Data collection and reliability analysis of power plants in the Netherlands

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1 Introduction

Failure data for powerplants have been collected for quite some time. Statistical data are present at NRG dating back to 1976. Failure data analyses have been performed and discussed at the powerplants by KEMA ever since 1988. All this information is documented in still readily accessible databases. The 4 Dutch production companies that were operating together as Sep gathered statistics for databases in operation from 1994 on, however this stopped in 1997. NRG continues to update its databases with data gathered during projects, to be used at future projects. In the original Sep SBS databases, information about the failure or event could be filled in by the powerplants production & maintenance personnel and sent to Sep, while reports from other Sep powerplants could be read online for all parties having access to the databases.

The results of the combined efforts are that data for the analyses of power plant failures are available from 1976 on. These data are not only collected or analyzed. The data have also been extensively used, for instance to optimize the availability and maintainability of powerplants such as the combined steam and gas plant (STEG) as shown in figure 1.1. The data can readily be applied from a special database, see figure 1.2, while the original data are still accessible for further analysis.

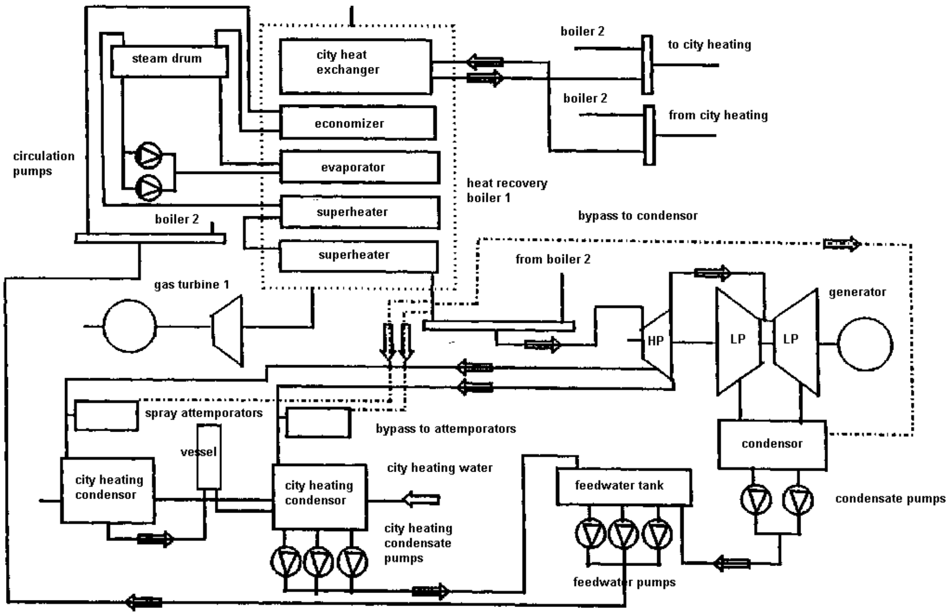
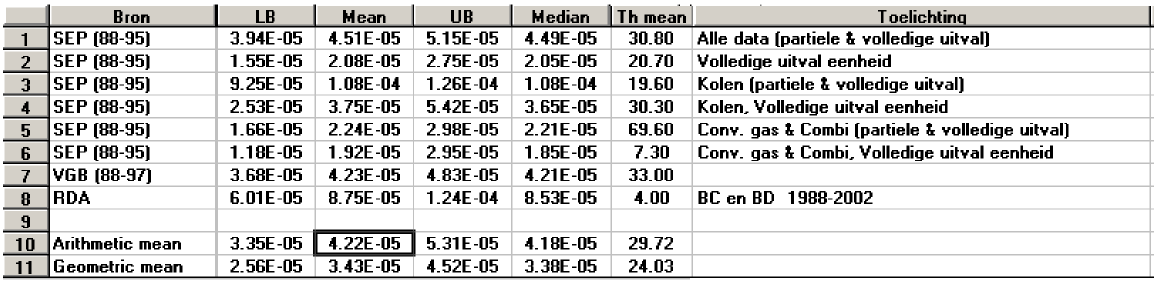


