SIMULATION ANALYSIS FOR EVALUATING DANGEROUS CARGOIN PORT

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ABSTRACT

In order to quantitatively assess the risks associated with dangerous cargo accidents in ports, we identify the factors that cause port risks and provide a method for evaluating them. The risk analysis method for the dangerous cargo accidents in the port is classified into 4 kinds of factors such as human, physical, other, and unknown in the process of deriving dangerous factors. Dangerous factors are set as the number of accidents, frequency of occurrence, and amount of damage. The dangerous level impacts are based on the severity and the risk level, and the level of risk management is prioritized according to the survey results through the AHP analysis method.

Other factors are considered to be the lowest severity with low occurrence frequency and are not subject to major control. Human factors go into a criterion with a high frequency but a low severity. Material factors fall into the criterion of high severity with low occurrence frequency. Unknown causes are included in the areas where the importance is low and the severity is the highest. The results of the Monte Carlo simulations for the risk assessment showed no significant differences in the amount of damage, severity, and risk for human and physical factors, but other factors were relatively low in damage amount, severity, and risk. The amount of damage, severity, and risk were very high, indicating that priority management was needed.

As a result of comparing the analysis value of the data on the dangerous cargo accident and the simulation result, the severity was high in the simulation result, human factor, other factors, unknown cause, and the risk was low. Therefore, it can be seen that the risk of a dangerous cargo accident in a port is estimated to be relatively lower than that of a dangerous cargo accident data obtained from a simulation experiment.

Keywords :Simulation, Cargo, Risk, AHP(Analytic Hierarchy Process)

1. INTRODUCTION

In recent years, the risk of disasters such as earthquake and subsequent safety accidents in Kumamoto Prefecture has increased. In addition, interest in the national safety net is increasing due to periodic bird flu, foot-and-mouth disease, and provocation by North Korea. In the port area, 171 people were killed, 12 people were missing, 700 people were injured and 6 thousand people were injured in Tianjin port explosion in August 2015.(Report on Special Fire and Explosion Accident Investigation in Tianjin Port "8 · 12")

In addition, we have experienced major accidents caused by harbor dangers such as accidents at chemical storage warehouse in Busan Sasang District (2015.8.) and dangerous material explosion at Inchon New Port (2015.8.).

As the international community continues to increase international trade volume and raise awareness of security and safety, it is increasingly strengthening the management and control of hazardous materials. Especially, advanced countries are continuously trying to guarantee safety from hazardous materials transportation accident by strengthening international management regulations on dangerous goods transportation or strengthening import regulations on their own countries(Korea Transport Research Institute, 2012).

Therefore, international cooperation such as UN, OECD, EU, international standardization, and multilateral agreement security management system are strengthened internationally. In the future, the management system of domestic port dangerous materials should be improved according to international standards. To this end, we should systematically discuss the efficient management of hazardous cargo in the port, including the improvement of domestic laws and systems and prevention of accidents.

The purpose of this study is to analyze the problems of the port hazardous materials management system in Korea and to improve the port hazardous materials management in order to improve the safety management system of dangerous goods in the port of Korea.

2. DERIVATION OF PORT DANGEROUS FACTOR

In case of port, the amount of damages due to safety accidents reaches an average of 123.06 million won per year. Such safety accidents have various types of accidents, and port safety accidents have caused deterioration in port operation efficiency and many economic losses. Looking at the trend of accidents, the number of incidents and the amount of accidents occur irregularly every year. This phenomenon indirectly suggests that consciousness and countermeasures for safety accidents are not performed effectively in terms of port operation, and it is necessary to reduce the number of accidents and damage amount by implementing continuous and consistent management measures.

Especially, in case of port container terminal, risk types are classified according to work area and risk is calculated by taking into account frequency and severity of accidents by each type. However, in spite of the huge amount of damages caused by the port hazardous material accident, it is difficult to classify severity by type and to calculate the risk because the frequency of accidents is low every year.

