Risk Based Decision for Reinvestments in Distribution Systems

M. K. Istad, D. E. Nordgård, O. Gjerde, M. D. Catrinu, A. Nybø and B. E. Birkeland

***Abstract*--This paper illustrates the challenges associated with risk assessment for reinvestments decisions. A holistic framework for risk assessment in electricity distribution systems will be described first and then used to structure the analysis and decision making in a case study concerning cable reinvestment. These decisions are generally multi criteria decisions, including risks related to e.g.; economy, environment, reputation, safety and quality of supply.**

The paper describes the use of different types of decision support tools used to aid reinvestment decision making in electricity distribution systems, with emphasis on multi criteria decision analysis (MCDA).

***Index Terms*--Decision support, electricity distribution systems, estimation of probabilities, multi criteria decision analysis, reinvestment decisions, risk assessment**

I. Introduction

SUBSTANTIAL changes have taken place in the electricity distribution sector in Norway during the last 15 years since the deregulation of the sector, which was introduced by the revised energy act of 1991.

During the deregulation period there has been increasing focus on cost cutting, and the regulatory regime has given economic incentives towards extending the lifetime of existing components and postponing reinvestments. This has resulted in an increasing average age of the distribution network components [1], and the existing system infrastructure is operated closer to its limits. This stresses the importance of maintenance and reinvestments in the network.

There is an increasing focus on whether or not the distribution companies are still performing their business with acceptable risk. The principles of risk assessment are therefore recognized as relevant tools for decision support in the electricity distribution sector, when making decisions regarding maintenance and reinvestments in the network [2].

Such decisions usually include multiple, and often contradicting, decision criteria. The decision criteria typically involve economy, environmental concerns, company reputation, safety and quality of supply [2].

There is a need to balance cost effectiveness and risks for the distribution companies; seeking solutions where all different risks are being sufficiently taken care of [2]-[3].

M. K. Istad (e-mail: maren.istad@sintef.no), O. Gjerde, M. D. Catrinu and A. Nybø are with SINTEF Energy Research, NO-7465 Trondheim, Norway.

D. E. Nordgård is with the Norwegian University of Science and Technology, NO-7491 Trondheim, Norway and B. E. Birkeland is with Fredrikstad Energinett AS, NO-1616 Fredrikstad, Norway.

This paper first describes a framework for risk assessment in distribution systems. It further exemplifies how to use this framework to provide a risk informed decision basis for a reinvestment case study and how to incorporate this into a multi criteria decision support procedure. Finally some key challenges regarding the use of risk assessment in this context are pointed out.

II. Risk Assessment

During the last decade the electricity distribution sector has been increasingly focused on the principles of *asset management*. The concept and discipline of asset management in general has evolved during the same period of time, collecting input from a number of industrial sectors. *Risk assessment* is an integrated and important part of asset management. In this paper *risk assessment* is defined as by ISO/IEC in [4]: *the overall process of risk analysis and risk evaluation*. In addition, the decision making process is included.

Fig. 1 shows a proposed framework for risk assessment for distribution systems [2]. The framework contains three main phases; *risk study planning, risk identification* and *risk modelling, analysis and decision making*. In addition *risk communication* is important in all phases of risk assessment, as illustrated to the right in the figure.

Risk study planning involves defining and limiting the problem to be analyzed. It is important to formulate objectives and restrictions, as well as the time horizon for the study. For communication purposes a common terminology should be established and agreed upon.

Risk identification is the process of finding, listing and characterizing sources of risk and identifying unwanted events and possible unwanted consequences.

Risk modelling, analysis and decision making include choosing risk analysis methods and models to be used in the analysis and assigning values to the probabilities and consequences of risks. An evaluation of whether risks are acceptable or not must also be performed. In addition, ways to treat unacceptable risk is addressed.

Risk communication is important in all phases of the total process and involves exchanging or sharing of information about risk between the analyst/decision maker and other stakeholders.

