MULTI-CRITERIA DECISION SUPPORT IN DISTRIBUTION SYSTEM ASSET MANAGEMENT

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ABSTRACT

There is an increased awareness among distribution companies that new tools and methods are needed to support their decision making. This paper presents ongoing research, reporting on introducing Multi Criteria Decision Analysis to decision-makers, by testing it on a simplified decision case.

INTRODUCTION

Asset management in energy/electricity business is a complex decision making process. Originally used in the financial industry the term denotes the art of trading-off risks and returns. However, the management of energy industry assets requires a different approach. Unlike the financial assets, energy distribution assets require maintenance and replacement and they are a part of a highly complex interconnected system. Asset management in energy industry has therefore gained an extended meaning as the art of balancing cost, performance and risk [1]. Achieving this balance requires the alignment of corporate objectives, management decisions and technical decisions.

The decision-making hierarchy for distribution systems asset management covers three functional decision levels: the asset owner, asset manager and asset service provider [1]. Owners focus on corporate strategy, managers focus on planning and budgeting and service providers focus on the operation of the distribution system. In this context, asset management is the process that links owners, managers and service providers in a manner that allows all decisions to be aligned with the corporate objectives.

One of the essential problems in today's asset management is to find which the best maintenance strategy among the following: replacing after failure, upgrading and refurbishment or total replacement. The complication appears when these alternatives must be judged based on many criteria, some less tangible (public opinion, regulatory risk, politics) than others (costs, profits).

Risk and uncertainties add another dimension to the decision making process. A decision maker must take into consideration the fact that the impacts of a decision are uncertain. Uncertainty resides both in the fact that most assumptions that drive the decision (future loads, prices, decision preferences, etc) may turn out to be wrong, and also in the fact that some events in the future are difficult to predict but have significant impact on the outcome of a decision (e.g. environmental / climatic stress).

This paper reports ongoing research in this field at SINTEF Energy Research, investigating the use of multi-criteria decision analysis (MCDA) in supporting decision-making for distribution system asset management (DSAM).

on multi-criteria decision analysis

Multi-Criteria Decision Analysis (MCDA) is the discipline that studies methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the management planning process.

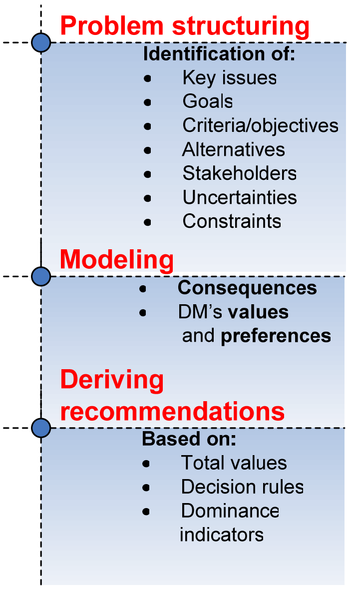
The use of MCDA in DSAM is justified by the simple fact that not all aspects that matter (and must be considered) in distribution system asset management can easily be given a monetary value. When using MCDA light can be shed on what tradeoffs, uncertainties and value judgments are crucial to the decision and what issues do not matter.

MCDA is a process which seeks to help decision makers (DMs) learn about and better understand the problem they face, their own values and priorities and the different perspectives of other stakeholders. Practice showed that MCDA's recommendations are often at least as good as the choices based on intuition (as most decisions are made) [3].

The MCDA process (Figure 1) starts with problem identification and structuring. Sometimes, in real-life decision situations goals are not so clear, nor the options that will satisfy these goals in the long run. MCDA can thus help DM's in understanding what they really want to do, ensuring that they look at the 'right problem'.

The next step is modeling. There are two types of modeling for MCDA: the modeling of *consequences* (*impacts)* each decision may have in terms of the relevant goals and the modeling of *decision-makers' preferences* regarding their options (decision alternatives) with respect to the chosen goals.

Figure 1 The MCDA process



Preferences in terms of each individual criterion and preferences across criteria will be aggregated into a preference model or *value model*.

A *value model* focuses on and clarifies many complex issues. For example it is usually not possible to achieve the best level to all objectives in a decision situation. The question then is: *''How much should be given up with regard to one objective to achieve a specified improvement in another?''* Moreover in circumstances that could lead to relatively undesirable consequences with any given alternative, an important factor that contributes to the decision, and that can be modeled, is DM's risk attitude.

Thus, the advantage of a multi-criteria approach is that both value tradeoffs and risk attitudes can be explicitly addressed. The scope is to provide insights into a complex situation and to complement intuitive thinking.

A PILOT CASE-STUDY

To exemplify how MCDA can be used in DSAM, a pilot case-study has been developed, in collaboration with the main energy distribution company in the city of Trondheim.

