Using Risk Analyses in a Multi Criteria Decision Making framework for evaluation of hydropower maintenance projects

Dag Eirik Nordgård, Jørn Heggset, Jan Daleng*

Abstract: **The paper presents a framework for using risk analysis together with multi criteria decision making methods as an analysing strategy for evaluating and prioritising different types of maintenance and renewal projects within a power company. Projects are being subject to risk evaluation related to a set of qualitative criteria, together with calculation of economic key figures such as the net present value of the project. The basics of the strategy are illustrated by experience data from risk evaluation of the project portfolio of a Norwegian hydropower production company.**

Keywords
Maintenance optimisation, Risk Analysis, Multi Criteria Decision Making, Hydroelectric power generation

I. INTRODUCTION

Since the early 1990's the Norwegian electricity sector has operated under deregulation, and both the electricity production and distribution industries have gone through substantial changes during these years. The deregulated operating regime has put focus on cost-effectiveness, and one of the effects seen from this is an almost stop in building of new production and distribution systems. The average age of the components in the electricity system are thus increasing.

This has lead to an increased awareness on the importance of maintaining the existing system in an optimal manner, with the aim of extending lifetimes and thus reducing the need for reinvestments. Performing the renewal of components at the right time is also an important part of this picture.

This must be done while still operating the system within a set of constraints, and one important aspect when evaluating maintenance and renewal projects is to take into consideration more than an economic optimisation of investment and operation costs. Other factors, that are difficult to quantify in monetary terms, will also appear within the decision frame. These factors are typically *safety to personnel or public*, *working environment* and *environmental considerations* - which all are important parts of the overall decision process, [1]. A common term for such factors is *qualitative criteria*.

This paper presents an approach for handling such composite decision problems, where the concept of risk analysis is being used to handle the qualitative criteria in a holistic and consistent manner.

II. THE PRACTICAL CHALLENGE

The maintenance management of hydropower production companies will typically have a large number of proposed maintenance and renewal projects to evaluate and to give priorities within given constraints. The constraints are typically economic limits or limited resources with respect to labour and/or time.

The production companies have very often (groups of) power plants in geographically dispersed locations being manned and operated more or less as autonomous units within the organisation. The decision process leading to the overall company priorities is however centrally coordinated and controlled. The different geographical regions will propose their maintenance and renewal projects for a wide range of reasons, including economic benefits of the projects, safety reasons, environmental concerns, or any combination of these criteria.

The qualitative criteria are characterised by the fact that their impacts are difficult to quantify, at least in monetary terms. Therefore, a holistic evaluation scheme for the maintenance projects including all the different criteria is not easily available. A way of dealing with this task is to include Multi Criteria Decision Making (MCDM) methods as part of this decision process, [1-5].

The companies' maintenance management are facing the challenge of structuring and comparing the proposed maintenance and renewal projects in a unified manner. The

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framework described in this paper helps to compare different projects based on a set of criteria, in order to gain a better basis for maintenance and renewal decisions and to obtain a list of priority for the proposed projects.

Risk analysis has been used as the tool to quantify and structure the evaluation of the projects' impact on the qualitative criteria.

III. MCDM USED FOR EVALUATING MAINTENANCE PROJECTS

The overall project evaluation strategy can be illustrated as shown in Fig. 1.

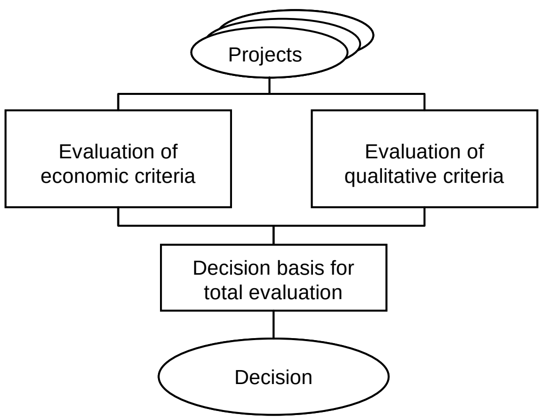

Fig. 1 Structure of project evaluation

The chosen approach separates the evaluation of *economic criteria* and *qualitative criteria* before combining the results in a more holistic decision basis for the total project evaluation.

