Modeling the Interconnectivity of Risks in ERM

Neil Allan, School of Management, University of Bath
Yun Yin, School of Management, University of Bath
Neil Cantle, Milliman, ASA, FIA

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Abstract

The Strategic Risk Register System (SRRS) is proposed by the authors as a new approach to modeling and visualizing the interconnectivity of risks in an ERM context. SRRS has been successfully applied in practice, and a case study is deployed to demonstrate the methodology. The process provides a rich understanding of real risk exposure by considering the connectivity and hence the potency of individual risks within the overall ERM system. This then allows for effective monitoring and interventions to be managed more effectively. Our approach differs from contempory risk modelling techniques in that we use linear algebra and graphic theory techniques within a holistic, complex system framework. The approach builds on a three-year research program called STRATrisk, at the University of Bath, which was funded by the U.K. Department of Industry and now Milliman.

1. Introduction

Ulrich Beck (Beck, 1992) argues that the incremental changes in social practices and knowledge in a modern society eventually expose that society and its organizations to complex and significant risks. Furthermore, these risks are created by the interconnectivity of those small, often hidden changes (Giddens, 1990).

Beck highlighted four characterizations of modern risks:

1. Decision-making is increasingly ambiguous and ambivalent, leading to risks being caused by people's ignorance or biased knowledge.
2. Risks are not confined within certain boundaries as before, and, with globalization, risks are more easily distributed.
3. Risks are tending to become immeasurable and incalculable in terms of possibilities and impacts (Campbell and Currie, 2006).
4. Some modern risks, such as ecological hazards, are out of control due to the above statements.

Beck recognized that new approaches need to be sought to explore this interconnected and uncertain world (Liedtke and Courbage, 2002). Indeed, Beck's generalized observations give hints on how to improve risk management practices in modern organizations. For instance, a reflexive approach enables people to be equipped with a relatively open and modifiable strategy to cope with emerging risks (Ward and Chapman, 2003). Secondly, we argue that the interconnectivity of risks should be important to risk management; some have gone further and argue that connectivity is universally important (Walker, 2005). Thirdly, perceptions of information and knowledge are closely interwoven with risks, in particular their identification.

A recent report (Lewin and Allan, 2006), sponsored by the actuarial profession in the United Kingdom, emphasizes the importance of interconnectivity and recommends involving all the key decision makers in the risk management process, rather than delegating responsibility to specialist risk professionals. It is important to ensure managers understand the interconnectivity of risks and thereby avoid ignoring risks that are not in their domain. Only through understanding of their interconnectivity does the decision maker arrive at a holistic view of the risk system (Allan and Davis, 2006). Yet nearly all the most common techniques used in risk assessment and management fail to highlight this important aspect of real world risks.

Soft systems approaches and cognitive mapping have been proposed to aid holistic thinking and the understanding of the interrelatedness of risks (Checkland, 1990). However, these techniques are unfamiliar to most managers and difficult to implement as they are seen as too subjective and qualitative. There is a need to develop techniques that can introduce the complexity of interconnectivity, whilst at the same time remaining familiar and pragmatic. The Strategic Risk Register System (SRRS) proposed in this paper attempts to bridge that gap. The SRRS uses existing risk registers from different parts of the business and applies a *connectivity matrix* to them to highlight those risks of strategic importance, which is measured by what we call the *potency value*. This insight allows managers to prioritize their efforts on managing these "potent" risks, as these are by definition the most highly interconnected and can seed chain reactions within the organization or project.

It is particularly important for managing strategic risks to integrate the risk knowledge across the entire organization as this allows hidden patterns to be identified in the risk system (Lewin and Allan, 2006).

2. The New Approach

In conventional probabilistic approaches, risks are evaluated by their expectations (R), which equal likelihood (L) times impact (I) and are expressed as:

$$R = L \times I \quad (1)$$

On the enterprise level, risks may be rooted in different business domains across the organization. Considering the structural differences, risks can be notated as R_{ij}, where i stands for the *i*-th cluster and j stands for the *j*-th risk factor. The likelihood and impact of risk factors can be encoded as L_{11}, L_{12}…L_{ij}, and I_{11}, I_{12}…I_{ij} respectively. Thus, for each individual risk the expectation can be obtained and allocated into the risk register matrix.

However, this approach is not adequate for understanding and managing the complexity of current enterprise risks. The SRRS distinguishes itself from conventional approaches by integrating the third dimension of risks, the connectivity (C), into the matrix to provide the potency values (P) of the risk.

2.1 Using the Connectivity Matrix

An elicitation process of connectivity is needed to ensure participants adopt a reflective approach in thinking about risks. In most circumstances, connectivity is assessed by considering such parameters as closeness, coupling, hierarchy, sequential order or timeliness. The source of connectivity values can be historical data, as well as expert knowledge and experiences. The connectivity of risks can be derived by scrutinizing risks pair-wisely, and the range of values is assumed to be between the range negligible and extremely high. There are two considerations for selecting a very small value, e.g., 0.05, as the lower end of the scale rather than zero. Firstly, system literature (Marchal, 2003) would suggest that when taking a holistic approach to risk all risks are to some degree connected; secondly, the value of 0.05 is often adopted by statisticians as being of negligible significance (Bewbold 2007). Individual connectivity can be coded as C_{1112}, C_{1113}, ... C_{111n}, C_{1211}, … $C_{mnm(n-1)}$, and allocated into a matrix (2).

$$\text{Connectivity Matrix:} \quad \begin{bmatrix} 1, C_{1112}, C_{1113}, C_{1114}, ...C_{11mn} \\ C_{1211}, 1, C_{1213}, C_{1214}, ...C_{12mn} \\ ..... \\ C_{m(n-1)11}, ...1, C_{m(n-1)}, C_{m(n-1)mn} \\ C_{mn11}, C_{mn12} .....C_{mnm(n-1)}, 1 \end{bmatrix} \quad (2)$$

