AN APPROACH FOR MODELING THE RISK TRANSFORMATION PROCESSES

Amy H. I. Lee[1], Chiou-Shuei Wei[1, 2] and Yu-Cheng Lee[1]

[1]Graduate Institute of Technology Management, Chung Hua University, Taiwan
[2]Department of Industrial Management, Lunghwa University of Science and Technology, Taiwan.

One of the most critical issues that every decision maker needs to face is the risk in association with the decisions to be finalized and the actions to be taken. It is not only due to the future uncertainties involved, but also the decision maker's inability of adapting himself to the changing environments. Formulating better plan and finding best personnel to execute the plan may potentially reduce the possibility of risk occurrence. However, it is still not possible for the decision maker to eliminate all risks that will potentially affect the outcome of the decision, because an exhaustive list of risk events is difficult to obtain. Previous researches seldom focused on the risk transformation phenomenon, and therefore cannot provide a complete and overall exploration of risk management. The objective of this study is to develop a model that can predict the transformation of the risk that may be exhibited during the execution of a decision and an operation.

Significance: Risks are traditionally and statically explored using four steps: (1) risk identification, (2) risk analysis (both qualitative and quantitative), (3) risk response planning, and (4) risk monitoring and controlling. The dynamic transformation of risk from a source to a target is studied in this paper.

Key words: Risk, risk transformation.

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1. INTRODUCTION

The potential risk inherent in the decisions is one of the most vital factors that obstruct the success of operations of any organization, and it can be hidden and difficult to discover or obvious but being ignored. Both cases induce crisis, damage or even disaster to the organization facing the risks. Risks can have many titles in different industries, such as financial risks for enterprises operation and individual career; life risks in insurance sector; investment risks for investors or company; political risks for politician or stability of a country; war risks for both groups in war, for regional security or even the economic situation of the entire world. Besides, risks can be caused by natural force, by someone's mistake or erroneous decision, by misunderstanding between two parties, or by poor capability of planning, implementing, and controlling certain events. Factors that trigger the risks are twofold, the controllable and the uncontrollable. If one can ease the controllable factors, the possibility of the risk occurrence may be significantly reduced; and if one can predict the uncontrollable factors and pre-specify the countermeasures, the damage due to the risks can be greatly slashed. Unfortunately, factors that block the way to success are always difficult to foresee, and factors being disclosed that will potentially lead to decision failure are often neglected. In other words, people tend to produce risks rather than preventing them, and ignoring risks instead of discovering problematic events. If they are not carefully handled, risks can have impacts on many areas including human factors such as stakeholders; environmental impact such as ecological concerns; confidence of outsiders such as image about an organization; legal issues such as civil liability and contractual performance obligations; political consideration such as investigative hearings and legislation draft conducted by lawmakers; operational interruption of ongoing business functions; material items such as buildings and equipment that are not replaceable and easily valued insurable items. Many researches have been done to develop models that can analyze the possibility of risk occurrence and prioritize the risk events, and allocate resources to mitigate, avoid, or transfer the risks accordingly, such as Monte-Carlo simulation, decision tree analysis, fault tree analysis, the failure mode and effects analysis. These techniques are mainly applied to predict the possibility of potential risks at certain point of time, while the transformation of the risks is not considered. This study intends to develop a risk transformation model that can disclose the risk behaviors and illustrate how a decision system is consecutively infected if one risk event has occurred.

2. LITERATURE REVIEW

One of the vital elements that lead to successful outcomes when making any decision or taking any action is the ability of forecasting the future uncertainties, and it is those uncertainties that will cause problems to the decision makers and degrade the performance of the actions. Researches conducted range from financial sectors, political issues and medical safety to

