AN ANALYSIS TO DETERMINE INDUSTRY'S PREFERRED OPTION FOR AN INITIAL GENERIC RELIABILITY DATABASE FOR CANDU

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Abstract

The paper presents a multi-attribute analysis approach that was used to choose the industry's preferred option in developing a generic reliability database for CANDU.

The Risk and Reliability Working Group (sponsored by CANDU Owners Group – Nuclear Safety Committee – COG NSC) was faced with the decision to assess in depth the following four options: a) Use External Data Base Only; b) Full CANDU generic database (All Utilities); c) CANDU Specific plus External Generic Databases; d) Ontario Power Generation (OPG)/ Bruce Power (BP) Experience Only.

Nine decision criteria were utilized to rank the proposed options (alternatives). The Analytic Hierarchy Process (AHP) was used in carrying out the ranking process.

1. Introduction

CANDU owning utilities (Canadian and foreign) have expressed interest in developing an initial Generic Component Reliability Database (GC-CRDB) for CANDU. This situation can largely be explained through both a new regulatory environment related to reliability and risk assessment (new Regulatory Standards S-98 and S-294), and the increasing use of Probabilistic Safety Assessment (PSA) and risk-informed applications in the industry.

As the CANDU utilities have now collectively amassed a fairly significant CANDU operating experience (more than two decades of operating history), and data from Canadian as well as overseas plants, a generic reliability database for CANDU may also now be feasible.

Some benefits of having such a common database include, but are not limited to:New Build and Plant Life Extension – generic data for CANDU lend more credibility to design-assist assessments.

- Credible quantification of time-average Core Damage Frequency (CDF) for licensing support of operating plants.
- Supplement plant-specific data for statistical adequacy for Risk-informed decision making, trending, control ageing and degradation (Life-cycle Management).
- The availability and use of GC-CRDB will also facilitate compliance with CNSC Regulatory Standards S-98 and S-294.

The COG Nuclear Safety Committee (COG NSC) mandated the Risk and Reliability Working Group (R&R WG) to scope a proposal for developing a GC-CRDB.

Due to the complex decision-making situation that arose through discussions within the R&R WG (multiple options and multiple criteria), it has decided to proceed with a more elaborate analysis with regard to both the decision criteria used, and proposed options suggested. The Analytic Hierarchy Process (AHP) Method has been applied. This method has been widely used in such situations due to its capability for facilitating multi-criteria decision-making.

A survey has been carried out among the members of the WG first. The obtained responses have been analyzed through a multi-attribute analysis technique. Results have been presented to the COG NSC, which recommended refining the analysis, and submitting a new report. The final report has been issued by the end of 2007 [1]. The paper aims at presenting both the final results obtained, and conclusions/recommendations drawn.

2. Approach

The realized work on the topic consisted of the following steps:

1) Develop a survey questionnaire and send it to the R&R WG members.
2) Compile responses, and develop pertinent tables.
3) Perform a ranking of both decision criteria, and proposed alternatives.
4) Perform a sensitivity analysis of obtained results.
5) Summarize obtained results and make recommendation.

A description of the steps carried out, and obtained results is summarized in subsequent sections.

3. Results

3.1 Survey questionnaire

The aim of the questionnaire was to solicit opinions and judgements of the Working group members regarding this issue. The questionnaire has been developed based on discussions the R&R WG had at a meeting. The decision-making process has been structured in order to define the goal, nine decision criteria, and analyze four alternatives (options). Figure 1 depicts the functional relationship between these elements.

The first step consisted of ranking criteria with regard to the goal (Table 1). The next step performed a ranking of alternatives against decision criteria. Table 2 shows an example of a ranking table for the alternatives with regard to the criterion “Costs”.

The questionnaire was sent to the WG members. In total, nine members have returned their responses [OPG, BP, New Brunswick (NB) Power, Nuclear Safety Solutions (NSS), Atomic Energy Canada (AECL) and Hydro-Quebec (HQ) representatives]. These responses are shown as Answ(i) (i = 1,…9) in Table 3. Based on the obtained responses, it was concluded that other survey iterations were not needed.

