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THE EVIDENTIAL REASONING APPROACH FOR RISK MANAGEMENT IN LARGE ENTERPRISES

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Enterprise Risk Management (ERM) is a framework that is used by large organizations to manage risk as a whole. The key difference between ERM and traditional risk management is that in the latter risks are managed individually, whilst the former requires the aggregation of risks to facilitate risk management. However, current methods for risk aggregation have various limitations when applied under the context of ERM, such as the requirement for accurate and complete information about risk factors, the inability to handle different kinds of uncertainty which are inevitable during the risk aggregation process, and so on. Due to its unique advantages in accommodating different forms of both complete and incomplete information and handling different kinds of uncertainty, the Evidential Reasoning (ER) approach together with its implementation entitled Intelligent Decision System (IDS) is introduced in this paper for risk aggregation in ERM to overcome the limitations and to provide a comprehensive analysis for risk management based on the aggregation result. To demonstrate the applicability of the ER approach and IDS in ERM, a case study is analyzed in detail regarding risk aggregation and risk management for a health care organization in North England.

Keywords: Enterprise risk management; evidential reasoning; health organization; intelligent decision system.

1. Introduction

Large enterprises operating under complex environments with multi-level organizational structures have to deal with various types of risks that are often interconnected. If risks are treated separately in isolation of each other, it is difficult to get a general view on the overall risk of a certain department in an enterprise or the enterprise itself, which makes it inconvenient for senior managers to conduct risk management for the enterprise. For example, in a health care organization in North England, around 60 key risk indicators are identified from its daily operations per month, and each risk is individually measured by a numeric value referred to as risk score, generated by the product of the likelihood of occurrence of an incident and its consequence, both of which are measured by a numerical value scaled from 1 to 5. However, representing risk in this way cannot capture different kinds of uncertainty inherent in risk assessment for a large enterprise operating in a complex environment. In addition, as revealed by the example, currently, risk management in large enterprises does not usually take into account risks throughout the enterprise as a whole, although it is essential to aggregate key risk indicators to generate an overview of risk in different levels within an enterprise to support risk-related decision making by senior management teams. Therefore, a comprehensive risk management methodology is needed to measure, aggregate, and manage risk in a consistent and systematic way.

Enterprise Risk Management (ERM) is a systematic and integrated approach to manage risks within a large enterprise.[1] The most important difference between ERM and traditional risk management in enterprises lies in the fact that ERM considers risk portfolio, instead of individual risks.[1] In other words, all kinds of risks throughout the entire enterprise can be considered as a whole in ERM.[2] In current research on ERM, individual risks are usually described by various kinds of probability distributions with estimated parameters,[1,3–7] which requires the calibration of accurate parameters in probability distributions according to complete information of individual risks. In addition, it is well-accepted in ERM that risk portfolio is not a simple sum of individual risks, correspondently, some statistical methods, such as correlation matrix and correlation coefficients among pairs of risks,[3] variance-covariance matrix,[8] regression models,[9] etc. are applied for risk aggregation. However, the application of statistical methods regarding interaction among risks also requires plenty of complete and quantitative information. Under the context of ERM, the requirements mentioned above lead to the following limitations: (1) For a large enterprise operating in a complex environment, it is possible that risk information, especially information for newly-identified risk, may not be fully available or fully understood,[1,6] however, conventional probability distributions and statistical methods currently applied in ERM are incapable of dealing with such uncertainty caused by incompleteness and vagueness. (2) Some risks, e.g., operational risks and strategic risks, in large enterprises are intangible and not easily quantifiable, thus it is difficult to determine their probability distributions[1] and it is impractical to identify the correlation matrix among risk factors.

Different from the methods based on probability distributions and statistical models, the Evidential Reasoning (ER) approach, which is a tool for information aggregation in Multi Criteria Decision Making (MCDM) problems under uncertainty, can provide a framework to accommodate different forms of information, can handle different kinds of uncertainty in the information aggregation process, and thus can generate an overview of risk in an enterprise operating in complex environments according to different individual risk factors. Therefore, to overcome the limitations of current methods for risk aggregation in ERM and to facilitate risk management in large enterprises, in this paper, we intend to: (1) develop a model based on the ER approach to aggregate individual risks in large enterprises, and (2) provide comprehensive analysis according to the aggregation result to assist risk management in large enterprises with the application of the Intelligent Decision System (IDS), a software for the implementation of the ER approach.

