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Multi Criteria Decision on Selecting Optimal Ship Accident Rate for Port Risk Mitigation*

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Contents

Abstract

Large ports have potential catastrophic accidents by handling enormous amount of hazardous and dangerous materials which tend to increase the risk of port and the facilities in its vicinity. In the paper, we propose a mathematical method to identify the ship accident types affecting risk in port areas which propagate into death of people as a consequence of the accidents. We consider a multi criteria port risk problem and a goal programming modeling is constructed for calculating accident rates of each accident type. The obtained results can be employed by decision makers or port authorities in implementing the port risk mitigation measures or in designing (planning) future port construction.

For the study, we use the accident data for the 12 domestic ports over the last 5 years from 2002 to 2007.

Key Words : port risk, transition probability, accident rate, goal programming

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I. Introduction

As the role of ports becomes critical carrying enormous number of freight cargoes not to mention transporting passengers, the increase in shipment of hazardous materials, among others, makes the ports and their vicinities much more risky places when unexpected accidents occur. A quantitative risk analysis has been successfully employed as a useful tool estimating the consequences and the frequencies of an accident in many industrial areas to calculate the possible risks in a probabilistic way.

Usually, major accidents occurring in port areas bring in a loss of containment of hazardous and dangerous materials which can turn into a great threat to nature and people if it widely spreads along the water or catches fire. Reflecting on the crucial importance of maritime operations and continuing increase in the transport of various cargoes through ports, researches on risk analysis for the impact of ship accidents have been actively performed. The main focuses for port risk have been on the transport of hazardous material and the effect on the human, surrounding facilities, economic or monetary loss, and nature.

Kim et al proposed a methodology to perform a risk analysis on the effects of ship accidents in domestic ports and presented the resulting risk with FN curve.[1] Ronza et al performed a quantitative risk analysis on hydrocarbon terminals in ports.[2] Rao et al described the methods to identify the types of hazardous events and analyzed the consequences of chemical releases by way of the cause-consequence technique.[3] Trbojevic et al presented a methodology for risk assessment to establish hazard barriers.[4]

Typically, an initiating event is the spill of a hazardous material, which can propagate through possible intermediate events in sequential order into final consequences such as a fire, explosion, toxic gas cloud or even fatality of human.

However, since the port risk leading to the death of people is usually initiated from different types of initial accidents, preventive measures to control the accidents types resulting in huge damages to port and human lives should be taken. Moreover, the port risk mitigation requires various risk related criteria corresponding to diverse accident types.

In this regards, we consider a multi criteria problem with risk related objectives for ports and present a goal programming formulation to calculate the ship accident rates of different kinds. In general, an optimization problem can be solved with one objective of either minimization or maximization through diverse mathematical techniques. However, in many

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[1] Kim et al (2008).
[2] Ronza et al (2006).
[3] Rao et al (1996).
[4] Trbojevic et al (2000).

maximization through diverse mathematical techniques. However, in many applications, the optimal solution requires the trade off among different factors some of which usually conflict with each other and the decision maker should consider more aspects than just one objective for problem modeling.

Yang and Choi employed the goal programming method for rice processing industry where cost and managerial performance were identified as the two criteria.[5] Gunnec and Salman presented a two stage stochastic programming model for optimal selection of emergency centers in case of an earthquake.[6] Badri combined the AHP method with the goal programming model for selection of production locations overseas, where the AHP weights were used for the qualitative factors.[7]

For the study, the criteria are chosen with main focuses on fatality rate, expected risk, and accident rates. For each criterion, corresponding priority level is assigned. A goal programming is constructed for identification of accident rates of each type affecting port risk using the ship accident data for the 12 domestic ports over the 5 year period from 2002 to 2007 and the obtained results can be employed by decision makers or port authorities in implementing the port risk mitigation measures or in designing (planning) less risky port construction.

II. Mathematical modeling for accident rate identification

The following notation for the risk is widely used.[8]

$$R=P\cdot C \tag{2.1}$$

where, R = risk of an accident, P = the frequency(rate) or probability of occurrence of an accident, and C = the consequence of an accident.

1. Transition probabilities and structure of the event propagation

The following <Table 1> shows the ship accident data in 12 domestic ports from January 2002 to August 2007 and each accident was classified as one of the 5 accident types, i.e., collision, fire, foundering, oil pollution, and others.