Table 1: Decision criteria and their ranking with regard to the goal "Select Industry's Preferred Option for an Initial Generic Reliability Database for CANDU"

Code	Description of criteria	Criterion Priority Number (CPN) (See Note A)				
		N	L	M	H	VH
A	Costs	1	2 3	4 5	6 7	8 9
B	Benefits	1	2 3	4 5	6 7	8 9
C	Technical rationale	1	2 3	4 5	6 7	8 9
D	Credibility of the reliability studies and/or PSA	1	2 3	4 5	6 7	8 9
E	Address CNSC concerns	1	2 3	4 5	6 7	8 9
F	Life Cycle Management issues	1	2 3	4 5	6 7	8 9
G	Statistical accuracy of generic databases	1	2 3	4 5	6 7	8 9
H	Political or other industry reasons for having a CANDU reliability database	1	2 3	4 5	6 7	8 9
I	Technical difficulties of getting CANDU data	1	2 3	4 5	6 7	8 9

Legend for Criterion Priority Number – (CPN)

VH – very high (rank 8 or 9)
H – high (rank 6 or 7)
M – moderate (rank 4 or 5)
L – low (rank 2 or 3)
N – negligible (rank 1)

Note A: A Criterion Priority Number (CPN) expresses the importance of a given criterion with regard to the goal ("*Select the preferred option regarding the use of a generic reliability database in CANDU nuclear industry*").

Encircle only one CPN value per criterion please; Example: **"Address CNSC concerns"**, one might encircle 5 (in Moderate CPN category). In this case one cannot encircle other CPN values for the same criterion.

It is allowed to assign the same CPN value for two or more criteria (i.e. several criteria may have the same CPN value).

Important: The preferred answers have to be given for all the criteria listed in Table 1.

Table 2: Ranking of the alternatives with regard to the criterion "Costs"

Ranking the alternatives with regard to the criterion "Costs"						
Code	**Description of alternatives**	**Alternative Priority Number (APN)** (See Notes 1 and 2)				
		N	**L**	**M**	**H**	**VH**
A1	Use of external existing databases (T-Book, EiReDa, EPIX, EPRI, etc)	1	2 3	4 5	6 7	8 9
A2	Full CANDU generic database	1	2 3	4 5	6 7	8 9
A3	CANDU specific + external generic database	1	2 3	4 5	6 7	8 9
A4	OPG/BP common DB	1	2 3	4 5	6 7	8 9

Legend for Alternative Priority Number – (APN)

VH – very high (rank 8 or 9); an alternative is ranked very high (or highly advantageous) with regard to a given criterion.

H – high (rank 6 or 7); an alternative is ranked high (or very advantageous) with regard to a given criterion.

M – moderate (rank 4 or 5); an alternative is ranked as moderate (or advantageous) with regard to a given criterion.

L – low (rank 2 or 3); an alternative is low ranked if it is considered with little advantages with regard to a given criterion.

N – negligible (rank 1); an alternative is ranked as negligible if it has no impact or almost no impact regarding a given criterion.

Note 1: Encircle one value only per alternative.

Note 2: An Alternative Priority Number (APN) expresses the importance of an alternative with regard to a given criterion. A higher importance of an alternative regarding a criterion signifies a higher APN value. It is allowed to assign the same APN value for two or more alternatives related to a given criterion (i.e. several criteria may have the same APN value vs a criterion).