The paper is organized as follows. In Sec. 2, the ER approach is briefly reviewed and the rationality of applying ER in ERM is analyzed. A case study is conducted in Sec. 3 to demonstrate the application of ER together with IDS in ERM. The paper is concluded in Sec. 4.

2. Using Evidential Reasoning approach to assess Enterprise Risk

2.1. *Evidential reasoning approach*

Based on Dempster-Shafer (D-S) theory, which was developed around 1970s,[10–12] the ER approach[13,14] was proposed to aggregate information with different kinds of uncertainty in MCDM problems.

Specifically, in an MCDM problem, suppose an alternative A is described by L criteria, with the ith criterion being represented by $e_i\left(i \in \{1,2,...,L\}\right)$, which can be described by a set of mutually exclusive and collectively exhaustive grades $H=\{H_1,H_2,...,H_N\}$. A weight ω_i is assigned to e_i according to its relative importance among $e_1,e_2,...,e_L$. An assessment of e_i can be described by a belief distribution: $S(e_i)=\{(H_n,\beta_{n,i}),n=1,2,...,N\}$, in which, $\beta_{n,i}$ represents the degree of belief to which grade H_n is used to assess e_i, with $\beta_{n,i}\geq 0$ and $\sum_{n=1}^{N}\beta_{n,i}\leq 1$. $S(e_i)$ is complete if $\sum_{n=1}^{N}\beta_{n,i}=1$ and it is incomplete if $\sum_{n=1}^{N}\beta_{n,i}<1$.

The degrees of belief can be transformed into basic probability masses using the following equations[14]:

$$m_{n,i}=\omega_i\beta_{n,i} \tag{1}$$

$$m_{H,i}=1-\sum_{n=1}^{N}m_{n,i}=1-\omega_i\sum_{n=1}^{N}\beta_{n,i} \tag{2}$$

$$\bar{m}_{H,i}=1-\omega_i \tag{3}$$

$$\tilde{m}_{H,i}=\omega_i\left(1-\sum_{n=1}^{N}\beta_{n,i}\right) \tag{4}$$

With $m_{H,i}=\bar{m}_{H,i}+\tilde{m}_{H,i}$ and $\sum_{i=1}^{L}\omega_i=1$.

In (1)–(4), $n\in\{1,2,...,N\}$, $i\in\{1,2,...,L\}$, $m_{n,i}$ represents the basic probability mass assigned to H_n, $m_{H,i}$ represents the basic probability mass assigned to the whole set H and it is divided into 2 parts: $\bar{m}_{H,i}$ and $\tilde{m}_{H,i}$, where $\bar{m}_{H,i}$ is caused by the relative importance of e_i while $\tilde{m}_{H,i}$ is caused by the incompleteness of information regarding e_i.

Based on (1)–(4), the analytical ER algorithm is given as follows[15]:

$$m_n=k\left[\prod_{i=1}^{L}\left(m_{n,i}+\bar{m}_{H,i}+\tilde{m}_{H,i}\right)-\prod_{i=1}^{L}\left(\bar{m}_{H,i}+\tilde{m}_{H,i}\right)\right] \tag{5}$$

$$\tilde{m}_H = k\left[\prod_{i=1}^{L}\left(\bar{m}_{H,i} + \tilde{m}_{H,i}\right) - \prod_{i=1}^{L}\bar{m}_{H,i}\right] \tag{6}$$

$$\bar{m}_H = k\left[\prod_{i=1}^{L}\bar{m}_{H,i}\right] \tag{7}$$

$$k = \left[\sum_{n=1}^{N}\prod_{i=1}^{L}\left(m_{n,i} + \bar{m}_{H,i} + \tilde{m}_{H,i}\right) - (N-1)\prod_{i=1}^{L}\left(\bar{m}_{H,i} + \tilde{m}_{H,i}\right)\right]^{-1} \tag{8}$$