Therefore, in order to express the relative severity and risk, we have summarized the number of accidents by type of hazardous materials through analyzing the present state data on safety accidents related to dangerous goods in ports. A total of 85 hazardous material incidents occurred in 2015, 37% more than the total number of 62 cases in 2014. In 2015, 76 out of 85 cases (89.4%) were caused by the dangerous goods of the 4th class. Of the 18 municipalities, large petrochemical complexes were located, and Gwangyang Port and Ulsan Port located in Jeollanam and Ulsan, where sea transportation volume was high, were high, and Gyeongbuk and Gyeongbuk were relatively high. Therefore, Incheon Port, Gwangyang Port, and Ulsan Port, where many hazardous materials are handled at ports, can be classified as areas where dangerous goods accidents occur frequently. As shown in Table 1, flammable liquids, which are dangerous substances of Category 4, are frequently used for transport tank storage every year.

Table 1 Accident status by type of hazardous material

Division	Property	Number of accidents by type of dangerous goods	
		2015	2014
Category 1	Oxidizing solid	0	0
Category 2	Combustible solid	1	2
Category 3	Pyrophoric substances and gold-water-based substances	3	3
Category 4	Flammable liquid	76	54
Category 5	Self-reactive material	1	1
Category 6	Oxidizing liquid	2	1
Etc		2	1
Sum		85	62

Table 2 Accident status by type of hazardous material accident

Type	Fire	Explosion	Leakage	Sum
2015	53	13	19	85
2014	32	10	20	62
Sum	85	23	39	147

Fire hazard (62.4%), leakage (22.4%) and explosion (15.2%) were the most frequent occurrences of hazardous material accidents. However, explosions have resulted in a smaller scale, but larger damage. In case of total hazardous material accidents, the damage of accidental property of two hazardous materials in outdoor store was 1.78 million dollar, and the amount of property damage in one of the logistics centers in Gyeonggi Province reached 1.75 million dollar.

Hazardous material accidents tend to occur mainly in the daytime, and the time of accidents is in the order of 09:00 to 12:00, 12:00 to 15:00, and 15:00 to 18:00. The specificities of the hazardous material accident in 2015 are that the frequency of accidents at early morning, evening and early morning hours has greatly increased.

We present the relative severity and risk of each accident by analyzing the status of hazardous material accidents in the port. The severity is defined as the relationship between the amount of damage per accident and the severity of the hazardous material accident. The risk consists of two factors, the annual average frequency of accidents and the severity of accident consequences.

Severity = Damage Amount ÷ Number of Accidents

Risk = Frequency of Occurrence × Severity

The degree of impact of each hazardous material on the accident is calculated as a loss scale (cost), but it is easy to express it as a severity. The occurrence frequency, severity, and risk analysis are generally used (railway, construction site accident interpretation, etc.) and are based on this concept, and are used in various fields such as economy and management. Human factors such as management and supervision are neglected, erroneous operation of machinery, neglect of maintenance work, neglect of measures, etc., and physical factors include corrosion and aging, design failure, failure and damage, and construction defect.

Table 3 Hazard rating by cause of dangerous goods accident

Cause of accident	Number of Accidents (2 years)	Annual Incidence	Amount of Damage (one million won)	Severity Rating	
				Severity	Risk
Human Factors	77	38.5	1637.1	21.3	818.6
Physical Factors	29	14.5	1775.5	61.2	887.8
Other Factors	28	14	385.1	13.8	192.6
Unknown Cause	13	6.5	4189.4	322.3	2094.7

Table 3 shows the severity and the risk level for the risk assessment based on the number of accidents, frequency, and amount of damage by the cause of the hazardous material accidents in the last two years. The severity of the risk was the highest in cases of unknown cause, followed by physical factors, human factors, and other factors. The risk was in descending order of cause unknown, material factor, human factor, and other factors.

A high risk of a hazard means that the amount of damage is high even if the frequency of the accident is low. As shown in Table 3, the annual incidence is low at 6.5, but the amount of damage per accident is as high as 3.49 million dollar, so the severity is high and the risk is very high.

