사단법인 한국원자력학회
KOREAN NUCLEAR SOCIETY

Value Tree Analysis Approach for Integrated Risk Informed Decision Making: Revision of Allowed Outage Time

Poorva Kaushik and Sok Chul Kim*

*Korea Institute of Nuclear Safety
Department of Nuclear and Quantum Engineering
Korea Advanced Institute of Science and Technology (KAIST)

October 28, 2016

KOREA INSTITUTE OF NUCLEAR SAFETY

KAIST

Contents

Problem Definition

- Experience with plant operation has indicated that AOT may require revision to optimize the safe plant operation.
- Revision of an AOT is an example of IRIDM that requires consideration of deterministic analysis , probabilistic analysis, operating experience, economic implications etc.
- IRIDM is a multi-attribute problem that considers a wide variety of inputs. Quantitative determination of the relative significance of these inputs and their impact on the final decision is difficult.
- Decision makers usually rely on their subjective decree to evaluate inputs and there is no strategy commonly applied to deal with this issue.
- However in the nuclear field, where we want to keep risk as low as possible, good reasoning is as important as the decision itself. Objectivity, transparency, and auditability are the foremost requirements for decisions on nuclear safety.
- In the present work a new approach to IRIDM input evaluation for AOT optimization based on VTA methodology resulting in objective and transparent decision making is proposed.

Value Tree Analysis

- VTA method is used in multiple criteria decision making in which objectives/inputs are arranged hierarchically.
- Each input is defined by attributes. Attributes are the measure of inputs.
- There can be several layers of inputs. Attributes are added to the lowest level of objectives to construct the value tree .
- A value tree outlines the hierarchical relationship between multiple layers of objective, inputs and attributes.

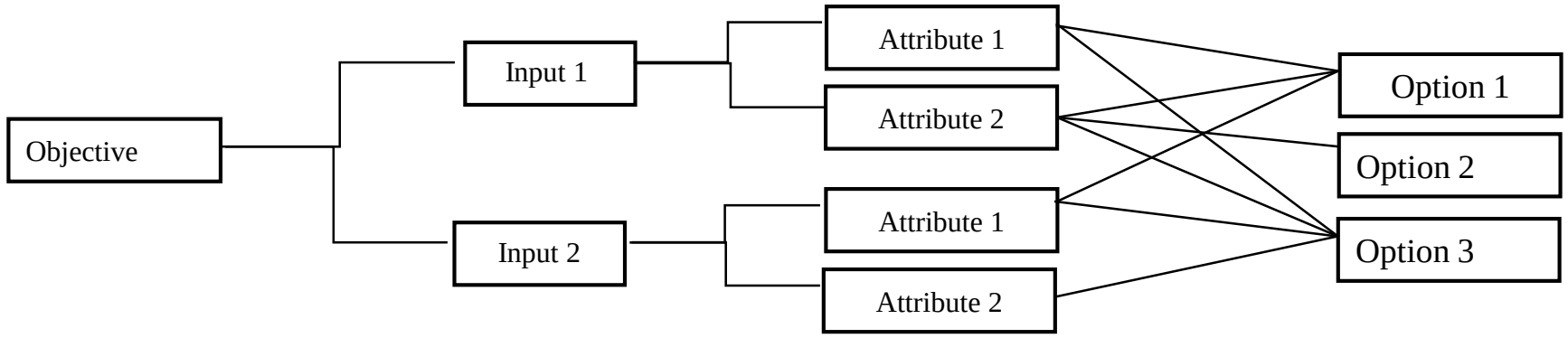


Figure 1 *VTA Hierarchy structure*

Framework

Problem Structuring

- To enhance the understanding of the decision problem. It is carried out in following steps:
  - The first step is clear definition of an issue and identification of various decision alternatives
  - The second step involves careful selection of inputs that need consideration for making the decision
  - The third step is the identification of attributes for respective inputs

Preference Elicitation

- To set up the hierarchical order between various inputs and attributes to construct the value tree. It is carried out in following two steps:
  - Weightage Elicitation: To assign priorities among various inputs and their attributes. (Wi, Aij)
  - Value elicitation: To describe the importance and desirability of achieving different performance levels of the given attribute for each alternative. (Consequence Factor Sijk)