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internet payment. To explore the market risk, Sobehart (2003) has introduced a dynamical model of securities prices based on a particular notion of irrational exuberance and market fear generated by the under-reaction or over-reaction of market participants. Wu (2002) has indicated that a quantile measure of losses such as value-at-risk may not contain enough, or the right, information for risk managers. He presented an arch quantile regression approach to estimate the left-tail measures (LTMs). Crouhy and Turnbull (1999) have argued that the commonly employed methods may result in decisions that adversely affect shareholder value, and proposed an alternative methodology called adjusted RAROC to correct the inherent limitations of the existing methods. Cruz et al. (1998) have constructed a quantitative operational risk measurement model based on extreme value theory to measure and control the operational risk, such as those that occurred at Barings, Daiwa and Sumitomo. Laye and Enciso (2001) have discussed how the comprehensive approach can identify which business processes should not be or can be interrupted to insure continuity of critical business processes, and proposed seven impact categories that can determine when to apply business continuity or other strategies. Gheorghe and Vamanu (1998) have introduced integrated decision support system software called KOVERS to assist emergency management in the case of potential unclear and chemical accidents involving fixed installations or transportation activities. Seeking to encourage wider debate across the multidisciplinary field of risk management research, Mckinnon (2004) has outlined critically the tenets underpinning Social Risk Management (SRM) and highlighted the policy limitations of the innovative World Bank venture. Dekay et al. (2004) have presented a decision-analytic model for avoiding a risky activity. The model considers the benefit and cost of avoiding the activity, the probability that the activity is unsafe, and scientific tests or studies that could be conducted to revise the probability that the activity is unsafe. Bone et al. (2004) have reported on an experiment designed to test whether pairs of individuals are able to exploit *ex ante* efficiency gains in the sharing of a risky financial prospect and the results indicate that fairness is not a significant consideration, but rather that having to choose between prospects diverts partners from allocating the chosen prospect efficiently. Xie and Wang (2001) have investigated how situational (gain-loss), informational (opportunity-threat framing), and dispositional (achievement motive and avoidance motive) variables affected opportunity-threat perception and risky choice in managerial decision-making contexts. Progel (1992) has indicated that the risk management of avoiding lawsuits for dentists is a retroactive pastime instead of being proactive. What this means is that we often take action only after a problem has manifested itself, rather than identifying potential problems and correcting them. Hulett (2001) has identified several factors that contribute to the maturity of project risk management, such as organization culture, data quality, professionalism, benchmarking, use of risk management tools and metrics. Hood and Nawaz (2004) have indicated that globalization and liberalization of markets have led to increased opportunities for multi-national companies. However, there are a number of inherent risks associated with such ventures. Lynch (2002) has identified the risks and made recommendations to mitigate the exposure to unlawful activity of transferring funds anonymously through Internet.

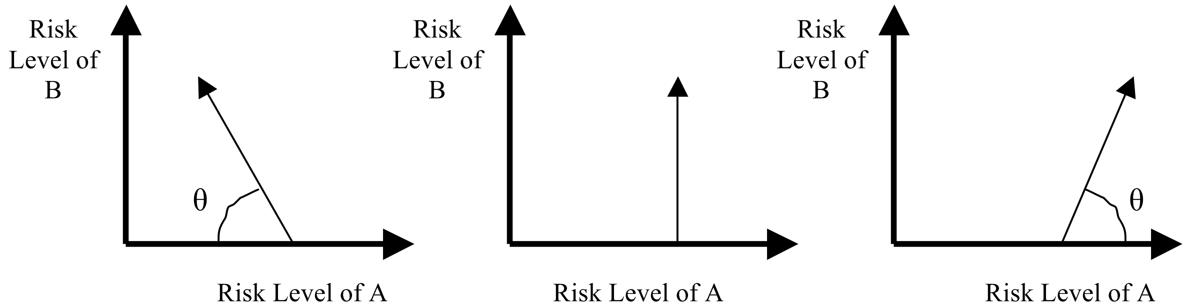
3. MODEL FORMULATION

The most important issue that organizations face when dealing with business operation, project management, political crisis, battlefield management and the likes is the uncertain events hindering the success of the decisions, strategies and operations. The uncertain events are comprised of probability of the occurrence, detect-ability of the events and severity of the consequence, and these factors are either difficult or impossible to precisely predict. As a result, risks are inevitably embedded in the relevant decisions, strategies and operations. Moreover, due to its dynamic and changing nature, risks can be (1) transferred from one area to another along the least resistant process, (2) expanded to the nearby surrounding tangible or intangible areas, (3) mitigated by sifting risks to other areas, (4) deteriorated if appropriate measures are not existent, (5) decreased over period of time. This study intends to develop a model to describe various evolutional phenomena of the risks, and numerically quantify their effects on the decisions, strategies and operations. The authors believe that this is one of the few papers devoted to the quantitative analysis of risk transformation.

3.1 Problem Statement

A decision, strategy or an operation composed of n potential risk events is to be formulated or executed in expectation of achieving the pre-specified outcomes, and each risk is characterized by the risk level which describes the co-joint effects of the risk probability, risk detectability and risk severity. The risk events may be caused by the (1) weak or incompetent personnel or organization, such as shortage of R&D staff and insufficient deployment or training of military forces, (2) low willingness of resistance, such as combat in the battlefield, (3) poor sense of alarm, such as ignorance of certain symptoms, (5) homogeneity of the risk source and the target, such as the bacteria's searching for the victim, (6) inability of making quality plan, and (7) others. It is observed that three categories of risk transformation can occur, and Figure 1 depicts the differences.

Figure 1 illustrates the risk transformation from risk event (location or area) A to risk event (location or area) B, and it can be seen that plot (a) indicates that the risk level of event A decreases, while risk level of event B increases; example of this kind can be found in contract terms and conditions where the risk owner of certain event, such as cost due to fire, is shifted to the supplier from the buyer.



