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Recent advances in application of intelligent decision support software systems for inspection planning in power plants

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ABSTRACT: Within the BE5935 joint project of the Commission of the European Communities and European industry a new concept of advanced multi-criteria decision making (MCDM) has been developed and applied onto several selected practical problems (bridges, offshore structures, power plants). The example in the area of power plants concerns the planning of periodic inspections (overhauls). The paper describes the concept as applied and customized for power plant related practical applications, and presents the results obtained in 1994 and early 1995. The results confirm the high relevance of the concept for the practice.

1. INTRODUCTION

A recent inquiry among several European utilities performed within the SP249 SPRINT Project of the European Commission (see Hagn, 1994), as well as the market research performed by MPA Stuttgart, Germany (see von Rössing, Jovanovic, 1994) covering more than 2000 power plants world wide, have identified and quantified industrial need for improved inspection systems in power plants. This need has been obvious in electric power industry, especially in the area of conventional (fossil fueled) power plants, where neither the unified regulation nor the de facto standardized practice are available. The need has also been recognized by the European Commission, which has supported the development of the decision making methodology and preliminary software tools as respective subtasks in the BRITE/EuRam Project BE5395.

In practical terms, the need means that it is important that the inspection plans reflect all the implications of the available information on the (often unstated) assumptions of design, quality in manufacturing, as well operational and maintenance history. Much of this information is incomplete and must be complemented by human expertise.

However, such expertise is typically scattered within and between organizations, and this problem is emphasized by the modern trend to minimize the number of employees per installed MWe (this ratio is currently up to 4 times higher in Europe than the US average). In addition; modern plants perform a systematic collection and recording of an increasing amount of plant operation data, which, in principle, helps to obtain a

better insight in the plant state, but, very often, due to decreasing amount of people (with often lower level of professional qualification!) leads to the “information glut” - i.e. to the loss of overview and transparency of collected data, in particular in terms of their usability for planning of inspections.

The BE5935 project has recognized these needs and developed a multi-criteria decision making (MCDM) methodology allowing to optimize the decision relevant for inspection planning and optimization in power plants. The paper describes the concept as applied and customized for this practical application, and presents the results obtained in 1994 and early 1995

2. BE5935 PROJECT

The project is a BRITE/EURAM project with the foreseen duration of three years (1993-1995). It addresses the MCDM problems in three application areas, namely in

- a) offshore structures,
- b) bridges, and
- c) power plants.

The BE5935 consortium (D’Appolonia Italy, AGIP Italy, Snamprogetti Italy, COWI Denmark, DNV Norway, MIT Germany, MPA Germany, GKM Germany, Laborelec Belgium, IVO Finland and VTT Finland) is led by MPA Stuttgart. In the area of power plants the project addresses two main issues:

- a) refurbishment of power plants, and
- b) inspection planning and optimization.

The inspection planning and optimization issue is dealt with mainly by MPA, IVO/VTT and GKM.

3. BASIC PRINCIPLES OF INSPECTION PLANNING AND OPTIMIZATION

The most important factors affecting the conclusions made from the inspection results of the hot pipework are

- service history and its deviations from the expected (in design) range;
- inspection history, i.e. the results from earlier measurements;
- materials and manufacturing / repairs / modifications; and
- expected consequences of failure (cost and safety aspects).

Very often the conclusion resulting from the inspections or other measurements is a recommended time period to next inspection. In principle, length of such a period is limited by

- extent and quality of the available information of details e.g. in the service history and future service, as well as in the maintenance history;
- optimum failure risk level for the plant and the component;
- inherent inaccuracies in the evaluation methods for limiting failure; and
- limited systematics (holistics) in producing the final conclusions.

4. DECISION PROBLEM FORMULATION

The applied MCDM methodology reduces the decision problem to two main categories, namely to:

- a set of criteria, and
- a set of alternatives.

The decision is in fact the choice of the most favorite alternative (from a set of pre-defined alternatives) according to the set of pre-defined criteria. For the inspection planning and optimization process three such decisions are of major importance, namely:

- WHAT components to inspect,
- HOW (i.e. using which methods and to what extent) to inspect, and
- WHEN components to inspect.

The first two decision nodes are tackled in this paper (the third one is based on intelligent flowcharts and described more in the work of Jovanovic and co-workers, 1995). The final result of this chain of decisions is the detailed inspection plan, like the one in Table 1.

Table 1: Final result of the decision making in inspection planning and optimization (example from a Finnish power plant)

Comp. No.	Comp. ID	Component type	Next inspection (e.g. in year 199x)	Method	Extent
8	#507	Steam mixer	Monitoring + next year int. inspection	MT/PT, RT, UT at welds	MT/PT for welds 100mm wide; RT acc. to indications; UT for body
6	#813	Butt weld	within next 15,000 h	MT/PT, RT	MT/PT 100mm wide; RT acc. to indications;
1	#803	T-piece weld	within next 20,000 h	MT/PT, RT	MT/PT 100mm wide; RT acc. to indications;
7	#815	Terminal weld to reduction valve body	within next 20,000 h	MT/PT, RT	MT/PT 100mm wide; RT acc. to indications;

5. COMPONENT RANKING AND CHOOSING OF THE INSPECTION STRATEGY - "WHAT TO INSPECT" AND "HOW TO INSPECT"

Power plant components to be inspected are "alternatives" in the sense of MCDM. The following ones are considered in BE5935:

- **BOILER COMPONENTS:** air preheaters, major fans, feedwater tanks, water treatment plant, feedwater pumps, economiser, water preheaters, heat exchangers, burners (nozzles), refractories, ash system, evaporator, evaporator header / drums + downcomers, flue gas ducts and cleaning, steam drum, superheaters and reheaters, superheater + reheater headers, steam coolers / injectors, safety valves, blow-out valves, stop valves, water level control devices
- **STEAM PIPING COMPONENTS:** major steam valves + welds, reduction valves + welds, T- and Y-pieces + welds, mixers, , flange joints esp. near fixed points, deaeration / dewatering nozzles, piping supports (hangers, glide supports, fixed supports)
- **STEAM TURBINE:** steam chest, connecting pipes + welds, control + stop valves + welds, casings, rotors, blading, bolting, flange joints (in piping connections, main turbine flanges), glands / sealing, condensers, gears / protective devices
- **GAS TURBINE COMPONENTS:** combustion cans (coatings), compressor blades, turbine blades (coatings, dimensions), rotor, glands / sealing, bearings, gears / protective devices
- **GENERATOR COMPONENTS:** rotors, winding, cooling system, insulation, end caps, bearings

The criteria for the ranking of components can be crisp (e.g. “diameter 125 mm”), fuzzy (e.g. “poor accessibility”), and stochastic variables (e.g. “number of equivalent hours at given temperature 545 °C estimated by normal distribution with $\mu=175,000$ and $\sigma=5,000$ ”). Major advantage of the BE5935 methodology is that it can combine these variables within a consistent framework, without having to “reduce” them to some artificial equivalent. An example of applied criteria (for component ranking) is given in Table 2.

Table 2: Sample criteria for component ranking

Name of criteria	Input type	Rel. weight
Fundamental importance of the component	Fuzzy	0.122 (70)
Results of previous inspections	Crisp	0.175 (100)
Cost of replacement	Crisp	0.122 (70)
Safety aspects	Fuzzy	0.070 (40)
Environmental aspects	Fuzzy	0.070 (40)
Qualitative past service history	Fuzzy	0.105 (60)
Quantified past service history	Crisp, Stoch.	0.053 (30)
Expected change in the operating conditions	Fuzzy	0.140 (80)
Alternative supply patterns	Fuzzy	0.140 (80)

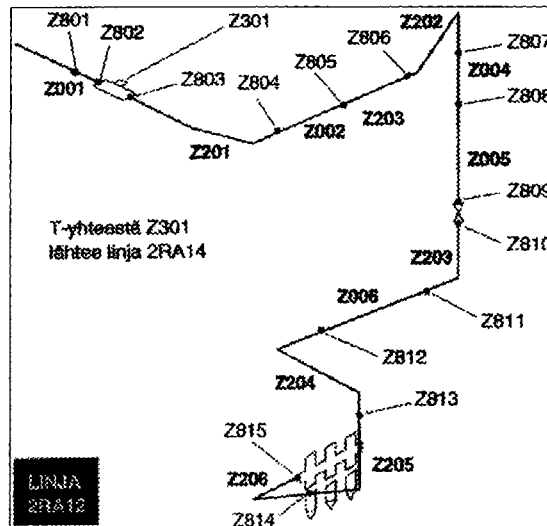
The inspection strategy (“which methods and to what extent”) is chosen according to the criteria like these in Table 3, form a set of alternatives like e.g. “zero-attention” program, “low-profile” program, “standard” program, “extended” program, etc.

Table 3: Sample criteria for choosing the inspection strategy

Name of criteria	Type of input	Optimization goal
Inspection and other related maintenance cost	Fuzzy	Minimize (for higher level inspection patterns cost are increasing)
Additional difficulties due to access	Fuzzy	Minimize (more difficult access to inspection region forces lower level inspection pattern)
Implicit risk due to safety aspects	Fuzzy	Minimize (higher safety needs forces higher level inspection patterns)
Component priority (result from COLOR)	Crisp	Maximize (higher component priority forces higher level inspection patterns)

6. PRACTICAL (TRIAL) APPLICATIONS

For trial practical applications piping system in a Finnish power plant has been chosen (Figure 1). The complete analysis has been performed following the steps described in detail in the work of Jovanovic and co-workers (1995). Final results (Table 1 and Table 4) have shown excellent agreement with experts' opinion.

**Figure 1: Piping system selected for the trial application**

7. CONCLUSIONS

The approach and the system presented in the paper will be refined and developed further in late 1995. Currently (early 1995) they are being subjected to further practical tests in German power plants. The system will be possibly coupled with inspection

result databases and other software (e.g. SP249 or ESR software, see Jovanovic 1994). The system will, however, be used primarily for preliminary screening and "drafting" of the annual inspection plans. Experts' revision of these drafts will remain a mandatory part of the overall procedure.

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Table 4: Final results of component ranking

BE5935 rank	Comp. ID	Component description	Suggestion for inspection agrees with expert's one	Ranking agrees with the expert's one
1.	#507	mixer	yes	yes
2.	#815	reduction valve	yes	no (at place 4)
3.	#803	T- piece weld	yes	yes
4.	#813	Weld	yes	no (at place 2)
...
23.	#202	pipe bend	-	-

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