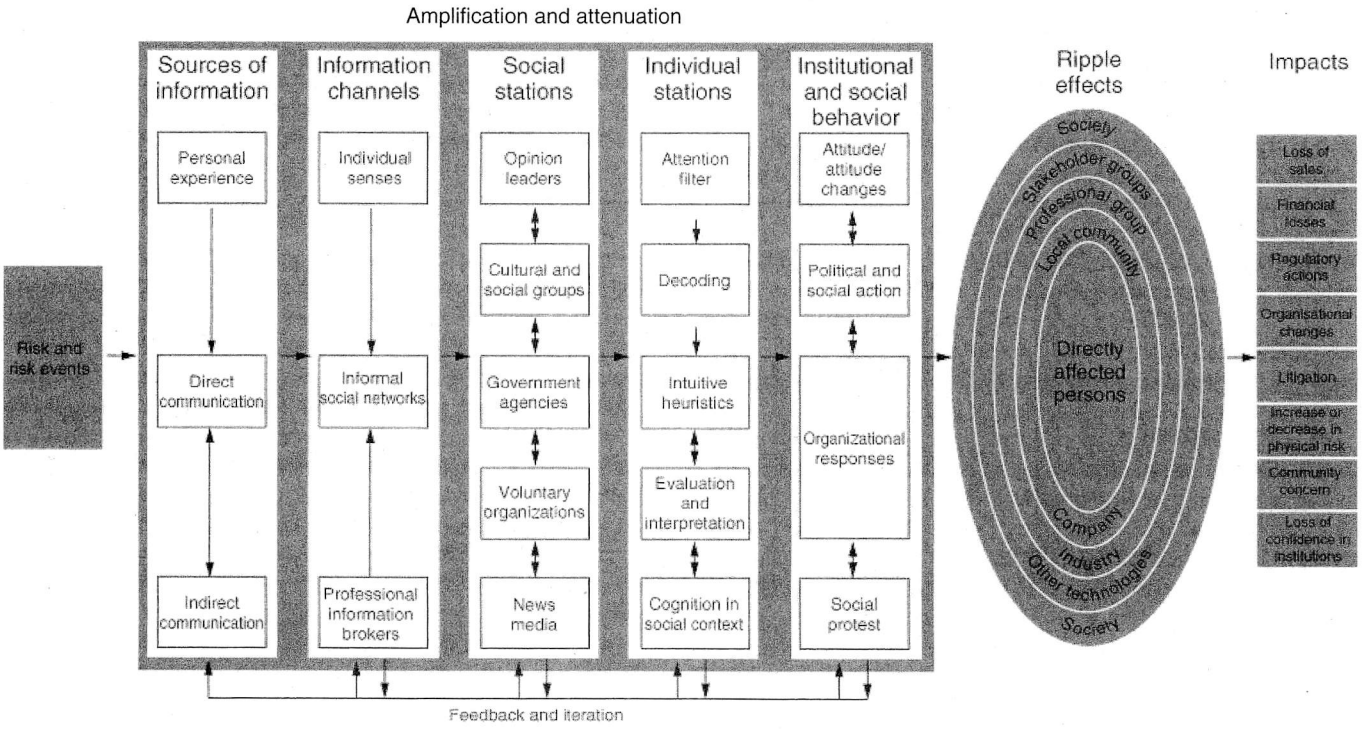

FIGURE 3 Conceptual SARF (*11*, *12*).

- Information channels. Individual instincts of non-Japanese shipping companies were different from those of Japanese shipping companies largely because of different cultural backgrounds. Professional information brokers of non-Japanese shipping companies were mainly non-Japanese agents, whereas those of Japanese shipping companies were local agents in Japan. Because of the language difficulty, these differences led to dissimilar informal social networks between them.
- Social stations. Main communication stations of non-Japanese shipping companies were located outside Japan, and those of Japanese shipping companies were located in Japan. This may have led to a different understanding of the contexts in the decision-making process between non-Japanese and Japanese shipping companies.
- Individual stations. Individual stations outside Japan may have had biased intuitive heuristics because of information disseminated through mass media and the opinions of people who experienced the disaster directly and indirectly. Non-Japanese shipping companies shared information among themselves through the Japan Foreign Steamship Association, in which the behavior of one non-Japanese shipping company can have a great impact on that of other non-Japanese shipping companies.
- Institutional and social behavior. The radiation measurement was implemented voluntarily by Hapag-Lloyd AG as its organizational response. Hapag-Lloyd measured the radiation levels not only of the containers and the vessels but also of its container yards in Japanese ports and at its local offices in three major cities in Japan. German shipping companies were more concerned about the nuclear disaster than other shipping companies were. German companies have strong labor unions and must address union concerns about safe working conditions.

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

- Information channels and social stations. Some of the non-Japanese shipping companies skipped Keihin ports immediately after the disaster; however, they again called at these ports after 1 or 2 months. This route deviation means that the information channels mainly comprised informal social networks formed with limited stations immediately after the disaster, and then greatly increased as the companies began accessing more stations beyond their original social groups or government agencies to collect information. The Japanese government and port managers, such as the manager at the port of Yokohama, also began providing information in response to requests from agents in the maritime sectors and this 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 the managers of the port of Yokohama. This enabled the non-Japanese shipping companies to evaluate the risk by comparing the observed radiation level with the ordinary radiation level. By using unfiltered information about the radiation level, stakeholders were able to assess the risk and provide appropriate risk communication. Use of unfiltered information also enabled the reduction of exaggerated risk evaluation, inappropriate decoding, and overreference of the social context.
- Social and individual stations and institutional and social behavior. A comparison of observed radioactive levels with levels in ordinary cases convinced decision makers and social networks that Japanese ports were safe for normal business. This comparison also contributed to discontinuation of further amplification of risk.

CONCLUSIONS

This paper focused on contamination-related impacts of the Fukushima Daiichi nuclear power plant disaster on seaport activities and international maritime shipping and analyzed risk communication and perception after the disaster. A literature review of newspapers and interviews with maritime actors was used to collect information about a series of events related to maritime shipping 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. The events observed after the disaster were explained within the framework of social amplification of risk communication.

The lessons and policy implications from this study are as follows:

- Radiation concerns of maritime shipping stakeholders were amplified in different ways and to different degrees. The SARF suggested that they were 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. Subsequently, the effective actions for removing the factors that amplify 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 assuring other countries about the safety of the country. The provision of objective data effectively removes fear among people and avoids the social amplification of risks.
- Radiation measurement could be conducted more systematically under an international agreement. Inspections by Port State Control, which was established by the International Maritime Organization, may be the most important mechanism for ensuring world marine safety. Port State Control was established to ensure that foreign ships are seaworthy and do not pose a pollution risk and to ensure a healthy and safe working environment and compliance with relevant international conventions (*43, 44*). Better performance for radiation measurement could be expected if Port State Control would consider radiation level as one of the main factors of pollution risk.

Issues for further research are summarized as follows. First, the literature review and interviews covered a small range of maritime stakeholders, including the Japanese government, port managers, and shipping companies. Stakeholders such as crews, captains, and ship owners should be included for a complete picture of the SARF. This would result in more comprehensible risk communication plans. Second, this study focused 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. quantified the substantial economic costs that could result from the detonation of a radiological dispersal device in the heart of a major city (*45*). The Fukushima Daiichi nuclear power plant disaster is a real example that can be used to verify these models. The results, together with elaborated evaluation models and systems, may be useful for estimating future catastrophic risks in maritime shipping.

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