Improving probability impact diagram matrices using multiple criteria decision analysis tools

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ABSTRACT

Risk matrices (i.e. tables mapping "frequency" and "severity" ratings to corresponding risk priority levels) have been recommended by international organizations and are widely used as a framework for practical risk analysis by many organizations and risk consultants. Nevertheless, available studies indicate that the use of risk matrices might generate inconsistencies in risk management and risk matrices do not respect important theoretical properties. This study investigates how multiple criteria decision analysis (MCDA) tools can be used to improve the design and the deployment of risk matrices in the context of prioritization of risks and of risk reductions. Using MCDA, it is proposed a modeling approach based on: (1) the use of a multicriteria additive value model using the Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) to measure risk impacts, and of the MACBETH methodology to build subjective probabilities; (2) the transformation of a risk matrix into a Probability Impact Graph (PIG) that uses probabilities and multicriteria value scores and that overcomes jump discontinuity problems; (3) the use of multicriteria and non-compensatory classification procedures to classify risks from the PIG by urgency of intervention; (4) and the use of multicriteria resource allocation models that combined with PIG can be used to identify which set of interventions are most effective to reduce risk, while taking into account of costs and other constraints. The proposed modeling approach is illustrated with data from a real case study developed at ALSTOM Power. The multicriteria additive value model was developed at ALSTOM following a socio-technical approach involving facilitation methods; and the application of the methods was supported by the M-MACBETH and PROBE decision support systems.

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INTRODUCTION

Risk managers frequently use risk matrices which entail several problems, such as they can produce non-compensatory decision rules that do not reflect the risk trade-off preferences of real decision-makers (DM) across risk impacts in different criteria (Cox Jr., 2008) and they violate the principle of translation invariance (Bertsch, 2008). This study explores how MCDA tools (that have strong theoretical foundations (Keeney and Raiffa, 1976) (Belton and Stewart, 2002)) can be used to improve risk matrices. The tools are applied to construction and commissioning related risks at ALSTOM Power.

MODELLING APPROACH

Fig. 1 presents the activities developed to apply MCDA tools, as well as the outputs generated by the proposed methods.

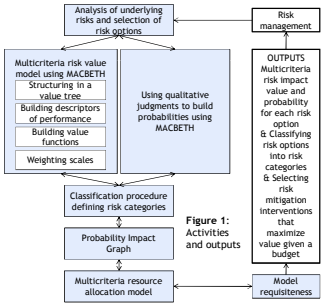


Figure 1: Activities and outputs

The activities should be iteratively developed until the model is requisite (Phillips, 1984). The starting point is the use of a socio-technical approach to build a Multicriteria Risk Impact Value (MRIV) model (additive model, Eq. (1)) and to build probabilities. That approach employs participative methods and the MACBETH methodology. MACBETH (Bana e Costa et al., 2010) aids the DM to convert qualitative judgments into quantitative values, having been used in the past in many evaluation contexts (for example, (Bana e Costa et al., 2008)).

$$\mathrm{MRIV}(x_j) = \sum_{i=1}^{n} k_i \times v_i(x_j), \sum_{i=1}^{n} k_i = 1, k_i > 0, v_i(\text{good}) = 100, v_i(\text{neutral}) = 0 \quad (1)$$

With x_j standing for the j risk option; $v_i(.)$ and k_i being the value function and weighting scales for criterion i; and good and neutral being the chosen reference points.

MULTICRITERIA VALUE MODEL USING MACBETH

Structuring the evaluation of risk impact at ALSTOM resulted in the value tree shown in Fig. 2 (with 6 criteria in blue). Tab. 1 provides examples of key information used to build descriptors of performance. Tab. 2 displays the qualitative judgments from applying MACBETH to build the value function for Health and Safety; and Tab. 3 the judgments to build weighting scales. Fig. 4 exhibits the partial and multicriteria risk impact values for a set of 16 risks from ALSTOM (details on this available in Figueiredo and Oliveira (2009)).

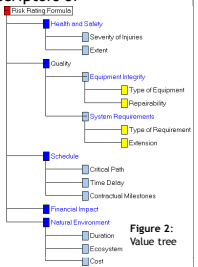


Figure 2: Value tree

Table 1: Examples of information used to build descriptors of performance

Criteria	Sub-Criteria	Sub-sub Criteria	Descriptor of performance	Lower Level	Higher Level
1. HSaf		1.1 Extent of the consequence	Number of Injuries	Single	Multiple
	1.2 Severity of injuries	1.2.1 First Aid Accident (FAI)	Yes/No	No	Yes
		1.2.2 Medical Treatment Incident (MTI)	Yes/No	No	Yes
		1.2.3 Loss Time Incident (LTI)	Yes/No	No	Yes
		1.2.4 Fatality	Yes/No	No	Yes
4. Fini	4.2 Threat	4.2.1 Threat Monetary Value	Threat Value, in M€	0 M€	> 2 M€