Then, the potency values of risks can be obtained by integrating the expectations (R) and connectivity (C) values. A simple algorithm can be demonstrated as:

$$P(Potency) = (R_{ij} + R_{qr}) \times C_{ijqr} \quad (3)$$

This equation indicates that the potency of a pair of risks is not only determined by the robustness of connectivity itself, but also by the expectations of risk factors. On the other hand, the influences of this risk pair are adjusted by their interconnections. This approach would suggest that risks could activate others as well as be activated by others, and thus help people capture a more holistic view of risks. The potency values of risks can be located into the matrix as below.

$$\text{Potency Matrix:} \quad \begin{bmatrix} R_{11}, P_{1112}, P_{1113}, P_{1114}, \ldots\ldots\ldots P_{11mn} \\ P_{1211}, R_{12}, P_{1213}, P_{1214}, \ldots\ldots\ldots P_{12mn} \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ P_{m(n-1)11}, \ldots\ldots\ldots R_{m(n-1)}, P_{m(n-1)mn} \\ P_{mn11}, P_{mn12} \ldots\ldots\ldots\ldots P_{mnm(n-1)}, R_{mn} \end{bmatrix} \tag{4}$$

2.2 Interpreting and Visualizing the Potency Matrix

Up to now, the expectations of every single risk and the potency values of every two risks have been located into the potency matrix. From equation (3), it can be identified that every value in the potency matrix is influenced by the values on the diagonal. In other words, each value on the diagonal influences both the column and row in which it locates. Therefore, it is rational to elicit the relative importance of the values on the diagonal by normalizing the matrix. The method we have used for this is similar to one of the normalization methods that are proposed by the Analytical Hierarchy Process (AHP) (Saaty, 1980), which is:

1. Calculate the mean value of a row and locate it into every grid in the row;
2. Calculate the mean value of the column and locate it into every grid in the column;
3. Calculate the weighted value of every grid by averaging column and row values for that grid.

The result of this normalization process can be demonstrated as below:

$$\text{The Normalized Potency Matrix:} \quad \begin{bmatrix} P'_{11}, P'_{1112}, P'_{1113}, \ldots\ldots P'_{11mn} \\ P'_{1211}, P'_{12}, P'_{1213}, \ldots\ldots P'_{12mn} \\ \ldots\ldots\ldots\ldots P'_{ijqr} \ldots\ldots\ldots\ldots \\ P'_{m(n-1)11}, \ldots P'_{m(n-1)}, P'_{m(n-1)mn} \\ P'_{mn11}, P'_{mn12} \ldots\ldots\ldots\ldots, P'_{mn} \end{bmatrix} \tag{5}$$

For any grid in matrix (4), the normalized potency value can be obtained by:

$$P'_{ijqr} = \frac{\sum_{q=1}^{m}\sum_{r=1}^{n} P_{ijqr} + \sum_{i=1}^{m}\sum_{j=1}^{n} P_{ijqr}}{2mn} \tag{6}$$

Values on the diagonal of matrix (4) represent the potency of individual risk factors correspondingly. Furthermore, the normalized potency matrix can be visualized. In graph

theories, every value in an adjacency matrix can indicate the causal or other logic relationships between the two variables, including the connectiveness (Wilson, 1996). Matrix (5) can be transformed into an adjacency matrix by selecting criteria to determine whether or not a potency value is tolerable for the business. Then, risks can be displayed as nodes, and potency values of risk pairs can be viewed as the edges between nodes. We therefore have the ability to represent the interconnectivity of a risk system that allows a clearer understanding of which are the key potent risks and why. Detailed steps of this process are explained in the case example below.

3. Applying the Connectivity Matrix in Practice

It is recognized that the practicality of the proposed methodology might be limited due to the complication in gathering the connectivity values and interpreting outcomes when risk registers become large. Given that a company has four major divisions of risks and each cluster has six risk factors, 552 values would need to be obtained to elicit the connectivity of risk factors. It is therefore necessary to minimize the elicitation process to enhance the applicability. Two solutions are suggested:

1. A group consolidation approach; and
2. An individual assignment approach.

3.1 The Group Consolidation Approach

In business practices, risks are often hierarchically categorized into different sub-systems and levels, aligning with the organization's structure or businesses. This kind of arrangement is based on the assumption that someone's expert knowledge of risks is associated with his or her position in the organization (Ford, 1999). Senior management are likely to have more knowledge of risks on a strategic level, whereas frontline employees may acquire more understanding of specific risks at their operational level. Therefore, the process of elicitation of connectivity can be reduced by consolidating expert knowledge from within expert groups. In practice this can be done by including a connectivity feature on the risk dashboard that individual managers are responsible for updating.

3.1.1 Building the Hierarchical Structure

So we now make the assumption that all risks are connected hierarchically. A detailed risk on the lower level is connected with others via the risk cluster to which it belongs, which is mathematically shown in equation (7) below:

$$\forall C(x,y) = C(X,Y),\ x \in X, y \in Y \tag{7}$$

Essentially a master connectivity matrix is used to record the connectivity values of different risk clusters, and a detailed connectivity matrix to record the connectivity values of detailed risks within a risk cluster. For instance, Risk r_{ij} and Risk r_{qr} come from different risk cluster R_i and R_q. The connectivity value of r_{ij} and r_{qr} equals that of R_i and R_q.

There are four advantages of this approach. Firstly, the efficiency of data collection is enhanced. Risks can be hierarchically connected via clusters, and fewer values are required to construct the connectivity matrix. Secondly, the judgments from management level

participants can be adjusted to carry more weight since they probably have more of an overview of the business. Thirdly, consistency in participants' judgements can be maintained by reducing the number of questions to be asked. Lastly, this approach allows for an open channel of communication both up and down the organization. Now, further evaluations of the potency of individual risks can be conducted using an expanded matrix.

