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Using Mathematics to Quantify Subjective Decisions: Application of Analytic Hierarchy Process to Risk Assessment

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ABSTRACT

Risk management requires human judgements, from risk identification, assessment to response. Although automated tools are useful in handling large amounts of data and in performing complex calculations rapidly, humans undertake the entire risk management process. They bring to the process their intuitions, insights, previous experiences and skills. Therefore, creating a rich source of information of risks faced by an organisation. Ignoring human factors may impoverish information and limit risk management to only measurable factors. This study contributes to the field of decision-making and risk assessment by investigating and discussing in detail how to quantify subjective judgements using the Analytic Hierarchy Process (AHP). AHP is used to assess risk of an insurance company. It discusses how to do risk assessment by combining both intuition and analytic in the decision-making process. The study defines intuition as knowledge and experience, and analytic as the mathematics or quantitative analysis to derive the result. It demonstrates how Analytic Hierarchy Process (AHP) - a flexible multi-attribute or multi-criteria decision making tool, enables risk managers to use both intuition and analytic to do risk assessment. Risk assessment using AHP produces global priority weights representing the overall risk ranking of an insurance company. The study develops a risk assessment problem and uses AHP to organise and structure risks and sub-risks of the problem. It uses formative evaluation method with open-ended questionnaires to obtain feedbacks from risk managers on AHP. Three employees of a risk management department in a government agency assesses the risks using AHP. AHP strengths are easy to use and understand, improves risk assessment and useful for risk assessment problems that have scarce or no data. AHP limitation are the numbers and repetitiveness of the pairwise comparisons. The participants either ignore some of the pairwise questions or they answer randomly instead of deliberate judgements.

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1. Introduction

The Holy Grail of risk management is to find the best possible decision in an uncertain environment [1]. Rebonato [14] stated risk management is not about measuring risks or assessing probabilities; rather, it is about making decisions in situations of uncertainty. The power of risk management lies in risk managers' ability to make good decisions [1]. Decision making is an important component of risk management. Risk managers have to face the difficult task of making far-reaching decisions in an uncertain environment. According to Shafie *et al.*, [18], managers have to make multitudes of decisions every day. They have to make decisions in the complex and fast changing business environment. They are require to make decisions even if they are not willing to do so. Hillson and Webster [9] stated risk management requires human judgement. Human factors represent an important aspect of the risk management process, from risk identification and assessment to response. Therefore, a framework for a structured approach to risk management should take into consideration the human factors in managing risks. Although automated tools are useful in handling large amounts of data and in performing complex calculations rapidly, humans undertake the entire risk management process. They bring to the process their intuitions, insights, previous experiences and skills, thereby creating a rich source of information of the risks faced by the business. Ignoring human factors would impoverish information and limit risk management to only measurable factors.

This study aims to address the concerns. First, it demonstrated how to do risk assessment using both intuition and analytic decisions. It defines intuition as knowledge and experience, and analytic as the mathematics or quantitative analysis to derive the result. It demonstrated how Analytic Hierarchy Process (AHP) - a flexible multi-attribute or multi-criteria decision making tool, enables risk managers to use intuition and analytic to do risk assessment. Intuition and analytic are sequential steps in AHP. The first part of AHP requires risk managers to use their knowledge and experience to structure and organise all identified risks into a hierarchy, and then assess the risks. The second component is the quantitative analysis of the assessments using linear algebra and matrix multiplication. The output is the weights of the risks. The weights represent the order of relative importance of the risks, i.e. the rank of the risks. Second, the study investigate the practical usability of AHP. Three risk managers evaluate AHP practical usability as a risk assessment tool. Their feedbacks are used to identify AHP strengths and limitations.

2. Overview of Risk Assessment

This section explains current tools and techniques use in risk assessment. Risk assessment is a process for evaluating and ranking the likelihood of risks occurring and the magnitude if they occur. The purpose is to rank risks, for firms to focus on managing significant risks. Risk ranking is also used to inform decisions on the appropriate risk response. Firms use the output of risk assessments to plan their risk responses or strategic risk management actions. Therefore, the risk assessment technique needs to produce an accurate risk ranking. Risk assessment answers the following questions: (i) which risk is more important? or (ii) how should risks be prioritised from a set of important risks?