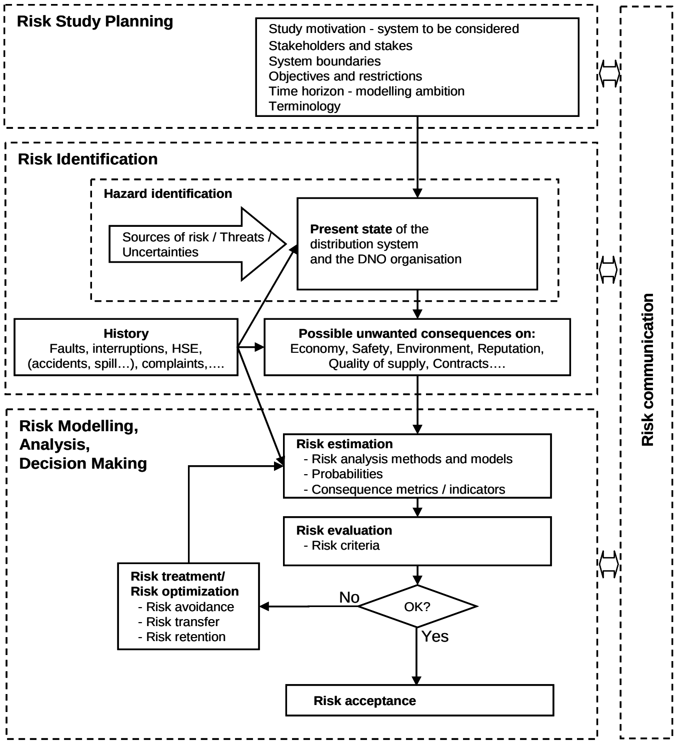


Fig. 1. Framework for risk assessment for distribution systems [2].

III. Description of the Case Study

In the following the framework in Fig. 1 is used to perform a risk assessment for the case described below. The case concerns cable failure and a subsequent reinvestment decision which has to be made as a consequence of this failure.

A. *Risk study planning*

During the summer of 2007, one out of three cables supplying a group of islands at Hvaler, outside Fredrikstad in Norway, failed. The supply and voltage conditions during peak load are tolerable in this situation, but an additional failure of one of the two remaining cables will, according to load flow analysis, result in voltage and supply problems. Prior to the failure, Hvaler was divided into three areas where cables 1, 2 and 3 supplied one area each; hence the cables served as backup for each other. Since cable 2 failed, there are now only two areas with 18 kV networks, as illustrated in Fig. 2. Area 1 is supplied by cable 3, while area 2 is supplied by cable 1. The two areas are supplied separately, but can be connected if any of the two remaining cables fails. The total peak load for area 1 and 2 is approximately 7 MW.

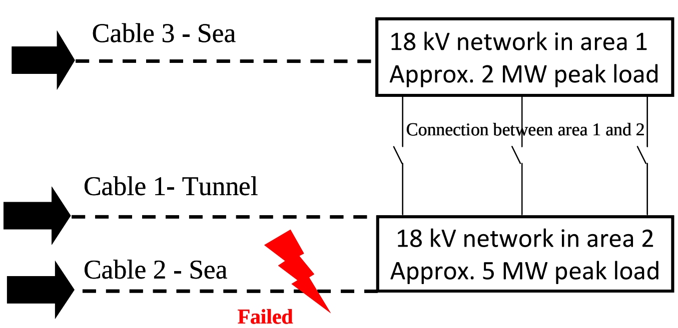


Fig. 2. The area in question supplied by cables 1, 2 and 3.

It is considered not to be a feasible solution to repair cable 2. This cable also failed in 1995 and it was then concluded that the cable was approaching its end-of-life. However, the cable was repaired and has been in operation until the summer of 2007. Information about the cables can be found in Table I. Table II summarizes some key information from the risk study planning.