$$\beta_n = \frac{m_n}{1-\bar{m}_H} \tag{9}$$

$$\beta_H = \frac{\tilde{m}_H}{1-\bar{m}_H} \tag{10}$$

In the above equations, β_n and β_H are the degrees to which the alternative A can be described by H_n and H respectively, and β_H is the degree of ignorance in the aggregated result. Therefore, the overall assessment of A is represented by (11):

$$S(A) = \left\{\left(H_n, \beta_n\right), n = 1, 2, ..., N\right\}. \tag{11}$$

In addition, it has been proved that $\sum_{n=1}^{N}\beta_n + \beta_H = 1$.

For the convenience of comparison among different alternatives, a utility $U(A)$ is generated for A from (11). When $\beta_H = 0$, $U(A)$ is calculated by (12) with $U(H_n)$ being the utility of grade H_n:

$$U(A) = \sum_{n=1}^{N}\beta_n U(H_n). \tag{12}$$

If $\beta_H \neq 0$, $U(A)$ is given by an interval with lower and upper bound being calculated by (13) and (14) as follows:

$$U(A)_{\max} = \sum_{n=1}^{N-1}\beta_n U(H_n) + (\beta_N + \beta_H)U(H_N), \tag{13}$$

$$U(A)_{\min} = (\beta_1 + \beta_H)U(H_1) + \sum_{n=2}^{N}\beta_n U(H_n). \tag{14}$$

In (13) and (14), it is assumed that $U(H_{n-1}) < U(H_n)$ for $n = 2, 3, ..., N$.

2.2. *The ER approach and ERM*

As discussed in Sec. 1, the main difference between traditional risk management and ERM is that the former considers individual risk separately and in the latter risks within an enterprise can be considered as a whole. In ERM, one of the key tasks is to aggregate individual risks to generate an overview of risk in a rational way. As the ER approach can be used to deal with risk aggregation problems with both quantitative and qualitative risk factors with different kinds of uncertainty, it is applied to support risk aggregation in ERM in this paper.

To use the ER approach under the context of ERM, each risk is assessed individually and considered as a criterion while the risk profile of a department in an enterprise or the enterprise itself is generated by aggregating the information of relevant criteria. In addition, a set of grades need to be defined to assess individual risk according to the product of two elements: likelihood of the occurrence of an incident regarding the risk and the corresponding consequence. In current practices, both the elements are usually measured by a score scaled from 1 to 5, so that risk is measured by a score from 1 (when both the score of likelihood and that of consequence are scored as 1) to 25 (when both the score of likelihood and that of consequence are scored as 5).[16] Based on the risk score, different grades, such as Low/Medium/High or Green/Amber/Red, are proposed to describe the risk. However, in this case, the difference among individual risks with the same grade but with different scores cannot be reflected, leading to loss and even distortion of information in risk aggregation. To avoid such information loss or distortion, in this paper, risk scores are selected as grades to describe individual risks. Since both the likelihood of the occurrence of an incident and its consequence can take values from 1 to 5, the risk score can be 1, 2, 3, 4, 5, 6, 8, 9, 10, 12, 15, 16, 20 and 25. In addition, if at the time of assessment, there is no risk regarding a factor or a department within the enterprise, the risk score would be 0. Therefore, the whole set of grades used to describe individual risks can be represented as:

$$H = \{H_0, H_1, H_2, H_3, H_4, H_5, H_6, H_8, H_9, H_{10}, H_{12}, H_{15}, H_{16}, H_{20}, H_{25}\}. \quad (15)$$

In addition, the utility of a belief distribution based on (15) can be calculated based on (12) or (13)–(14). The utility can then be grouped to risk levels such as Low/Medium/High or Green/Amber/Red for risk related decision making.

To facilitate the calculation using the ER approach, IDS[17] can be used to generate risk assessment results, based on which further analysis can be conducted.