Risk assessment techniques can be categorised into quantitative and qualitative. Quantitative techniques include probabilistic distribution and loss experience. The probabilistic technique measures the likelihood and magnitude of risks using probability distributions. Techniques employed in probabilistic risk assessments are at-risk models such as value at risk, earnings at risk, cash flow at risk, assessment of loss events and back testing [20]. Qualitative techniques include expert judgement and risk mapping using impact and frequency or industry benchmark. Expert judgement is a subjective assessment by experts on the level of risks using a nominal, ordinal, interval or ratio measure. Benchmarking is assessing the likelihood and magnitude of a risk against specific risks.

3. Risk Assessment using Risk Matrix

Many risk managers use risk matrix as a risk assessment tool [3, 21]. A risk matrix is a graphical representation of risks. Risks are plotted on a graph, with the vertical axis representing likelihood or probability and the horizontal axis representing impact or magnitude. The matrix is divided into four quadrants: (i) low impact, low, likelihood; (ii) low impact, high likelihood; (iii) high impact, low likelihood; and (iv) high impact, high likelihood. Likelihood and impact are evaluated using a scale of 1 to 9. Other scales are sometimes used to evaluate likelihood, such as: (i) low, medium, high; (ii) improbable, possible, probably, near certainty, certainty; and (iii) slight, not likely, likely, highly likely, expected. Other scales used to evaluate impact are: (i) low, medium, high; (ii) minor, moderate, critical, survival; and (iii) monetary value such as $1 million, $5 million [19].

Moeller [12] explains how to conduct a risk assessment using a risk matrix. For example, a firm has identified six risks: R1 to R6. The risk management group consists of four people from different business units. Each group member evaluates the likelihood and impact of the risks individually. The following questions are used to assess the risks. *What is the likelihood of the risk occurring in one year?* Use a score of 1 to 9 to assign the best score. Score 1 if no chance of the risk occurring in one year. Score 9 if the risk will certainly occur in one year. Score 2 to 8 if the risk occurrence is between no chance and certain. *What is the financial impact of the risks to the organization?* Score 1 for very low. Score 9 for very high. Score 2 to 8 for between very low and very high.

The risk assessment is for a specific time horizon. Moeller [12] proposes a one-year interval or fiscal year, and proposed developing a separate risk matrix to address different time horizons. The group individual assessment is averaged, and the values are plotted on the risk matrix presented in Figure 1. To obtain risk scores, the likelihood and impact are multiplied. The risk scores is the ranking of risks. Table 1 shows the risk score calculation. Risks 3 and 6 have the highest risk score. The risks are plotted at the upper-right-hand quadrant, which is the high likelihood and high impact quadrant. Risks 3 and 6 are the most important risks compared to other risks. Therefore, the firm needs to focus on planning responses to these risks. Moeller [12] proposes that risk management teams develop a risk matrix and ranking table for every unit and level in the firm. The rankings are then aggregated to obtain the overall risk rankings for the firm.