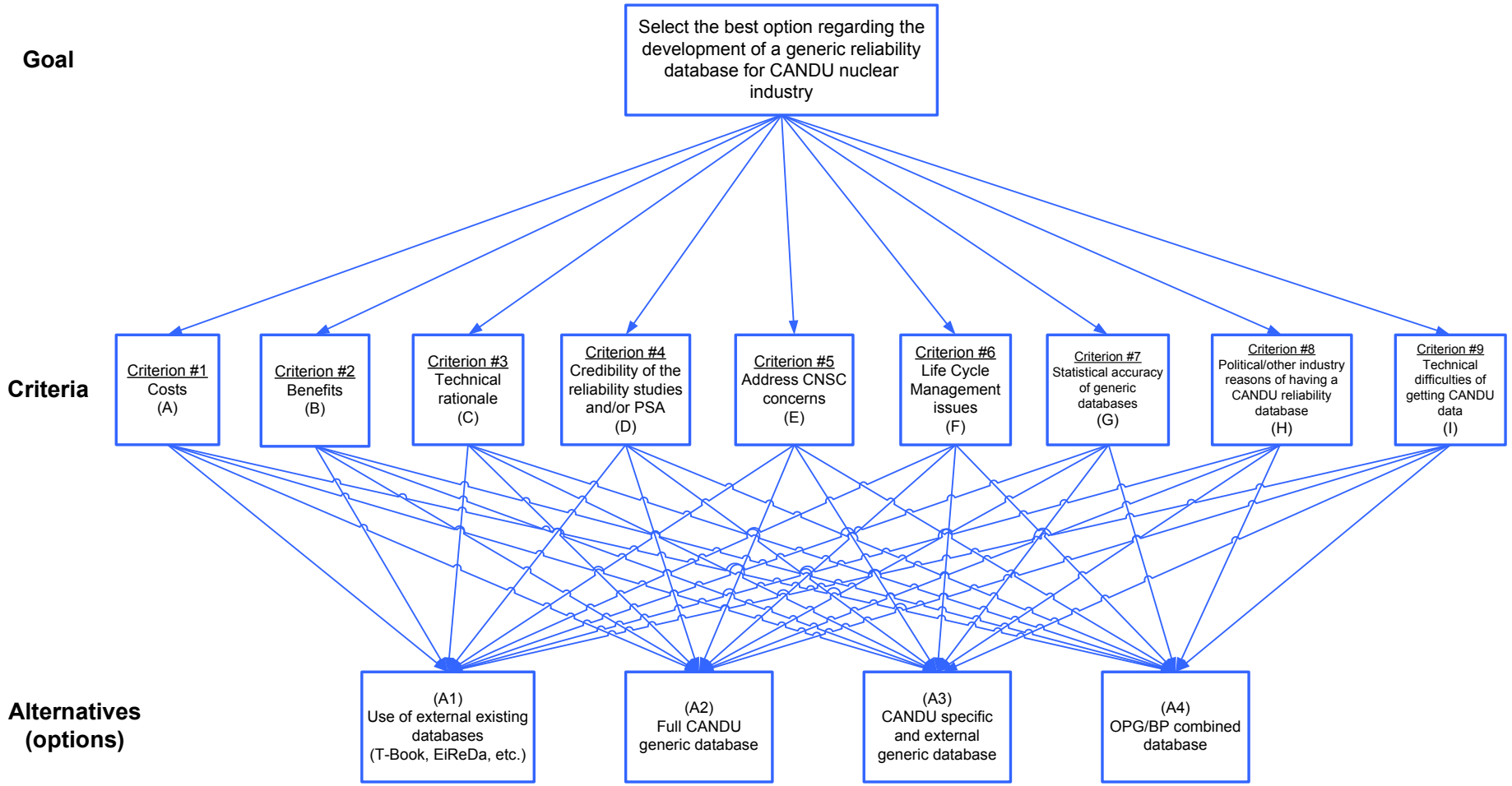

Figure 1: Decision-making process for selecting the preferred alternative regarding a generic reliability database

3.1.1 *Description of analyzed options with regard to a Generic CANDU Component Reliability Database*

While discussing potential options related to a CANDU Generic Database, Risk and Reliability Working Group has suggested defining and assessing in more depth the four options:

1) Use External Data Base Only

2) Total CANDU Experience (All Utilities)

3) CANDU Specific plus External Generic

4) OPG/BP Experience Only

Option 1)

This alternative means that no specific CANDU reliability data would be used in generating the CANDU generic database. Instead, existing international Light Water Reactors (LWR) generic databases (non-CANDU) would be used or combined to form the generic database for CANDU use. The generic LWR database candidates are listed in next section. For CANDU specific components, reliability data will be collected and generated at the utility level.

Option 2)

The full CANDU Database from all Utilities would be combined as generated by a full scale reliability data collection industry-wide. If CANDU experience is statistically inadequate, it can be supplemented by non-CANDU external data to form the CANDU Generic Database.

Option 3)

The third alternative is that failure data from all Utilities for equipment/components that are specific to CANDU will be combined to produce the CANDU generic database for those components. The rest of equipment/components that are also in non-CANDU reactors will have international (LWR) generic databases as the basis for their failure data in the CANDU generic database.

Option 4)

This Option is the same as Option 2) except only OPG/BP failure data will be combined as opposed to all CANDU Utilities. As in 2), if CANDU experience is statistically inadequate, it can be supplemented by non-CANDU external data to form the CANDU Generic Database.