In the following the different parts of the project evaluation will be described.

A. Evaluation of economic criteria

The net present value (NPV) is obviously important when analysing a project. The NPV could very well be treated as one of the criteria handled by the AHP method (see next section), where the NPV is given a relative weight compared with other criteria. However, in our approach we have not included the economic criteria together with the qualitative criteria. In our opinion, it is better to do two separate analyses and thereafter combine the economic and qualitative figures (as indicated in Fig. 1).

An economic analysis of a maintenance or renewal project is often performed with a minimum cost approach. We have chosen a different strategy: In order to focus on the profitability of the projects, we treat every positive economic effect of a project as an income, including a reduction in failure probability due to the accomplishment of the project. In such a case the income is calculated as the difference in failure probability if the project is carried out or not, multiplied with the expected loss if a failure should occur. Deferment of investments is also regarded as income in the approach.

In other words, the NPV of the analysed project is compared with the NPV of a reference project, usually the so-called *0-alternative*.

From this analysing strategy the following cost elements are taken into account:

- Ressources (labour, spare parts, transport, etc.).
- Unavailability costs during the project.
- Maintenance introduced faults.
- Other costs.

The income side comprises the following elements:

- Increased power efficiency.
- Increased availability (reduced failure probability).
- Deferment of future investments.
- Other incomes.

All these values, some of them being annual, are discounted to the time of analysis (usually the present time), tax rules are applied, and the NPV are calculated.

In order to quantify the probabilities of different losses due to failures an event tree starting from the initiating event, usually the failure, is suitable. This is illustrated by an example in Fig. 2. The different losses are then multiplied with the corresponding probabilities and summarised in order to get the expected loss value. This value is multiplied with the failure probability (for both the analysed maintenance action and the reference alternative) for each year in the analysing period, in order to assess the reduction in the annual expected failure costs.

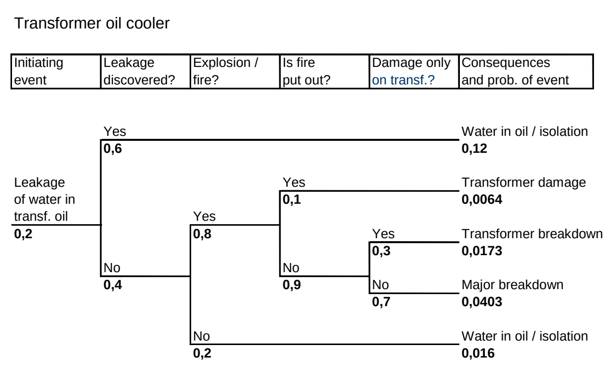

Fig. 2 Example of event tree for mapping of failure consequences

B. Evaluation of qualitative criteria

To aid the inclusion of qualitative criteria into the decision process, MCDM-methods are useful, and there exist quite a number of methods developed during the last decades supporting MCDM in different ways, [5-8].

The aim of these methods is to find a way of quantifying a utility value also for the qualitative decision criteria.