Evaluation

- Assuming the independence amongst the attributes and additive model, once the values of all attributes for each input are determined, best option with the highest score can be identified by using the following equation:

$$S_k = \sum_i Wi \sum_j Aij.Sijk$$

Method of Weightage Elicitation

- SMARTER – Simple Multi Attribute Rating Technique Exploiting Rank
- In this method inputs or attributes are ranked first, then the weight Wi or Aij is determined .
- It is based on the idea that if the only fact known about weights is that there sum is equal to 1, and no previous knowledge of preference of one weight over another exists, equal weights for each input will be assigned. If knowledge of the rank order weights is available, the set of acceptable weights will change.
- Edward and Baron have derived the following equation for the weights (where W1>W2>W3…. Wn)

$$W_i = \frac{1}{N} \sum_{n=i}^{N} 1/n$$

- It has been shown that without requiring any difficult subjective judgments this method is an improvement to SMART and performs about 98% accurately as SMART

Method of Value Elicitation

- Direct Rating:
  - Appropriate when no commonly agreed scale of measurement exists or performance levels of the attribute is practical to be judged by subjective measures.
  - It is carried out by experts. In this method, first the worst and the best alternative are identified
  - The value of the remaining alternatives is then considered in such a way that the relative spacing between them reflects the strength of the preferences for one alternative over another.
- Value Function Form Assessment:
  - Preferred method for quantitative attributes.
  - A value function of different shape can be applied to each measurable attribute .
  - It can be obtained as a function of any parameter X, the variation of which will decide the performance level of an attribute.
  - The form of the value function is specified in order to describe the relation between the value of X and the Sijk.

Problem Structuring for AOT

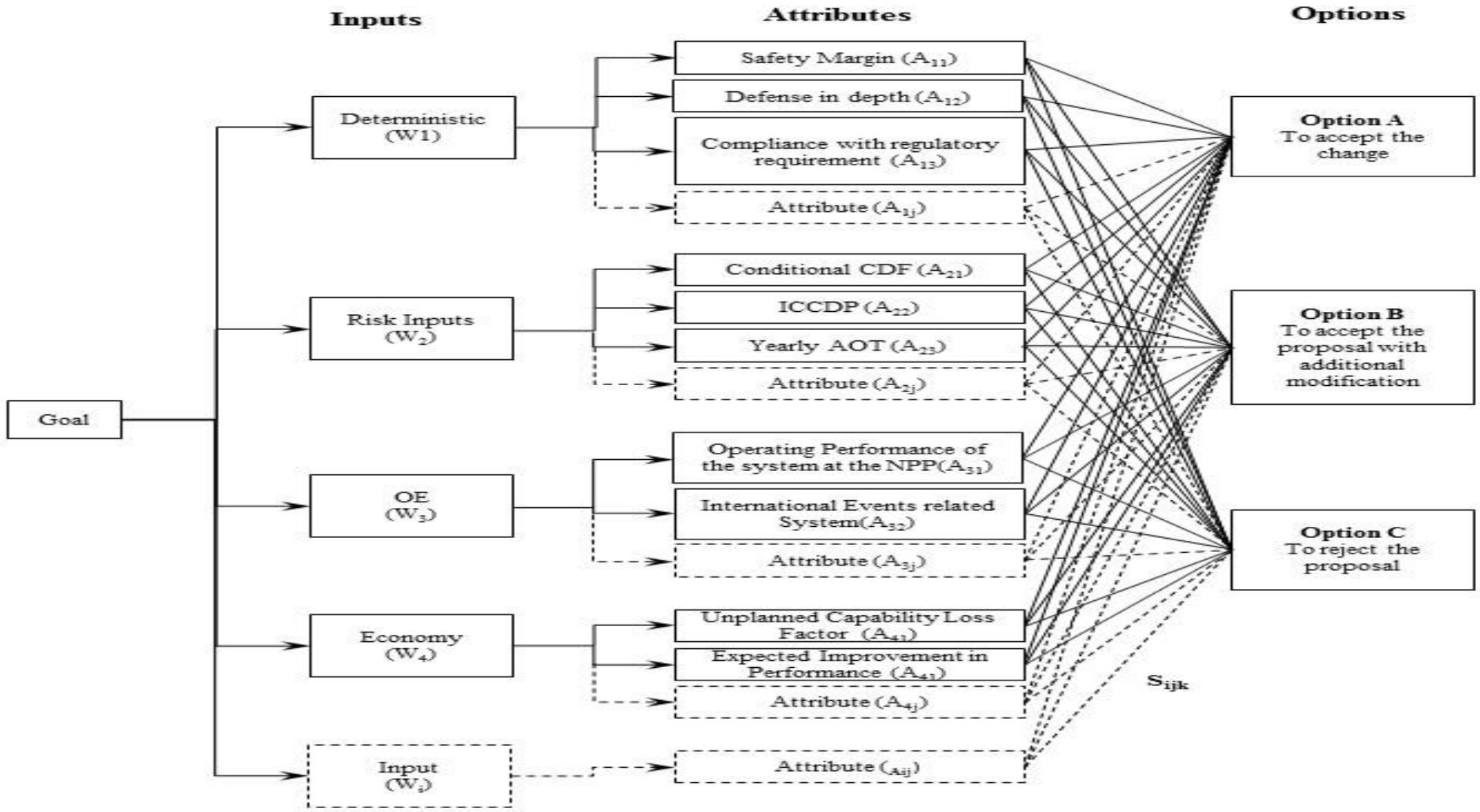
- Major decision alternatives identified for this case are:
  - ✓ Accepting the change, Denying the change, or Accepting the change after additional modifications.
- Four major inputs are identified for decision making of AOTs.
  - ✓ Deterministic ,Probabilistic, Operating experience and Economy