TABLE I
Cable Information for the Case

	Cable 1	Cable 2	Cable 3
Type (insulation)	TXSP 1x3x95Al (XLPE)	HKRA 1x3x50Al (Mass impregnated)	DKBA 1x3x95Al (Mass impregnated)
Rated voltage [kV]	24	24	24
Trace	In tunnel	In sea	In sea
Length [km]	3.84	1.65	1.03
Installed (age)	1990 (17 years)	1960 (47 years)	1977 (30 years)
Comments	Condition unknown	Failed in 2007 Also failed in 1995	Condition unknown

TABLE II
Risk Study Planning

Stakeholders and stakes	Distribution network operators: Increased cost, bad reputation and poor reliability Customers: Interruptions and poor voltage quality
System bounderies	The area in question is the 18 kV network illustrated in Fig. 2. The supply to this area is not included in the analysis.
Objective	The objective is to maximize the utility for the stakeholders, hence find out whether or not to reinvest and when to do this.
Time horizon	A time horizon of 30 years is used in the net present value analysis.

B. *Risk identification*

The following sources of risk have been identified for this case study:

- The condition of cables 1 and 3 is unknown. In addition, various future hazards which are difficult to predict, might trigger failures of the cables.
- Future load increase in the area and uncertainty in the estimates of the load duration curve.

Failures of cable 1 or cable 3 are unwanted events that will have a direct effect in the energy supply to Hvaler, with unwanted consequences for:

- Economy: Cost of energy not supplies (CENS) [5] and repair costs.
- Quality of supply: Supply and voltage problems.
- Reputation: Bad publicity in the local media because of interruptions, unsatisfied customers.

IV. Risk Modelling, Analysis and Decision Making

The last phase of the framework in Fig. 1., *Risk modeling, analysis and decision making,* is described in this chapter.

A. *Input data*

As an input to the analysis of the supply to Hvaler, the failure rates of cable 1 and cable 3 were estimated. Available sources of information were statistics and expert judgements. Different sources for failure rates for XPLE cables, relevant for cable 1, are shown in Table III. Cable 1 is buried next to the road in a tunnel and some of the threats that this cable is exposed to are:

- Ageing
- Possible damage from previous blasting in the tunnel
- High number of cable joints.

TABLE III
AVERAGE FAILURE RATES FOR XLPE CABLES

Failure rate [failures/100 km year]	Comments	Sources
2.1	Applies to 1-22 kV cables, XLPE insulated in soil, water and air, both internal and external failure causes	[6]
0.84	Applies to 24 kV cables, XLPE insulated in soil, water and air, only internal faliure causes	[7]

The statistics diverge, as can be seen from Table III. Based on expert judgements it was assumed that the cable is in worse condition than the average failure rate reported in [6]. For the case analysis the following failure rates were chosen:

- Minimum: 0.8 faliures/100 km year
- Average: 2.5 failures/100km year
- Maximum: 5 failures/100 km year.

The same was done for cable 3 and the failure rates from different sources for mass impregnated cables are shown in Table IV. Cable 3 is a submarine cable and some of the threats that this cable is exposed to are:

- Ageing
- Anchoring boats
- Ice
- Increased mechanical forces resulting from uneven seabed conditions.

TABLE IV
AVERAGE FAILURE RATES FOR MASS IMPREGNATED CABLES

Failure rate [failures/100 km year]	Comments	Sources
1.1	Applies to 1-22 kV cables, all insulations in water, both internal and external causes	[6]
5	Applies to 24 kV cables, 30 years old, mass impregnated in soil, water and air, only internal causes	[8]
1.2	Applies to 10 kV cables, 30-40 years old, mass impregnated in soil, water and air, only internal causes	[9]
0.32	For 137 submarine cables from the 1980's	[10]

Altogether this cable was estimated to be of average condition for a 30 year old mass impregnated cable as suggested in [8]. This source consider only internal failure causes, like for instance aging, hence an addition of 10 % to this average failure rate was used to include external failures causes, like anchoring boats and ice. For the case analysis the following failure rates were chosen:

- Minimum: 1.1 failures/100 km year
- Average: 5.5 failures/100km year
- Maximum: 11 failures/100 km year.

The cost of energy not supplied (CENS) to be used in the analysis was found using load flow analysis and the experience of the distribution company.