Figure 1.1 Configuration of a STEG plant



	Bron	LB	Mean	UB	Median	Th mean	Toelichting
1	SEP (88-95)	3.94E-05	4.51E-05	5.15E-05	4.49E-05	30.80	Alle data (partiele & volledige uitval)
2	SEP (88-95)	1.55E-05	2.08E-05	2.75E-05	2.05E-05	20.70	Volledige uitval eenheid
3	SEP (88-95)	9.25E-05	1.08E-04	1.26E-04	1.08E-04	19.60	Kolen (partiele & volledige uitval)
4	SEP (88-95)	2.53E-05	3.75E-05	5.42E-05	3.65E-05	30.30	Kolen, Volledige uitval eenheid
5	SEP (88-95)	1.66E-05	2.24E-05	2.98E-05	2.21E-05	69.60	Conv. gas & Combi (partiele & volledige uitval)
6	SEP (88-95)	1.18E-05	1.92E-05	2.95E-05	1.85E-05	7.30	Conv. gas & Combi, Volledige uitval eenheid
7	VGB (88-97)	3.68E-05	4.23E-05	4.83E-05	4.21E-05	33.00	
8	RDA	6.01E-05	8.75E-05	1.24E-04	8.53E-05	4.00	BC en BD 1988-2002
9							
10	Arithmetic mean	3.35E-05	4.22E-05	5.31E-05	4.18E-05	29.72	
11	Geometric mean	2.56E-05	3.43E-05	4.52E-05	3.38E-05	24.03	

Figure 1.2 Data for a forced draft fan

2 Applications

Reliability data should be applied during construction, production and maintenance of powerplants. The data may be used for:

- planning of the production park
- benchmarking
- trend analysis
- improving plant components
- risk related to overhauls
- Reliability Centered Maintenance RCM
- High Impact Low Probability HILP failures
- spare parts optimisation
- Design review
- Optimum redundancy
- Structural reliability
- RAM specification

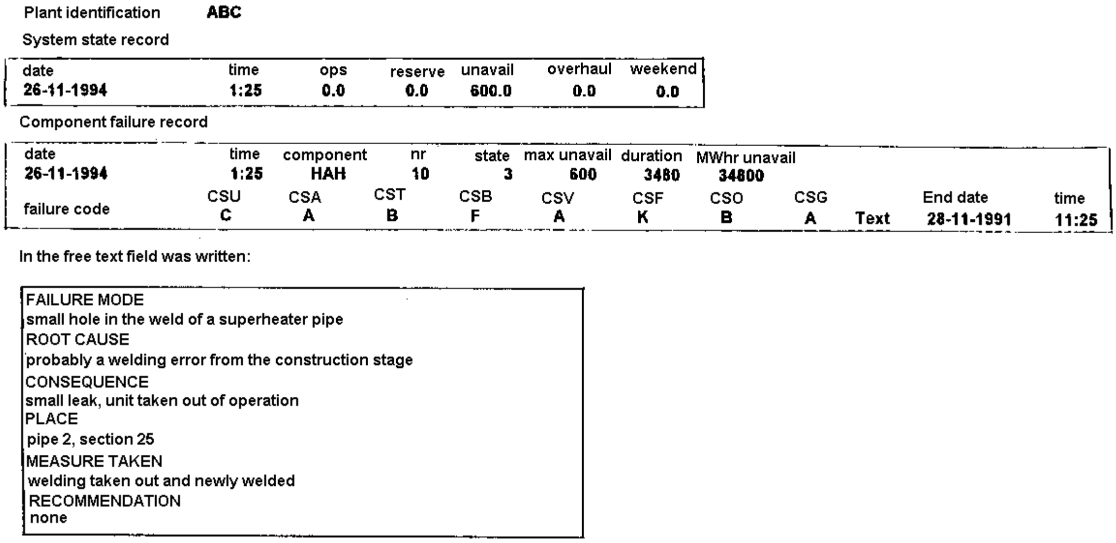
An enquiry to production personnel showed that data for existing units would be most profitable when used for benchmarking the performance of units, the elaboration of maintenance concepts during RCM, the prevention of HILP fialures, the optimization of spare parts and the betterment of components. Of course, production personnel scored the items Redundancy, Design Review, etc. low. However, RAM experience with existing units should be input for newbuilding units.