3.1 Risk Matrix Limitations

The risk matrix is a tool for determining important risks. The technique is easy to use and has an intuitive appeal. Risk assessors only consider the function of risk in terms of likelihood and magnitude. The technique is useful for cases in which quantitative data are scarce or do not exist. However, Shenkir and Walker [19] argue that the likelihood-magnitude approach does not consider the preferences and value judgements of the decision makers, which are important in determining significant risks and planning actions to mitigate the risks. Emblemsvag and Kjolstad [7] state that the logic of the likelihood and impact risk assessment is unclear. Further analysis to improve the assessment is not possible. The final act is to place the risks in a likelihood and impact matrix without any inconsistency check or sensitivity analysis. Cox [3] notes the ability of the risk matrix to improve decision making, arguing that the risk matrix has the following limitations. First, risk matrices make an accurate comparison on only a small number (less than 10 per cent) of randomly selected hazards. Second, they can mistakenly assign higher qualitative ratings to quantitatively smaller risks. Third, they are ineffective in allocating resources to mitigate risks. Fourth, ratings in risk matrices depend on the subjective judgements of risk assessors. Therefore, different risk assessors may have opposite ratings on the same risk. Duckert [6] notes the validity of using subjective judgement in assessing risks, stating that a true risk assessment should consist of three steps: (i) identifying the risk; (ii) calculating the probability of occurrence; and (iii) determining the effect. Duckert [6] emphasises the importance of using data to calculate the probability of risk occurrence. Data can accurately predict the probability of risks occurring. Risk assessments using subjective judgements rely on guesses and not a true risk assessment. A subjective risk assessment lacks consistency. A different person will give a different assessment of the same risk. Even the same person will give different assessments of the same risks in different situations or at different times. However, Chapman [2] explains the following reasons for why subjective estimations should be used to evaluate risks: (i) data have never been collected; (ii) data are expensive to obtain; (iii) past data are no longer relevant; (iv) data are sparse, requiring expert opinions to fill in the gaps; and (v) the area of risk is new.

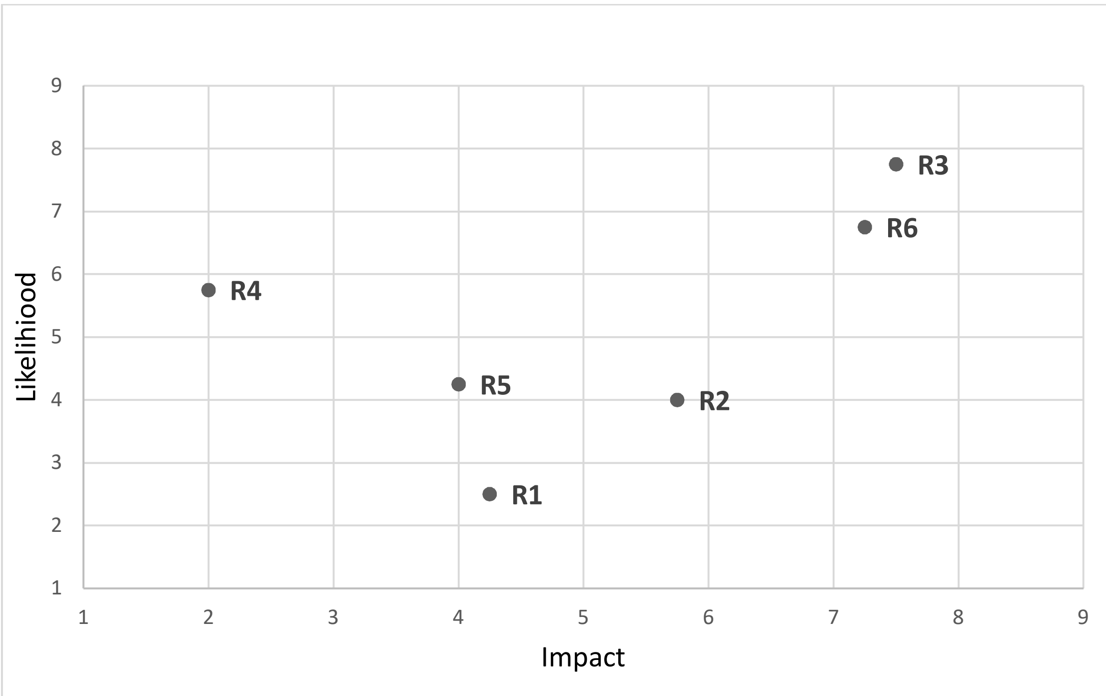

Fig. 1. Risk Matrix Example

Table 1
Risk Score Calculation

Identified Risk	Impact (P)	Likelihood (L)	Risk Score (PxL)	Risk Rank
Risk 1	4.25	2.5	10.63	6
Risk 2	5.75	4	23.00	3
Risk 3	7.5	7.75	58.13	1
Risk 4	2	5.75	11.50	5
Risk 5	4	4.25	17.00	4
Risk 6	7.25	6.75	48.94	2