The outage cost will be lower if cable 3 fails because the interrupted load is then expected to be approx. 2.5 MW, compared to approx. 5 MW for cable 1. The type of load affected also differs for the two cables. If cable 1 fails the CENS is estimated to be 145 000 NOK/hour, while if cable 3 fails the CENS is estimated to be 42 700 NOK/hour. Both the repair time and repair cost for cable 3 is considered to be higher than for cable 1, since cable 3 is a submarine cable. The total interruption cost, including both CENS and repair costs, is estimated to be 1 500 kNOK for both cable 1 and cable 3.

The investment cost for a new cable was found to be 4 000 kNOK according to a call for tenders made by the distribution company.

B. Analysis methods to help decision making

This paper highlights a decision situation often encountered by asset managers (AM) in electricity distribution companies. In this case, the challenge the AM faces is to make a decision on *whether or not* and if applicable *when* to reinvest in a new cable, given limited information about several key issues: the probability of failure of the two remaining cables, future load increase in the area, etc.

In this chapter, methods to aid the decision making are presented. Load flow calculations, statistical analyses for estimating the probability of cable failures and economical calculations, like Net Present Value (NPV) calculations, have been used.

In the following economical calculations and multi criteria decision analysis (MCDA) are presented.

C. Economical calculations

NPV calculations are used to analyze an investment by looking at the expected future cash flow. As a rule, if the opportunity window for investing is now (i.e. "invest now or never"), a company should invest if the NPV is positive [11]. This translates in our case into investing if the PV (present value) of the investment cost is less than the expected costs of not reinvesting.

In the NPV calculation for this case study the following cost elements were considered:

- Investment cost
- Interruption costs, including cost of energy not supplied (CENS) and repair costs.

It was assumed that regardless of the decision the operation and maintenance costs and the costs of power losses were unchanged and was not included in the analysis. Further, the failure rates for both cables were added and a fixed interruption cost of 1 500 kNOK was used no matter which of the cables that fails as explained earlier.

Three values for the failure rates were used in the calculations, the minimum, average and maximum failure rates estimated in the previous sub-chapter. In addition, for the average failure rate, a 5 % yearly increase in interruption costs, due to increasing failure rate and load, was investigated. A time horizon of 30 years was used in the analysis and a real interest rate of 6 %.

NPV calculations have been performed for the four different assumptions of failure rates and the results are shown in Fig. 3. For the average failure rate, the reinvestment has a negative NPV of about 850 kNOK assuming no increase in interruption costs with time, while assuming a 5 % yearly increase implies a positive NPV approaching 2 000 kNOK.

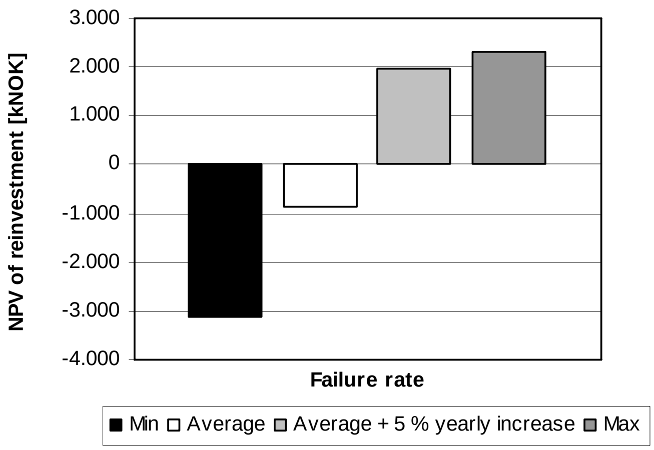


Fig. 3. Net Present Value of reinvestment now (compared to not reinvesting) assuming different failure rates.

Other important information that can be derived using NPV calculations is *when* to reinvest. The timing of the reinvestment will consist of a trade-off between the immediate cost (investment) and the future cash flows.

For the average failure rate with a 5 % yearly increase, the result of this analysis suggests investing in year 5, as shown in Fig. 4.

