The International Emergency Management Society
13th Annual Conference Proceedings, May 23 – 26, 2006
Seoul, South Korea

QUANTITATIVE HAZARD ANALYSIS OF INFORMATION SYSTEMS USING PROBABILISTIC RISK ANALYSIS METHOD

Dr. Young-jai Lee[1], Taeho Kim[2]
Dongguk University

Keywords: hazard analysis, probabilistic risk analysis, activity based costing, business process, information systems

Abstract

Hazard analysis identifies probability to hazard occurrence and its potential impact on business processes operated in organizations. This paper illustrates a quantitative approach of hazard analysis of information systems by measuring the degree of hazard to information systems using PRA and activity based costing (ABC) technique. Specifically the research model projects probability of occurrence by PRA and economic loss by ABC under each identified hazard. To verify the model, each computerized subsystem which is called a business process and hazards occurred on information systems are gathered through one private organization. The loss impact of a hazard occurrence is produced by multiplying probability by the economic loss.

Introduction

Organizations have demanded hazard analysis and emergency preparedness about all hazards such as computer and communication breakdowns, and cyber terror as business activities dependency on information systems increased continuously. Hazard analysis identifies probability to hazard occurrence and its potential impact on business processes operated in organizations. This paper is focused on how hazard analysis manages quantitatively.

Crisis management and quantitative/qualitative hazard analysis about information systems were investigated. In addition, several case studies by the probabilistic risk analysis (PRA) method described other subjects such as nuclear, intelligent traffic system, and industrial engineering, etc. These subjects have involved in this research.

This paper illustrates a quantitative approach of hazard analysis of information systems using a case study.

Research Model

The research model is represented as following:

$$f(Ri)=\sum Pi \times Li \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

---

[1] Professor, University of Dongguk, KOREA
yjlee@dgu.edu
[2] Graduate Student
kimclub1@empal.com

- f(Ri): The sum of risk loss impact from the beginning to "i"th event-path
- Pi: The probability of hazard occurrence of "i"th event-path
- Li: Loss amount of "i"th event-path

Probability of hazard occurrence (Pi)

The Probabilistic Risk Analysis (PRA) is used to measure probability of the hazard occurrence (Pi) in this research. Specifically among the PRA methods, the Event Tree technique takes as modeling of the hazard analysis and the MCS (Monte Carlo Simulation) as a probabilistic analysis technique.

PRA means a model that allows the uncertainty of the business to be quantitative through the probability distribution of the resulted variables. Also, it is the accumulated probability distribution as taking the assumption that the probability distribution of the hazard variables is related to the business uncertainty [(US.DOT, 1996)].

The formula to produce Pi refers to Cho's model (2000) and makes it by using the Event Tree technique as following.

$$Pi=P(Cn)(Ci...k)=P(Ti)P(E1)P(E2)......P(Ek) \qquad .... \qquad (2)$$

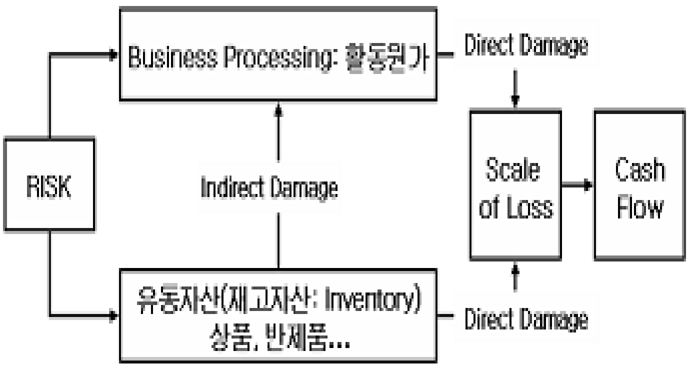
In this model, ***P(Cn)*** indicates the probability of an event to be the possible stirring (***Ti***). ***P(Ci...k)*** means that the probability of each event can be possibly occurred from ***P(E1)*** to ***P(E11)*** on an event-path. In other words, an event that can be possibly occurred is caused by a stirring event. ***Pi*** produces a result by multiplying ***P(Cn)*** by ***P(Ci...k)***.