(a) A decreases and B increases (b) B increases (c) A and B increase

Figure 1. Categories of Risk Transformation from A to B

Plot (b) indicates that the risk level of event A remains unchanged, whereas risk level of event B increases; and plot (c) implies that the risk level of both risk events A and B increases, the spread of diseases can be a good example. Additionally, the angle θ in plots (a) and (c) represents the increasing rate of the risk level of event B, and it can be linear or nonlinear depending on the type of the risk, the mode of transformation, and so on. Figure 2 demonstrates an operational environment or situation that is composed of many potential risk events. It is apparent that Figure 2 shows a matrix containing many blocks, and each block indicates either one unit of the organization, one spatial location in the battlefield, or one intangible management area in an organization. Careful examination of Figure 2 reveals that the property of each block is represented by an identification label coupled with various kinds of shell and texture, which imply the current state of the organization, location or management area in terms of the capability of resisting the risk, which can be interpreted as the proper deployment of a risk control system, the quality of risk management processes, or even the risk control equipment and facilities that can prevent risks from endangering the block. The resisting coefficient is set as 0 for non-resistance, and 1 for full resistance. The shell of the block is further divided into four levels according to the thickness, i.e., fragile, thin, thick and concrete. Fragile shell means that the block can't resist the risks, thus, the resisting coefficient is 0; while the concrete shell implies that the specific block has the greatest resistance, thus the resisting coefficient is 1. The thin and thick blocks are set as 0.4 and 0.8 respectively. Moreover, the strength of the block is represented by the content of the block, and is also divided into four types, the empty content, lattice content, course content and dense content. The content of the block portrays the easiness of escalating the risk level of the block. Therefore, the block with empty content means that, once the block shell is broken, the risk level of the block will be most easily increased, whereas the dense block implies that the risk level of the specific block is difficult to be escalated. The strength coefficient is set as 0 for empty content, and 1 for dense content. The strength coefficient for lattice and course are set as 0.4 and 0.8 respectively. Moreover, it is natural that the similarity between two blocks will affect the spread of the risk, for instance, one specific disease can be commonly found in one tribe, race or one kind of animal, such as bird flu. The similarity is obtained by comparing the block content, and the similarity coefficient of 1 is applied to two blocks without similarity, such as (dense, empty), (dense, lattice), (empty, course); 1.5 with semi-similarity, such as (dense, course), (empty, lattice), (lattice, course) and 2 with full similarity, such as (dense, dense), (course, course), (lattice, lattice), and (empty, empty). Additionally, the distance between two blocks is also an important factor in transferring the risk, and it is measured by the length of the straight line between the centers of two blocks. The farther the distance between two blocks, the more difficult it is for the risk transformation to take place. The problem considered by this study is the determination of the risk transformation process when one risk event occurs at certain location, specific business area or management control point of an operational environment. For demonstration purpose, it is assumed that the risk event occurs at block 1, and only the block with the largest risk level at certain point of time will occur.

3.2 Algorithm

Step 1: Investigate the risk level of each block R_i, and identify the block with the largest risk level, where R_i = risk level of block i, and i = 1, 2, …, n. For simplicity, let $R_i \in (1, 2, 3, 4, 5, 6, 7, 8, 9)$, and if two blocks with the same largest risk level, the one with less resisting and strength coefficient will be chosen. Moreover, it is assumed that any block with risk level greater than 9 will be destroyed.

Step 2: Determine the similarity coefficient m_{ij} between the block with the largest risk level and others.

Step 3: Determine the risk resisting coefficient r_j and strength coefficient s_j of each block.

Step 4: Compute the risk flow R_{ij} between block i and block j, where i and j are the source and target of the risk flow respectively, and let $R_{ij} = \{R_i - (1 - r_j - s_j)R_j\} \, m_{ij} / d$, where d is the distance between block i and block j.