Moeller [12] argues that low-medium-high risk mapping is suitable for a small number of risks. For a large number of risks, probability estimation is more appropriate for ranking the risks. Hargreaves [8] states that the low-medium-high approach works well for a one-person risk analysis. To evaluate risks at each level of an organisation, a number of people will be involved. Different people will have a different perspective of the risks and a different understanding of the low, medium and high scale. The situation requires a tool that can synthesise all judgements, as well as a standardised and formalised risk assessment process.

4. Risk Assessment using AHP

This section explains in detail how to do risk assessment using AHP. In this study AHP is applied to risk assessment of an insurance company. Thomas L. Saaty developed AHP while he was at Wharton Business School, University of Pennsylvania [15]. Saaty [16] defines AHP as a mathematical theory of measurement and decision making. It derives a ratio scale from both discrete and continuous paired comparisons. In AHP, first, the risks are structure in a hierarchy, follow with a prioritisation process. In the prioritisation process risk managers compare two risks to determine the dominance of a risk over another with respect to a specific criterion or property.

The following outline AHP risk assessment steps:

1. Determine decision goal. Determine the decision goal. For this application, the decision goal is to assess inherent risks. Inherent risks refer to gross risks-that is risks before any action or control is implemented to mitigate them.

2. Identify all risks. First risk managers identified scenarios threatening a company. From the scenarios, the sources of risks and sub-risks are identified. The sub-risks are then categorised into similar characteristics or attributes. Table 2 presents the sources of risk, sub-risks and risk categories of an insurance companies. The information is obtained from insurance companies annual reports. The purpose of risk categorisation is to prepare for the risk assessment. Categorising the risks requires deconstructing an unstructured list of risks into a smaller and manageable number of risks. It also enables easier pair wise comparisons; it is easier to compare risks with similar attributes.

3. Organise the risks and sub-risks in a hierarchy. Structure the risks and sub-risks in a hierarchy. The hierarchy has three levels. The first level is the decision goal, the second level is the risks (risk categories) and the third level is the sub-risks. Figure 2 presents the hierarchy.

4. Determine Decision Time Frame. Determine the risk assessment time frame. Identifying the time frame helps to avoid making a risk assessment at one point in time. For this application, the time frame is one year.

5. Assess risks by making trade-of within a risk category and across risk categories. AHP uses pair wise comparisons to assess the risks and sub-risks. The pair wise comparisons require risk assessors to assess risks in terms of dominance and intensity. Risk assessors need to (i) decide which risk or sub-risk is more important (dominance) and (ii) decide the strength of importance (intensity) using a scale of 1 to 9. Table 3 presents the comparison scale.

Based on Figure 2, first, sub-risks are compared within their category. Second, risks are compared across categories. The following presents the pair wise comparison questions. *Compare sub-risks within their category.* For example, in terms of strategic risk, compare regulation (change in regulation) and market change (change in market preference). Which sub-risk is more important and by how much more? In terms of strategic risk, compare regulation (change in regulation) and competitor (competitor activities). Which sub-risk is more important and by how much more? An example of a risk assessor's judgements are presented in Table 4. The left-hand side of Table 4 shows the decision matrix of sub-risks within a risk category. *Compare risks across categories.* For example, compare strategic and operational risk. Which risk is more important and by how much more?

Compare strategic and insurance risk. Which risk is more important and by how much more? An example of a risk assessor's judgements are presented in Table 5. The left-hand side of Table 5 shows the decision matrix of risks across or between risk categories.