3. AHP FOR HAZARDOUS MATERIAL MANAGEMENT LEVEL SETTING

In order to convert the causes of hazardous material accidents into factors for management, three factors such as human resource management, S/W management, and H/W management, which are classification standards understood by the port practitioners. Therefore, the detailed evaluation items are selected as shown in Table 4 so that the human factors are classified into human resource management, material factor, H/W management, and other factors.

In order to establish the level of risk management according to the hazardous materials impact, the AHP(Analytic Hierarchy Process) analysis was conducted to evaluate the dangerous goods risk assessment action as an evaluation factor and to evaluate the priority according to the importance of these factors. Based on the results of surveys received from the port hazard experts, weights and priorities of the detailed evaluation items were derived.

In the risk assessment, risk factors were composed of human resource management, software management, and hardware management. Human resource management is composed of management measures such as strengthening of safety education, improvement of management personnel work, securing of managerial proficiency in terms of management of human resources among risk material risk assessment activities.
S / W management is a management aspect of software activities during the hazardous material risk assessment activities. It consists of supplementing the operating system, supplementing the safety manual, and developing related programs. H / W management is a hardware activity among hazardous material risk assessment activities, and it is composed of management measures such as supplementing dangerous goods facilities, introducing new management equipments, and improving performance of management equipments.

Table 4 Dangerous goods risk management detailed factors

Measurement Objective	Evaluation Factor	Main Content	Detailed Evaluation Items
Dangerous Goods Risk Evaluation	Human Resources (HR) Management	Management aspects of human resources in hazardous material risk assessment activities	Strengthen safety education
			Improve management personnel
			Secure managerial proficiency
	S/W Management	Management of software activities during hazardous material risk assessment activities	Supplementing the operating system
			Safety manual supplement
			Related program development
	H/W Management	Management of hardware activities during hazardous material risk assessment activities	Supplementing dangerous goods facilities
			New introduction of management equipment
			Improve management equipment performance

As a result of the consistency test of the respondents, 0.00699, which is less than 0.1, showed consistency. In the case of importance, human resource management was the highest with 0.543, followed by S / W management 0.244 and H/W management 0.213.

Table 5 First tier analysis result

Evaluation Factor	Importance	Consistency Index
Human Resources (HR) Management	0.543	0.00699
S / W management	0.244	
H / W management	0.213	

As a result of analyzing the weights of the three sub-items of human resource management factors, the factors of securing the managerial proficiency (0.400) were most important, followed by the strengthening of the safety education (0.317) and the improvement of the management personnel (0.283) Respectively.
The three subscales of the S/W management factor were the most important (0.426) in the supplement of the operating system (0.299) and the related program development (0.274).
For the detailed evaluation items of H / W management factors, the importance of supplementing hazardous materials facilities (0.412) was the highest, followed by the improvement of management equipment performance (0.304) and the introduction of management equipment (0.284).
As a result of the consistency test, the consistency index of the detailed evaluation items for each evaluation factor was less than 0.1 and consistency was secured.

Table 6 Weights and priorities for detailed evaluation items

Key Factors	Detailed Evaluation Items	Importance	Priority	Consistency Index
Human Resources (HR) Management	Strengthen safety education	0.176	2	0.00
	Improve management personnel	0.157	3	
	Secure managerial proficiency	0.222	1	
S/W management	Supplementing the operating system	0.100	4	
	Safety manual supplement	0.070	6	
	Related program development	0.064	7	
H/W management	Supplementing dangerous goods facilities	0.087	5	
	New introduction of management equipment	0.060	9	

	Improve management equipment performance	0.064	7	

As a result of evaluating the relative importance of the nine sub-evaluation items, the factor of securing the managerial proficiency (0.222) among the nine sub-evaluation items was found to be the most important factor and it is the most preferable management alternative for the strengthen safety education(0.176) and improvement of management personnel(0.157). Therefore, management of human resources is the most important, and it is recognized as a priority dangerous material management alternative. It can be seen that the detailed evaluation items of S / W management and the detailed evaluation items of H / W management have low priority and the importance as a management plan is low. As a result of the consistency test, the consistency index of the detailed evaluation items for each evaluation factor was 0.00 and consistency was secured.
The priorities of the derived sub-items will be used in setting the level of Dangerous Goods Management and will serve as a priority for applying the Action to the main persons.