Attributes for Deterministic Input	• Sufficiency of the safety margin • Compliance to regulatory standards • Adequacy of DID
Attributes For Probabilistic Input	• Instantaneous Core Damage Frequency • Incremental Core Damage Probability and • Yearly AOT risk
Attributes For OE Input	• Operating Performance of the System at the NPP • International Events related to System
Attributes For Economy Input	• Unplanned Capability Loss Factor • Expected Improvement in Performance

Weightage Elicitation of Inputs and Attributes

- SMARTER method is proposed to be used, owing to its less subjectivity and yet easy application and accuracy.
- In ranking the inputs, the deterministic input is considered as the most important input followed by the probabilistic input. OE is ranked third and economy as fourth.
- For the significance order: Deterministic (W1) > Probabilistic (W2) > OE (W3) > Economy (W4), the SMARTER method would produce the weights as follows: W1= 0.521, W2= 0.271, W3= 0.146 and W4= 0.063.
- Similarly, the weightage elicitation for all the attributes can be done by various prioritization methods.
- SMARTER can be used to weigh the attributes for probabilistic, OE and economy inputs. Deterministic attributes can be weighed equally through direct rating since all three attributes have equal priority.

Value Tree Diagram for AOT



Value Elicitation for consequence factor

- For value elicitation, Consequence Factor of all the attributes has to be measured for each decision option.
- Qualitative attributes for deterministic input can be measured by direct rating. Direct rating of safety margin can be carried out by engineering judgment with respect to the compliance and consequences of exceeding the acceptable values of the corresponding safety parameters. In the case of evaluation for AOT, it can be considered enough if assumption made in final safety analysis are complied with.
- To assess the adequacy of DID, various elements have been identified by US NRC and the fulfilment of these can be the basis of rating.
- Quantitative attributes, in the case of probabilistic input, can be evaluated through identification of value function. Value function can be identified as a function X given by the following equation.

$$X = \frac{xa - xf}{xa - xi}$$

- The shape of the curve should also be specified in order to describe the relation between the X value and the Sijk. For example when any changes in the lower region of the parameter X space are more important to the decision makers then the changes of the same size in the upper region the concave curve should be chosen.
- Attributes for OE and economy similarly can be assessed either by identification of value function or direct assessment.