2.3. *Advantages of using ER approach in ERM*

Compared with current methods used to aggregate individual risks in ERM, most of which are based on probability distributions and statistical methods, the advantages of the ER approach when it is applied for risk aggregation in ERM are summarized as follows:

- With the introduction of belief distributions, different forms of information (e.g., quantitative information, subjective judgments) regarding individual risks with different kinds of uncertainty (e.g., uncertainty caused by incompleteness or vagueness) can be represented, and then handled by the ER approach;
- By using the ER approach for information aggregation, the aggregated view of risks at different levels within a large organization can be generated, and the information loss during the aggregation process can be minimized;

- By using IDS, risk aggregation becomes more convenient and comprehensive analysis based on risk aggregation result can be conducted.

3. Case Study

3.1. *Case background*

From October 2003 to September 2009, 3,875,241 patient safety incidents have been reported within National Health System (NHS) in UK, including incidents caused by manual handling or due to exposure to hazardous substances, and the overall trend in incident reporting is upwards.[18] Besides incidents relating to patient safety, there are other risks involved in the operation of NHS organization, such as risk in finance, risk in staffing, etc., which are reflected from risk registers of some certain NHS organizations. It can be seen that, risks are prevalent in daily operations in NHS. Further, as indicated by NHS staff, one of the important causes of incidents is the inefficient risk reduction strategy, which is potentially caused by under or over estimation of risk levels within organizations. Therefore, risk assessment is very important for organizations within NHS.

In the case study, risks in an NHS organization in North England are assessed and analyzed using the ER approach and IDS. In the organization, around 60 risk factors are identified per month in its daily operations, and each risk is measured by a score as the product of the likelihood of the occurrence of an incident regarding the risk and the corresponding consequence. Currently, a risk report is generated regularly for senior managers to develop risk control strategies.

There are several limitations in current practices for risk management in the organization as mentioned above:

- Due to the lack of aggregated view on risk of each department within the organization and the whole organization itself, it is time consuming for senior managers to review the risk reports, and it is difficult for senior managers to know how risky the whole organization is and which is the most risky department within the organization at the time of the reporting, leading to difficulty in developing effective risk control strategies;
- To represent risk by a numerical score cannot reflect different kinds of uncertainty inherent in risk assessment;
- Some risks are difficult be quantified due to their nature, and the information of some risks may not be available or fully understood. A more flexible framework is therefore needed to represent risk in different forms and to handle different kinds of uncertainty involved in individual risks;
- No comprehensive analysis can be conducted based on the information represented by risk score of each individual risk.

To overcome the limitations mentioned above and to facilitate risk management in the organization, the ER approach together with IDS is applied to provide an overview of risk for different departments as well as the whole organization and to generate a comprehensive analysis of risk based on the available information.

3.2. *The ER approach for risk aggregation*

3.2.1. *Framework for risk assessment*

Before risk can be assessed using the ER approach, the framework to organize individual risk factors identified in the organization needs to be investigated.

Currently, risk factors are organized according to the business units in the organization. In addition, in the organization, there also exist some committees and different committees focus on different sets of risk factors. For example, Figure 1 shows the risk assessment framework according to the risk factors identified in June 2010 in the organization.

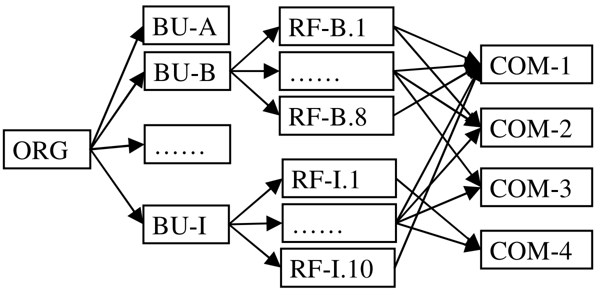

Fig. 1. Framework for risk assessment of the organization.

In Fig. 1, ORG, COM, BU and RF stand for "Organization", "Committee", "Business Unit" and "Risk Factor" respectively. It can be seen that the organization has 9 business units (BU-A to BU-I), and different sets of risk factors are identified in different business units, e.g., there is no risk factor in BU-A and there are 8 risk factors in BU-B (RF-B.1 to RF-B.8). In addition, there are 4 committees in the organization (COM-1 to COM-4), and each committee focuses on a certain set of risk factors, e.g., COM-4 concerns RF-I.1 and some other risk factors in BU-I except RF-I.10. Note that, a risk factor can be concerned by different committees at a time.