The decision problem

The problem was to decide which is the best maintenance strategy (maintain or replace) for the existing switchgear equipment (air insulated breakers) in an in-house MV/LV substation located in an urban area. The building accommodating three circuit breakers, a transformer (315kV, oil-filled) and additional equipment, is in a rather poor condition. The roof and the foundation are deteriorated allowing water infiltrations. The humid environment has a negative impact on the installations inside the building. There have been registered partial discharges on the cable terminations connected to the circuit-breakers. The equipment of this substation has been under surveillance and several events have been reported:

- *Circuit-breaker A*: discharges (partial spark-over) and corrosion observed since 2002; no failure reported until now.
- *Circuit-breaker B*: spark-over followed by failure recorded in 2004. The cable terminations have been damaged. The circuit-breaker and cable terminations have been replaced in 2004.
- *Circuit-breaker C*: corrosion and damaged cable terminations; failure was recorded in 2006 and has not yet been repaired.

The discussion with the DM has revealed the lack of a formal decision-support procedure for finding which would be the best maintenance strategy: *replacing* after failure, *upgrading* and *refurbishment* or *total replacement*?

Problem structuring

Identification of criteria

The DM needed to decide over a maintenance strategy by considering several issues: *costs*, *safety* of personnel, distribution network's *reliability* and *public opinion*.

Identification of alternatives:

The DM took an active part in identifying possible actions. Six alternatives have been identified:

1. **New substation**: Replace the existing substation with a new one;
2. **Partial rehabilitation** of the existing substation: change the damaged switches and cable terminations;
3. **Total rehabilitation** of the existing substation (changing switchgear and renovate the building);
4. **Relocation**: remove and rebuild the substation in another location, not in the sight of the public (total removal is not an option);
5. **Change** to SF_6 insulated **circuit-breakers;**
6. **Take no action**.

Modeling consequences

The first challenge was to measure consequences by using these criteria, in a way that would make comparisons among different consequence levels meaningful.

For the *cost* criterion, estimations based on the current procedures and practice in the distribution company, have been used.

Safety issues related to the operation of air-insulated switchgear in sub-stations have been divided into minimizing the *risk of injuries* when operating circuit-breakers and minimizing the *risk of intoxication* (by inhaling nitric acid and ozone resulting from partial discharges on cable terminations). A first step in estimating safety risks was to analyze the technical condition of the equipment and the working procedures, as proposed in [5]. The risk levels have been classified by observing the probability of an event and its consequences. It has been assumed that the probability of an event depends on both the design and the state of the installation at a given moment and on how often people are present near the installation. The consequence depends on work protocols and safety measures if any. In this case-study, a risk matrix has been used, as proposed in [5]. Base on experience, the DM estimated possible consequences for each alternative, for the 'personal safety' criterion. A scale from 1(small) to 5(large) has been used to indicate the probability and the seriousness of consequences.

Table 1 The risk matrix

Risk level		Consequence of event				
		1	2	3	4	5
Probability of event	1	Small	Small	Small	Small	Medium
	2	Small	Small	Medium	Medium	High
	3	Small	Medium	Medium	High	High
	4	Small	Medium	High	Very high	Very high
	5	Medium	Medium	High	Very high	Very high

The *reliability of supply* from this substation has been measured through the expected cost of energy not supplied (CENS). Both residential and commercial customers are connected to the substation and a relatively high penalty cost (6000 NOK/h) has been the basis for estimations. It has been supposed that in alternatives proposing partial rehabilitation have a higher probability of interruptions.

Public opinion is strategically important, because a negative reputation can affect company's activity in other businesses: cable TV provider, internet access provider, etc. Public opinion was an issue of concern for DM because the substation under analysis is located in a frequented area close to the center of Trondheim.

Figure 2 shows a recent picture taken of this substation. The decision maker knows from experience that a negative aesthetical impact may trigger a negative public opinion, especially if it is associated with electricity price increases and occasional lower power quality and reliability.

Figure 2 The substation

To measure public opinion we supposed in this example that we can assign a numerical indicator to several possible impact levels. The following scale was chosen: ***1*** public support, ***0*** neutrality, ***-1*** controversy (the public is against, although nobody takes opposing action), ***-2*** action oriented position and ***-3*** strong action oriented position.

For example it has been supposed that if no action is taken and the substation will look and function as it is today, then it has a negative visual impact (painted, damaged building) and causes frequent interruptions, the *public opinion* is set to the lowest level.

The consequences of the six alternatives in the five criteria considered are summarized in Table 2. The decision maker has played an active role in building up the consequence table by providing the cost data and by estimating the effect of every decision alternative on safety, reliability and public opinion.