Software tool

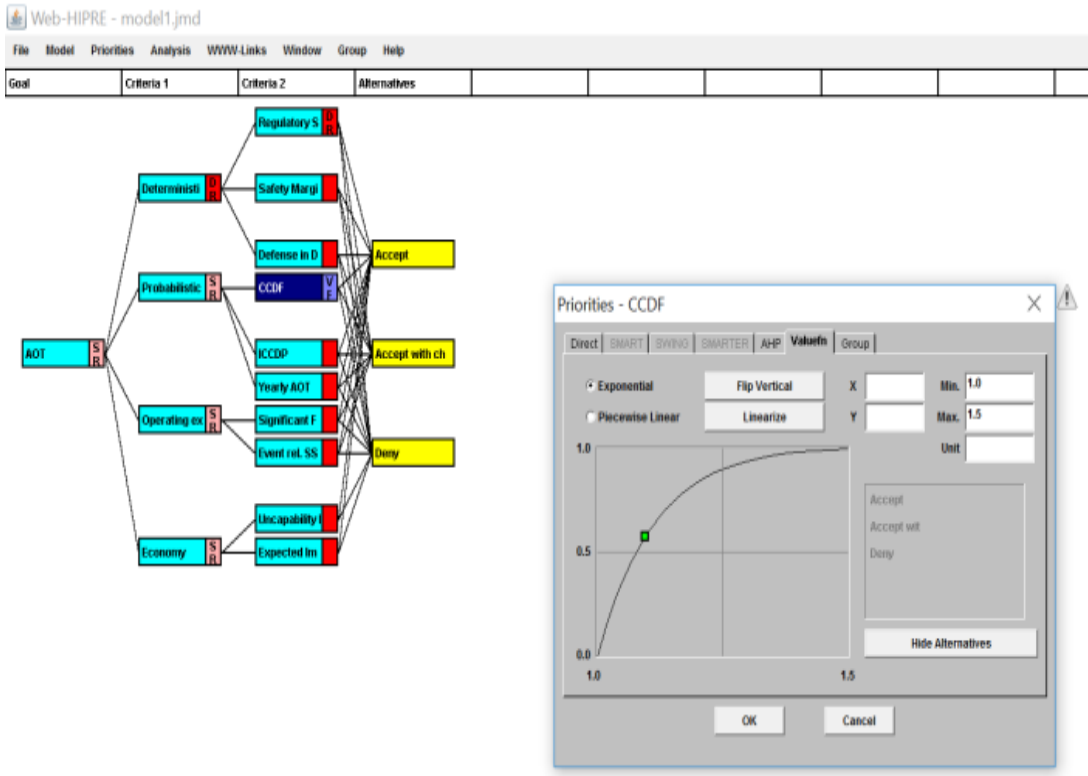


Fig. 2.Example for Value Elicitation for “Conditional Core Damage” attribute through value Function in Web-HIPRE

- HIerarchial PREference (HIPRE) is a software tool that can be used by decision makers for multi criteria decision analysis.
- It has visual graphical interface which is easy to understand.
- The prioritization methods available in HIPRE are based on Multi Attribute Value Theory.
- A decision problem is visually structured into a value tree of objectives/attributes. Each decision alternative is assessed in a performance matrix

Case Study : Consequence Factor Sheet

Consequence Factor Direct Assessment Sheet

Value Tree Analysis Approach for Integrated Risk Informed Decision Making: A Case Study for Revision of Allowed Outage Time

Expert names	SonalGandhi, Devendra,Nishikant,Monalisa
Division	Operating Plant Safety Division
Organization	Atomic Energy Regulatory Board