4. DEVELOPMENT OF RISK ASSESSMENT MODEL

Risk is composed of quantified values of the frequency of accidents and the severity of accidents. Therefore, rather than only assessing risk values as a method of classifying risks, classify incidence and severity as classes and evaluate risk using risk matrix Is commonly used. This is because the risk matrix has the advantage of being able to easily grasp not only the risk level but also the occurrence frequency and the severity level.

In this study, the frequency and severity of port dangerous material accidents are classified into five levels and the criteria and results of matrix risk assessment are presented. When the frequency and severity of incidence are classified into a matrix structure to determine the severity of the hazard, the risk level should be multiplied by the incidence frequency and the severity. Table 7 distinguishes five levels of occurrence frequency, severity, and risk, sets range of values for each step, and can use this range as a criterion. The frequency of occurrence (F1 to F5) and severity (S1 to S5) are empirically calculated values, and the risk (R1 to R5) is not set as the product of frequency and severity.

Table 7 Frequency, severity, risk criteria

Frequency		Severity		Risk	
F1	＜10	S1	＜20	R1	＜400

F2	＜20	S2	＜40	R2	＜600
F3	＜30	S3	＜60	R3	＜1000
F4	＜40	S4	＜80	R4	＜1500
F5	＜50	S5	＜100	R5	＜2200

The matrix structure is completed as shown in Table 8 so that the risk level can be determined according to the occurrence frequency and the severity level of Table 7. Table 8 shows the risk level of the port hazardous materials accident based on the determination of the risk level by using the matrix of occurrence frequency and severity.

Table 8 Matrix structure Risk grading criteria and results

division		Severity				
		S1	S2	S3	S4	S5
Frequency	F1	R1	R2	R2	R3	R4
	F2	R1	R2	R3	R3	R5
	F3	R2	R3	R4	R5	R5
	F4	R3	R3	R5	R5	R5
	F5	R3	R5	R5	R5	R5

In order to apply the criterion to each criterion, if the risk level obtained in Table 7 is applied to the criterion in Table 8, the human factor is F 2 (F = 38.5)) Is 818.6, so it corresponds to R3, so it is indicated in R3 area in Table 8. Since the frequency of occurrence (F) of the physical factor is 14.5, F2, the severity (S) is 61.2, S4, and the risk (R) is 887.8. The other factors are represented by R1 in Table 9 because the frequency of occurrence (F) is 14, F2, the severity (S) is 13.8 and S1 is the risk (R) is 192.6.

Table 9 compares the risk numbers multiplied by the incidence frequency and the severity, and the risk grades of the matrix structure method. As a result, human factors were R5, material factors were R4, and other factors were R1. When we look at the characteristics of each factor, the other factors are low in occurrence frequency and the severity is the lowest. Human factors go into a criterion with a high frequency but a low severity. Physical factors enter a criterion of high severity with low occurrence frequency. Unknown causes are included in the areas where the importance is low, but the severity is the highest.

Therefore, the cause of the unknown is relatively low, but the severity is high, so it is judged to be one step higher than the risk grade in the matrix structure risk grade judgment.

Table 9 Comparison of the results of the risk grading

division	Risk Level Scale	Matrix Structure	Judgment
Human factors	R3	R3	Same
Physical factor	R3	R3	Same
Other factors	R1	R1	Same
Unknown cause	R5	R4	No match

5. SIMULATION ANALYSIS

Monte Carlo Simulations are a way to overcome the limitations of traditional deterministic analytic methods with a single value. This is an appropriate method for analyzing the risk with uncertain volatility of the future as a variable. Especially, it can be used to evaluate the risk of accidents considering future uncertainties after selecting various scenarios.