3 Information to be collected

Figure 3.1 shows a record for an event. Distinction is made between the effect on the unit (described by a sequence of events) and the effect on the system/component (the failure as a whole concisely described). In the NRG data base the emphasis is on system/component failure data. For every failure (main criterion often is a curtailment in available power of the unit) the following data are at minimum collected:

A starttime and endtime
B effected component (preferably by KKS code)
C duration, maximum unavailable power, unavailability of energy (calculated from time history of the event)
D description of the event in order to understand what happened

This is the minimum information that has to be collected for the uses described in chapter 2, to be easily be gathered in a spreadsheet or database.



Plant identification **ABC**

System state record

date	time	ops	reserve	unavail	overhaul	weekend
26-11-1994	**1:25**	**0.0**	**0.0**	**600.0**	**0.0**	**0.0**

Component failure record

date	time	component	nr	state	max unavail	duration	MWhr unavail			
26-11-1994	**1:25**	**HAH**	**10**	**3**	**600**	**3480**	**34800**			
	CSU	CSA	CST	CSB	CSV	CSF	CSO	CSG	End date	time
failure code	**C**	**A**	**B**	**F**	**A**	**K**	**B**	**A** Text	**28-11-1991**	**11:25**

In the free text field was written:

FAILURE MODE
small hole in the weld of a superheater pipe
ROOT CAUSE
probably a welding error from the construction stage
CONSEQUENCE
small leak, unit taken out of operation
PLACE
pipe 2, section 25
MEASURE TAKEN
welding taken out and newly welded
RECOMMENDATION
none

Figure 3.1 Format for failure data

For the dominant failures the failure mode, the cause, measures taken, components of repair time (for instance waiting for spares, cooling down) etc. may be collected. Detailed analysis of the dominant failures definitely takes more work, but it is necessary in order to answer questions why the event could occur and how to improve. It is also necessary to answer these questions for improvements on systems without redundancy.

According to Pareto's 80-20 rule for only 20% of the failures deepening of information as mentioned before is needed. This 20 % will clarify 80% of the EFOR. Management should decide upon which type of components will be analyzed or for which events deepening of information is needed. A Pareto type of analysis that shows the main components causing the majority of EFOR (figure 3.2) can easily be done with the minimum data.