In total, there are 59 risk factors identified in June 2010 in the organization and currently the available information regarding the risk factors is the score of likelihood of occurrence and the score of consequence corresponding to each individual risk factor.

3.2.2. *Risk assessment for different levels within the organization*

To generate risk in different levels in the organization based on the available information, the ER approach is applied in this section.

Take BU-F as an example. In BU-F, 5 risk factors, RF-F.1 to RF-F.5, are identified, and the scores corresponding to the factors are summarized in Table 1 as follows:

Table 1. Information of risk factors identified in BU-F.

Risk Factor	Likelihood	Consequence	Risk Level
RF-F.1	2	3	6
RF-F.2	3	4	12
RF-F.3	3	2	6
RF-F.4	3	2	6
RF-F.5	4	3	12

Therefore, the belief distributions representing risk levels of the 5 risk factors are:

S (RF-F.1) = {(H0, 0), (H1, 0), (H2, 0), (H3, 0), (H4, 0), (H5, 0), (H6, **1**), (H8, 0), (H9,0), (H10, 0), (H12, 0), (H15, 0), (H16, 0), (H20, 0), (H25, 0)}; (16)

S (RF-F.2) = {(H_0, 0), (H_1, 0), (H_2, 0), (H_3, 0), (H_4, 0), (H_5, 0), (H_6, 0), (H_8, 0), (H_9, 0), (H_{10}, 0), (H_{12}, **1**), (H_{15}, 0), (H_{16}, 0), (H_{20}, 0), (H_{25}, 0)}; (17)

S (RF-F.3) = {(H_0, 0), (H_1, 0), (H_2, 0), (H_3, 0), (H_4, 0), (H_5, 0), (H_6, **1**), (H_8, 0), (H_9, 0), (H_{10}, 0), (H_{12}, 0), (H_{15}, 0), (H_{16}, 0), (H_{20}, 0), (H_{25}, 0)}; (18)

S (RF-F.4) = {(H_0, 0), (H_1, 0), (H_2, 0), (H_3, 0), (H_4, 0), (H_5, 0), (H_6, **1**), (H_8, 0), (H_9, 0), (H_{10}, 0), (H_{12}, 0), (H_{15}, 0), (H_{16}, 0), (H_{20}, 0), (H_{25}, 0)}; (19)

S (RF-F.5) = {(H_0, 0), (H_1, 0), (H_2, 0), (H_3, 0), (H_4, 0), (H_5, 0), (H_6, 0), (H_8, 0), (H_9, 0), (H_{10}, 0), (H_{12}, **1**), (H_{15}, 0), (H_{16}, 0), (H_{20}, 0), (H_{25}, 0)}; (20)

In addition, as among the 5 risk factors in BU-F, risk scores of RF-F.2 and RF-F.5 are higher than risk scores of the other 3 risk factors, accordingly, more attention should be paid on RF-F.2 and RF-F.5. Therefore, RF-F.2 and RF-F.5 are considered to be more important than the other 3 risk factors. Thus, in this paper, the weight assigned to each risk factor is proportional to the corresponding risk score, and within BU-F, according to the risk score of each risk factor, the corresponding weights are generated as follows:

$$\omega_{RF-F.1} = \omega_{RF-F.3} = \omega_{RF-F.4} = 0.143 \tag{21}$$

$$\omega_{RF-F.2} = \omega_{RF-F.5} = 0.286 \tag{22}$$

Using Eqs. (16)–(22) and (1)–(10), the risk profile of BU-F can be generated as:

S (BU-F) = {(H_0, 0), (H_1, 0), (H_2, 0), (H_3, 0), (H_4, 0), (H_5, 0), (H_6, **0.3798**), (H_8,0), (H_9,0), (H_{10}, 0), (H_{12}, **0.6202**), (H_{15}, 0), (H_{16}, 0), (H_{20}, 0), (H_{25}, 0)}; (23)

In addition, the score of each grade, $U\left(H_i\right)$, is assumed as:

$$U\left(H_i\right) = i \text{ for } i = 1, 2, \ldots, 25 \tag{24}$$

From (12), (23) and (24), the score of BU-F is 9.7. According to the NHS risk assessment policy,[16] the relation between risk score and risk level is shown in Table 2.