3.1.2 *List of suggested LWR generic databases*

The Canadian nuclear industry has used so far several existing international generic LWR databases. They are also recommended for future use in developing a Generic CANDU Database. The potential candidates are listed as follows:

- NUREG/CR-6928 [2];
- T-Book [3];
- EIReDA [4];
- WANO [5]
- EPIX

- Long Term Asset Management Database – LAMDA [6]
- ZEDB [7]

The extent and relevance of these databases will be defined along with the work on the Generic CANDU Database.

3.2 Ranking of decision criteria, and proposed alternatives

Based on returned responses, an analysis was performed in order to rank both decision criteria, and proposed options. The Analytic Hierarchy Process (AHP) was used in carrying out the ranking process.

The AHP method has a number of desirable attributes, which are relevant in an option selection process. These attributes are as follows: (i) it is a structured decision-making method, which can be documented and replicated, (ii) it is applicable to decision situations involving multi-criteria, (iii) the AHP is applicable to decision situations involving subjective judgment, (iv) it uses both qualitative and quantitative data, (v) it provides measures of consistency of preference, (vi) there is ample documentation of AHP applications in the academic literature, (vii) commercial AHP software is available with technical and educational support[1)], (viii) the AHP is suitable for group decision-making, and (ix) the AHP facilitates a comprehensive and logical analysis of problems for which considerable uncertainty exists.

The AHP is especially suited for application to problem evaluations in which qualitative factors dominate. This method helps to accommodate both the effects of uncertainty on decisions, and a need to clarify decision objectives and carefully formulate decision alternatives [8]. AHP also facilitates a comprehensive and logical analysis of problems for which considerable uncertainty exists. In fact, the power of AHP (and to a large degree its uniqueness) lies in its ability to consider qualitative goals and attributes within its framework.

Saaty [9, 10] recommends four steps to be used the AHP application: (i) build a decision "hierarchy" by breaking the general problem into individual criteria - User/Analyst Modeling Phase, (ii) gather relational data for the decision criteria and alternatives and encode using the AHP relational scale - User/Analyst pairwise comparison input), (iii) estimate the relative priorities/weights of the decision criteria and alternatives, and (iv) perform a composition of priorities for the criteria, which gives the rank of the alternatives (usually lowest level of hierarchy) relative to the top-most objective - AHP software or a spreadsheet.

The calculations required for the AHP method in the current study have been performed through Excel® spreadsheets. Table 3 presents a compilation of the obtained responses, while Table 4 shows calculations carried out to produce numerical values for AHP pairwise comparisons.

[1)] Expert Choice ® is a widely used AHP commercial software

Table 3: Performed Evaluations by WG members for decision criteria

Criterion code	**Criterion**	Answ1	Answ2	Answ3	Answ4	Answ5	Answ6	Answ7	Answ8	Answ9	geometric mean	Mean	Value for further calculations **RNA**
A	Costs	8	8	8	5	6	4	5	6	5	5.94	6.11	**6**
B	Benefits	8	8	9	7	9	8	8	7	5	7.57	7.67	**8**
C	Technical rationale	8	7	7	5	9	8	7	7	8	7.25	7.33	**7**
D	Credibility of the reliability studies and/or PSA	8	6	9	5	9	7	7	8	8	7.33	7.44	**7**
E	Address CNSC concerns	8	6	7	6	5	7	8	6	6	6.49	6.56	**6**
F	Life Cycle Management issues	7	5	6	3	2	5	6	4	5	4.50	4.78	**5**
G	Statistical accuracy of generic databases	6	6	7	3	1	9	7	7	5	4.91	5.67	**5**
H	Political or other industry reasons for having a CANDU reliability database	5	4	3	3	1	4	9	3	3	3.38	3.89	**3**
I	Technical difficulties of getting CANDU data	5	7	5	5	7	2	3	4	3	4.24	4.56	**4**

Table 4: Pairwise comparison between criteria (AHP)

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
A	1	0.333	0.5	0.5	1	2	2	4	3
B	3	1	2	2	3	4	4	6	5
C	2	0.5	1	1	2	3	3	5	4
D	2	0.5	1	1	2	3	3	5	4
E	1	0.333	0.5	0.5	1	2	2	4	3
F	0.50	0.25	0.333	0.333	0.500	1	1	3	2
G	0.5	0.25	0.333	0.333	0.5	1	1	3	0.5
H	0.25	0.167	0.2	0.2	0.25	0.333	0.3	1	1
I	0.333	0.2	0.250	0.250	0.333	0.5	2	2	1
Inconsistency : 0.02									

The values of RNA (Table 3) are obtained by combining both geometric and arithmetic mean of obtained responses (Answ 1 – 9).