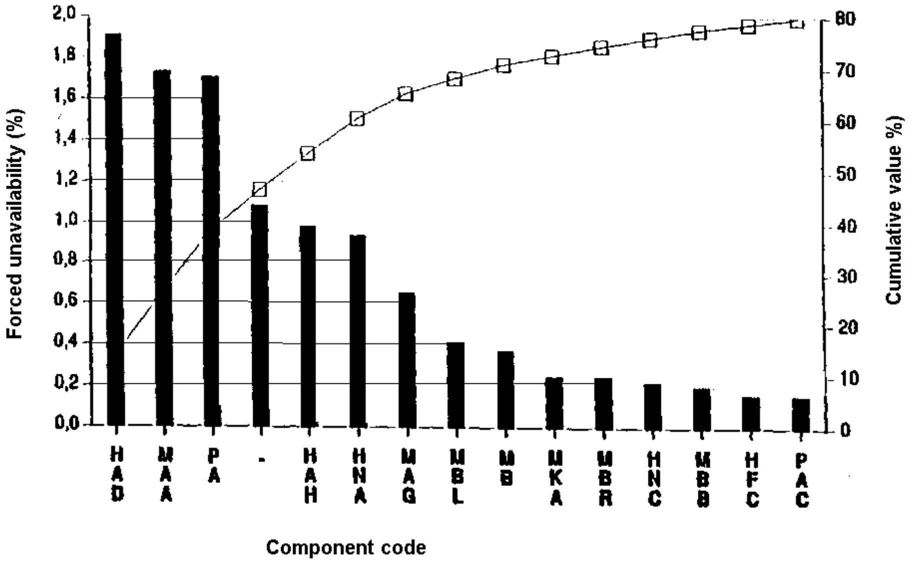


Figure 3.2 Pareto analysis

With the aid of this minimum information, already the amount of redundancy in the systems in a power plant can be optimized. The optimization of the optimum number of pumps, coal milling equipment, etc. is standard. Keep in mind some alternative configurations that may be not standard but can be very attractive, such as different STEG configurations (with or without auxiliary burners, etc.).

4 Statistics

The use and analysis of failure data is not a science (it may be a craft however). It is for instance not possible to predict the exact time at which future time failure of a component will occur from reliability data. Also, the mean time between failures (given the events occur random in time) is only known accurately within certain statistical boundaries.

Therefore, the unavailability of powerplants and components in power plants has a random character. While, as shown in figure 4.1, the EFOR per year per unit can fluctuate strongly, over a longer period of time the differences between units can be made visible. This is something to keep in mind when comparing production units: do not benchmark over too short a period in time.

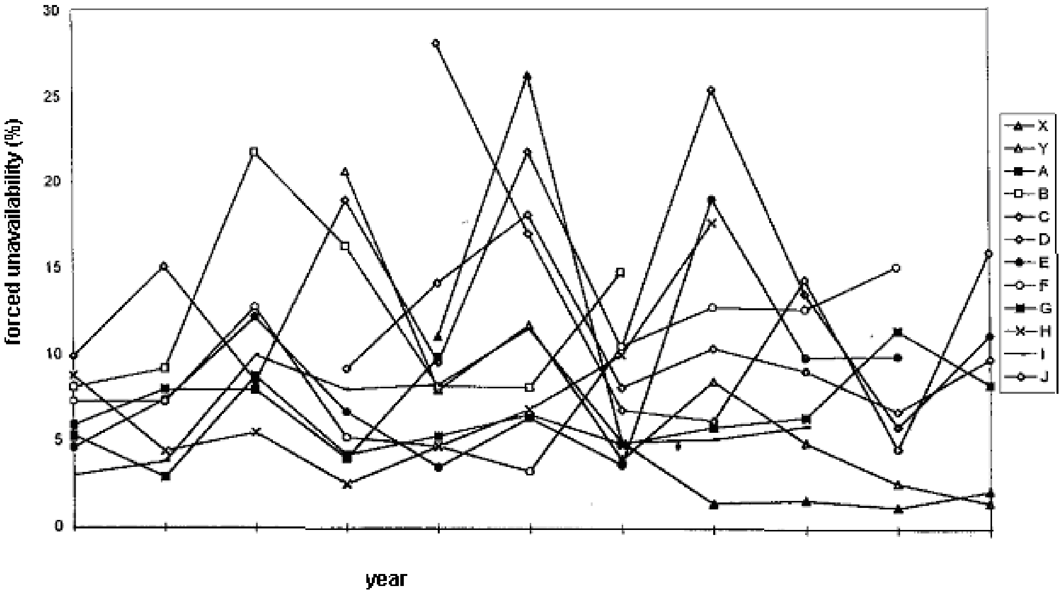


Figure 4.1 Forced unavailability of coal fired units

The statistical character of failures is also the reason to use intervals when comparing types of components or manufacturers. Figure 4.2 shows that there appears to be no difference between gasturbines of type 1 and 3, given the statistical uncertainty in EFOR. Between the types 2 and 7 a difference can be shown: the difference is statistically large enough to exclude chance.