The procedure to measure ***Pi*** is as followings:
i) The classification between a stirring event and an event occurrence
ii) Build up the event tree scheme
iii) The calculation of probability of the event occurrence is related to each event-path using MCS

Loss Amount (Li)

The measurement of the loss impact is based on the Activity Based Costing (ABC) method. Fig. 1 shows the ABC model. If a crisis strikes an organization, business processes, assets, property, or a business image, they are damaged. Those elements affect the decrease of sales volume of the organization directly and indirectly, which produces bad cash flow as a result. The major concern is how business processes and inventories that are damaged by a business crisis, measure quantitatively in terms of information systems.

<Fig. 1> ABC Model for Economic Loss Measurement



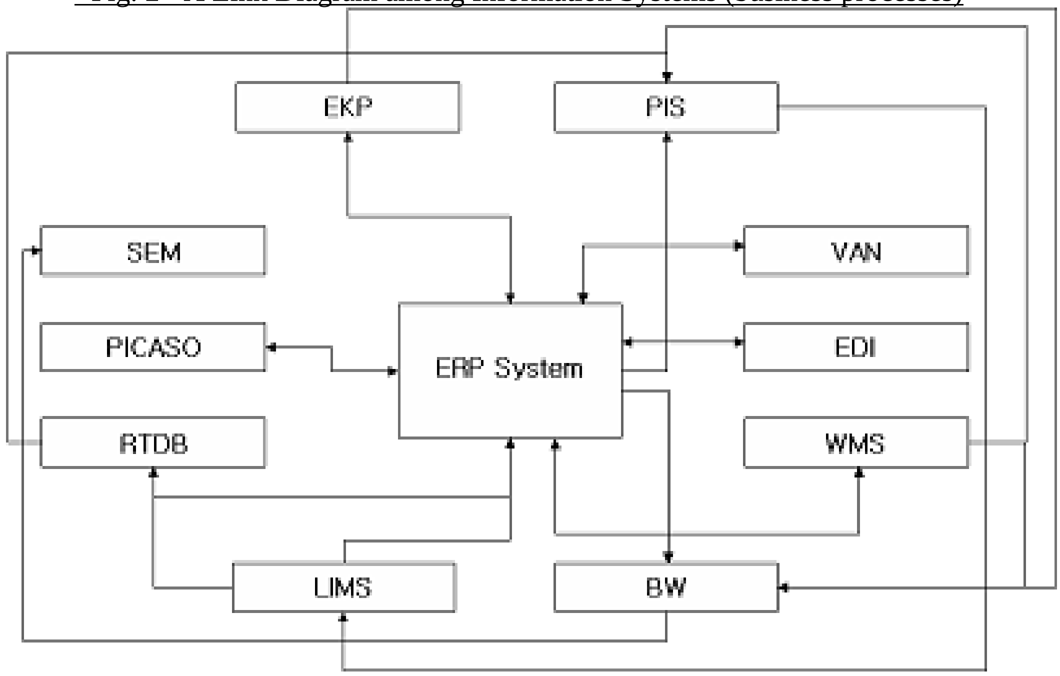
Research Model Analysis

The research model is verified through a case study that illustrates a big chemical engineering company being composed of the headquarter and a factory in the local area. It assumes that the hazard strikes the information systems in the organization.

Analysis of Information System Asset

The information system includes ERP and 13 legacy systems, in which each system is consisted in detailed business processes. Fig. 2 shows a link among each system, which means that a linked system is affected if one system breaks down because the systems share the data. PICASO, RTDB, LIMS, PIS, and WMS subsystem supports the manufacturing process. SEM provides executive management based on data which are produced by the BW subsystem. EKP operated by a groupware system is a kind of knowledge management system.

<Fig. 2> A Link Diagram among Information Systems (business processes)



The expenses element with the amount gathered as the following: IT expense ($1,919,629), IT property ($1,919,629), Salary ($47,009,496), department expense used by employees ($24,263,771), external project ($322,099), and business profit ($162,685,177).