The Monte Carlo simulation can be used to simulate the major components of the port risk assessment model by repeatedly simulating the number of incidents, frequency of occurrence, and amount of damage as specific variables and evaluate the risk at a future point in time.

In terms of application of the probability distribution applied to the input variables, we tried to apply the property values that match the characteristics of each variable based on the analysis of actual data such as the number of accidents, frequency of occurrence, amount of damage. However, in case of port hazardous materials accident, it is difficult to apply to simulation because of small number of accidents.

The number of accidents and the amount of damage are calculated by random number generation 500 times, and the severity and risk are estimated by random number generation. Table 10 shows the simulation results based on the basic property values.

Table 10 Monte Carlo simulation results

Division	Amount of Damage	Severity	Risk
Repeat Execution	500	500	500
Average	2920.7	39.9	42.1

Minimum Value	5.0	0.1	0.0
Maximum Value	5772.0	89.9	176.9
Mode	4158.0	89.9	0.0
Standard Deviation	1640.8	22.9	44.7
Variance	2,692,330.4	524.0	1998.8

The results of the Monte Carlo simulations for risk assessment showed no significant differences in the amount, severity, and risk of injury to human and physical factors, but other factors such as damage amount, severity, and risk were relatively low. The amount of damage, severity, and risk were considerably high, indicating that priority management was required.

Table 11 Hazardous material accident causes and hazards

Cause of Accident	Hazardous Material Accident Data Analysis Value			Simulation Result Value		
	Amount of Damage	Severity	Risk	Amount of Damage	Severity	Risk
Human Factors	1637.1	21.3	818.6	820.2	21.7	410.1
Physical Factor	1775.5	61.2	887.8	812.3	21.4	406.1
Other Factors	385.1	13.8	192.6	196.4	14.0	98.2
Unknown Cause	4189.4	322.3	2094.7	2126.0	350.5	1063.0

Table 11 compares the analysis results of the data on the hazardous material accidents and the simulation results. The severity was high in simulation results, human factor, other factors, unknown cause, and the risk was low in simulation results.
Therefore, it can be seen that the risk of a port hazardous material accident is estimated to be relatively lower than that of a hazardous material accident data through a simulation experiment.

As a main evaluation variable of the Monte Carlo simulation, the damage amount, severity, and risk were selected, and the values obtained through 500 simulations were derived from the existing statistical values. It is also necessary to obtain an objective comparison standard by calculating the severity and risk of a hazardous material accident. In the case of Monte Carlo simulation, it is necessary to evaluate the probability

distributions for the input variables by estimating the appropriate distributions. However, assuming that the data are insufficient, the random numbers are assumed to be the random distributions.
However, the limitation of the analysis is limited by the fact that due to the limitation of the port accident data collection of port, the basis period of the input variable was unspecific ally estimated and the time series analysis data were not compared with the actual value using the probabilistic method.

6. CONCLUSION

In this study, the factors for improvement of port hazardous materials safety management were selected and the importance and priority of those factors among various improvement plan factors were analyzed through AHP analysis.

In order to assess the relative severity of each accident by analyzing the current status of dangerous goods accidents in the port, the characteristics of each type of dangerous material accident occurrence are considered to be the lowest and the severity of the accident is low. Human factors go into a criterion with a high frequency but a low severity. Physical factors enter a criterion of high severity with low occurrence frequency. Unknown causes are included in the areas where the importance is low, but the severity is the highest.

The results of the Monte Carlo simulations for risk assessment showed no significant differences in the amount, severity, and risk of injury to human and physical factors, but other factors such as damage amount, severity, and risk were relatively low. The amount of damage, severity, and risk were considerably high, indicating that priority management was required.
As a result of comparing the analysis value of the data on the hazardous material accident and the simulation result, the severity was high in the simulation result, human factor, other factors, unknown cause, and the risk was low.
Therefore, it can be seen that the risk of a port hazardous material accident is estimated to be relatively lower than that of a hazardous material accident data through a simulation experiment.

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