Table 2. Relation between risk score and risk level.

Risk Level	Risk Score Range	Risk Level	Risk Score Range
Low	1–3	Moderate	4–7
High	8–14	Extreme High	15–25

Therefore, for BU-F, its risk is “High”.

The risk level of BU-F together with its risk profile in (23) provides a whole view of its risk. Similarly, the risk profile of other business units can be generated.

Besides risk profile of each business unit, risk profile of each committee is also concerned by senior managers of the organization, and the risk profile can be generated in the same way as above. For example, COM-3 concerns the following risk factors: RF-B.6, RF-I.4 and RF-G.1 to RF-G.7. According to the risk score and the corresponding weight of each risk factor, the risk profile of COM-3 is generated as:

S (COM-3) = {(H0, 0, (H1, 0), (H2, **0.1019**), (H3, 0), (H4, **0.1019**), (H5,0), (H6, **0.4905**), (H8, **0.1019**), (H9, **0.1019**), (H10, 0), (H12, 0), (H15, 0), (H16, **0.1019**), (H20, 0), (H25, 0)} (25)

From (12), (24) and (25), COM-3’s risk score is 6.9, and thus its risk is “Moderate”.

Further, regarding the whole organization, as a risk factor may be managed by different committees at the same time, while it can only belong to one business unit at a time, it is more appropriate to generate risk profile of the whole organization based on risk profiles of the 9 business units, instead of the 4 committees. According to risk profiles of different business units, the risk profile of the whole organization is:

S (Organization) = {(H0, 0.1064), (H1, 0.0029), (H2, 0.0142), (H3, 0.0117), (H4, 0.1234), (H5, 0.0069),(H6, 0.1599), (H8, 0.0481), (H9, 0.1183), (H10, 0.0328), (H12, 0.2323), (H15, 0.0249),(H16, 0.0923), (H20, 0.0000), (H25, 0.0258)} (26)

From (12), (24) and (26), the risk score of the organization is 8.6, indicating the organization’s risk is just above “Moderate” and is categorized as “High” on average.

Note that, it is not sufficient to describe risk by risk score or risk level only. For example, regarding the whole organization, although the risk level is just above “Moderate” on average, from (26), it is known that there is still a small degree (0.0258) assigned to the grade of H25, revealing that the organization is with extreme high risk as measured in terms of certain risk factors. Since the risk scores are 25, the corresponding incidents are almost certain to happen and the corresponding consequence is catastrophic. Therefore, such risk factors must be identified for significant attention by both senior managers and the managers of the corresponding business units and committees.

3.3. *Comprehensive analysis based on risk assessment result*

In addition to the risk assessment in different levels in the organization, by using IDS, a comprehensive analysis can also be provided to senior managers for risk management.

3.3.1. *High risky area identification*

As revealed previously, although the risk of the organization is just above "Moderate" on average, its risk profile reveals that there are still some areas with extreme high risk. It is therefore necessary to identify the areas quickly at a senior management board meeting.

By using IDS, the above concern can be conveniently resolved. For example, Fig. 2 shows the business units in the organization with risk score above 8 (32% of 25, which is the highest risk score), i.e., the business units with "High" risk according to Table 2.