Scoring values ($SV_{A\to B}$) for a pairwise comparison (Table 4) between two criteria was carried out using an approach as follows:

$$SV_{A\to B} = \begin{cases} RNA_A - RNA_B + 1 & \text{for} \quad RNA_A - RNA_B \geq 0 \\ \dfrac{1}{RNA_B - RNA_A + 1} & \text{for} \quad RNA_A - RNA_B < 0 \end{cases} \tag{1}$$

Basic elements of the AHP method are presented below [9, 10]. More details can be found in the specialized literature on this topic.

For computing priorities of the elements, it is required to develop a judgmental matrix. For the present study, the calculated scoring values ($SV_{A\to B}$) are used to define the latter as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & & a_{nn} \end{bmatrix} \tag{2}$$

Where $\boldsymbol{a_{ij}}$ represents the pairwise comparison rating between the element ***i*** and element ***j*** of a level with respect to the upper level. In the current study, the elements $\boldsymbol{a_{ij}}$ correspond to the calculated scoring values ($SV_{A\to B}$). The entries $\boldsymbol{a_{ij}}$ are governed by the following rules:

$$a_{ij} > 0 \ \{a_{ij} \text{ takes values } 1,...,9\}; \ a_{ij} = \frac{1}{a_{ji}}; \ a_{ii} = 1 \forall i \tag{3}$$

The priorities of the elements can be estimated by finding the principal eigenvector $\overrightarrow{W}$ of the matrix A:

$$A \cdot \overrightarrow{W} = \lambda_{\max} \cdot \overrightarrow{W} \tag{4}$$

When the weight vector $\overrightarrow{W} = [w_1,...,w_n]^T$ is normalized, it becomes the vector of priorities of elements of one level with respect to the upper level. The parameter $\boldsymbol{\lambda max}$ is the largest eigenvalue of the matrix A. In other words, the weight vector $\overrightarrow{W}$ is the eigenvector of A corresponding to its maximum eigenvalue $\boldsymbol{\lambda max}$.

In cases where the pairwise comparison matrix satisfies transitivity for all pairwise comparisons it is said to be consistent and it verifies the following relation:

$$a_{ij} = a_{ik} \times a_{kj} \quad \forall i, j, k \tag{5}$$

Table 5 gives the generic comparison scale used in the AHP method.

Table 5: The AHP pairwise comparison scale

Numerical values	Description	Explanation
1	Equal importance of both elements	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgment favour one element over another
5	Strong importance of one element over another	An element is strongly favoured
7	Very importance of one element over another	An element is very strongly dominant
9	Extreme importance of one element over another	An element is favoured by at least on order of magnitude
2, 4, 6, 8	Intermediate values between two adjacent judgments	Used to compromise between two judgments

Saaty [9, 10] has shown that to maintain reasonable consistency when deriving priorities from paired comparisons, the number of factors being considered shall be less or equal to nine. The AHP method allows inconsistency, but provides a measure of the inconsistency in each set of judgments. The consistency of a judgmental matrix can be determined by a measure called the consistency ratio (CR), defined as:

$$CR = \frac{CI}{RI} \tag{6}$$

Where:

CI – consistency index

RI – Random index

Table 6 presents the values of RI.

Table 6: Average consistencies of random matrices (RI values)

Size	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

The value of CI is calculated as follows:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{7}$$

n – order of matrix

In general, an inconsistency ratio of 0.1 or less is considered acceptable. Its value is of 0.08 for matrices of size four, and 0.05 for matrices of size three. If the value is higher, the judgments may not be reliable, and should be elicited again.