6. Calculate priority weight of risks and sub-risks. The study uses the geometric mean method to calculate the priority weight of the risks. The geometric mean method is also known as the Log-Least Square Method [4, 5, 11]. The geometric mean calculation is easier compared to other techniques [10]. The following outline steps of the geometric mean priority weight calculation [13].

i. A consistent pair wise comparison matrix A is develop from a risk assessor judgement.

$$A=\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

a_{ij}, $i,j = 1,2\ldots n$ is a risk assessor's judgement on the importance of $Risk_i$ compared to $Risk_j$. The value is 1 to 9.

ii. Calculate the product of each rows in matrix A.

$$\prod_i = \prod_{j=1}^{n} aij \quad i = 1,2,\ldots.,n \quad (2)$$

iii. Calculate the n-degree root:

$$\sqrt[n]{\prod_i}. \quad (3)$$

iv. Sum up the value obtain in (iii):

$$\sum_{i=1}^{n} \sqrt[n]{\prod_i}. \quad (4)$$

v. Normalised the value by dividing each element by the sum producing the weights:

$$p_i \frac{\sqrt[n]{\prod_i}.}{\sum_{i=1}^{n} \sqrt[n]{\prod_i}.} \quad (5)$$

p_i is the priority weight of the risk. The priority weight presents the order of importance of the risks and sub-risks. Table 4 shows the decision matrix and local priority weights of sub-risks within strategic risk. Table 5 shows the decision matrix and priority weights for risks.

7. Check decision consistency. The accuracy of the decisions is measured by computing consistency ratio (*CR*) and Consistency Index (*CI*):

$$CR = \frac{CI}{RCI}, CI = \frac{\lambda_{max} - n}{n-1} \quad (6)$$

λ_{max} equals the maximum eigenvalue of the judgement matrix. *n* is the number of elements in the decision matrix. *RCI* is random consistency index. It is a pre-defined average random index derived from a sample size of 500 of randomly generated reciprocal matrices. A RCI value depends on the number of elements being compared [17]. The RCI values correspond to the number of elements being compared is presented in Table 6. CR equals or less than 10 per cent is acceptable indicating a judgement is consistent. CR exceeding 10 per cent indicates inconsistency in judgement. The elements in the pairwise comparisons are not properly evaluated. CR larger than 10 per cent requires revising the pair wise comparison judgement.

8. Aggregate Weights to obtain Overall Priorities of Risks. Table 7 shows the global or overall priority weight of sub-risks. The local priority weight of sub-risks and risks are multiplied to obtain the global priority weight of sub-risks.

9. Discuss and Approve Results. From Table 7, AHP produces three outputs: (i) ranking of risks; (ii) ranking of sub-risks; and (iii) overall ranking of sub-risks. Risk managers can extract top ten risks from the overall ranking of sub-risks. The top ten risks are sub- risks with largest priority weights. The sub-risks are: (1) changing regulation (regulation); (2) increased in insurance claims frequency and severity (claims); (3) inability to offer product matching customer preference (competitor); (4) failure to implement strategic business planning or business strategy does not work out as planned (business planning); (5) insufficient investment income due to changes in interest rate and real estate price (interest rate); (6) IT or system failure (system); (7) extreme events causing deviations in claims level or lack of data to model risks (underwriting); (8) insufficient fund to meet obligations to counter parties (counter party); (9) change in customer preference (market change); (10) inability to meet financial obligations and higher financing rates (financial obligations).