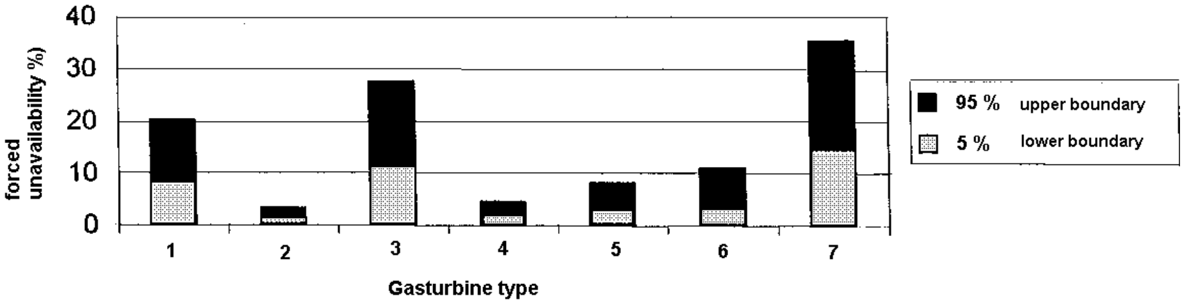


Figure 4.2 Comparing gasturbine types

5 Comparing power plants

Figure 5.1 shows a Reliability Blockdiagram for a system within a power plant. The expected value for EFOR, valid as an average over several years can be calculated both for the plant and for its subsystems / components. As a next step, the EFOR for different configurations can be compared, given failure data or estimates for each configuration.

Figure 5.1 Reliability Block diagram

For present day power plants, redundancy is more complex than simply doubling pumps or increasing the number of coal milling equipment. Figure 5.2 gives 2 examples of a Combined cycle plant (STEG) for E production and steam delivery to the industry.

Option A (1 GT, a heat recovery boiler, ventilator in operation when the GT fails) clearly differs from option B (2 GT's, 2 heat recovery boilers, possibility of an auxiliary boiler etc.) with regard to price, availability and maintainability. NRG uses the RBDA program to calculate the system states that occur due to failures, the number of occurrences per year, the fraction of time and the mean duration of these states. This allows to optimize the configuration of a STEG, the number of auxiliary boilers, the capacity of heat storage buffers, etc..

NRG has recently modeled all power plants of one of the electricity production companies in the Netherlands, as well as a plant in the Dutch Antilles (for which a complete Risk Analysis was carried out). The model included the optimum spinning reserve for a set of units, the calculation of the amount of repair time during “rush hour” and the effects to postpone repairs for instance to the weekend.