3.1.2 Constructing the Expanded Matrix

If there are m risk clusters and s risk factors in total, there will be m detailed connectivity matrices, which are connected through a master connectivity matrix. Hence, an expanded connectivity matrix with s×s factors can be built to contain those m detailed connectivity matrices. For any connectivity value of risks from different clusters, it equals the corresponding value in the master connectivity matrix and can be expressed:

$$C_{ijqr} = C_{iq} \tag{8}$$

Therefore, the expanded connectivity matrix can be demonstrated as below:

$$\begin{bmatrix} 1 & C_{1112} \ldots & C_{1i} \ldots & & C_{1m} \\ C_{1211} & 1 \ldots & C_{1i} \ldots & & C_{1m} \\ \ldots & & & & \\ C_{i1} \ldots & & 1 & C_{i1i2} \ldots & C_{im} \\ \ldots & & & & \\ C_{i1} \ldots & & & 1 \ldots & C_{iq} \ldots \; C_{im} \\ \ldots & & & & \\ C_{q1} \ldots & & C_{qi} \ldots & & 1 \ldots \; C_{qm} \\ \ldots & & & & \\ C_{m1} \ldots & & & & C_{mnm(n-1)} \quad 1 \end{bmatrix} \tag{9}$$

3.1.3 Calculating the Potency Values

Equations (1) and (3) can be applied to data with the help of expanded connectivity matrix. For a pair of risks from different clusters, the potency value is:

$$P_{ijqr} = (R_{ij} + R_{qr}) \times C_{iq} \tag{10}$$

Equation (6) can be utilized to normalize the potency values, and the values on the diagonal of the expanded matrix characterize the relative importance of individual risks.

3.2 The Individual Assignment Approach

An alternative approach to the group consolidation approach is to simply ask each individual risk owner what he believes could influence his risks and conversely what other risks might be impacted if his risks become enacted. They are encouraged to think of risks outside of their domain, and it is often relatively easy for them to do so if they are familiar with the risk management process generally within the organization. This does allow them to indicate how interconnected and critical they believe their risk to be to the whole organization, and provides some alignment to strategic objectives.

This approach does tend to leave a more sparsely populated connectivity matrix and so a non-response is left rated as negligible (0.05) connectivity. The calculation of the potency matrix follows the same procedure in principle for expanding the matrix as the group consolidation approach described above, so it is not described here.

4. Case Study

This SRRS application case study is to demonstrate that it can be simply applied in practice and then on a more realistic set of data to illustrate the group consolidation approach in more detail. We have used an original risk register that is based on a financial institution's report and Basel II Accord (BIS, 2004).

4.1 The Simplified Risk Register Case

4.1.1 Data Input

The original risk register is simplified into six risk factors and presented in Table 1.

TABLE 1
Original Risk Register

Risk Factor	Impact (I)	Likelihood (L)	Expectation (I×L)
A. Market Risk	1.0	0.1	0.1
B. Operational Risk	0.50	0.40	0.20
C. Credit Risk	0.80	0.50	0.40
D. Legal Risk	0.20	0.10	0.02
E. Pension Risk	0.20	0.10	0.02
F. Reputation Risk	0.80	0.05	0.04

The values of Impact (I) and Likelihood (L) are derived and modified from results of a workshop style survey using a Likert technique with five intervals, or six points, which are encoded as negligible (0.05), very low (0.10), low (0.20), high (0.50), very high (0.80), and extremely high (1.00). As pointed out before, the connectivity of risk can be elicited pair-wisely and evaluated consistently with the same scale. The values are recorded in matrix (11). For example, if interviewees consider "the market risk exerts great influence over the operations of the business and will lead to greater operational risks," the connectivity of the two risk factors can be recoded as $C_{AB}=1$ and it will go to row 1, column 2. All values of connectivity from a workshop are demonstrated in matrix (11).

$$\text{Connectivity Matrix:} \quad \begin{bmatrix} & A & B & C & D & E & F \\ A & 1 & 1 & 0.8 & 0.8 & 0.2 & 0.8 \\ B & 0.5 & 1 & 0.5 & 0.8 & 0.5 & 1 \\ C & 0.8 & 0.8 & 1 & 0.8 & 0.5 & 0.2 \\ D & 0.2 & 0.2 & 0.5 & 1 & 0.05 & 0.8 \\ E & 0.05 & 0.2 & 0.1 & 0.1 & 1 & 0.2 \\ F & 0.5 & 0.05 & 0.2 & 0.05 & 0.05 & 1 \end{bmatrix} \tag{11}$$

4.1.2 Applying the Matrix Analysis

The potency values of risk pairs can be calculated following equations (1) and (3), and the results are demonstrated in the following matrix.

$$\text{Potency Matrix:} \quad \begin{bmatrix} & A & B & C & D & E & F \\ A & 0.1000 & 0.3000 & 0.4000 & 0.0960 & 0.0240 & 0.1120 \\ B & 0.1500 & 0.2000 & 0.3000 & 0.1760 & 0.1100 & 0.2400 \\ C & 0.4000 & 0.4800 & 0.4000 & 0.3360 & 0.2100 & 0.0880 \\ D & 0.0240 & 0.0440 & 0.2100 & 0.0200 & 0.0020 & 0.0480 \\ E & 0.0060 & 0.0440 & 0.0420 & 0.0040 & 0.0200 & 0.0120 \\ F & 0.0700 & 0.0120 & 0.0880 & 0.0030 & 0.0030 & 0.0400 \end{bmatrix} \tag{12}$$

Similarly, because each value in the matrix is affected by the value on the diagonal, the matrix can be normalized. Matrix (12) contains the final results, and the potency values for individual risks are highlighted.