5 Yang and Choi (2007).
6 Gunnec and Salman (2006).
7 Badri (1999).
8 Vinnern (2007).

<Table 1> Accident types for 2002-2007 period in ports and on waters

Year	Total	Collision	Fire	Foundering	Oil pollution	Others			
						Contacting	Grounding	Human accident	Water intrusion
2002	21	9	2	5	3	1	-	1	-
2003	14	3	2	1	6	-	1	-	1
2004	55	4	2	7	27	10	2	1	2
2005	52	9	4	8	19	5	3	3	1
2006	79	22	5	4	18	16	7	1	6
2007.8	49	19	9	5	-	3	8	3	2
Total	270	66	24	30	73	35	21	9	12
(%)	(100)	(24.5)	(8.9)	(11.1)	(27.1)	(13.0)	(7.8)	(3.3)	(4.4)

Source: Ministry of Land, Transport and Maritime Affairs (2008)

Along with the accident data in <Table 1> and the official accident log for each accident the conditional probabilities from 5 (initial) accident types to the ensuing(second stage) events are calculated in the transition matrix form as shown in <Fig. 1>, where each row elements sum to 1. Transition probability matrix from the second stage to the last stage is presented in <Fig. 2>.

Combining the two conditional probabilities obtained from <Fig. 1> and <Fig. 2>, the overall structure of the propagation of accident events is modeled through Bayesian networks in <Fig. 3>, where each event is denoted by rectangle, the arrow from an event represents the direction in the following event, and the fractional value for each arrow is the conditional probability from current event to the next.

<Fig. 1> Transition probability matrix from initial events

	Foundering	Oil pollution	0 death	1 death	2 deaths	3 deaths
Fire	0	0	23/24	1/24	0	0
Collision	10/66	6/66	50/66	0	0	0
Foundering	0	5/30	25/30	0	0	0
Oil pollution	0	0	1	0	0	0
Other	0	3/77	66/77	8/77	0	0

<Fig. 2> Transition probability matrix from second stage events

	0 death	1 death	2 deaths	3 deaths
Foundering	6/10	2/10	1/10	1/10
Oil pollution	1	0	0	0
0 death	1	0	0	0
1 death	0	1	0	0

2. Calculation of the rates for accident events and fatalities

The accident rates for foundering and oil pollution in second stage and the rates for fatalities (deaths) are calculated using the initial accident types. For simplicity, we let each event be denoted by first two letters, the initial accident rate of an event type x by , the accident rate of an event type y in second stage by and the rate for i fatalities by

$$\begin{aligned} R^0(fo) &= R(co)\,P(fo|co) \\ &= 0.15\,R(co) \end{aligned} \quad (2.2)$$

$$\begin{aligned} R^0(oi) &= R(co)\,P(oi|co) + R(fo)\,P(oi|fo) + R(ot)\,P(oi|ot) \\ &= 0.09\,R(co) + 0.17\,R(fo) + 0.04\,R(ot) \end{aligned} \quad (2.3)$$

$$\begin{aligned} R^0(0fa) &= R(fi)P(0fa|fi) + R(co)P(fo|co)P(0fa|fo,co) + \\ &\quad R(co)P(0fa|co) + R(fo)P(oi|fo)P(0fa|oi,fo) + \\ &\quad R(fo)P(0fa|fo) + R(oi)P(0fa|oi) + \\ &\quad R(ot)P(oi|ot)P(0fa|oi,ot) + R(ot)P(0fa|ot) \\ &= 0.96R(fi) + 0.94R(co) + R(fo) + R(oi) + 0.86R(ot) \end{aligned} \quad (2.4)$$

$$\begin{aligned} R^0(1fa) &= R(fi)P(1fa|fi) + R(co)P(fo|co)P(1fa|fo,co) + \\ &\quad R(ot)P(1fa|ot) \\ &= 0.04R(fi) + 0.03\,R(co) + 0.10\,R(ot) \end{aligned} \quad (2.5)$$