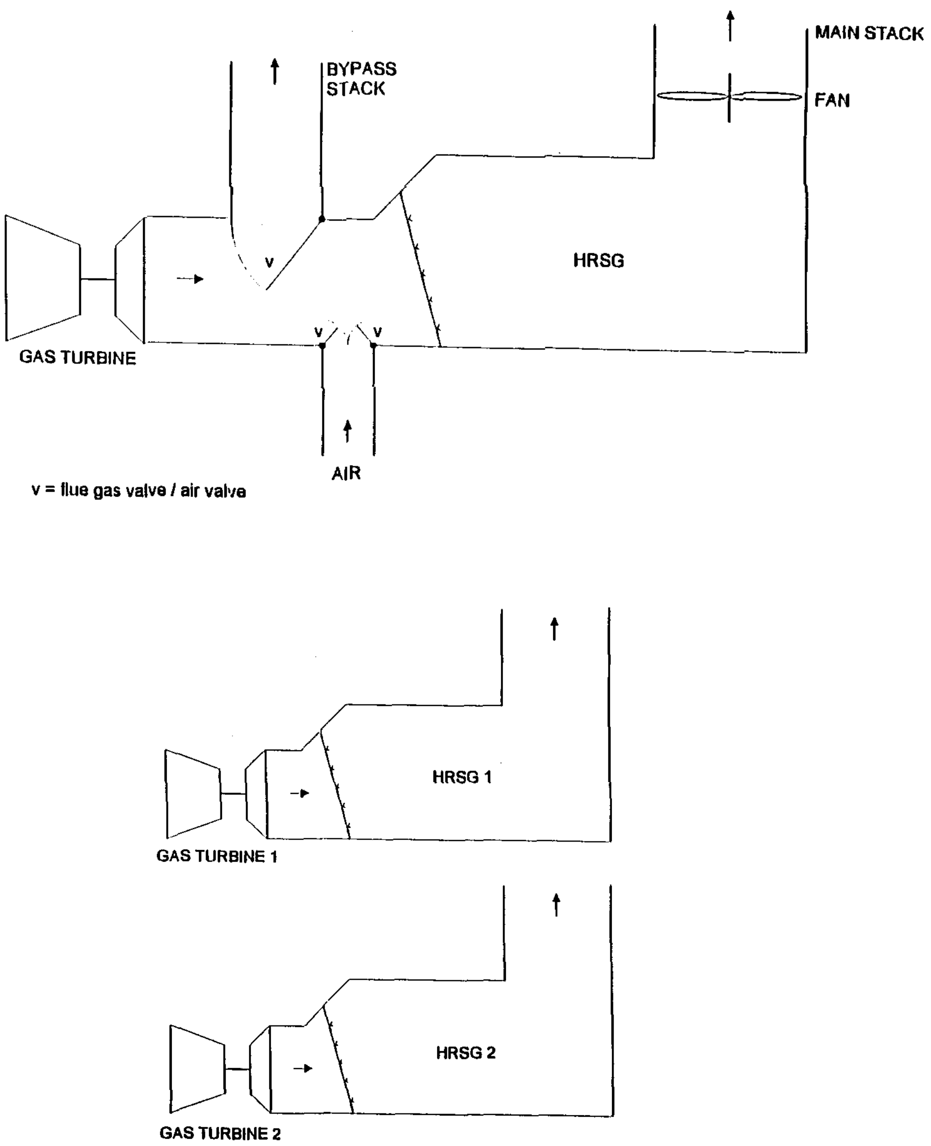


Figure 5.2 STEG configurations

The EFOR of a unit, certainly if measured over a short period of time, has a random character. This randomness should be investigated when determining the EFOR as a criterion to be used together with a fine (RAM-specification) when the EFOR is less than expected. The role of chance should be calculated preferably by simulation according to the Monte Carlo Principle. Figure 5.3 for example shows that the EFOR of a STEG measured during a short period of time due to its random character can differ strongly from the EFOR that is measured over a longer period. This is certainly the case when HILP events are taken into account.