$$\text{Normalized Potency Matrix:} \quad \begin{bmatrix} & A & B & C & D & E & F \\ A & \mathbf{0.1485} & 0.1760 & 0.2060 & 0.1389 & 0.1168 & 0.1310 \\ B & 0.1605 & \mathbf{0.1880} & 0.2180 & 0.1509 & 0.1288 & 0.1430 \\ C & 0.2220 & 0.2495 & \mathbf{0.2795} & 0.2124 & 0.1903 & 0.2045 \\ D & 0.0915 & 0.1190 & 0.1490 & \mathbf{0.0819} & 0.0598 & 0.0740 \\ E & 0.0732 & 0.1007 & 0.1307 & 0.0636 & \mathbf{0.0414} & 0.0557 \\ F & 0.0805 & 0.1080 & 0.1380 & 0.0709 & 0.0488 & \mathbf{0.0630} \end{bmatrix} \tag{13}$$

4.1.3 Data Interpreting and Visualizing

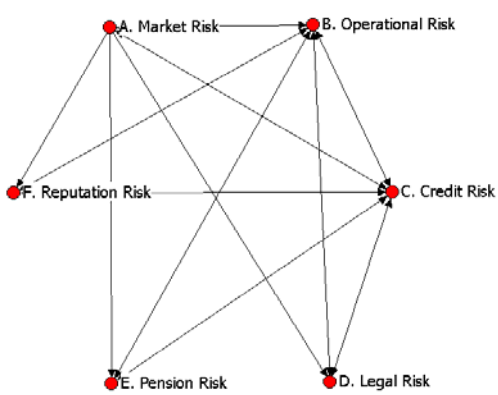
In the original risk register, risks are analyzed as a set of isolated factors. In some circumstances, the importance of risk factors cannot be distinguished, i.e., D and E. Bringing the connectivity of risk factors into consideration, a greater understanding of the risks is presented. Values on the diagonal of matrix (13) indicate the relative importance of the risk factors, which can be utilized to assist decision makers to focus on the risks that may seed the system. In this case, risk factor D, the legal risk, has a greater influence value than E, the pension risk, and therefore D needs more attention from key decision makers. In reality, from the survey participants' viewpoints, the legal issues are more risky than pension issues.

Furthermore, an adjacency matrix can help people capture a direct impression of the result. The first step is to select a potency value, which may indicate the tolerance of risks. Then, the adjacency matrix can be obtained by comparing values in the normalized potency matrix (13) with the pre-selected potency value. If a value in matrix (13) is greater than the pre-selected potency value, it can represent an edge, which connects a risk pair, and the value can be recorded as 1 in the adjacency matrix. Otherwise, the value in the adjacency matrix is 0 correspondingly. It should be noted that the diagonal of the adjacency matrix is intentionally left blank since the self-connectiveness is beyond the scope of this paper. For instance, if the potency value is selected as 0.15, the adjacency matrix can be obtained as:

$$\text{Adjacency Matrix: } \begin{bmatrix} 0 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 \end{bmatrix} \tag{14}$$

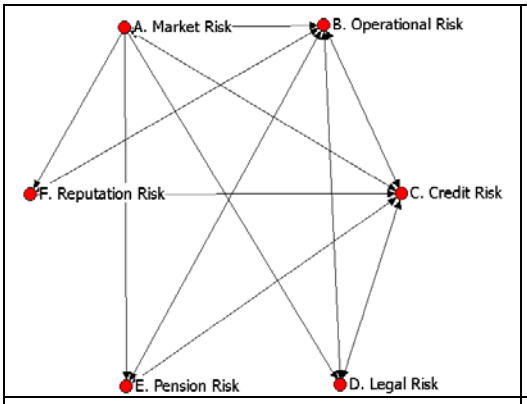
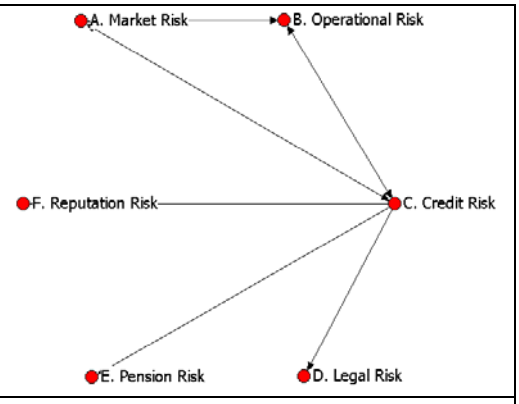
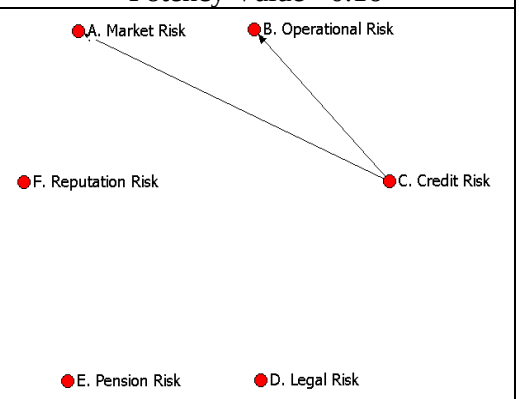
Thus, a risk map can be obtained as:

FIGURE 1
Risk Map at Potency Value=0.15



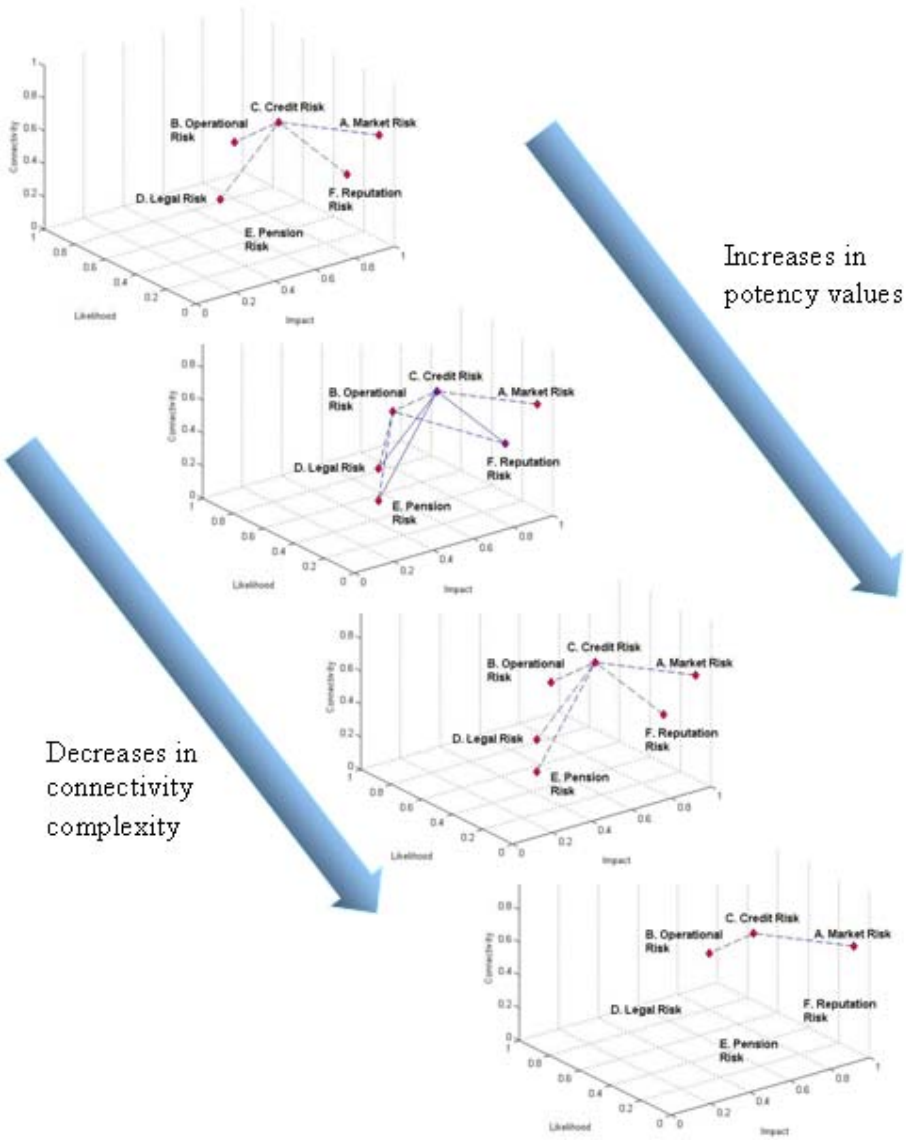
With the change of pre-selected potency value, a series of risk maps can be drawn. The following table demonstrates how the risk factors connect four different scenarios.

TABLE 2
Risk Maps

	
Potency Value=0.1	Potency Value =0.16
	
Potency Value =0.2	Potency Value =0.22

Furthermore, risk maps in Table 2 can be further transformed into 3-D maps as follows:

TABLE 3
3-D Visualization of Risk Maps



4.2 The Group Consolidation Approach

In practice, most of the institutions have a large number of risks recorded and monitored. The methods introduced above may be limited because it seems impractical to ask all participants to elicit hundreds of risk connections. Therefore, it is reasonable to follow the group allocation approach that is introduced in previous sections. A more realistic risk register is shown as below in Table 4:

TABLE 4
Detailed Risk Register

Risk Factor	Impact (I)	Likelihood (L)	Expectation (I×L)
A. Market Risk	1	0.1	0.1
A1. Equity Risk	1	0.5	0.50
A2. Interests Risk	0.8	0.5	0.40
A3. Currency Risk	0.5	0.8	0.40
A4. Commodity Risk	0.8	0.8	0.64
B. Operational Risk	0.5	0.4	0.2
B1. Operation System Risk	0.8	0.1	0.08
B2. Process Risk	0.5	0.5	0.25
B3. HR Risk	0.2	0.8	0.16
B4. Fraud	0.2	0.8	0.16
B5. Damage to Property	0.5	0.1	0.05
C. Credit Risk	0.8	0.5	0.40
D. Legal Risk	0.2	0.1	0.02
E. Pension Risk	0.2	0.1	0.02
F. Reputation Risk	0.8	0.05	0.04

It can be observed that some risks have been further decomposed to detailed factors, compared with the original risk register in Table 1. In other words, the structure of risks is redefined so that there are two layers of risks. The risks in the higher hierarchy are notated as A, B, C, D, E and F, while the second level risks are labelled as A1, A2, etc.

In this case, the management level experts will provide knowledge about how risk clusters are connected on a strategic level while the frontier level experts will provide judgments of detailed risks. The master connectivity matrix of risk clusters is assumed to be the same as that in Case I.

$$\text{Master Connectivity Matrix: } \begin{bmatrix} & A & B & C & D & E & F \\ A & 1 & 1 & 0.8 & 0.8 & 0.2 & 0.8 \\ B & 0.5 & 1 & 0.5 & 0.8 & 0.5 & 1 \\ C & 0.8 & 0.8 & 1 & 0.8 & 0.5 & 0.2 \\ D & 0.2 & 0.2 & 0.5 & 1 & 0.05 & 0.8 \\ E & 0.05 & 0.2 & 0.1 & 0.1 & 1 & 0.2 \\ F & 0.5 & 0.05 & 0.2 & 0.05 & 0.05 & 1 \end{bmatrix} \tag{11}$$