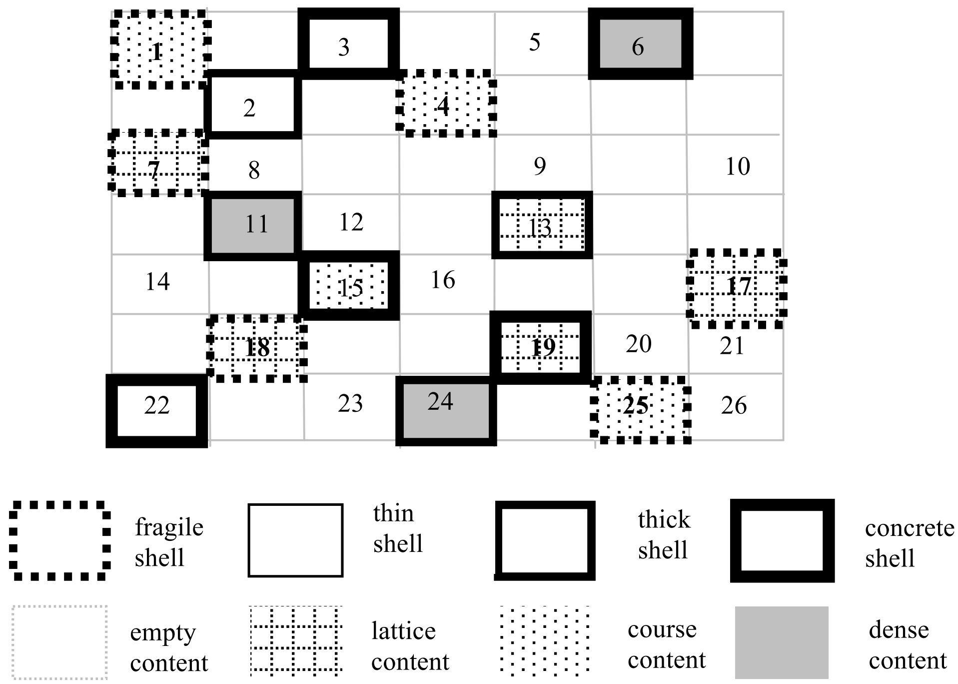


Figure 2. Operational Environment with Potential Risks

Step 5: Determine the target block j to which the risk of source block i will be transferred, i.e.,R_{ij} = Max R_{ij}, where i = 1, 2, …, n, and j = 1, 2, …, n. Finding the maximum risk flow implies that the one with the largest compound risk value will be the next location or area to have the risk event to occur.

Step 6: Compute the risk level of block i and block j after transformation, and it is assumed that category (a) in Figure 1 occurs between two blocks without similarity, and category (c) is utilized for two blocks with full similarity, while category (b) is applied to two blocks with semi-similarity.

(1) $R_i = R_i - R_i \cos \theta$, for blocks without similarity,
(2) $R_i = R_i$, for blocks with semi-similarity,
(3) $R_i = R_i + R_i \cos \theta$, for blocks with full similarity,
and
(1) $R_j = R_j + R_j \sin \theta$, for blocks without similarity,
(2) $R_j = 1.5 \, R_j$, for blocks with semi-similarity,
(3) $R_j = R_j + R_j \sin \theta$, for blocks with full similarity.

Step 7: Stop if no risk event occurs, otherwise go to Step 1. It is assumed that a risk level less than or equal to 5 is viewed as one with no possibility of risk occurrence.

The algorithm proposed in this study will be applied to an example depicted below to demonstrate the suitability and applicability of the risk transformation model. The risk level of each block is shown as indicated in Figure 3; the first number in the bracket is the block number, while the second number represents the current risk level of the block.

4. ILLUSTRATIVE EXAMPLE

The potential risk conditions shown in Figure 3 will be adopted to illustrate the risk behavior of the risk transformation phenomena. It is assumed that the risk event in block 1 has occurred, and it is hoped that the risk transformation mechanism can be predicted in order to deploy adequate risk control measures.

Step 1: Investigate the risk level of each block, and for those blocks with risk level greater than 6, identify the one with the largest risk level, i.e., $R_i = Max\{R_i | R_i \geq 6\}$. It can be seen from Figure 3 that the risk level of block 14 has the largest risk level, i.e., $R_{14} = 8$.

Step 2: Determine the similarity coefficient m_{ij} between block 14 and other blocks, and it can be obtained by comparing the content of the block. Table 1 lists the results.

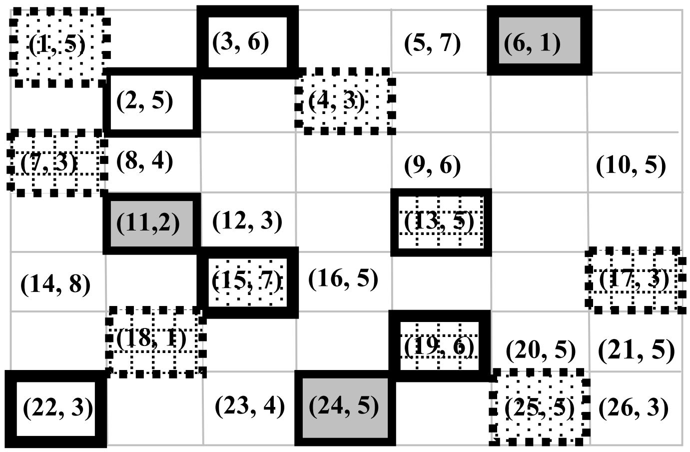


Figure 3. Illustrative Example

Table 1. Similarity Coefficient Between Block 14 and Others

m_{ij}	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
14	1	2	2	1	2	1	1.5	1	1	1	1	2	1.5	1	1	1.5	1.5	1.5	2	2	2	2	1	1	2

Step 3: Determine the risk resisting coefficient r_i and strength coefficient s_i of each block. The risk resisting coefficient is measured by the thickness of the block, whereas the strength coefficient is obtained from the content of the block. Table 2 shows the details.