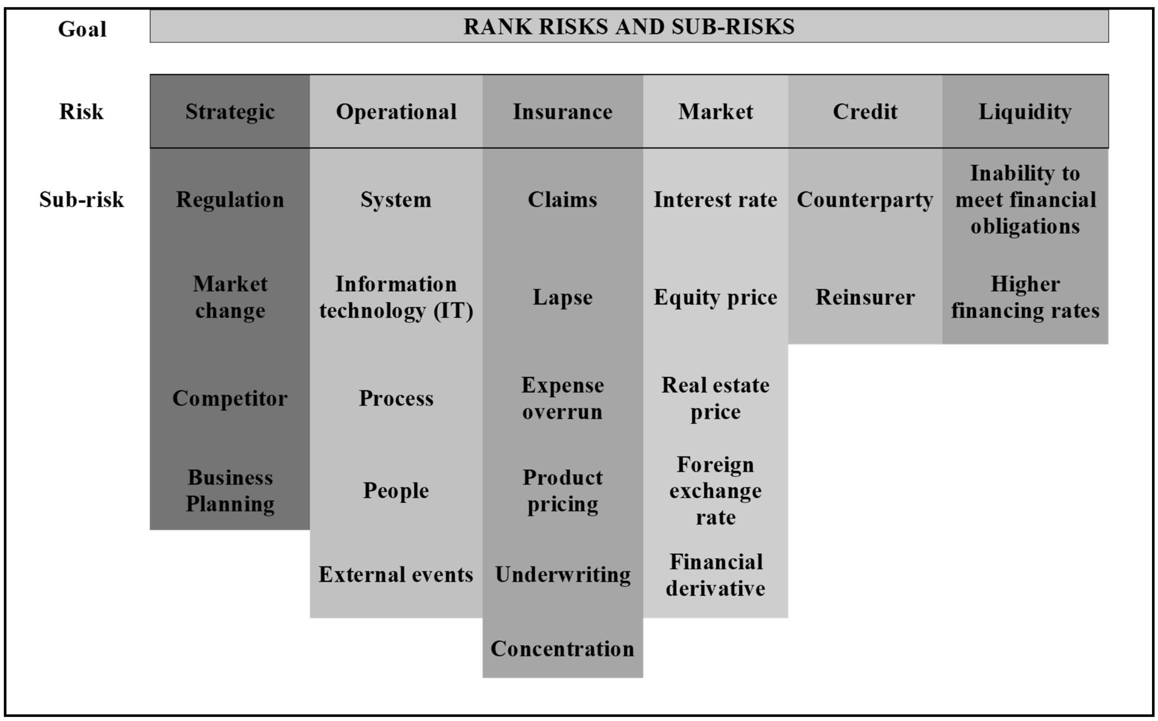

Fig. 2. Hierarchy of an insurance company's risks

5. Evaluating AHP as a Risk Assessment Tool

Employees of risk management department in a government agency evaluates AHP. This study uses formative evaluation approach. The purpose is to investigate whether AHP can be used as a risk assessment tool. Feedbacks from the evaluation are used to understand AHP strengths and limitations as a risk assessment tool. Three participants took part in the evaluation session. The followings are the findings of the evaluation session.

Table 2
Source of risk, sub-risks and risks

No.	Source of risks	Sub-risks	Risk
1	Changing regulation	Inability to keep up with the regulation	Strategic
2	Credit and capital market disruptions	Inability to meet financial obligations and higher financing rates	Liquidity
3	Slowing of the economy	Decrease product demand and increase lapse/termination/surrender	Insurance
4	Global financial disruption	Foreign exchange rate volatility	Market
5	Insufficient investment income	Changes in interest rate and real estate price	Market
6	Change in customer preference	Market changes	Strategic
7	Stock market downturn	Changes in equity and financial derivatives prices	Market
8	Higher mortality rate than the premium charged	Product pricing	Insurance
9	Higher sickness rate than the premium charged	Product pricing	Insurance
10	Administrative costs exceeded from what can be earned from policies.	Expense overrun	Insurance
11	Inability to offer product matching customer preference	Competitor risks	Strategic
12	Human error or misconduct	People or process risks	Operational
13	IT or system failure	IT or System risks	Operational
14	Reinsurer fails or delay in meeting obligations	Credit risk	Credit
15	Insufficient fund to meet obligations to counter parties	Credit risk	Credit
16	Increase claims frequency and severity	Claims risks	Insurance
17	Extreme events causing deviations in claims level	Underwriting risks	Insurance
18	Lack of data to model risks	Underwriting risk	Insurance
19	Unforeseen management expenses	Expense overrun	Insurance
20	Investment in high proportion in specific equities	Concentration risk	Insurance
21	Business concentration on specific geographical area or economic sectors.	Concentration risk	Insurance
22	Failure to implement strategic business planning	Business Planning	Strategic
23	Business strategy does not work out as planned	Business Planning	Strategic