Hazard Analysis of Information Systems

The Incident/Accident history with the interview to the system director is gathered to analyze the hazards related to the information systems.

Table 1 shows hazards that were controlled orderly within a specific time period during one year (2003). This research is focused on the technological hazards such as human error, and equipment failure (except natural hazards and civil hazards). The organization was faced with cyber terror, and the virus had the highest rate among the hazards.

<Table 1> Accidents that occurred on Computer & Information Systems

Category	Accident	number	Rate(%)	Acc. No.
Operation Defect	Virus	9	30.0	T1
	Data deletion on PC	1	3.3	T2
	Operator error on Servers	1	3.3	T3
	Lack of DB management	1	3.3	T4
	Defect of computer devices	1	3.3	T5
Operation Defect / System Defect	Server breakdown	2	6.7	T6
System Defect	Network down & defect	3	10.0	T7
	Defect of Web service	1	3.3	T8
	Data transmission delay	1	3.3	T9
	Server disk error	2	6.7	T10
	DB defect	1	3.3	T11
Infrastructure Defect	Air conditioner trouble	4	13.3	T12
	UPS defect & trouble	3	10.0	T13
Total		30	100.0	

Scenario Development of Hazard Analysis

1. Event on Hazard Analysis

The PRA measures probability of the event occurrence with the event tree model, which is developed by a predefined scenario. There are two kinds of scenarios. One is for stirring event and the other is for the event that can possibly occur. The stirring event promotes an event that is possible to occurrence, which may be a series of events. The accident that shows in Table 1 indicates a stirring accident. A breakdown of business process (such as ERP system that shows in Fig. 2) is affected by a stirring event, which refers to an event that is possible to occur.

Accordingly, we called that the process breakdown of ERP, EKP, BW, SEM, PICASO, LIMS, RTDB, WMS, VAN, EDI, PIS into E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11 sequentially.

2. Scenario Development of Accident Occurrence

The purpose to develop the scenario related to the accident occurrence is due to the lack of historical data in the organization. The scenario was created based upon a few historical data.

Table 2 shows the total number and the rate of each stirring event that explains accident occurrence, which is derived from a scenario during two years. Virus (29%) is the most and DB defect is the least (2%) among the stirring events.

<Table 2> Stirring Events by Scenario

분류	세부사건	사고번호	기간																								총사고수	사고비율
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
운영장애	바이러스	T1	0	0	1	1	0	1	1	0	0	1	1	1	0	0	2	1	0	0	1	0	0	1	1	0	13	0.29
	PC안 정보삭제	T2	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0.04
	운영자의 서버장비조작실수	T3	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0.04
	DB관리미숙	T4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0.04
	전산주변장비장애	T5	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0.04
시스템장애	서버다운	T6	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	3	0.07
	네트워크다운 및 장애	T7	0	1	0	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	4	0.09
	웹서비스장애	T8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0.04
	데이터전송망딜레이	T9	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	2	0.04
	서버디스크에러	T10	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	3	0.07
	데이터베이스 장애	T11	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0.02
기반시설장애	서버에어컨고장	T12	1	0	0	1	0	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	1	5	0.11
	UPS장애 및 고장	T13	1	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	4	0.09
총계																											45	1.00

Table 3 refers to the total number and the rate of breakdown of each business process that indicates an event occurrence, which is derived from a scenario during two years.
ERP breakdown (24%) is the most among event occurrences.

<Table 3> Events Occurrence by Scenario

Process명	사건번호	기간																								SUM	사건발생비율
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
ERP	E1	1	0	0	1	0	0	1	0	0	1	1	0	1	0	1	1	0	1	1	0	1	0	0	0	11	0.24
EKP	E2	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	1	6	0.13
BW	E3	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	0.07
SEM	E4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0.04
PICASO	E5	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	5	0.11
LIMS	E6	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.07
RTDB	E7	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4	0.09
WMS	E8	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	0.07
VAN	E9	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0.07
EDI	E10	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	3	0.07
PIS	E11	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0.04
총계																										45	1.00

3. Scenario Development of Event-Path
An event-path scenario that is shown in Table 4 develops on the basis of the link among the business processes like Fig. 2.