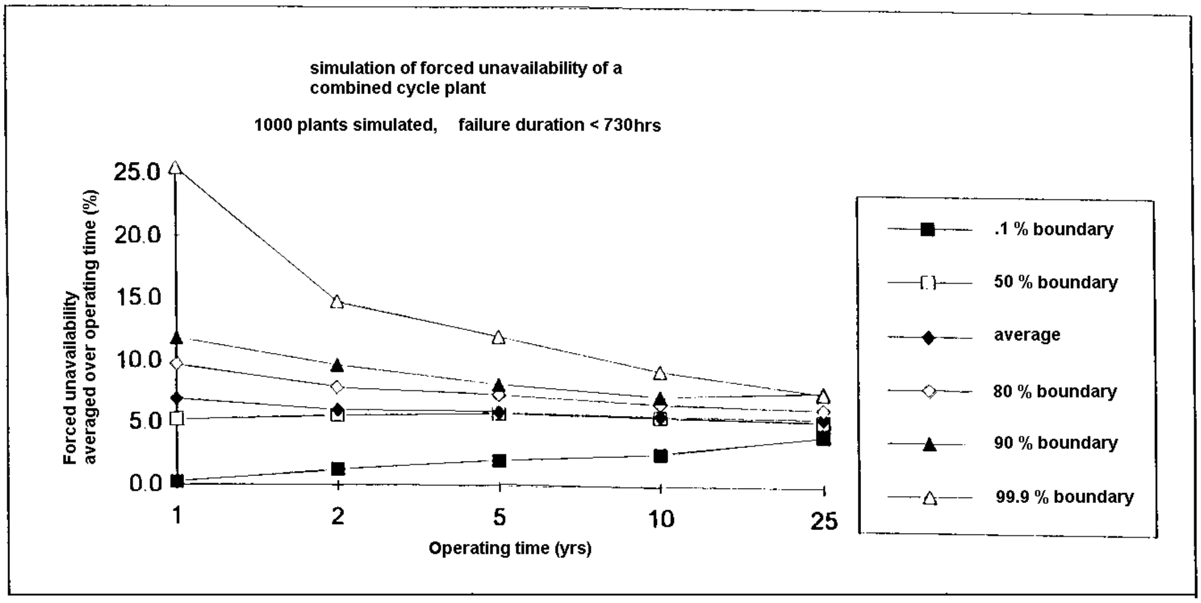


Figure 5.3 Monte Carlo simulations for RAM

Reliability Block diagrams are especially useful for newbuildings. However, it can also be advantageously used in the decision making process for modifications etc.. For a coal fired power plant after the failure of a cross-flow duct in the fluegas system, the value of that duct with regard to a reduction in EFOR of the unit was investigated. The expected EFOR value with and without cross-flow ducts was calculated with Reliability Block diagrams. Moreover, using Decision Analysis techniques, the effects on costs of the uncertainties in the calculations were quantified.

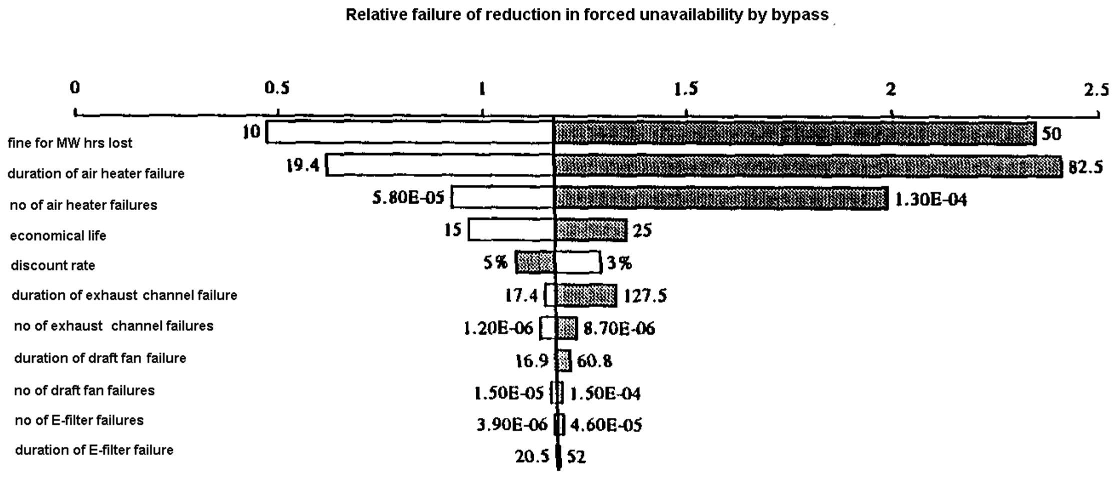


Figure 5.4 Value of reduction in forced unavailability costs by bypass

Figure 5.4 shows that the decision to repair or plug (blind) the cross-flow ducts depends mainly on the fine for MWhrs lost, uncertainties in failure rates and repair time of certain equipment, etc. By combining all uncertainties, as a next step the maximum, minimum and average = expected value of the ducts can be calculated. The utility company decided on the basis of the analysis to blind the cross-flow ducts and not restore the original design. The same type calculations were done for example for a proposed modification of milling air ventilators in a coal fired unit.

6 Trending analysis

Trending analysis is used to analyze whether certain phenomena are time dependent. See for an example figure 6.1. This figure shows the cumulative number of gasturbine failures as a function of operation time. The figure shows:

- the number of events for some GT's is clearly much larger than for other GT's (differences between GT types, differences in operation and/or maintenance)
- the angle of inclination on the average decreases often as a function of time. In general the time between events increases and the problems as a result of a new and untried construction are solved
- a sudden increase of the cumulative number of events at certain points in time may occur. This indicates that a new problem was met and solved, although this took time.