The detailed connectivity matrices of risks in every risk cluster are surveyed as below:

$$\text{Detailed Connectivity Matrix in A: } \begin{bmatrix} & A1 & A2 & A3 & A4 \\ A1 & 1 & 0.1 & 0.1 & 0.1 \\ A2 & 0.8 & 1 & 0.8 & 0.8 \\ A3 & 0.2 & 0.5 & 1 & 0.8 \\ A4 & 0.5 & 0.2 & 0.2 & 1 \end{bmatrix} \tag{15}$$

$$\text{Detailed Connectivity Matrix in B: } \begin{bmatrix} & B1 & B2 & B3 & B4 & B5 \\ B1 & 1 & 0.8 & 0.2 & 0.5 & 0.1 \\ B2 & 0.8 & 1 & 0.5 & 0.8 & 0.1 \\ B3 & 0.8 & 0.1 & 1 & 0.2 & 0.05 \\ B4 & 0.1 & 0.2 & 0.1 & 1 & 0.05 \\ B5 & 0.1 & 0.1 & 0.1 & 0.05 & 1 \end{bmatrix} \tag{16}$$

Then, all factors from different layers of the risk hierarchy can be allocated into the following expanded connectivity matrix:

$$\begin{bmatrix} 1.00 & 0.10 & 0.10 & 0.10 & 1.00 & 1.00 & 1.00 & 1.00 & 1.00 & 0.80 & 0.80 & 0.20 & 0.80 \\ 0.80 & 1.00 & 0.80 & 0.80 & 1.00 & 1.00 & 1.00 & 1.00 & 1.00 & 0.80 & 0.80 & 0.20 & 0.80 \\ 0.20 & 0.50 & 1.00 & 0.80 & 1.00 & 1.00 & 1.00 & 1.00 & 1.00 & 0.80 & 0.80 & 0.20 & 0.80 \\ 0.50 & 0.20 & 0.20 & 1.00 & 1.00 & 1.00 & 1.00 & 1.00 & 1.00 & 0.80 & 0.80 & 0.20 & 0.80 \\ 0.50 & 0.50 & 0.50 & 0.50 & 1.00 & 0.80 & 0.20 & 0.50 & 0.10 & 0.50 & 0.80 & 0.50 & 1.00 \\ 0.50 & 0.50 & 0.50 & 0.50 & 0.80 & 1.00 & 0.50 & 0.80 & 0.10 & 0.50 & 0.80 & 0.50 & 1.00 \\ 0.50 & 0.50 & 0.50 & 0.50 & 0.80 & 0.10 & 1.00 & 0.20 & 0.05 & 0.50 & 0.80 & 0.50 & 1.00 \\ 0.50 & 0.50 & 0.50 & 0.50 & 0.10 & 0.20 & 0.10 & 1.00 & 0.05 & 0.50 & 0.80 & 0.50 & 1.00 \\ 0.50 & 0.50 & 0.50 & 0.50 & 0.10 & 0.10 & 0.10 & 0.05 & 1.00 & 0.50 & 0.80 & 0.50 & 1.00 \\ 0.80 & 0.80 & 0.80 & 0.80 & 0.80 & 0.80 & 0.80 & 0.80 & 0.80 & 1.00 & 0.80 & 0.50 & 0.20 \\ 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.50 & 1.00 & 0.05 & 0.80 \\ 0.05 & 0.05 & 0.05 & 0.05 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.10 & 0.10 & 1.00 & 0.20 \\ 0.50 & 0.50 & 0.50 & 0.50 & 0.05 & 0.05 & 0.05 & 0.05 & 0.05 & 0.20 & 0.05 & 0.05 & 1.00 \end{bmatrix} \tag{17}$$

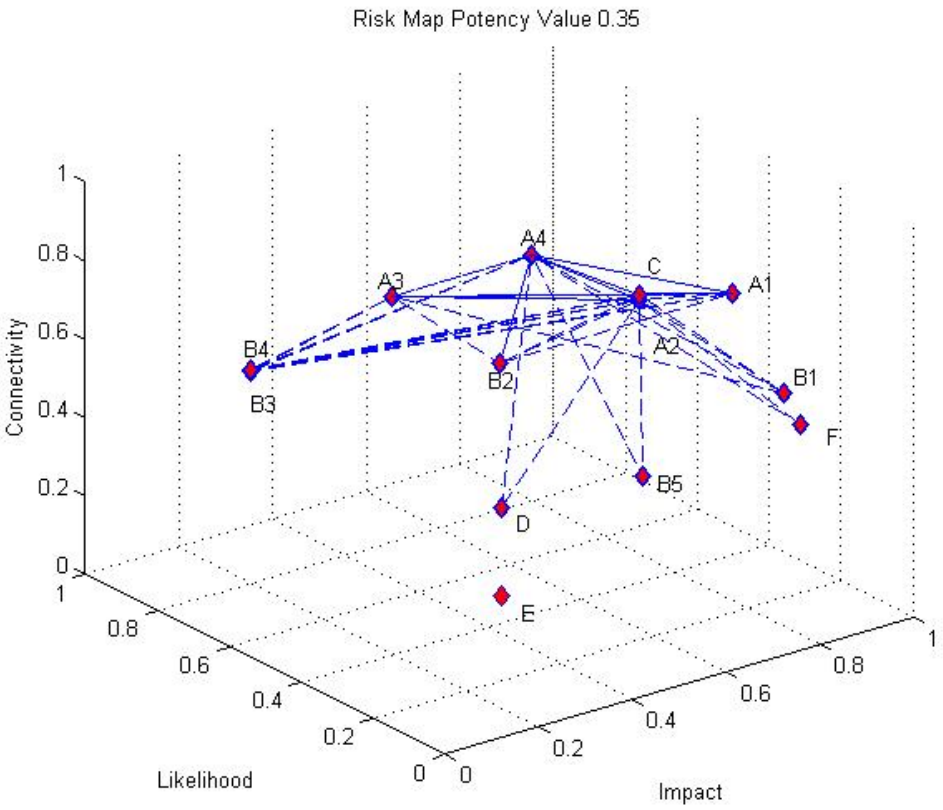
Following equation (6), an expanded potency matrix can be obtained as below:

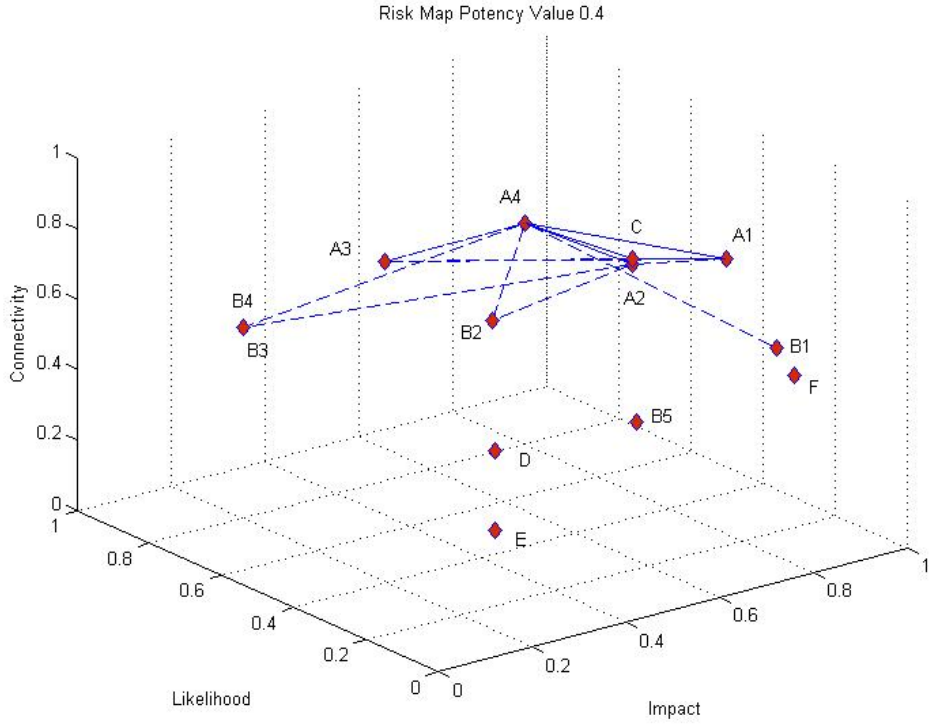
$$\begin{bmatrix}
0.5000 & 0.0900 & 0.0900 & 0.1140 & 0.5800 & 0.7500 & 0.6600 & 0.6600 & 0.5500 & 0.7200 & 0.4160 & 0.1040 & 0.4320 \\
0.7200 & 0.4000 & 0.6400 & 0.8320 & 0.4800 & 0.6500 & 0.5600 & 0.5600 & 0.4500 & 0.6400 & 0.3360 & 0.0840 & 0.3520 \\
0.1800 & 0.4000 & 0.4000 & 0.8320 & 0.4800 & 0.6500 & 0.5600 & 0.5600 & 0.4500 & 0.6400 & 0.3360 & 0.0840 & 0.3520 \\
0.5700 & 0.2080 & 0.2080 & 0.6400 & 0.7200 & 0.8900 & 0.8000 & 0.8000 & 0.6900 & 0.8320 & 0.5280 & 0.1320 & 0.5440 \\
0.2900 & 0.2400 & 0.2400 & 0.3600 & 0.0800 & 0.2640 & 0.0480 & 0.1200 & 0.0130 & 0.2400 & 0.0800 & 0.0500 & 0.1200 \\
0.3750 & 0.3250 & 0.3250 & 0.4450 & 0.2640 & 0.2500 & 0.2050 & 0.3280 & 0.0300 & 0.3250 & 0.2160 & 0.1350 & 0.2900 \\
0.3300 & 0.2800 & 0.2800 & 0.4000 & 0.1920 & 0.0410 & 0.1600 & 0.0640 & 0.0105 & 0.2800 & 0.1440 & 0.0900 & 0.2000 \\
0.3300 & 0.2800 & 0.2800 & 0.4000 & 0.0240 & 0.0820 & 0.0320 & 0.1600 & 0.0105 & 0.2800 & 0.1440 & 0.0900 & 0.2000 \\
0.2750 & 0.2250 & 0.2250 & 0.3450 & 0.0130 & 0.0300 & 0.0210 & 0.0105 & 0.0500 & 0.2250 & 0.0560 & 0.0350 & 0.0900 \\
0.7200 & 0.6400 & 0.6400 & 0.8320 & 0.3840 & 0.5200 & 0.4480 & 0.4480 & 0.3600 & 0.4000 & 0.3360 & 0.2100 & 0.0880 \\
0.1040 & 0.0840 & 0.0840 & 0.1320 & 0.0200 & 0.0540 & 0.0360 & 0.0360 & 0.0140 & 0.2100 & 0.0200 & 0.0020 & 0.0480 \\
0.0260 & 0.0210 & 0.0210 & 0.0330 & 0.0200 & 0.0540 & 0.0360 & 0.0360 & 0.0140 & 0.0420 & 0.0040 & 0.0200 & 0.0120 \\
0.2700 & 0.2200 & 0.2200 & 0.3400 & 0.0060 & 0.0145 & 0.0100 & 0.0100 & 0.0045 & 0.0880 & 0.0030 & 0.0030 & 0.0400
\end{bmatrix} \quad (18)$$