Table 3
AHP Comparison Scale

Value	Definition
1	Two risks are equally important
2	A risk is equally to moderately important over another.
3	A risks is moderately important over another.
4	A risk is moderately to strongly important over another.
5	A risk is strongly important over another.
6	A risks is strongly to very strongly important over another.
7	A risk is very strongly important over another.
8	A risk is very strongly to extremely important over another.
9	A risk is extremely important over another.
Reciprocals	Reciprocals for inverse comparisons

Table 4
Decision Matrix and Local Priority Weight of Sub-risks within Strategic Risk

Strategic risks	Regulation	Market change	Competitors	Business	Local Weight
Regulation	1	3	3	3	0.49
Market change	1/3	1	1/3	1	0.13
Competitors	1/3	1	1	1	0.22
Business	1/3	1	1	1	0.16

$\lambda_{max} = 4.15,\ CI=0.05,\ CR=0.06$

Table 5
Decision Matrix and Local Priority Weight of Risks

Risk	Strategic	Operational	Insurance	Market	Credit	Liquidity	Local Weight
Strategic	1	3	3	3	3	5	0.36
Operational	1/3	1	1/3	1/3	3	3	0.11
Insurance	1/3	3	1	3	3	5	0.25
Market	1/3	3	1/3	1	3	3	0.16
Credit	1/3	1/3	1/3	1/3	1	1	0.06
Liquidity	1/5	1/3	1/5	1/3	1	1	0.05

$\lambda_{max} = 6.47,\ CI=0.09,\ CR=0.08$

Table 6
Random Consistency Index (RCI)

n	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Table 7
Local Priority of Weight of Risks and Global Priority Weight of Sub-Risks

Risks	Strategic	Operational	Insurance	Market	Credit	Liquidity	Global weight
Local weight	0.36	0.11	0.25	0.16	0.06	0.05	
Regulation	0.49						0.18
Market change	0.13						0.05
Competitor	0.22						0.08
Business	0.16						0.06
System		0.47					0.05
IT		0.20					0.02
Process		0.16					0.02
People		0.07					0.01
External event		0.09					0.01
Claims			0.35				0.09
Lapse			0.06				0.01
Expense			0.12				0.03
Pricing			0.17				0.04
Underwriting			0.20				0.05
Concentration			0.10				0.02
Interest				0.33			0.05
Equity				0.22			0.03
Real estate				0.07			0.01
Foreign				0.11			0.02
Derivatives				0.27			0.04
Counter party					0.75		0.05
Reinsurer					0.25		0.02
Fin.obligations						0.83	0.04
Financing						0.17	0.01
Total	1.0	1.0	1.0	1.0	1.0	1.0	1.0

The study used open-ended questionnaire to obtain feedbacks from participants. The questionnaire consisted of the following questions:
The hierarchy. Participants evaluate the hierarchy as follows: does the hierarchy improve understanding of the problem?; does the hierarchy make the problem more structured and organised?; is disagreement constructively managed by presenting the problem in a hierarchy?; can overlook or missing risk be easily detected?; does the hierarchy make communication about the problem more focused?; do structuring and organising the problem in a hierarchy promote creative thinking?
Pairwise comparison and decision consistency. Participants evaluate the pairwise comparisons and decision consistency as follows: paired comparison is a natural way to make trade-off between risks; the pairwise comparison question is easy to follow and understand; the scales equal, moderate, strong, very strong and extreme are easily understood; decision consistency assists in making consistent judgement.
Decision making steps. Participants evaluate the usefulness of each step as follows: whether AHP is easy to use and the decision-making steps are easy to follow; whether the steps are useful; suggest the most useful steps; suggest new steps to be added to AHP; suggest a new AHP decision making steps or framework with the new step.
The results. Participants evaluate the results produced by AHP as follows: is the result produced by AHP useful; suggest other results AHP should produce.