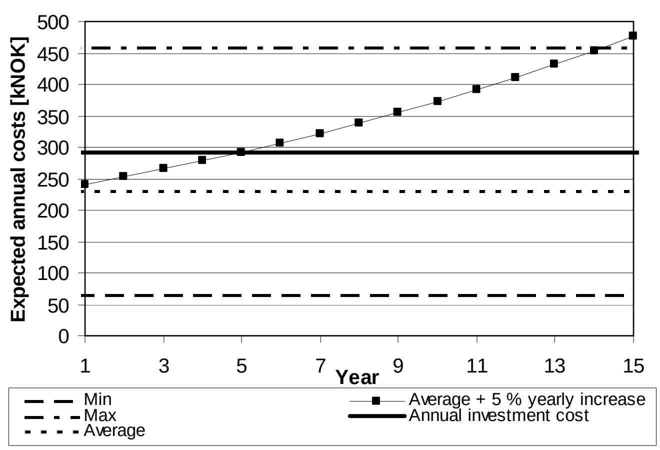


Fig. 4. Comparing the annual interruption costs with the annual cost of the investment.

Up to this point in the case study all the ordinary tools have been used: load flow analysis, analysis of statistical data, economical calculations, etc. However, the information needed for the final decision is still scattered and some questions need further analysis: Did we used the 'right' statistics? Do the 'right' statistics exist? Have all relevant risks been considered? What about public opinion?

In order to gain a better overview of these issues, Multi criteria Decision Analysis (MCDA) techniques were used. MCDA can be applied in a final stage in the case analysis when all information obtainable through other techniques have been gathered and documented in a structured way, allowing a final decision to be made.

D. Multi criteria decision making

MCDA techniques are a set of tools that can be used as decision support in decision situations where several criteria have to be taken into consideration simultaneously. MCDA can help AM to get a better structure and overview of all the calculations and available information.

In this case study, the AM had to decide whether to:

- Not reinvesting
- Reinvest now
- Reinvest later.

The economic calculations in the previous sub-chapter suggested a reinvestment in year 5. However, because this alternative implies a certain level of risk of power interruption and negative public opinion the AM decided to compare it further with *Not reinvest* and *Reinvest now*.

The three alternatives have been compared in terms of two economic criteria (*Investment cost*, *Expected Interruption costs*), *Public opinion* and *Uncertainty*. Table V summarizes the data available for the three alternatives considering the four criteria.

TABLE V
ALTERNATIVES AND CRITERIA

	Investment cost	**Interruption cost**	**Public opinion**	**Uncertainty**
Not reinvesting	0 NOK	High	Negative	High
Reinvest now	4000 kNOK	Low	Unchanged	Low
Reinvest in 5 years	4000 kNOK in 5 years	Medium	Decreasing	Medium

The economic calculations discussed previously have been used as basis for estimation the investment and interruption costs of each alternative.

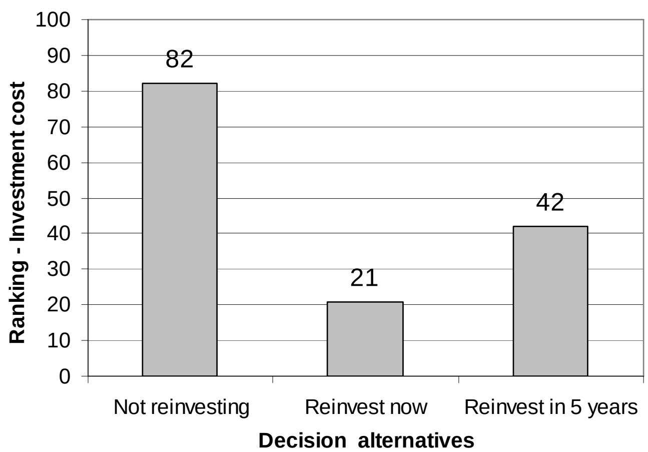
Public opinion has been estimated as the following:

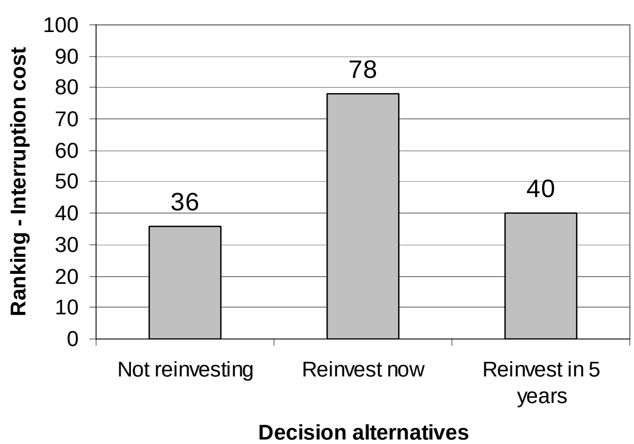
- Negative (and decreasing sharply) for the alternative *Not reinvesting*
- Unchanged (with potential for improvement) for the alternative *Reinvest now*
- Decreasing for the alternative *Reinvest in 5 years*.

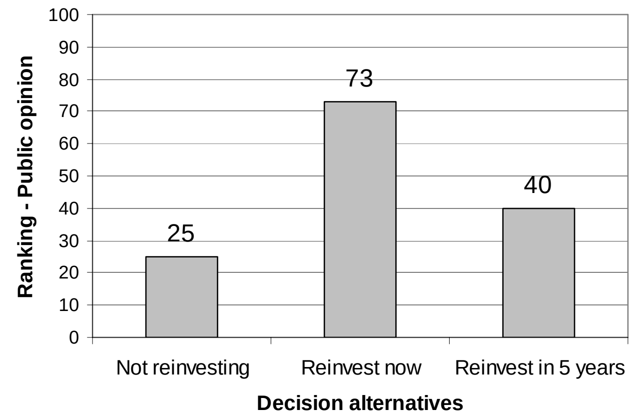
The level of *Uncertainty* associated with each alternative has been 'qualitatively' estimated as in the following: The economic and public opinion damage caused by cable failure is very uncertain. The distribution company might experience several cable failures during the next couple of years, or none at all for a long period of time. Therefore, the uncertainty of *Not reinvesting* (operate with only cables 1 and 3) is considered to be higher than the uncertainty of *Reinvest in 5 years*, while the alternative *Reinvest now* considerably diminishes the level of uncertainty.

The final analysis of the alternative for the relevant criteria has been carried out using a MCDA decision support software called V.I.S.A. [12]. This tool facilitates the representation of the decision problem in terms of alternatives and criteria in a way that is both visual and interactive. The decision support process had two main steps:

(i) *In the first step, the AM compared the alternative in terms of each criterion* – using Table V - and ranked them on a scale from 0 to 100. The AM has done this according to her preferences and the results are shown in Fig. 5. It can be observed that when it comes to economic criteria, lower levels of costs have been preferred. Thus *Not reinvesting* is the most preferred alternative in terms of *Investment cost* while *Reinvest now* is the most preferred alternative in terms of *Interruption cost.* When it comes to *Public opinion* and *Uncertainty* criteria, the alternative most preferred is *Reinvest now* because it offers the higher potentials for improvement in public opinion and in uncertainty reduction.







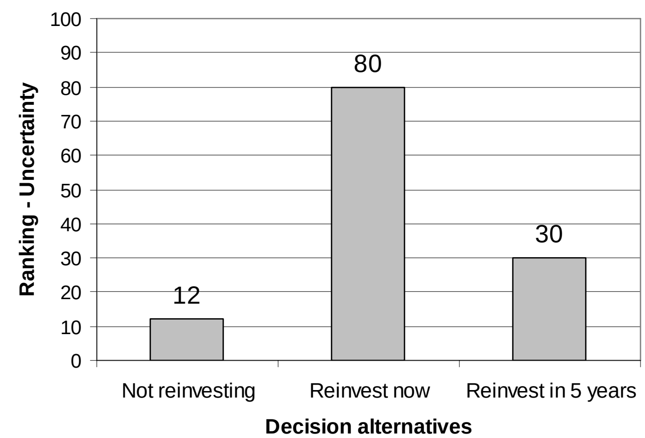


Fig. 5. Ranking alternatives in terms of each criterion.