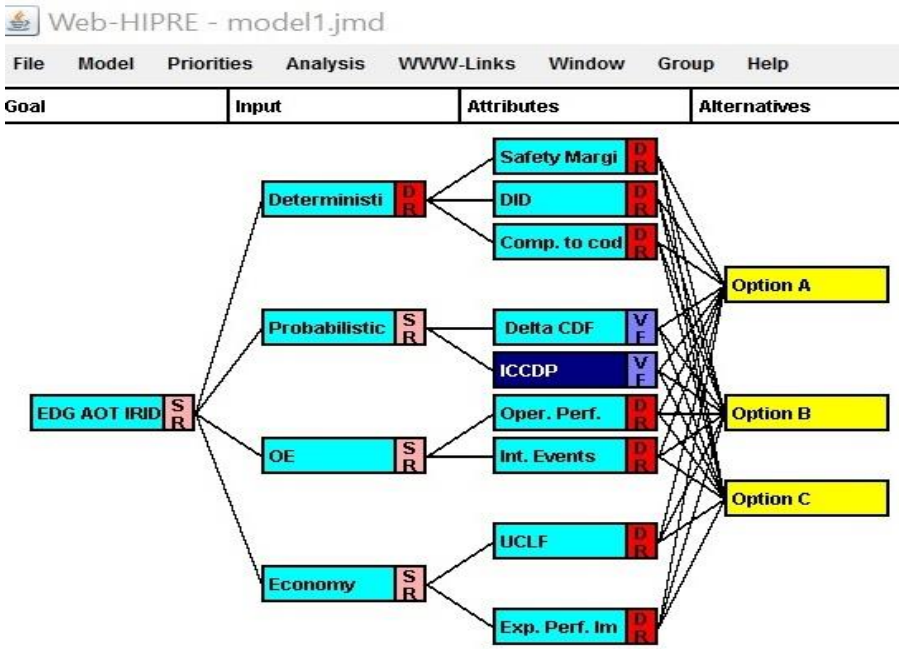
Purpose	This case study is to demonstrate the new approach to evaluation of various inputs to Integrated Risk Informed Decision Making (IRIDM) for Allowed Outage TIme (AOT) extension based on Value Tree Analysis methodology resulting in objective and transparent decision making.	
Description	Emergency Diesel Generator (EDG) are one of the most significant contributor to the core damge of Nuclear Power Plant. For the case study , extension of AOT of EDG is considered. The NPP under consideration have two EDGs (2 X 100%) providing class 1E power to the two independent Class 1E divisions. It has been proposed to extend the AOT of a single inoperable EDG from 72 hrs to 7 days.	
Major Inputs	To take decision, Deterministic,Probailistic,Operating Experience and Economy has been identified as major inputs. Moreover, respective attributes, to be evaluated through direct assessment ,of major inputs have been identified and listed in Table 1. The Weightage to these inputs and attributes have been assigned using Simple Multi Attribute Rating Technique Exploiting Ranking (SMARTER) and Direct Assesment method (see Table 1). Various Atributes of PSA has already been calculated through identification of value function thus are not part of this score sheet. Consequense factor for the remaining three inputs has to be assigned through Direct Assessment in this score sheet. The regulatory body has following three decision options :	
Option	Option A	Emergency Diesel Generator Allowed Outage Time Changed from 72 hrs to 7 Days
	Option B	EDG AOT Changes from 72 hrs to 7 Days but it should be ensured that the Alternate AC power (Non safety Class AC source of capacity equal to EDG) is available during EDG
	Option C	EDG AOT Remains unchanged
Consequence Factor	Consequence Factor (CF) for each attribute describes the effect that a chosen option will have on the given attribute. CF to each attribute for each option has to be assigned. **You are requested to assign CF to each attribute (in table 1) through a subjective judgement considering the aspects mentioned in the Table 2.** The value of CF will be from 0-1. Zero signifies major adverse effect on the attribute and CF of 1 is equivalent to no adverse effect on attribute.	
Evaluation	Once the values of CF for all attributes for each input are determined, best option with the highest score can be identified by the following equation $Sk = \sum W_i \sum A_{ij} X S_{ijk}$. Where, the relative importance for ith input is given by W_i and the relative importance of the jth attribute for the ith input is given by A_{ij}. S_{ijk} is the CF that describes how the implementation of the kth option would affect the jth attribute of ith input.	

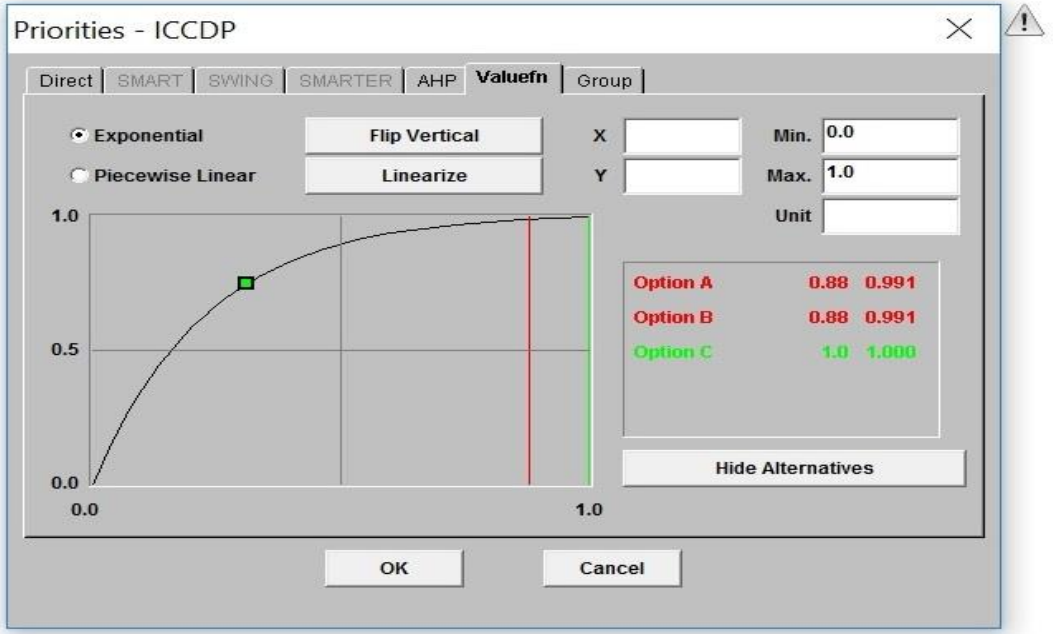
Table 1: Direct Assessment of Consequence Factor