Table 2. Risk Resisting Coefficient r_i and Strength Coefficient s_i

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
r_i	1	2	2	1	2	1	1.5	1	1	1	1	2	1.5	1	1	1.5	1.5	1.5	2	2	2	2	1	1	2
s_i	0	0.4	1	0	0.4	1	0	0.4	0.4	0.4	0.8	0.4	0.8	1	0.4	0	0	1	0.4	0.4	1	0.4	0.8	0	0.4

Step 4: Compute the risk flow R_{ij} between block 14 and others, where R_{ij} is obtained using the following equation, which considers factors including the resisting coefficient, strength coefficient, similarity coefficient, distance between two blocks, and risk levels. Table 3 shows the computation results, and it can be seen that the largest risk flow of 14 happens to be between block 22 and block 14.

$$R_{ij} = \frac{\{R_i - (1 - r_j - s_j)R_j\} m_{ij}}{d} \quad \dots \quad (1)$$

Table 3. The Risk Flow R_{ij} Between Block 14 and Others

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
R_{14j}	2	3	9	1.9	6.3	1.4	7.1	4.3	2.3	1.6	6.8	10.9	5.3	7.5	3.3	2.3	9	6.2	5.9	4.9	14	9.6	3.8	1.5	3.9

Step 5: Because block 14 and block 22 are 100 % similar to each other, the risk level of blocks 14 and 22 after risk transformation can be computed based on Figure 1 (c). It is assumed that θ is 30 degrees, meaning that risk level of block 14 is increased more than that of block 22 during the risk transformation process. R_{14} and R_{22} can be obtained as below:

Table 4. Risk Transformation of Block 14 and Block 22

	Risk level (Before)	Formula	Risk level (After)
R_{14}	8	$R_{14} + R_{14}$ cos30	14.93
R_{22}	3	$R_{22} + R_{22}$ sin 30	4.5

Therefore, risk levels of all risk events can be listed as in Table 5. It is noted that risk level of block 14 is greater than the value of 9; therefore, block 14 is destroyed and removed from the operational environment due to overloading.

Table 5. Risk Levels R_i of All Risk Events After Transformation

1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17	18	19	20	21	22	23	24	25	26
5	5	6	3	7	1	3	4	6	5	2	3	5	7	5	3	1	6	5	5	4.5	4	5	5	3

Based on the results obtained from Table 5, block 5 and block 15 will be the next potential location or areas to have risk occurring because of the risk level of 7. However, since block 5 has less resisting and strength coefficient than that of block 15, it will be the area that is most likely to have risk occurrence. Consecutively identifying the risk areas, one can obtain Table 6, and it is apparent that risk of eight blocks can occur due to the high level of risk value, i.e., blocks 14, 5, 15, 9, 13, 9, and 19. If risk of block 14 occurs, then block 22 will be the target block to receive the risk flow, and because both blocks are with empty content, Figure 1(c) is applied to the risk escalation computation. As a result, risk level of block 14 reaches 14.93, which is greater than 9, thus, it will be destroyed. The risk level of block 22 is increased from 3 to 4.5. Similarly, if risk of block 5 occurs, then block 3 will be affected, and risk levels of both blocks can be increased to 13.1 and 11.2 respectively. Consequently, both areas will be destroyed. The third risk occurrence can be found at block 15, and the victimized block is block 12. Since both blocks are without similarity, risk of block 15 decreases and risk of block 12 increases. Block 9 is the next location to produce risk occurrence, and the risk flow will go to block 13. Because both blocks exhibit semi-similarity, risk of the source block 9 remains the same, while risk of the target block 13 increases to 7.5. It is interesting to note that block 13 becomes the source block, and block 9 changes to the target block from iteration 4 to 6. In other words, both blocks affect each other during this period; as a result, the risk level of block 13 is significantly escalated, and therefore destroyed at iteration 6. Risk of block 9 reaches 9 from iteration 6, thus, it is surely the most risky event, and if it does occur, block 10 will be affected. Consequently, block 9 is destroyed, and risk of block 10 is changed to 7.5, which becomes the one with the highest risk level. Occurrence of risk event of block 10 leads to destruction of itself, and risk of block 21 becomes 7.5, which will be the largest risk value at this stage. Therefore, if block 21 triggers a risk, block 26 will be impacted and destroyed. Next, block 19 will possess the greatest possibility of risk occurrence and the risk of block 20 will be increased to 7.5, which then induces risk to block 19 again, and finally, block 20 will be destroyed at iteration 12. At iteration 13, block 19 produces another risk to block 24, which causes a series of chain reaction from iterations 14 to 16, and block 23 is destroyed. Interestingly, from iterations 16 to 19, block 22 consecutively influences block 18 without increasing its own risk level; consequently, risk of block 18 is raised from 1.5 to 5. Figure 4 graphically demonstrates the risk transformation process of the illustrative example. The cross sign in the figure indicates that the block is destroyed.

5. DISCUSSION

To make it easy for those who are interested in this study to understand and implement the algorithm proposed in this paper, this section provides brief explanations using real problem situations. Implementation issues and sensitivity of the algorithm are also presented.