(ii) *The second step in this process was the weighing of criteria* using a normalized scale from 0 to 1 [13]. The preferences of the AM decide the weights shown in Fig. 6. Here it can be observed that *Uncertainty* and *Public opinion* were the most preferred criteria followed by the economic ones.

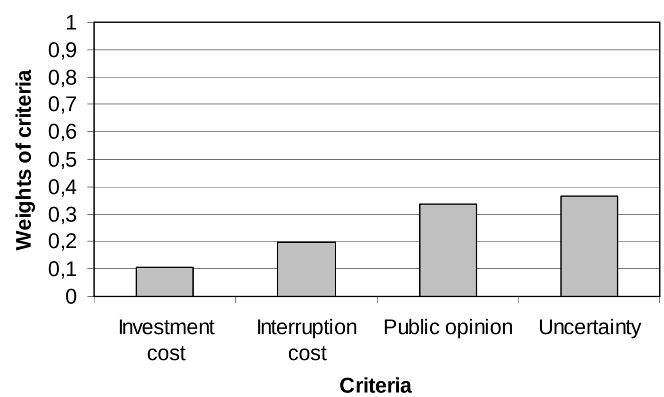


Fig. 6. Criteria weights.

The combination of the scores of the alternative and the criteria weighing leads to the following ranking of the alternatives, see Fig. 7.:

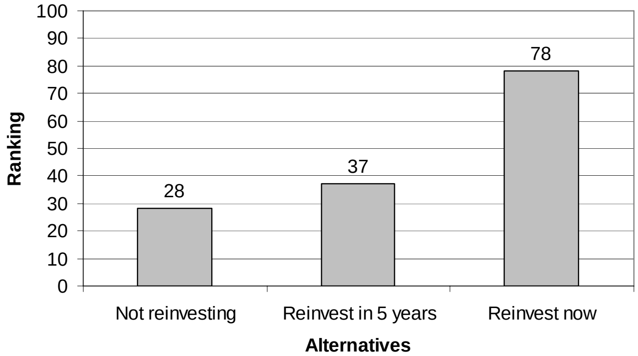


Fig. 7. Results from the MCDA.

The MCDA, with the assumptions mentioned, supports the decision to *Reinvest now*.

The MCDA software also offers the possibility to perform a more in-depth analysis of the decision problem. For example, the user can easily modify the ranking of alternatives in terms of each criterion or the weights and see how the final ranking changes. The advantage of this is that the user can perform a dynamic evaluation of the decision problem by modifying preferences, if for example new information becomes available. Examples are: new blasting in the tunnel (cable 1), new information about cable condition, signs of demand increase, etc.

V. Challenges

In this chapter some of the main challenges associated with the use of risk assessment for reinvestment decision making is outlined.

A. Change in culture

A risk based approach to reinvestment decisions challenges the way of thinking in a company, and it requires changes in order to establish a culture for risk assessment as guiding principles. This challenge must be met through adaptation of the organisation and competence building among staff.

B. Decision support methods and tools

An efficient implementation of a risk assessment requires a selection of the appropriate methods or tools to be used in each step of the process. The methods traditionally used by distribution companies can be complemented with new tools. New approaches may be needed to, for example, gather input data and document and present the risk evaluations which have been performed.

C. Deal with uncertainties in input data

It has been illustrated in this paper that finding numerical values to use in analyses is a challenging task. Experience shows that one often will find little help in statistical data – due to lack of comparable information and representative data. As shown in this paper there exist numerous sources of statistics, but the validity of these sources for the problem at hand is a difficult question to answer. It is the authors´ option that one has to choose an approach where the input from statistical data is used in combination with expert judgment.