Once the local priorities of elements of different levels are available, the final priorities are aggregated as follows:

$$S(a_i) = \sum_k w_k \times S_k(a_i) \quad (8)$$

Where:

w_k - local priority of the element ***k***

$S_k(a_i)$ – priority of alternative $\boldsymbol{a_i}$ with respect to element ***k*** of the upper level

Tables 7 and 8 depict an example of pairwise comparison between alternatives (options) with regard to costs. Equation (1) is used for generating numerical values in Table 6, which are obtained through responses presented in Table 7. A similar calculation has been performed for all remaining comparison regarding the alternatives vs criteria.

Figure 2 presents the results of an overall ranking of the decision criteria, and Figure 3 depicts in a graphical form the overall ranking of the alternatives.

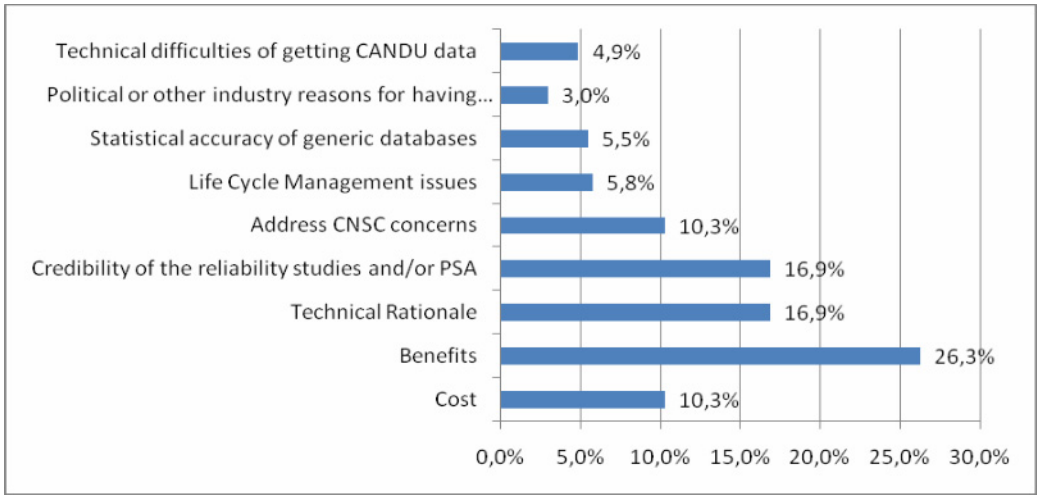

Figure 2 : Overall ranking of the decision criteria

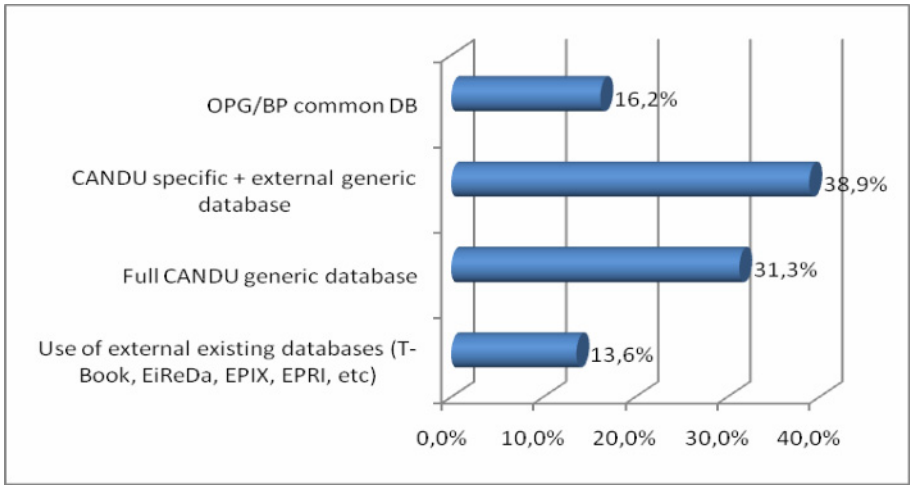

Figure 3: Overall ranking of the analyzed alternatives

Table 7: Obtained responses for ranking the alternatives with regard to the criterion "Costs"