6. AHP Strengths and Limitations

The followings discusses feedbacks from the participants. The feedbacks are group into strengths and limitations of AHP.

6.1 Strengths

The participants report the strengths of AHP as follows:
Easy to Use and Understand. AHP is easy to use and understand, and its process is simple and logical. The step by step process produces understandable, reliable and defensible decisions.
Improves Understanding of a Problem. The hierarchy organises the problem into risks and sub-risks. The hierarchy links the risks, sub-risks and the decision goal. Using a hierarchy, firm-wide risks are structured based on meaning and relations. The participants already had an underlying understanding of the flow of influence and connections of risks and sub-risks. The hierarchy systematically structured their understanding of the influences, connections and interactions.
Improve Risk Assessment. AHP improves risk assessments in the following ways. It converts subjective judgement into objective decision. AHP translated subjective judgement into numerical values. The values were used to obtain the priority weights of the risks. The priority weight is a rank of importance of risks based on the participants' knowledge, perspectives and feelings. The participants could record and document the risk rankings of every risk assessor. AHP enables individual risk rankings to be documented. This can be used to facilitate communication between risk assessors. It provides a systematic risk assessment process, which increases the participants' confidence of the reliability of the risk rankings. It provides a clear and transparent risk assessment, which facilitates communication between risk assessors, risk managers and top management. It also facilitates debate and discussion of the risk rankings with decision makers or stakeholders, and with other stakeholders not directly involved in the risk assessment process. The pair wise comparisons assisted the participants to make explicit trade-offs between the risks. They were aware that they had to make trade-offs to determine

which risks were more important. The pair wise comparison facilitated them to make logical and thoughtful risk trade-offs.

AHP for Problem with Scarce Data. AHP is useful for problems with scarce data and intangibles elements. Therefore, the participants proposed it can be applied to risk management problems that have scarce or no data and require subjective judgements, such as operational risks. Risks categorised under operational are large and diverse such as potential loss resulting from failures of people, processes, technology and external dependencies.

6.2 Limitations

The following discusses AHP limitations.

The Pair Wise Comparison. Two limitations that arise from pair wise comparisons are the number of pair wise comparisons and decision fatigue. Number of pair wise comparisons. The number of criteria and alternatives determines the number of pair wise comparisons. Each decision matrix has n(n-1)/2 pair wise comparisons questions. The risk category has 6 types of risks. The participants have to answer 15 pair wise comparisons. Strategic risk has 4 sub-risks, requiring 6 pair wise comparisons. The participants have to answer 58 pair wise comparisons for the whole risk hierarchy.

Decision fatigue. Pair wise comparison questions are repetitive. As a result, the participants experienced decision fatigue. They did not answer all questions, or they randomly answered the questions. Not answering all of the questions created missing values. As a result, AHP could not produce the risk rankings. Randomly answering the questions increased decision inconsistency.

7. Conclusion

This study brings light to the human element that is often under-appreciated and under-served in the automatic and technology space of decision making. The common practice is to automate the decisions governing business operations. However, the reality is that many operational and business decisions require human components. Risk management is one of business components that rely heavily on human judgements. This study contributes to decision-making and risk assessment in that the human decision-making or risk assessment components should be amplified with processes to refine and bolster it. The application of AHP on risk assessment amplifies risk managers' ability to make judgements on prioritizing risks among important. The first part of AHP brings human judgement to the centre stage of the risk assessment process. The AHP structure and representation is geared for risk managers to use their intuitions, emotions, experiences and skills into the decision. The second part of AHP uses quantitative analysis to produce an objective and meaningful ranking of the risks. The decision matrix and linear algebra calculations captured the trade-off and relative importance of the risks. Direct ranking of risks (e.g. 1, 2 and 3, or low, medium and high) does not represent the trade-off and relative importance of a risk over another. The priority weight of each risks reflect the relative importance and provides meaningful interpretation of the relative importance of the risks.

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