<Table 4> Event Path Scenario of ERP Business Process

Scenario No	T	P1	P2	P3	P4	P5	P6	P7
1	T1	E1	E2	E3	E4			
2	T1	E1	E5					
3	T1	E1	E6	E7	E11			
4	T1	E1	E6	E7	E8	E11		
5	T1	E1	E6	E7	E8	E3	E4	
6	T1	E1	E6	E11				
7	T1	E1	E11	E6	E7	E8	E3	E4
8	T1	E1	E9					
9	T1	E1	E10					
10	T1	E1	E8	E11	E6	E7		
11	T1	E1	E3	E4				

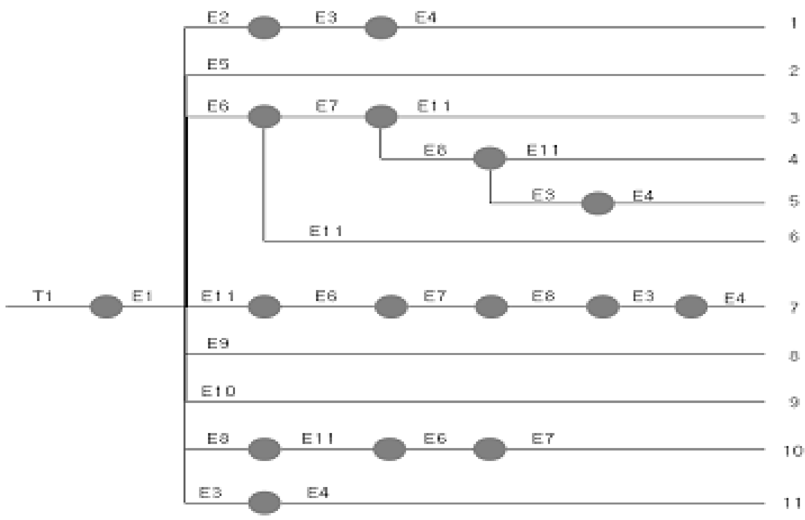
T: stirring event, P: business process

In the case of scenario number 1, for example, T1 (stirring event, virus) affects E1 (event occurrence, ERP) breakdown. E1 induces E2 (EKP) breakdown, and E2 brings about E3 (BW) breakdown, and E3 causes E4 (SEM) breakdown. Scenario 1 refers to an event-path. Table 4 includes 11 event paths stirred by a virus accident (T1). Accordingly, event paths can be created by each stirring event, that is, overall accidents in the organization.

Event Tree Modeling

The event-paths can be transformed to an event tree that represents the relationship between a stirring event and event occurrences. The Event Tree that comes from the event paths in Table 4 shows a causal relation between E1 (ERP) and the other Legacy system, induced by T1 (virus stirring event)[Fig. 3]

<Fig. 3> Event Tree Induced by a Stirring Event T1



Monte Carlo Simulation

@RISK 4.5.2 simulation software for the Monte Carlo simulation selects a P method among several probabilistic distributions. P distribution requires the average and standard deviation of each stirring event that shows in Table 5, and the average and standard deviation of each event occurrence that shows in Table 6. Table 5 and Table 6 make on the basis of Table 2 and Table 3.

<Table 5> Average & Standard Dev. of Stirring Events

분류	세부사건	사건번호	평균 사건발생수	표준편차
운영장애	바이러스	T1	0.541666667	0.588229966
	PC안 정보삭제	T2	0.083333333	0.282329851
	운영자의 서버장비조작 실수	T3	0.125000000	0.337831962
	DB관리미숙	T4	0.083333333	0.282329851
	전산주변장비장애	T5	0.125000000	0.337831962
시스템장애	서버다운	T6	0.166666667	0.380693494
	네트워크다운 및 장애	T7	0.250000000	0.442325868
	웹서비스 장애	T8	0.083333333	0.282329851
	데이터전송망딜레이	T9	0.083333333	0.282329851
	서버디스크 에러	T10	0.166666667	0.380693494
	데이터베이스 장애	T11	0.083333333	0.282329851
기반시설장애	서버에어컨 고장	T12	0.291666667	0.464305621
	UPS장애 및 고장	T13	0.208333333	0.414851117