	Description	Answ1	Answ2	Answ3	Answ4	Answ5	Answ6	Answ7	Answ8	Answ9	geometric mean	Mean	Value for further calculations **RNA**
ALT1	Use of external existing databases (T-Book, EiReDa, EPIX, EPRI, etc)	8	8	9	7	7	4	2	2	8	5.35	6.11	**6**
ALT2	Full CANDU generic database	3	5	3	3	7	7	7	7	4	4.78	5.11	**5**
ALT3	CANDU specific + external generic database	3	6	7	2	9	7	7	8	8	5.77	6.33	**6**
ALT4	OPG/BP common DB	3	7	8	9	1	6	5	3	6	4.54	5.33	**5**

Table 8 : Pairwise comparison of alternatives (ALT1,2,3,4) regarding « Costs »

	ALT1	ALT2	ALT3	ALT4
ALT1	1	2	1	2
ALT2	0.5	1	0.5	1
ALT3	1	2	1	2
ALT4	0.5	1	0.5	1
Inconsistency : 0.00				

In accordance with obtained responses, the criterion "*Benefits*" got the highest rank of 26.3% followed by two other criteria "*Technical rationale*" and "*Credibility of the reliability studies and/or PSA*" with 16.9% each (Figure 2).

As far as the alternatives are concerned, the obtained responses, and ulterior analysis show that the alternative "*CANDU specific + external generic database*" obtains the highest rank of 38.9% followed by the alternative "*Full CANDU generic database*", which rank reaches 31.3% (Figure 3).

3.3 Sensitivity Analysis

Since the number of responses is relatively small, and their dispersion sometimes significant, a sensitivity analysis has been carried out in order to verify robustness of the obtained ranking of alternatives.

The sensitivity analysis is performed by increasing the importance of an analyzed criterion while the importance of other criteria proportionally decreases. The change in the weight of the analyzed criterion also changes the importance of analyzed alternatives in accordance with Formula (8). Once the ranking of alternatives is modified, the importance (weight) of changed criterion is noted as break point in the criterion weight.

The sensitivity analysis shows that the final ranking of alternatives might change if the criterion *"Technical difficulties of getting CANDU data"* increases its weight from current 4.9% to approximately 60% giving as favourite the alternative "*OPG/BP common DB"* (Figure 4).

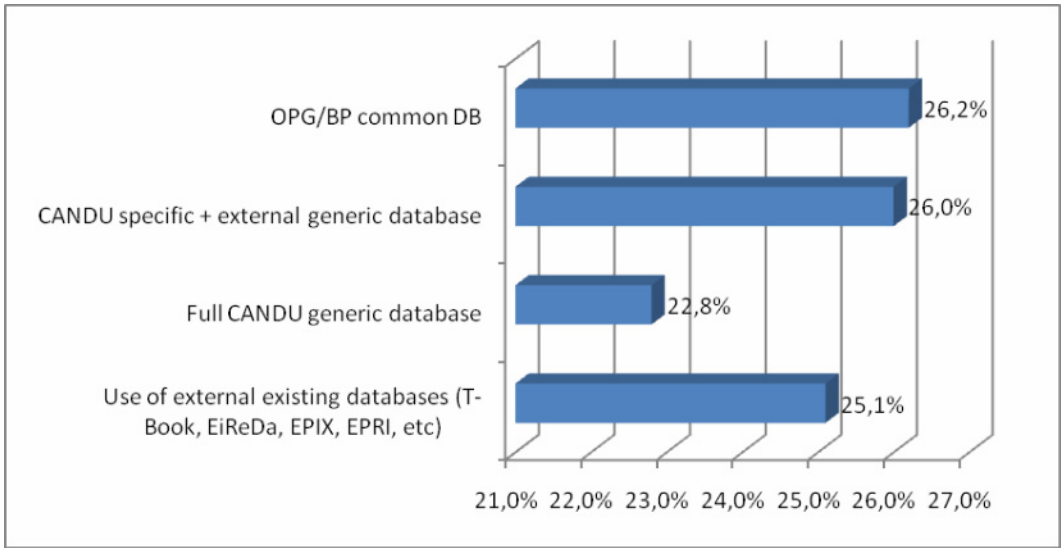

Figure 4: Sensitivity analysis with regard to the criterion "Technical difficulties"

Another sensitivity analysis has been performed where the final ranking of alternatives might change if the criterion *"Political and other industry reason of having a CANDU databases"* increases its weight from current 3.0% to approximately 35% giving as favourite the alternative *"Full CANDU Database"* (Figure 5).