Therefore, the final result of normalized potency values can be obtained as below:

$$\begin{bmatrix}
 & \text{A1} & \text{A2} & \text{A3} & \text{A4} & \text{B1} & \text{B2} & \text{B3} & \text{B4} & \text{B5} & \text{C} & \text{D} & \text{E} & \text{F} \\
\text{A1} & \mathbf{0.3983} & 0.3492 & 0.3584 & 0.4373 & 0.3434 & 0.3814 & 0.3555 & 0.3638 & 0.3197 & 0.4072 & 0.3187 & 0.2579 & 0.3244 \\
\text{A2} & 0.4382 & \mathbf{0.3891} & 0.3983 & 0.4773 & 0.3833 & 0.4213 & 0.3954 & 0.4037 & 0.3596 & 0.4472 & 0.3586 & 0.2978 & 0.3643 \\
\text{A3} & 0.4082 & 0.3591 & \mathbf{0.3683} & 0.4473 & 0.3533 & 0.3913 & 0.3654 & 0.3737 & 0.3296 & 0.4172 & 0.3286 & 0.2678 & 0.3343 \\
\text{A4} & 0.4712 & 0.4221 & 0.4313 & \mathbf{0.5103} & 0.4163 & 0.4543 & 0.4284 & 0.4367 & 0.3926 & 0.4802 & 0.3916 & 0.3308 & 0.3973 \\
\text{B1} & 0.2629 & 0.2138 & 0.2230 & 0.3019 & \mathbf{0.2080} & 0.2459 & 0.2200 & 0.2284 & 0.1843 & 0.2718 & 0.1832 & 0.1225 & 0.1890 \\
\text{B2} & 0.3155 & 0.2664 & 0.2756 & 0.3545 & 0.2606 & \mathbf{0.2986} & 0.2727 & 0.2810 & 0.2369 & 0.3244 & 0.2358 & 0.1751 & 0.2416 \\
\text{B3} & 0.2754 & 0.2263 & 0.2356 & 0.3145 & 0.2206 & 0.2585 & \mathbf{0.2326} & 0.2409 & 0.1968 & 0.2844 & 0.1958 & 0.1350 & 0.2015 \\
\text{B4} & 0.2693 & 0.2202 & 0.2294 & 0.3084 & 0.2144 & 0.2524 & 0.2265 & \mathbf{0.2348} & 0.1907 & 0.2783 & 0.1897 & 0.1289 & 0.1954 \\
\text{B5} & 0.2419 & 0.1928 & 0.2021 & 0.2810 & 0.1871 & 0.2250 & 0.1991 & 0.2074 & \mathbf{0.1633} & 0.2509 & 0.1623 & 0.1015 & 0.1680 \\
\text{C} & 0.4122 & 0.3630 & 0.3723 & 0.4512 & 0.3573 & 0.3952 & 0.3693 & 0.3776 & 0.3336 & \mathbf{0.4211} & 0.3325 & 0.2717 & 0.3382 \\
\text{D} & 0.2128 & 0.1637 & 0.1730 & 0.2519 & 0.1580 & 0.1959 & 0.1700 & 0.1783 & 0.1342 & 0.2218 & \mathbf{0.1332} & 0.0724 & 0.1389 \\
\text{E} & 0.1934 & 0.1443 & 0.1535 & 0.2325 & 0.1385 & 0.1765 & 0.1506 & 0.1589 & 0.1148 & 0.2023 & 0.1138 & \mathbf{0.0530} & 0.1195 \\
\text{F} & 0.2277 & 0.1785 & 0.1878 & 0.2667 & 0.1728 & 0.2107 & 0.1848 & 0.1931 & 0.1491 & 0.2366 & 0.1480 & 0.0872 & \mathbf{0.1537}
\end{bmatrix} \quad (19)$$

The potency values of individual risk factors are highlighted in matrix (19). When a potency value is selected, the result could be transformed into an adjacency matrix and visualized as that in the previous section. However, the added number of risks is better represented in a three-dimensional graph. This has the added benefit of identifying new risk clusters of risks with consideration of connectivity, likelihood and impact. This, coupled with the potency plots, gains valuable insights into the overall risk system. Two plots are shown on the following page.


Risk Map Potency Value 0.35
Connectivity
Likelihood
Impact
A4
C
A3
A1
B4
A2
B2
B1
B3
F
B5
D
E


Risk Map Potency Value 0.4
Connectivity
Likelihood
Impact
A4
C
A3
A1
B4
A2
B2
B1
B3
F
B5
D
E

5. Implications

There are several important implications that emerge from the SRRS approach:

- The potency of risks is represented as the values on the diagonal of the normalized matrices. Through potency measures risks can be understood more holistically, which is particularly important for complex organizations.
- The key risk linkages are recognized using the risk maps. The more connected, the more important they are.
- Some of the risk factors may not be directly connected at a certain potency value, but when showed in adjacency matrices or graphs, their potential connection can be identified.
- The potential interaction between new risks and current risks is not well treated using conventional techniques but SRRS is useful in making this explicit.
- Researchers (Thompson, 2002; Allan and Davis, 2006) point out that effective communications of risk issues are essential to achieving effective risk strategies. The "risk map" shows the necessary path of communication that will help mitigate the propagation of risks.

6. Conclusion and Further Studies

This paper introduces the concept of complexity in risk systems and a method of managing that complexity by investigating the interconnectedness of risks. The connectivity has been proposed as the third dimension of risk. A Strategic Risk Register System (SRRS) is proposed to provide a more systemic and holistic analysis of risk. A detailed case study has been provided to demonstrate the approach.

However, as an ongoing research project, several areas could be further explored:

- A collaborative environment needs to be established to ensure effective usability and successful deployment of the SRRS approach.
- Many decision-making studies (Goodwin, 2004), point out the inaccuracies in eliciting participants' views. New approaches to effectually elicit connections on a regular basis should be investigated. However, this is an issue with any risk process and to some extent the mapping at least seeks to understand the interrelationship between risks rather than relying on single event measures.
- Since the business environment becomes more turbulent, emerging risks might appear as new risks or new patterns of current risks. Looking for patterns and changing shapes may give some clue to spot emerging risks.

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