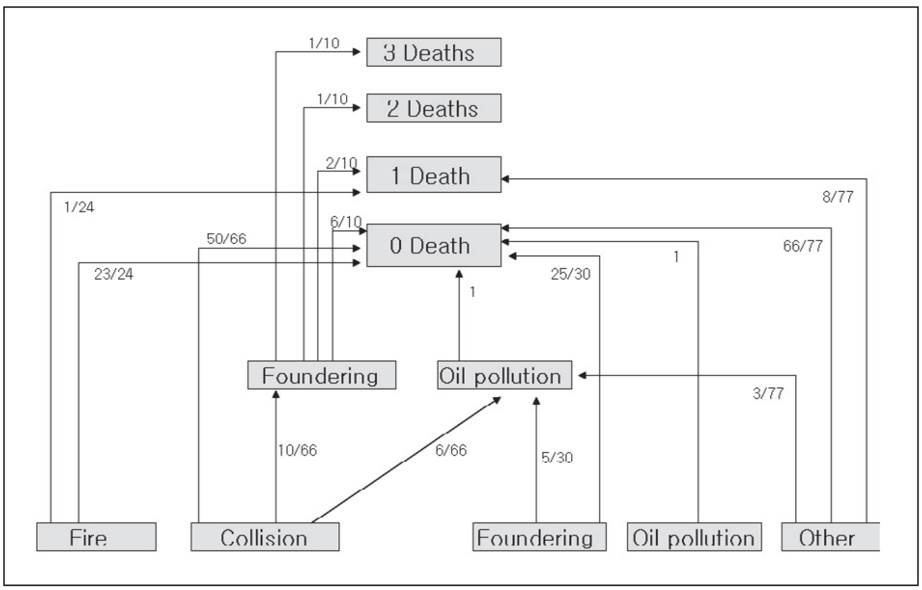
$$R^0(2fa) = R(co)P(fo|co)P(2fa|fo,co) = 0.02R(co) \tag{2.6}$$

$$R^0(3fa) = R(co)P(fo|co)P(3fa|fo,co) = 0.02R(co) \tag{2.7}$$

3. Goal programming modeling for determination of ship accident rates

Since all the accident rates, $R^0(y)$ and fatality rates, $R^0(i, fa)$ formulated in (2.2) - (2.7) are conditionally affected by the initial ship accident rates, $R(x)$, we model a multi criteria goal programming problem to derive the optimal accident ratefor each initial event. For this purpose, we minimize the overall deviations in the objective function given several goals with priority levels and various corresponding constraints.

< Fig. 3> Structure of the accident propagation



The goals, which can be used as multi criteria in objective function of goal programming formulation, are chosen in relation to the critical factors affecting fatalities, especially with main focuses on fatality rate for each number, expected risk considering all the possible fatalities, individual accident rate, and overall accident rate.

(1) Goals

Goal 1 : The rate of fatality

- The rate of more than 0 fatality is not greater than the target value.
- The rate of more than 1 fatality is not greater than the target value.
- The rate of more than 2 fatality is not greater than the target value.

Goal 2 : The rate of 0 fatality is not less than the target value.

Goal 3 : The expected risk of fatality is not greater than the target value.

Goal 4 : The rates of foundering and oil pollution in second stage are not greater than target values.

Goal 5 : The rate of each initial event is not greater than target value.

Goal 6 : The total rate of all initial events is not greater than the target value.

(2) decision variables

$R(fi), R(co), R(fo), R(oi), R(ot)$: the ship accident rates

(3) Goal programming model

Along with the goals and decision variables defined, the goal programming model is constructed as follows. The objective is to minimize the deviations, which stem from the prescribed goals and the target values. The priority levels and the number of goals can be adjusted at the decision maker's disposal depending on the relative importance of the risk criteria in the problem construction.

$$Minimize\ P_1(d_1^+, d_2^+, d_3^+), P_2(d_4^-), P_3(d_5^+), P_4(d_6^+, d_7^+), P_5(d_8^+, d_9^+, d_{10}^+, d_{11}^+, d_{12}^+), P_6(d_{13}^+)$$

$$subject\ \ to \tag{2.8}$$

$$0.04R(fi) + 0.07R(co) + 0.10R(ot) + d_1^- - d_1^+ = f_1 \tag{2.9}$$

$$0.04R(co) + d_2^- - d_2^+ = f_2 \tag{2.10}$$

$$0.02R(co) + d_3^- - d_3^+ = f_3 \tag{2.11}$$

$$0.96R(fi) + 0.94R(co) + R(fo) + R(oi) + 0.86R(ot) + d_4^- - d_4^+ = f_4 \tag{2.12}$$