<Table 6> > Average & Standard Dev. of Events Occurrence

Process	No	Average No.	St. Dev.
ERP	E1	0.458333333	0.508977378
EKP	E2	0.25	0.442325868
BW	E3	0.125	0.337831962
SEM	E4	0.083333333	0.282329851
PICASO	E5	0.208333333	0.414851117
LIMS	E6	0.125	0.337831962
RTDB	E7	0.166666667	0.481543412
WMS	E8	0.125	0.337831962
VAN	E9	0.125	0.337831962
EDI	E10	0.125	0.337831962
PIS	E11	0.083333333	0.282329851

Each result that is operated by 10000 simulations shows in Table 7 and in Table 8.

<Table 7> Simulation Result of Stirring Event

분류	Accident	No	Result
운영장애	바이러스	T1	0.5417
	PC안 정보삭제	T2	0.0833
	운영자의 서버장비조작실수	T3	0.1251
	DB관리미숙	T4	0.0834
	전산주변장비장애	T5	0.125
시스템장애	서버다운	T6	0.1665
	네트워크다운 및 장애	T7	0.2502
	웹서비스 장애	T8	0.0833
	데이터전송망딜레이	T9	0.0833
	서버디스크 에러	T10	0.1667
	데이터베이스 장애	T11	0.0832
기반시설장애	서버에어컨 고장	T12	0.2915
	UPS장애 및 고장	T13	0.2083

<Table 8> Simulation Result of Event Occurrence

Process	No	Result
ERP	E1	0.4583
EKP	E2	0.2499
BW	E3	0.125
SEM	E4	0.0834
PICASO	E5	0.0833
LIMS	E6	0.125
RTDB	E7	0.1667
WMS	E8	0.125
VAN	E9	0.125
EDI	E10	0.125
PIS	E11	0.0833

Economic Loss Measurement by ABC

The Economic value of each process includes the following elements: salary, department expense, IT expense, IT property, external project, and business profit. Salary is divided by activity volumes (business hours) of employees that are involved in business process. The department expense, external project expense, and the IT expense are divided into the business process according to a rate of salary allocated to the business process. The IT property is divided by the power of influence of the business process. Activity volumes of the employee and the influencing power are investigated through interviews and survey in the organization. As a result, Fig. 9 shows economic value of each business process.

<Table 9> Expense of Each Business Process

process	process expense	monthly expense
ERP	211,670,158,636	17,639,179,886
RTDB	5,769,834,780	480,819,565
PIS	1,396,831,319	116,402,610
PICASO	4,221,155,247	351,762,937
EKPEKP	2,132,444,341	177,703,695
SEM	2,634,597,246	219,549,771
BW	28,470,304	2,372,525
EDI	239,414,097	19,951,175
VAN	119,358,195	9,946,516
LIMS	15,181,420,053	1,265,118,338
WMS	10,080,703,923	840,058,660
Total	253,474,388,141	21,122,865,678

Result

In order to verify the proposed research model, probability of the event occurrence and economic loss are produced according to each event path. Table 10 refers to probability of event occurrence on each event path.

<Table 10> Probability of Event Occurrence on Each Event-Path

No	T	P1	P2	P3	P4	P5	P6	P7
1		E1	E2	E3	E4			
		0.4583	0.2499	0.125	0.0834			
2		E1	E5					
		0.4583	0.0833					
3		E1	E6	E7	E11			
		0.4583	0.125	0.1667	0.0833			
4		E1	E6	E7	E8	E11		
		0.4583	0.125	0.1667	0.125	0.0833		
5		E1	E6	E7	E8	E3	E4	
		0.4583	0.125	0.1667	0.125	0.125	0.0834	
6	T1 0.5417	E1	E6	E11				
		0.4583	0.125	0.0833				
7		E1	E11	E6	E7	E8	E3	E4
		0.4583	0.0833	0.125	0.1667	0.125	0.125	0.0834
8		E1	E9					
		0.4583	0.125					
9		E1	E10					
		0.4583	0.125					
10		E1	E8	E11	E6	E7		
		0.4583	0.125	0.083	0.125	0.1667		
11		E1	E3	E4				
		0.4583	0.125	0.0834				