Our approach in this context is seeking a decision model structure as shown in Fig. 3, where the steps toward this model include:

1. Identifying the criteria being important for the company
2. Establishing scales for each criterion suitable for evaluating projects
3. Establishing the weights between the criteria

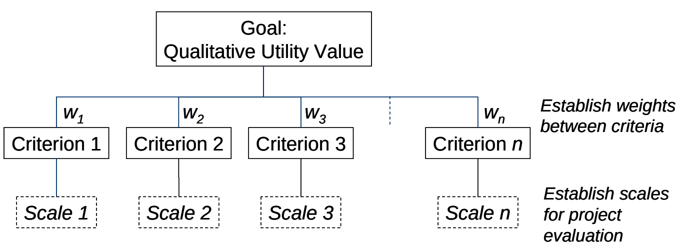

Fig. 3. Model for establishing a Utility Value for qualitative criteria

1) Identifying the relevant Decision Criteria

In the first step the decision makers (DMs) is challenged to find and formulate the criteria being the most important ones for the company to take into consideration when making their priorities for their renewal and maintenance activities. Experience has shown that Norwegian hydropower companies usually find 4-5 criteria to be sufficient, [1].

2) Establishing Scales for each Criterion

For each criterion a scale must be established that the projects can be measured by. To answer the challenge of establishing relevant and applicable scales for each of the qualitative decision criteria, risk analysis through risk matrices has been used.

It may be difficult to assess numerical values for probabilities and consequences for different potential events, in order to compute the risk level as the product of these two factors. Therefore the concept of risk matrices is being used as a well-known tool for assessing the risk associated with different events based on a more verbal description of the nature of the event.

This approach is e.g. also used in RCM analyses [9]. An example of a risk matrix is shown in Fig. 4.

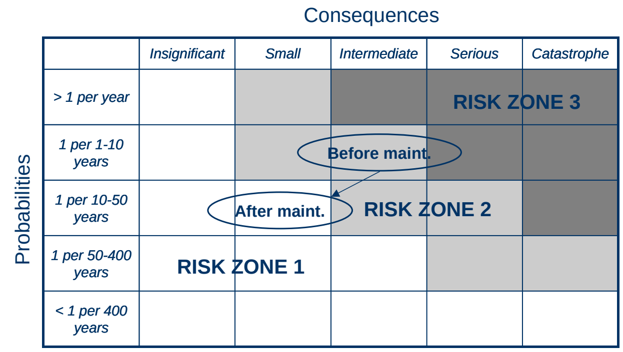

Fig. 4. Example of Risk matrix

The combination of the probability and consequence of an undesired event defines each square in the matrix. Situations in the upper right corner (dark grey) are defined as unacceptable, which clearly states that something has to be done. The risk level in the light grey area is acceptable but with a warning sign, while the lower left corner (white) is classified as a low risk area. One matrix for each criterion must be established.

The use of such matrices within the framework of project evaluation and ranking is illustrated by the terms *Before maintenance* and *After maintenance* in Fig. 4. The effect of a specific project is typically a transfer down and/or to the left in one or several of the risk matrices.

3) Establishing Weights between Criteria

When the criteria have been decided, and the scales established, the next step is to find the relative weights between them. In several project activities performed by SINTEF Energy Research the Analytic Hierarchy Process (AHP) [6] has been used to establish these weights and thereby to structure the handling of qualitative criteria, [1-4].

The reasons for choosing this method has been that it is easily understandable and applicable, it takes short time to learn to use the method (*which is important since the user typically will not be an expert in MCDM tools*), and – most important – the results obtained from using the method corresponds well with the user’s intuitive perception of the problem being analysed.

The AHP method is based on dividing the decision problem into a set of pairwise comparison of decision criteria. For the comparison the numerical / verbal scale shown in Table I is used to express the relative importance between the criteria, [6,7].

TABLE I
THE RATIO SCALE FOR PAIRWISE COMPARISON OF THE AHP METHOD

Numerical value	Description
1	*Equal*
3	*Slightly preferred*
5	*Strongly preferred*
7	*Very strongly preferred*
9	*Extremely preferred*

The comparisons are structured in an evaluation matrix, A_C, as illustrated in Table II.