D. Communication of results

Communication is a challenge, especially when communicating results from analysis based on estimation of future failure rates, cost estimates, interruption durations, load situations etc. This requires both a thorough understanding of the uncertainties involved and communication training. If the analysis is not performed by the persons making the decision, there can often be a gap between what the analyst wants to present and what the decision maker wants to hear. This is especially apparent when the decision makers want one number, for instance to know whether the net present values is positive or negative, while the analyst wishes to communicate the uncertainties related to the numerical estimates.

VI. Concluding Remarks

The proposed framework has proved to be a valid way to structure a decision process. The framework supplies a check list which can be used to make sure that all the necessary steps have been considered.

The use of multi criteria decision support makes it possible to include decision criteria which are difficult to incorporate using other methods. The MCDA software gives a visual representation of preferences and how changing preferences affect the results. The other methods, like load flow and NPV, form the basis for a reinvestment decision, but MCDA adds the AMs preferences to the decision process, which is an important added value to the total decision.

Epilogue: The distribution company has considered the risk of the current situation to be unacceptable and has decided to reinvest in a new cable which can make the supply to the area more reliable and the voltage conditions better.

VII. Acknowledgments

This paper is written in the project Risk-based Distribution System Asset Management (RISK DSAM) – a project sponsored by the Norwegian Research Council and 10 companies within electricity distribution in Norway and France.

The main objective of the project is to increase competence by developing and adapting methods, which can be used to describe the risk exposure for a distribution company and how alternative maintenance and reinvestment decisions affect the risk exposure.

More information about the project can be found on http://www.energy.sintef.no/Prosjekt/RISKDSAM/

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IX. BIOGRAPHIES

Maren K. Istad was born on June 5, 1980 in Ålesund, Norway. She received her MSc degree in Electrical Engineering from the Norwegian University of Science and Technology (NTNU) in 2006. She has been with SINTEF Energy Research, Department of Energy Systems since 2006, working mainly with maintenance in hydro-electric power stations and distribution systems.

Dag E. Nordgård was born on December 18, 1971 in Steinkjer, Norway. He received his MSc degree in e1ectricial engineering from the Norwegian Institute of Technology (NTH), Trondheim, Norway in 1994. He works as a research scientist at SINTEF Energy Research, Department of Energy Systems, but is currently pursuing a PhD degree at the Norwegian University of Science and Technology (NTNU), within distribution system risk management.

Oddbjorn Gjerde was born on May 16, 1970 in Volda, Norway. He received his MSc and PhD degrees in Electrical Engineering from the Norwegian University of Science and Technology (NTNU, former NTH), in 1993 and 1999. He has been with SINTEF Energy Research, Department of Energy Systems, as a research scientist since 2000, working mainly with analysis of reliability of supply, risk and vulnerability assessment.

Agnes Nybø was born on June 20, 1981 in Oslo, Norway. She received her MSc degree in Industrial Economics and Technology Management from the Norwegian University of Science and Technology (NTNU) in 2005. She has been with SINTEF Energy Research, Department of Energy Systems since 2005, working mainly with monopoly regulation, investment analysis and reliability.

Maria. D. Catrinu was born on December 24, 1975 in Campulung, Romania. She received her BSc and MSc degrees in Electrical Power Engineering and Power Systems Management from 'Politehnica' University of Bucharest in 1999 and 2000. She holds a PhD degree in Power Engineering from the Norwegian University of Science and Technology (NTNU), from 2006. She has been with SINTEF Energy Research, Department of Energy Systems since 2006, working mainly with energy systems planning, risk analyses and decision support.

Bjørn E. Birkeland was born on June 20, 1961 in Västerås, Sweden. He received his BSc degree in Electrical Engineering in 1982 from Østfold University Collage and MSc degree in Electrical Engineering from the Norwegian University of Science and Technology (NTNU, former NTH), in 1985. He has been Chief Engineer at Fredrikstad EnergiNett AS (FEN) since 2004, working mainly with asset management in the distribution network.