By Formula (2) of the research model, for instance, probability of event path 1 is 0.5%, which means 0.005 frequencies during one month happened. Also, the probability of event path 2 makes 2% although the other paths have very low frequencies.

The economic loss of each event path sums up the loss of each business process on the event path. For example, in the case of event path 1, the total economic loss adds up loss of E1, E2, E3, and E4. The total amount of event path 1 becomes the value of $18,588.00 that is shown in Table 11. Thus, the risked amount of event path 1 has a result ($96,178) by multiplying the occurrence probability by the loss amount. Table 11 shows the risked amount of each event path affected by the event occurrence (E1, ERP) and the stirring event (T1, virus).

<Table 11> Risk Amount of Each Event-Path

Event path	Occurrence Prob.	Loss amount ($)	Risk amount($)
1	0.005174174	18,588,164	96,178
2	0.02068015	17,816,883	368,455
3	0.000430923	18,701,160	8,058
4	5.38653E-05	18,721,112	1,008
5	6.74125E-06	18,349,218	123
6	0.002585019	18,698,788	48,336
7	2.69488E-05	19,189,277	517
8	0.031032639	17,649,126	547,698
9	0.031032639	18,904,298	586,650
10	5.36713E-05	18,721,112	1,004
11	0.002588122	18,107,345	46,864
Average Amount			$165,803

Cho (2001) researched that the average value (economic loss) of the total event paths per a stirring event refers to the level of a hazard. Therefore, the average of 11 event paths tells $165,803.00, which indicates that the economic value of the ERP process can be affected by the virus hazard in this case study.

Summary and Conclusion

This paper illustrates a quantitative approach of hazard analysis of information systems through a case study. The research model projects probability of occurrence by probabilistic risk analysis (PRA) and economic loss by activity based costing (ABC) under each identified hazard.

To verify the model, first, each computerized subsystem which is called a business process and hazards occurred on information systems are gathered through one private organization. Second, scenarios of an event-path, which means a relationship among business processes, are developed on the basis of gathered data. The probability of hazard occurrence and the probability of business process breakdown are extracted from the scenarios. Third, event-paths, which are affected by a hazard, are represented by an event tree technique. The operation of the event tree was conducted by Monte Carlo simulation using the @RISK4.5.2 simulation program. Fourth, economic loss of a business process is measured by the ABC method, in which the cost includes salary, direct and indirect expenses, IT property value, business profit, etc. Finally, the loss impact of an event-path is produced by multiplying probability by the economic loss. The quantitative degree of a hazard occurrence results in average economic loss impact of all event-paths.

It concludes that the possibility to measure the level of hazard quantitatively can show in spite of the limitation to the simulation operation and the scenario development process. The quantified level of the identified hazard is provided (can be helped) so that the senior management can make his decision effectively about hazard mitigation implementation.

References

US.DOT, “Probabilistic Risk Analysis or Turnkey Construction: A Case Study,” 1996.
@RISK 4.5.2 Guide to Using,” Palisade Corporation, 2002.

Hyonam Cho, “Probabilistic Risk Analysis for Construction using Fuzzy Uncertainty Modeling,” Korea Civil Engineering, Vol 21 No 3-D, 2001.

Author Biography

Dr. Young-Jai Lee

- Professor, MIS Department, Dongguk University
- Chairman, Korea BCP Association
- Vice-President, TIEMS
- Research Area: Risk-Based Decision Making, Information Management
- E-mail: yjlee@dgu.edu

Mr. Taeho Kim

- Graduate student, MIS Department, Dongguk University
- Research Area: Decision-Making, E-business
- E-mail: kimclub1@empal.com