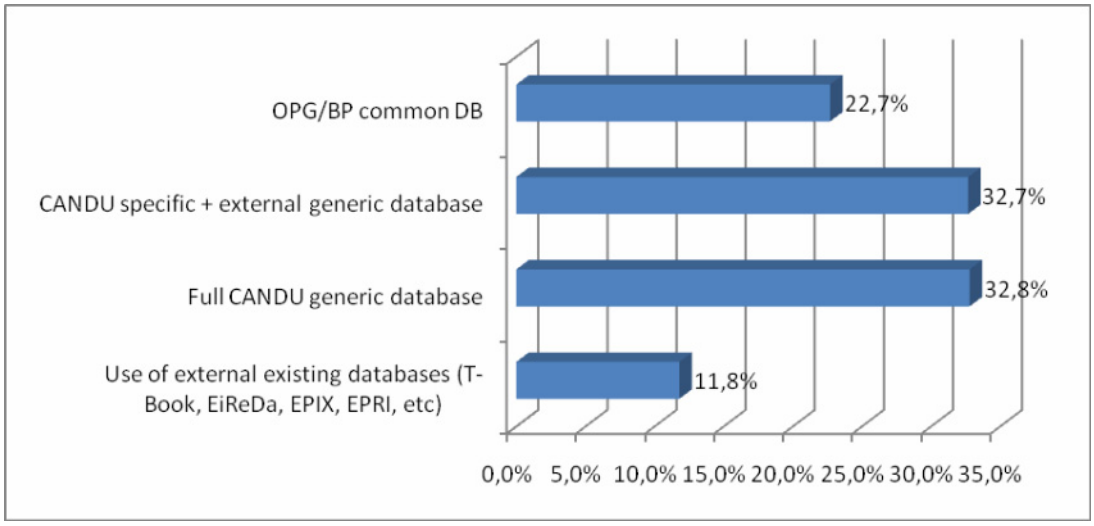

Figure 5: Sensitivity analysis with regard to the criterion "Political and other industry reasons of having a CANDU database"

As stated above, an increase in rank of a criterion implies a proportional decrease in rank (weight) of all the other analyzed criteria.

The change in weight of other decision criteria does not produce any changes in the final alternative ranking as obtained through the basic analysis (Figure 3). The sensitivity analysis demonstrates that the obtained ranking is stable.

4. Conclusions

The study performed here allows taking into account in a systematic manner relevant criteria in selecting the preferred option for an initial generic reliability database to be developed for the CANDU industry. A questionnaire has been developed in this regard, and responses from nine Risk and Reliability WG members (OPG, BP, NBPower, NSS, AECL and HQ representatives) were obtained and analyzed.

Based on obtained responses a ranking of both decision criteria, and alternatives was performed through the Analytic Hierarchy Process (AHP) method, which is generally recognized, and widely used in multi-attribute decision-making.

The obtained results indicate that the alternative "*CANDU specific + external generic database*" gets the highest rank of 38.9% followed by the alternative "*Full CANDU generic database*", which rank reaches 31.3%. The criterion "*Benefits*" obtains the highest rank of 26.3% followed by two other criteria "*Technical rationale*", and "*Credibility of the reliability studies and/or PSA*" with 16.9% each.

A sensitivity analysis was carried out in order to examine the robustness of the alternative ranking. The former shows that the criterion "Technical difficulties of getting CANDU data" should increase up to 60.2% for changing the final rank, and favour the alternative "*OPG/BP common DB*". If the criterion "Political and other industry reasons of having a CANDU database" changes from current 3.0% to approximately 35%, the alternative "*Full CANDU database*" may become a first choice. Since this increase in criterion weight is quite significant, one may indicate that the final ranking is stable. A change in other criteria does not initiate any change in the final alternative ranking.

The results of the present analysis may be useful and informative in a final decision-making process with regard to the choice of the preferred option in developing a generic reliability database for the CANDU nuclear industry. Since the responses have been obtained from all the utilities, the result represents an industry-wide position upon the analyzed topic. It is worth mentioning that these results are not prescriptive, and provide a strong support for structured discussions upon this question.

Based on obtained results, sensitivity analysis, and sub-team's internal discussions, it has been concluded to recommend "*CANDU specific + external generic database*" option as the most favoured by the industry for developing an initial Generic Reliability Data Base for CANDU.

5. References

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