Figure 3: M-MACBETH qualitative judgments and value function for H&Safety

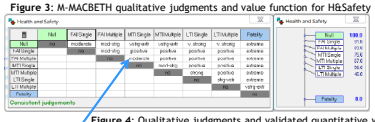


Figure 4: Qualitative judgments and validated quantitative weights

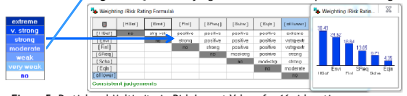
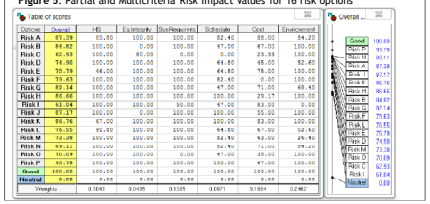


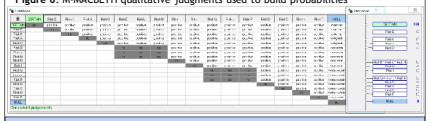
Figure 5: Partial and Multicriteria Risk Impact Values for 16 risk options



BUILDING PROBABILITIES USING MACBETH

Using MACBETH to build probabilities demands for asking the DM for qualitative evaluation of risk options, completing the statement "The probability of the risk event occurring is…"; and filling accordingly the matrix in Fig. 6. M-MACBETH assists in analyzing probabilities compatible with those judgments (see thermometer in Fig. 6).

Figure 6: M-MACBETH qualitative judgments used to build probabilities



CLASSIFICATION PROCEDURE

After the DM chooses the risk categories, we suggest adapting the technique proposed in Bana e Costa and Oliveira (2002). Through combinations of impacts and probabilities (see Fig. 7), compensatory and non-compensatory ranges of variation and a set of indifference profiles are defined.

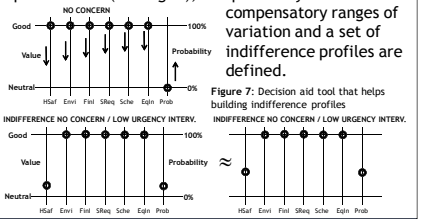


Figure 7: Decision aid tool that helps building indifference profiles

PROBABILITY IMPACT GRAPH

Using the MRIV, the probabilities and the risk category ranges, one obtains the following PIG where the selected 16 risks are displayed:

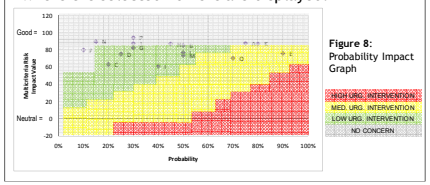


Figure 8: Probability Impact Graph

MULTICRITERIA RESOURCE ALLOCATION MODEL

In order to select the portfolio of risk mitigation interventions that maximizes risk adjusted Mitigation Value (MV) for a given budget and given relevant constraints (e.g. synergies between risk interventions), a resource allocation model is then proposed (Eq.s 2-7). The PROBE decision support system assists in computing and analyzing results (Lourenço and Bana e Costa, 2009) (Fig. 9).

$$\text{Risk adjusted MRIV}(x_j) = \text{MRIV}(x_j) \times \left(1 - \text{P}(x_j)\right) \quad (2)$$

$$\text{MV}(x_k) = \text{Risk adjusted MRIV}(x_k) - \text{Risk adjusted MRIV}(x_j) \quad (3)$$

$$\text{Maximize:} \quad \sum_{k=1}^{m} \text{MV}(x_k) \times l_k \quad (4)$$

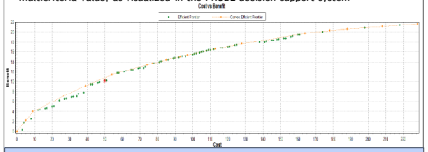
$$\text{Subject to:} \quad \sum_{k=1}^{m} c_k\, l_k \le B \quad (5)$$

$$l_k \in \{0,1\}, k = 1, \ldots, m \quad (6)$$

$$\text{Other linear constraints} \quad (7)$$

With $P(x_j)$ being the probability of risk option j; x_k being a risk option after adopting mitigation intervention k that affects risk j (with m interventions under consideration); l_k standing for a mitigation intervention selected within the budget; B and c_k being the budget available for mitigation and the cost of each mitigation intervention, respectively.

Figure 9: Portfolios of risk mitigation interventions that maximize risk adjusted multicriteria value, as visualized in the PROBE decision support system



CONCLUSION

MCDA tools have the potential to improve current practice in risk management.

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