TABLE II
EVALUATION MATRIX, A_C, FROM PAIRWISE COMPARISON USING THE AHP-METHOD

Criteria	C_1	C_2	C_3	..	C_n
C_1	*1*	p_{12}	p_{13}	..	p_{1n}
C_2	p_{21}	*1*	p_{12}	..	p_{2n}
C_3	p_{31}	p_{32}	*1*	..	p_{3n}
..	..	..	..	*1*	..
C_n	p_{n1}	p_{n2}	p_{n3}	..	*1*

where

- p_{ij} = rating of criterion i compared to criterion j {1/9,9}
- $p_{ij} = 1/p_{ji}$
- $p_{ii} = 1$

The relative weight between the criteria is now calculated as the normalised eigenvector, w, of the evaluation matrix that corresponds to the largest eigenvalue, λ_{max}.

$$A_C \cdot w = \lambda_{max} \cdot w \qquad (1)$$

The normalised eigenvector gives the relative percentage weight of each criterion, so that the sum of the weights of the criteria equals 100 %.

$$\sum_{i=1}^{n} w_i = 1 \qquad (2)$$

Restrictions in using the AHP-method

In the adapted MCDM framework used by Statkraft (see next section) the AHP is used only to find the weights between the identified top decision criteria. This helps to avoid some of the problems which have been identified using the method – mainly the possibility of rank reversal when including new (or removing) alternatives from the decision framework, [7,8].

The model for evaluating maintenance projects through risk matrices taking different criteria into account can now be illustrated as shown in Fig. 5, where risk matrices (as shown in Fig. 4) form the basis of the project evaluation, and w_1 – w_n are the relative weights of the qualitative criteria obtained from the AHP-model.

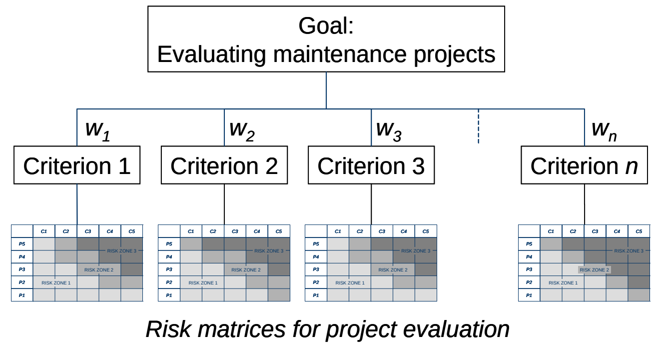

Fig. 5. Model for evaluation of qualitative criteria

Using such a formal evaluation scheme for evaluating all maintenance and renewal projects gives the maintenance management a structured framework for obtaining relevant project information.

There are several organisational challenges related to the use of such methods. One of the more important is establishing a common understanding on how the risk analyses should be performed. The only way of getting past this obstacle seems to be a trial-and-error pursuit where a common company practice is built through discussing the practical experience of the decision framework.

One should in any case not forget that there will be limitations in the accuracy of both the economic net present value calculations and in the evaluation of qualitative utility value, and that the results should be used with some caution in a formal decision frame.

C. Total Project Evaluation

As illustrated in Fig. 1, the results from the analysis of the qualitative criteria and the economical criteria are combined to achieve a more holistic decision basis for project evaluation. One way of combing the results is to present values for different projects in a plot, e.g. as indicated in Fig. 6.

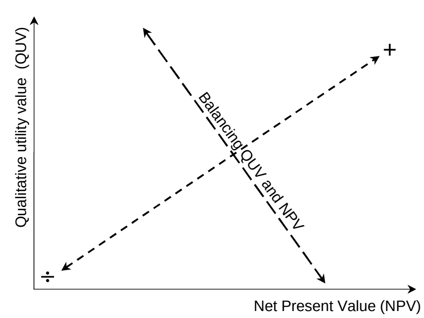

Fig. 6. Sketch of plotting results from qualitative and economic analysis

The most favourable locations in this plot are in the upper right region (+), while the least are in the lower left

(÷). Along the other axis indicated in the figure, a choice has to be made between projects with high profitability / low qualitative utility and projects with low profitability / high qualitative utility.