Table 2 The table of consequences

ALTERNATIVES	CRITERIA				
	Economy (cost, NOK*)	**Reliability** CENS (NOK*/year)	**Safety**		**Public opinion**
			Risk of injuries	Risk of intoxication	
1. New substation	560 000	small	small	small	1
2. Partial rehabilitation	99 000	40 000	medium	medium	-2
3. Total rehabilitation	430 000	small	medium	small	1
4. Relocation	700 000	small	small	small	0
5. Change circuit-breakers	270 000	medium	medium	medium	-2
6. No action	0	60 000	Very high	Very high	-3

*NOK = Norwegian krone, CENS = Cost of energy not supplied

Modeling values

As mentioned in the introductory chapter, MCDA provides support for modeling decision-makers' preferences or values. These values are the result of an extensive analysis process and represent the most important ingredient which contributes to the final decision. There are many methods and software that can be used to construct value models in energy-related decisions [3, 4], and for this test case we choose the software PRIME Decision, available for educational purpose at [6].

The use of this software resumes to three procedural steps: *problem structuring*, *preference elicitation* and *issuing a recommendation*. The advantage with PRIME is that it allows consequences to be described qualitatively and values to be defined imprecisely (in terms of intervals).

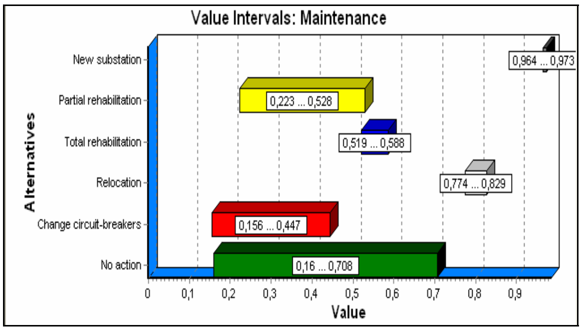
In this test case the DM has been asked to provide two types of preference information: single-criterion assessments and (inter-criteria) weight assessments. Single-criterion assessments consist of ordinal ranking (defining the preference order of consequences) and cardinal ranking (information about the strength of decision-maker's preferences, specified as a ratio with an upper and lower bound).

The second phase in preference elicitation was the assessment of weights. The weight of a criterion is the gain in overall value obtained by a change from that criterion's worst consequence to its best one. SWING with intervals is used as weighting method [7].

Issuing a recommendation

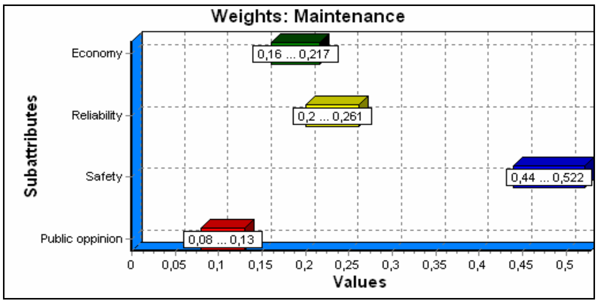
In PRIME Decisions DM's preferences have been used as input into a series of optimization sub-problems on values [6], and the results have been obtained in terms of total value intervals (see Figure 3) for each alternative. The spread of a value interval shows the uncertainty (or imprecision) in judgments and it depends on how much preference information DM has provided.

Figure 3 Value intervals



One can observe that alternative 1 (New substation) clearly dominates the others. This result can be easily justified, looking at DM's preferences. Figure 4 shows that the most important criterion for the DM was safety, then system reliability, economy and public opinion.

Figure 4 Weight intervals



When valuing the consequences in each criterion, the DM considered alternatives with very high safety risk as unacceptable. Therefore any reduction from any risk level to a lower one has been assigned a high value. Regarding the reliability criterion, the preferences were for lower cost levels. The same thinking applied to the economy criterion. Public opinion has been valued in such a way that public support and neutrality have been preferred.

Alternatives with the highest values for the DM were the ones with a low safety risk but also the most expensive ones. One can also observe that the DM was more imprecise and valued almost equally low the alternatives proposing partial rehabilitation or no action, when compared with the others (although these alternatives were the cheapest).

PRIME provides additional analysis possibilities allowing the DM to modify preferences if needed, but also to distil the results in the view of different decision rules (Maximax, Maximin, Central Values, and Minimax Regret).

CONCLUSION

This paper reports ongoing research in the field of decision support for distribution system asset management. The goal was to introduce the way of thinking support by MCDA to decision makers. The results are promising in the sense that the method applied has been found appealing by the DM involved. The advantages of such decision support procedure have been twofold:

1. the possibility to structure and take into consideration the most important (but sometimes intangible) issues has been considered very valuable.
2. DM appreciated the possibility to clarify, visualize and document preferences.

The logic behind investments in distribution networks must be clear, transparent and justifiable and MCDA can support the evaluation of options in the view of conflicting issues.

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