INPUT	Weightage Elicitaion of Inputs	ATTRIBUTE	Weightage Elicitaion of Attributes	CONSEQUENCE FACTOR (CF)		
				Option A	Option B	Option C
Deterministic	W_1= 0.521	Safety Margin	A_{11} =0.333	0.95	1.00	1.0
		Defense in Depth	A_{12}=0.333	0.75	0.88	1.0
		Compliance with Regullatory Requirement	A_{13}=0.333	0.80	0.90	1.0
Operating Experience	W_2= 0.146	Operating Performance of the EDG at the NPP	A_{21}=0.750	0.73	0.90	0.5
		International Events related to EDGs	A_{22}=0.250	0.67	0.75	0.6
Economy	W_4= 0.063	Unplanned Capability Loss Factor	A_{41}=0.750	0.88	0.78	0.4
		Expected Improvement in Performance	A_{42}=0.240	0.80	0.78	0.6

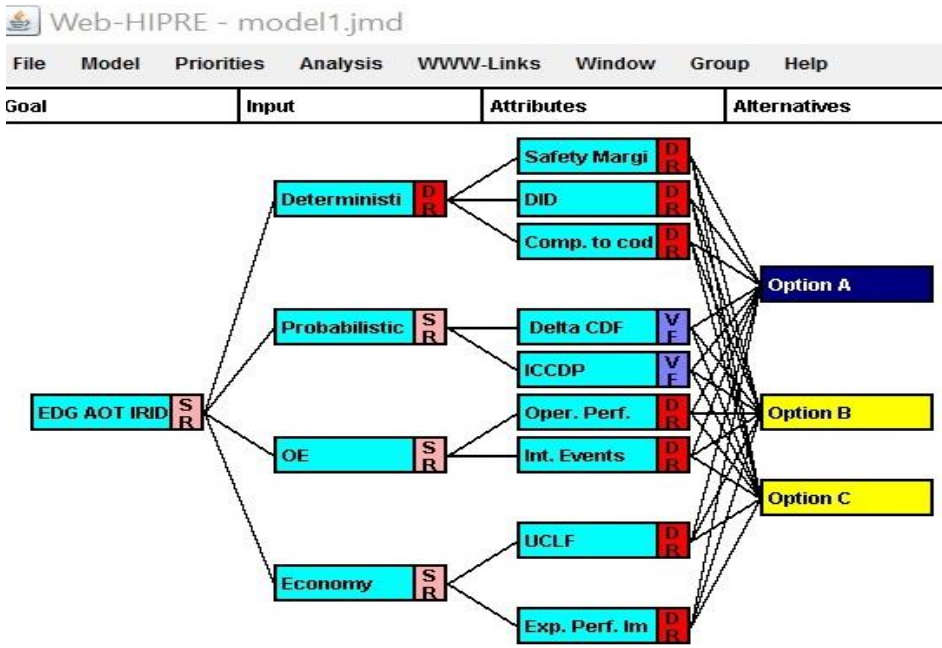
Table 2: Consideration during the estimation of CF for each attribute

Case Study: Value Function Elicitation of ICCDP





Case Study : Composite Analysis



Conclusion

- It is a systematic approach for the input evaluation and for weight assignment to each input evaluation and for weight assignment to each input and attribute.
- This approach significantly makes the IRIDM process well-structured and easier to apply.
- Present work puts forward a methodology of risk informed decision making for extension of Allowed outage time (AOT) of Safety System.
- The value tree approach complements the existing IRIDM framework proposed by IAEA. It also increases the accountability and auditability of decisions.

사단법인 한국원자력학회
KOREAN NUCLEAR SOCIETY

Thank you for your attention

Questions or comments are welcomed!

KOREA INSTITUTE OF NUCLEAR SAFETY

KAIST