IV. EXPERIENCES FROM USING RISK EVALUATION OF MAINTENANCE PROJECTS

During the latest years there has been done a significant amount of R&D projects in Norwegian Power companies to develop methods and tools for decision aid concerning evaluation and priorities of maintenance projects, [1,3,4].

Statkraft, the largest power producer in Norway, has participated actively in order to develop methods, and further to take such methods into practical operation within their organisation.

The maintenance management at Statkraft handles approximately 100 project proposals of a significant scale annually. The projects are being proposed from Statkrafts operating regions geographically dispersed all over Norway.

In order to obtain a holistic and comparable evaluation of the many proposed maintenance projects, Statkraft has implemented a standardised manner of performing a risk evaluation for these projects. The risk evaluation is performed based on five criteria identified as the most important:

- Public safety
- Health / Personnel safety
- Environment
- Reputation / PR
- Potential economic loss

Statkraft's work on the qualitative criteria so far includes the two first steps of the three-step procedure described in Chapter III. (*Statkraft are also implementing the standardised approach for calculating the NPV for their different projects. This is not further described in this paper.*)

Statkraft has so far chosen <u>not</u> to merge the risk evaluations for each criterion into one risk index, but rather use the five risk evaluations as they are, in a non-formalised decision process when making the final priorities on their ranking of projects.

Reasons for this is to introduce a formalised decision process step by step, and on the way gain experience from risk evaluation itself and to establish confidence in the analysis results in the organisation, before eventually adopting the rest of the MCDM framework.

For each of the qualitative criteria a risk matrix has been established, where probability and consequence scales have been adjusted for each criterion. Wherever possible the same risk matrices have been used as already established for Statkraft's RCM analyses.

Statkraft's project proposal portfolio for 2005 included originally 105 projects covering a wide variety of applications. After having gone through the risk evaluations and then made their priorities, the maintenance management has sorted out 73 projects to be commissioned during 2005.

Table III shows how the final 73 projects scored on the risk evaluation on the five criteria.

TABLE III
RISK EVALUATION OF 73 MAINTENACE PROJECTS
SCORES ON THE FIVE RISK CRITERIA

	Public safety	**Personell health and safety**	**Environment**	**Reputation**	**Potential economic loss**
High risk	11	13	15	5	15
Medium risk	18	12	8	11	24
Low risk	14	19	17	21	15

The columns do not add up to 73 because only the criteria where the projects had any impact where counted for.

Fig. 7 shows the distribution of *high*, *medium* and *low* risks identified among the projects in the chosen portfolio.

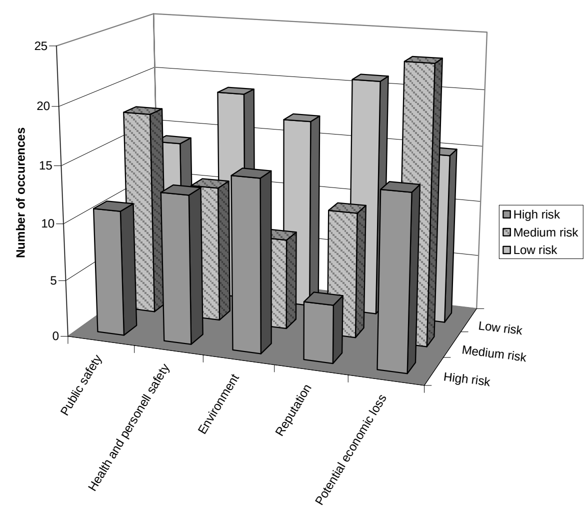

Fig. 7 Number of occurrences of *high*, *medium* and *low* risk for the selected project portfolio

Fig. 8 shows the summary of the risk evaluation results for the 73 chosen projects. One should be careful not to <u>over-interpreter</u> the ranking and sequence of the projects, but the figure shows an overweight of *high* and *medium* risk projects in the upper part of the listing. Some projects are left without any risk scores. These projects have been prioritised due to their economic benefits found in a net present value analysis, or for other special reasons.