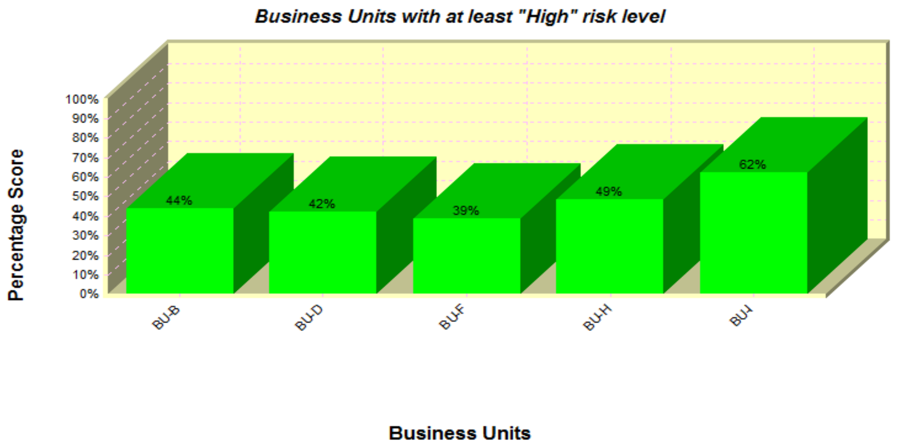

Fig. 2. High risk business units identification.

From Fig. 2, it can be seen that although the risk of the organization is just above "Moderate", there are still 4 business units, i.e., BU-B, BU-D, BU-F and BU-H, with "High" risk, and BU-I is with "Extreme High" risk. Accordingly, the managers of the above 5 business units, especially the manager of BU-I, should pay special attention to the risk factors existing in their own business unit during the risk management process.

3.3.2. *Report generation*

Within the organization, board meetings are held regularly, in which, a report for risk management should be provided. To facilitate the generation of the report, IDS can be applied to generate an initial draft of the report. The content of the draft includes: risk assessment result of different departments within the organization and the organization itself, high risky areas in the organization, possible ways to improve high risky areas, etc. The draft can be saved as a Word Document, which provides a basis for senior managers to further edit and generate a final risk report. As an example, the beginning part of the draft corresponding to the data in the case study is shown in Fig. 3.

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Risk Assessment Summary Report

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1. **Organization Overall Risk Score: 8.615**

The organization is operating with **High** risk according to the Risk Factors identified in June 2010.

2. **Key areas to consider (Risk Factors with "High" and "Extreme High" risk):**
    - RF-I.1
    - RF-I.2
    - RF-I.4
    - RF-H.5
    - RF-H.6

3. **Committee Level Risk Score:**
    - COM-1: 6.759
    - COM-2: 8.365
    - COM-3: 6.9175
    - COM-4: 8.3275

4. **Business Unit Level Risk Score:**

Fig. 3. Report generation.

3.3.3. *Trend analysis*

The results in the above analysis are about risk assessment at a certain time. However, to get a picture of risk trend over time is also important in risk management. In Fig. 4, the trend of the risk of the whole organization from January 2010 to June 2010 is indicated:

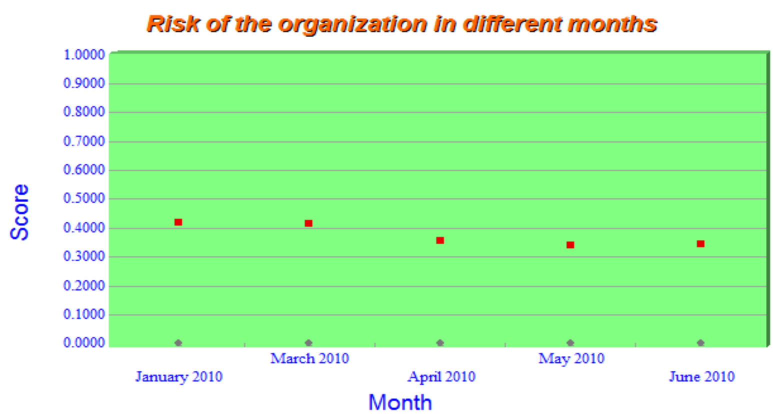

Fig. 4. Risk trend analysis.

Figure 4 shows that from January 2010 to June 2010, risk is decreasing in general, with the lowest risk in May 2010 and the highest risk in January 2010. Similar trend can also be generated at committee level, business unit level, and individual risk factor level.