5.1 Examples

5.1.1 Bird Flu Transformation

The bird flu is now becoming an international crisis that may globally endanger the life of thousands of people everywhere. The spread of this epidemic is similar to the risk transformation phenomenon in this study. Whether a specific nation will be invaded depends largely on: (a) the distance that a nation is away from the infected country, i.e., the distance *d* in Figure 2; (b) the measures undertaken by the government to prevent the bird flu from intruding that nation, and it can be divided into different levels, for example: 0, 2, 4, 6, 8, where 0 stands for non, and 8 means the best. The measures represent the thickness or resisting coefficient r_j of the block in Figure 2; (c) the public knowledge and awareness of controlling the bird flu, i.e., the strength coefficient s_j of the block in Figure 2. It can also be evaluated using scale with several levels, for example: 1, 3, 5, 7, where 1 represents the least and 7 indicates the best; (d) the similarity of living style, i.e., the sanitary level of the public facilities between the uninfected and the infected countries, i.e., the similarity coefficient m_{ij} between two blocks in Figure 2, for example:1, 5, 9, where 1 indicates no similarity and 9 means full similarity; (e) the risk levels of the source and target countries can be assessed using approaches developed by WHO (World Health Organization), for example: 1, 2, 3, 4, 5, 6, 7, 8, 9, where 1 is the least and 9 is the greatest. Based on the scenario discussed above, the 7x7 operational environment represented as a block matrix in Figure 2 will now become exactly the entire globe. Therefore, international issues such as bird flu and SARS can now be explored and investigated using simulation tools proposed in this study.

The bird flu transformation processes can now be demonstrated using the algorithm proposed in this study.

Table 6. Risk Transformation Process

Iteration	Block i	R_i (before)	Max R_{ij}	R_i (after)	Remark
1	14	$R_{14} = 8$	$R_{i22} = 14$ FS	$R_{14} = 14.93$ $R_{22} = 4.5$	Block 14 destroyed
2	5	$R_5 = 7$	$R_{i3} = 13$ FS	$R_5 = 13.1$ $R_3 = 11.2$	Blocks 5 & 3 destroyed
3	15	$R_{15} = 7$	$R_{i12} = 22.4$ WS	$R_{15} = 0.94$ $R_{12} = 4.5$	
4	9	$R_9 = 6$	$R_{i13} = 13.5$ SS	$R_9 = 6$ $R_{13} = 7.5$	
5	13	$R_{13} = 7.5$	$R_{i19} = 12.6$ SS	$R_{13} = 7.5$ $R_{19} = 9$	
6	19	$R_{19} = 9$	$R_{i13} = 18$ SS	$R_9 = 9$ $R_{13} = 11.25$	Block 13 destroyed
7	9	$R_9 = 9$	$R_{i10} = 8$ FS	$R_9 = 16.9$ $R_{10} = 7.5$	Block 9 destroyed
8	12	$R_{10} = 7.5$	$R_{i21} = 9.7$ FS	$R_{10} = 14.2$ $R_{21} = 7.5$	Block 10 destroyed
9	21	$R_{21} = 7.5$	$R_{i26} = 21.75$ FS	$R_{21} = 14.2$ $R_{26} = 4.5$	Block 21 destroyed
10	19	$R_{19} = 6$	$R_{i20} = 7.5$ SS	$R_{19} = 6$ $R_{20} = 7.5$	
11	20	$R_{20} = 7.5$	$R_{i19} = 20.3$ SS	$R_{20} = 7.5$ $R_{19} = 9$	
12	19	$R_{19} = 9$	$R_{i20} = 18.3$ SS	$R_{19} = 9$ $R_{20} = 11.3$	Block 20 destroyed
13	19	$R_{19} = 9$	$R_{i24} = 15.6$ WS	$R_{19} = 1.2$ $R_{24} = 7.5$	
14	24	$R_{24} = 7.5$	$R_{i23} = 13.8$ WS	$R_{24} = 1$ $R_{23} = 6$	
15	23	$R_{23} = 6$	$R_{i22} = 17.6$ FS	$R_{23} = 11.2$ $R_{22} = 6.75$	Block 23 destroyed
16	22	$R_{22} = 6.75$	$R_{i18} = 13.2$ SS	$R_{22} = 6.75$ $R_{18} = 1.5$	
17	22	$R_{22} = 6.75$	$R_{i18} = 12.7$ SS	$R_{22} = 6.75$ $R_{18} = 2.25$	
18	22	$R_{22} = 6.75$	$R_{i18} = 11.9$ SS	$R_{22} = 6.75$ $R_{18} = 3.38$	
19	22	$R_{22} = 6.75$	$R_{i18} = 10.66$ SS	$R_{22} = 6.75$ $R_{18} = 5$	

FS: Full Similarity; WS: Without Similarity; SS: Semi Similarity

5.1.2 Business Risk Transformation

Another example can be the operation of the enterprises, which are composed of many different functional units, including the product design, product manufacturing, product marketing, product delivery and customer service. Each functional unit can be evaluated based on several critical performance elements, i.e., (a) product design: level of innovation and speed of product development; (b) product manufacturing: conformance rate and production flexibility; (c) product marketing: market share, capability of acquiring new orders; (d) product delivery: on-time delivery and logistic capability; (e) customer service: customer satisfaction. The incapability level of these performance elements can be appraised using scale from 1 to 9, and thus, the higher the scale value, the worse the performance. Additionally, if the incapability level of a performance element is greater than a threshold value, then another element may be affected due to the close linkage to that particular source element.