Statkraft is working further with developing and implementing decision tools for maintenance planning. The next step is to implement better routines for establishing and documenting the economic benefits related to a project. This will replace the use of the risk matrix for quantifying the potential economic loss.

V. CONCLUSIONS

The method described in the paper represents an approach where both economic and qualitative criteria are being considered when evaluating maintenance and renewal projects.

Risk analyses using risk matrices have proven to be an efficient way of establishing scales for the projects' impact on qualitative criteria, and experience from Statkraft's application of risk analyses in project evaluation has shown that it is a suitable method for making comparable evaluations of highly inhomogeneous projects.

When using such a framework, the qualitative objectives are evaluated in a more structured and objective manner than before. This increases the probability of consistent project evaluation even if different engineers and decision makers have evaluated the various projects. Together with economic calculations of all relevant costs and incomes related to the projects, the framework provides a better and more complete basis for making maintenance decisions regarding the company's maintenance and renewal project portfolio.

It must be emphasised that the aim of using MCDM methods is not to actually make the decision for the decision maker, but rather to establish a better basis for complex decisions.

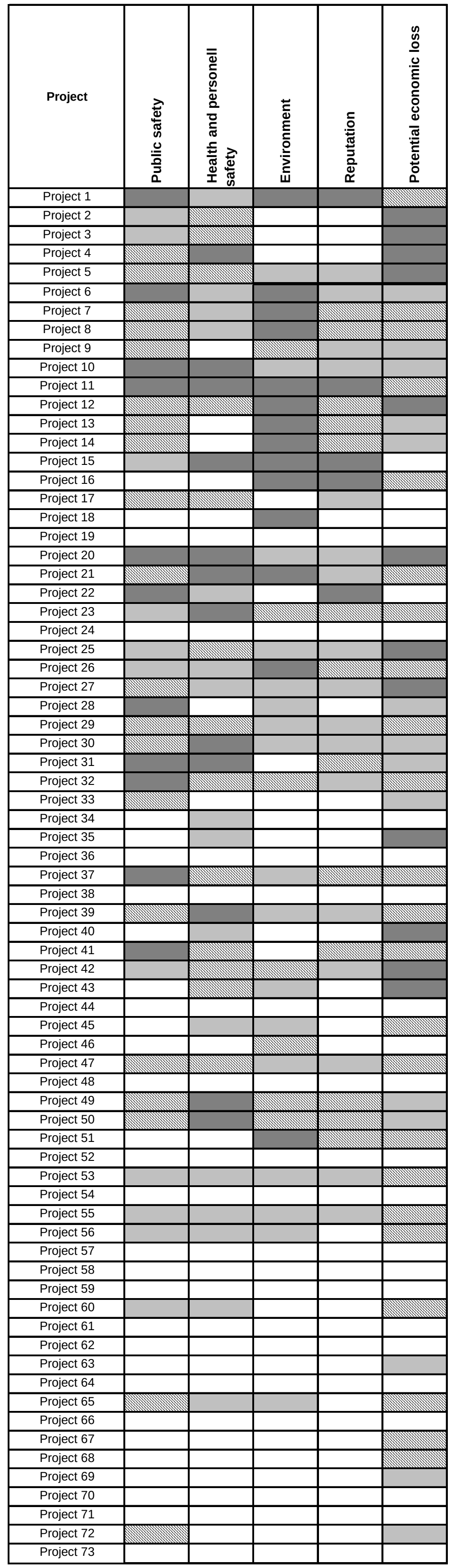

Fig. 8 Results from the risk analysis of the 73 chosen projects
Dark grey = High risk, Shaded grey = Medium risk, Light grey = Low risk

VI. REFERENCES

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VII. BIOGRAPHIES

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