3.4. *Discussion*

In the case study, the available information is the score of likelihood of the occurrence of an incident and the score of its consequence regarding a risk factor and both scores are precise values between 1 and 5. However, as risk assessment in large organizations is complex, it is not always possible to provide such accurate and complete information for each risk factor. Moreover, the scores may be provided by a group of people. For example, when a group of experts assess a certain risk factor, e.g., RF-F.1, if 60% of the experts think that the consequence is "Minor (2)[a]" while 40% of the experts consider it as "Moderate (3)", to use a single score to represent the consequence will cause information loss. Therefore, the consequence is represented by: {(2, 0.6), (3, 0.4)}. In addition, if the corresponding likelihood is represented by {(3, 0.5), (4, 0.5)}, the risk of RF-F.1 will be:

S (RF-F.1) = {(H0, 0), (H1, 0), (H2, 0), (H3, 0), (H4, 0), (H5, 0), (H6, **0.3**), (H8, **0.3**), (H9, **0.2**), (H10, 0), (H12, **0.2**), (H15, 0), (H16, 0), (H20, 0), (H25, 0)}.

Further, if according to the available information, it is known that the consequence for RF-F.2 is very likely to be "Minor (2)", but it is not certain as there are some factors influencing RF-F.2 and according to the available information, the influence is uncertain. In this case, the score of the consequence can be represented by: {(2, 0.9)}, with the degree of 0.1 unassigned to any grades. In the future, if more information is available, the degree of 0.1 may be assigned to certain grades accordingly. Meanwhile, if the score of the likelihood of the corresponding incident is 3, the risk score of RF-F.2 will be:

S (RF-F.2) = {(H0, 0), (H1, 0), (H2, 0), (H3, 0), (H4, 0), (H5, 0), (H6, **0.9**), (H8, 0), (H9, 0), (H10, 0), (H12, 0), (H15, 0), (H16, 0), (H20, 0), (H25, 0)}.

If RF-F.3, RF-F.4 and RF-F.5 are still given by (18)–(20), the risk of BU-F will be:

S (BU-F) = {(H0, 0), (H1, 0), (H2, 0), (H3, 0), (H4, 0), (H5, 0), (H6, 0.5495), (H8, **0.0399**), (H9, **0.0268**), (H10, 0), (H12, **0.3692**), (H15, 0), (H16, 0), (H20, 0), (H25, 0), (Unknown, **0.0147**)}. (27)

In (27), the belief of 0.0147 assigned to "Unknown" reflects the incompleteness of the information for RF-F.2. Further, according to (13), (14) and (27), the score of BU-F is now given by an interval [8.3, 8.5], indicating that the risk level of BU-F is "High".

The above way to handle uncertainty, particularly uncertainty caused by incomplete information, can provide a more realistic picture about risk in the organization.

4. Conclusion

To overcome the limitations of current risk aggregation methods applied in ERM, the paper applies the ER approach for risk aggregation in ERM. Based on the aggregation

[a] The value in the bracket is the score corresponding to the subjective word.

result, comprehensive analysis for risk management is generated by IDS. To show the advantages of the ER approach together with IDS over other existing methods for risk aggregation and risk management in ERM, a case study about risk assessment and risk management for an NHS organization in North England is proposed, from which, it can be seen that the application of the ER approach with IDS can facilitate risk management in large enterprises through:

- Generating an overview of risk for different levels in an organization, this is the most important advantage of applying the ER approach for risk management in ERM, especially in the NHS organizations across UK, as currently, this aggregated view of risk, which is very useful for risk management, cannot be generated;
- Providing a comprehensive analysis based on the risk assessment results, especially, the risk trend review over time, which is not available in the NHS organization currently, can provide an important reference on whether the previous risk reduction strategies applied in the organization are effective and how effective they are;
- Providing a flexible way to accommodate and handle different forms of information and different kinds of uncertainty regarding individual risks;
- Representing risk assessment results by both a risk score and a risk profile to provide a comprehensive view of risk with the application of the ER approach.

Apart from health organizations, the ER approach introduced in this paper can also be applied to support ERM for other kinds of large enterprises.

In summary, the paper provides a practical and rational tool for senior managers in large enterprises to assess risk in different levels in the enterprises and to conduct effective risk management based on informative risk analysis results generated by IDS.

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