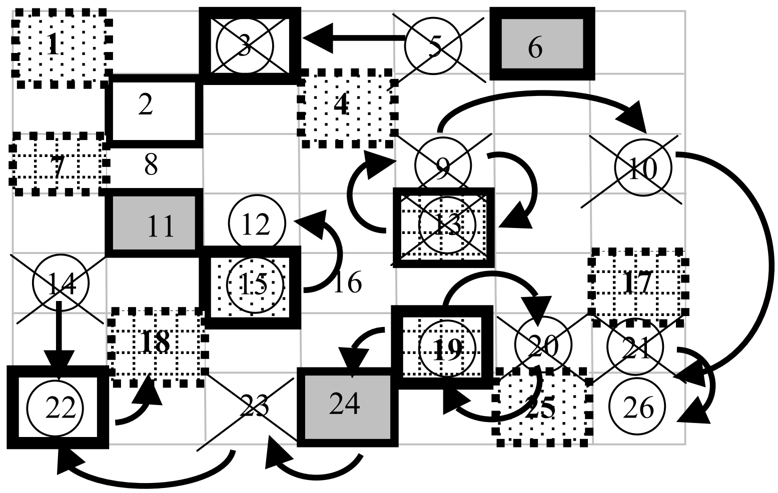


Figure 4. Risk Transformation Process

The above performance elements are interrelated to certain extent in nature; for instance, the level of innovation may affect the market share and customer satisfaction. The speed of product development may impact the market share as well. Moreover, the production flexibility certainly influences the capability of acquiring new orders, and therefore, deteriorates the market share. Similarly, other relationships can be obtained based on the relevancy between two elements. Therefore, the transformation of the business operational risk can be formulated in such a way that (a) the closeness between elements represents the distance in Equation (1), and it can be virtually measured in terms of the tightness along the core processes, for example: 10, 20, 30, 40, 50, 60, where 10 is the nearest and each time an additional 10 is added to the distance that is one step away; (b) the resisting coefficient of the block now becomes the spiritual will of those who are responsible for the element to prevent that element from being affected and downgraded, for example: 2, 4, 6, 8, where 2 means the worst and 8 is the best; (c) the strength of block in Figure 2 can be interpreted as the completeness of the polices and procedures related to that element, for example: 1, 3, 5, 7, where 1 indicates the weakest and 7 represents the strongest; (d) the similarity of elements indicates the similarity of the management framework between two elements, for example: 1, 5, 9, where 1 denotes no similarity and 9 implies full similarity; (e) the incapability levels of elements now replace the risk levels of the blocks, for example: 1, 2, 3, 4, 5, 6, 7, 8, 9, where 1 is the least and 9 is the greatest. Exploring the business operations in such a manner that the chain reactions of the business risk transformation can then be predicted, and therefore, preventive actions can be pre-specified.

5.2 Implementation Issues

To better utilize the proposed algorithm, several issues need to be addressed when applying the model to the real situations. Firstly, the distance parameter between the source and the target can be spatial or virtual distance. The spatial distance can be applied to any problems where the distance can be measured tangibly, while virtual distance is to be applied to situations where the distance becomes spiritual, philosophical or managerial. It is noted that the spatial distance can be evaluated in a relative manner using a proper scale. Moreover, the source and target can be personal, organizational, national or even international subject. Secondly, the risk level can be replaced by any factor that characterizes the negative effects deteriorating the system performance politically, economically or managerially. Thirdly, the resisting coefficient can be interpreted as any mechanism that defends the system from being invaded, and it can be physical, managerial or spiritual undertaking. Fourthly, the similarity coefficient between the source and the target can be measured based on the level of differences in various aspects such as the organizational policy, procedures, regulation; the social system, the cultural background, the standard of value, and the likes. Finally, the strength coefficient may stand for the personal health condition, the spiritual power of a group of people, the unity of an organization, a company or a nation. Besides, the cardinal scale required in the algorithm can be linear, such as 1, 3, 5, 7, or nonlinear scheme, such as 1, 2, 4, 8, to highlight the most risky event. The scale of 0 to 1, 1 to 10, or even 1 to 100 can be used, however, the decision of selecting scale should take into account the computation efforts.