$$0.04R(fi) + 0.13R(co) + 0.10R(ot) + d_5^- - d_5^+ = f_5 \tag{2.13}$$

$$0.15R(co) + d_6^- - d_6^+ = f_6 \tag{2.14}$$

$$0.09R(co) + 0.17R(fo) + 0.04R(ot) + d_7^- - d_7^+ = f_7 \tag{2.15}$$

$$R(fi) + d_8^- - d_8^+ = f_8 \quad (2.16)$$

$$R(co) + d_9^- - d_9^+ = f_9 \quad (2.17)$$

$$R(fo) + d_{10}^- - d_{10}^+ = f_{10} \quad (2.18)$$

$$R(oi) + d_{11}^- - d_{11}^+ = f_{11} \quad (2.19)$$

$$R(ot) + d_{12}^- - d_{12}^+ = f_{12} \quad (2.20)$$

$$R(fi) + R(co) + R(fo) + R(oi) + R(ot) + d_{13}^- - d_{13}^+ = f_{13} \quad (2.21)$$

$$R(fi), R(co), R(fo), R(oi), R(ot), d_j^+, d_j^- \geq 0, \quad j = 1, \ldots, 13 \quad (2.22)$$

The objective function (2.8) represents the 13 goals each of which is assigned the priority level by Pi. Constraints (2.9) - (2.11) are for the goal 1 and obtained from equations (2.5) - (2.7). The rate of fatality (goal 1) is the common criterion most widely employed in industry worldwide to present the risk in a visual way. Constraint (2.12) is the goal equation for fatality 0, which is obtained from (2.4). Constraint (2.13) is the expected risk, which is the weighted summation of possible individual risks in (2.5) - (2.7).

Constraints (2.14) - (2.15) are the goal equation for the second stage event rates, i.e., foundering and oil pollution, which is obtained from (2.2) - (2.3).

Constraints (2.16) - (2.20) are the upper limit condition for occurrence of each initial ship accident type and the last constraint (2.21) is for the total number of accident rates for all types.

(4) Identification of accident rates of each ship accident type

With the aid of QM for windows software program, the accident rates for each ship accident type are calculated and presented in <Table 2>, where the right hand side(RHS) value of each constraint is a hypothetical number.

Substituting the results in <Table 2> for equations in (2.2) -(2.7), the rates for second stage events and fatalities are obtained as

$$R^0(fo) = 0, \quad R^0(oi) = 5.1,$$
$$R^0(0fa) = 80, \quad R^0(1fa) = 0.45, \quad R^0(2fa) = 0, \quad R^0(3fa) = 0 \quad (2.23)$$

The reason the rates $R^0(fo), R^0(2fa), R^0(3fa)$ are all zeros' is just because these events are only connected from the collision having the accident rate 0.

<Table 2> Accident rates for initial ship accidents

Decision variable analysis	Value		
R(fi)	10		
R(co)	0		
R(fo)	30		
R(oi)	40		
R(ot)	.47		
Constraint Analysis	RHS	d+ (row i)	d- (row i)
Goal/Cnstrnt 1	60	0	59.55
Goal/Cnstrnt 2	80	0	0
Goal/Cnstrnt 3	50	0	49.55
Goal/Cnstrnt 4	40	0	40
Goal/Cnstrnt 5	30	0	30
Goal/Cnstrnt 6	30	0	24.88
Goal/Cnstrnt 7	20	0	20
Goal/Cnstrnt 8	40	0	30
Goal/Cnstrnt 9	20	0	20
Goal/Cnstrnt10	30	0	0
Goal/Cnstrnt 11	40	0	0
Goal/Cnstrnt 12	10	0	9.53
Goal/Cnstrnt 13	80	0	0

III. Conclusion

In this paper, we introduced a methodology to calculate the ship accident rates of different types under the multi criteria objective function. The transition probabilities and fatalities were derived from the actual accident data for the 2002-2007 periods and used as constraints in goal programming formulation. The main focus of the paper is threefold; (1) how to construct the event propagation starting from 5 ship accidents into consequences expressed in fatalities through the intermediate events; (2) how to calculate the rates for each event and consequence using transition probabilities; and (3) how to model the multi criteria goal programming to find the ship accident rates.

In the analysis, since the accident data we employed was not enough for the accuracy of transition probabilities and consequently the rates for each event, more reliable data should be accumulated for more fruitful results.

Nevertheless, this is one of the first researches on modeling the port risk with multi criteria mathematical programming in Korea and the methodology presented in this study possibly with some modifications in objective function and constraints can be used as a useful guide in practical decision making with regard to mitigating risk in port industry.*

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