5.3 Sensitivity of Algorithm

To further reveal the appropriateness of the algorithm, a sensitivity analysis is conducted by applying different parameter values to the model. As demonstrated in section 3 and for ease of comparison, the level of the resisting coefficient and strength coefficient are both set again as 1, 0.8, 0.4, 0, and the level of the similarity coefficient is set again as 1, 1.5, 2. By experimenting all possible combinations of the above three coefficients, this section intends to discover that, under what distance and source's risk level, the target risk will be escalated to a risky level of 6 if it's level is only 1 originally. Table 7 depicts the highest risk flow between the source and target with different distances. It can be seen that when the distance between the source and the target is reduced to 2.3, the risk level of the target reaches the risky threshold value of 6. In other words, all surrounding objects within this distance will be inflected by the source under this circumstance. Table 8 demonstrates the highest risk flow between the source and target with different source's risk values, and the corresponding distance within which the target risk level will be increased to a risky threshold of 6. It is obvious that, when the source's risk level increases, even the distance remains as 5, the target risk will be promoted from 1 to 2.8 ~ 4. When the risk level of the source reaches a significant value of 9, the risk of the target can only be changed to 4 if the distance is 5, which is not close enough to become a vital factor. It can also be seen that, when the distance becomes 2.3, 2.65, 3.3 and 3, the target will be seriously infected and cross the risky border if the risk level of the source is 6, 7, 8, and 9 respectively.

Table 7. Sensitivity Analysis with Different *d* Value

No.	R_i	R_j	r_j	s_j	m_{ij}	d	R_{ij}
1	6	1	1	1	2	5	2.8
3			1	1	2	4	3.5
4			1	1	2	3	4.66
5			1	1	2	**2.3**	6.09
6			1	0.8	2	2	6.8
7			1	0.4	2	2	6.4
8			1	0	2	2	6
9			0.8	1	2	2	6.8
10			0.8	0.8	2	2	6.6
11			0.8	0.4	2	2	6.2
12			0.4	1	2	2	6.4
13			0.4	0.8	2	2	6.2

Table 8. Sensitivity Analysis with Different R_i Value

No.	R_i	R_j	r_j	s_j	m_{ij}	d	R_{ij}
1	6	1	1	1	2	5	2.8
						2.3	6.09
2	7	1	1	1	2	5	3.2
						2.65	6.04
3	8	1	1	1	2	5	3.6
						3	6
4	9	1	1	1	2	5	4
						3.3	6.06

6. CONCLUSIONS

Risks commonly reside in individual's personal life, not-for-profit and for-profit enterprises, local and central government, entire nation, and international relationship. Risks can be divided into many different categories, including (1) risks that will endanger the life of human beings, and it is often reduced by better job training, utilization of mechanical instruments like robots and covered by life insurance; (2) risks that will damage the operation of business, and it can be reduced by formulating the right decisions, developing better business plan and action alternatives; (3) risks that will deteriorate the situations of international and national politics, and it is possibly resolved by the negotiation among conflicting parties; (4) other risks that may exist and potentially affect the benefits of people and organizations that are involved. Previous researches did not pay much attention to the mechanism of the risk transformation. This article proposes a model that can reveal how a risk event is transferred to the surrounding spatial, managerial, and even virtual environments. Two real examples are utilized to illustrate the applicability of the model, and the implementation issues and sensitivity of the algorithm are also discussed and analyzed. Being able to discover the risk transformation behaviors, the organizations in industry can pre-specify preventive countermeasures to reduce the negative impact of the possible future risk chain reaction. It is concluded that the proposed model can vividly demonstrate the risk transformation phenomenon that has not been explored by researchers before.

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BIOGRAPHICAL SKETCH

Amy H. I. Lee received the MBA degree from the University of British Columbia, Canada, in 1993 and Ph.D. degree in industrial engineering and management from the National Chiao Tung University, Taiwan in 2004. She is a professor in the Department of Technology Management at Chung Hua University, Taiwan. Her research interests include performance evaluation, supply chain management, production management and project management. She has published a number of papers in various refereed management and engineering journals. She has also served as a reviewer in many international journals.

Chiou-Shuei Wei obtained Ph.D. in technology management from Chung-Hua University in 2009, and he is now an Assistant Professor of the Department of Industrial Management at Lunghwa University of Science and Technology, Taiwan. His research areas include project management, risk management and knowledge management.

Yu-Cheng Lee is a professor in the Department of Technology Management at the Chung Hua University, Taiwan, Republic of China. He received his PhD in Industrial Engineering from National Tsing Hua University in 1992. His major interests include customer satisfaction survey, quality engineering, and quality management. He has published more than one hundred papers in The TQM Journal, Journal of Applied Sciences, Expert Systems With Applications, Service Industries Journal, Total Quality Management and Business Excellence, Information Technology Journal, Computers & Industrial Engineering, Journal of Failure Analysis and Prevention, etc. He was appointed to be the member of Quality Engineering Committee under Chinese Society for Quality in the period of 1989-1993 and Technical Committee of Chinese National Standard since 2004. He was elected to be the chairman of the Committee of Taiwan Customer Satisfaction under Chinese Society for Quality since 2005. He was appointed to be the chairman of Technology Management in the period of 2006-2009 and the dean of college of management since 2009 at the Chung Hua University. He got Outstanding Research Award in 2009 at Chung Hua University.