This gives credit to a good "root cause" analysis of failures. A recent analysis shows that for dominant systems in power plants, about 30 % of the failures is not adequately corrected and will occur again within 1 week.

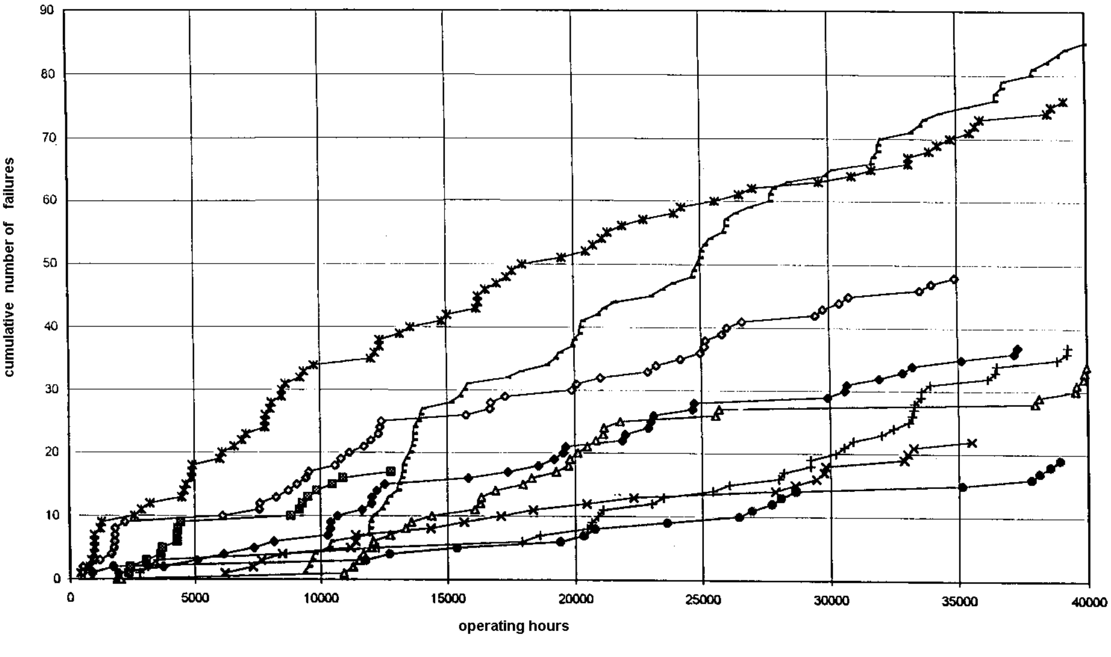


Figure 6.1 Trend analysis for gasturbines

Similar trending can be used to investigate the ageing behaviour of power plants. NRG recently carried out an trending analysis of the behaviour of power plants older than 25 years using international databases.

All available generic information should be translated as good as possible into the plant specific situation. Bayesian statistics and/or Structural Reliability can help in this respect. By using Bayesian statistics, one can determine the number of failures for a unit on the basis of the experience with the own unit, combined with data of other units. The result is a realistic, and neither too optimistic nor pessimistic estimate. Structural reliability is dealt with in chapter 8.

7 Overhauls

One possible risk during an overhaul (revision) period is an extension of the overhaul and an increase in time and/or costs. Figure 7.1 shows the historical mean overhaul extension of Dutch power plants units. The extension varies per type of plant and on the average is a few days. However, the probability on an increase is 25-50%! With computer aids such as RAS-PROJECT , SUPERTRAK and @RISK for PROJECT, the risks can be quantified. Conditions for a good quantification are:

- A good understanding of the planning of the revision, the work to be done and duration and costs. This should be certainly derived for those activities which are on the critical path with regard to duration and dominance in costs. A major amount of detail is not needed (figure 7.2).
- data concerning the usual spread in time needed and time applied(figure 7.3)
- data about possible unexpected events (from history or from interviews with experienced people) that can cause an overhaul extension. As examples: delay during the transport of a steamturbine rotor, unexpected cracks found during inspection, etc..

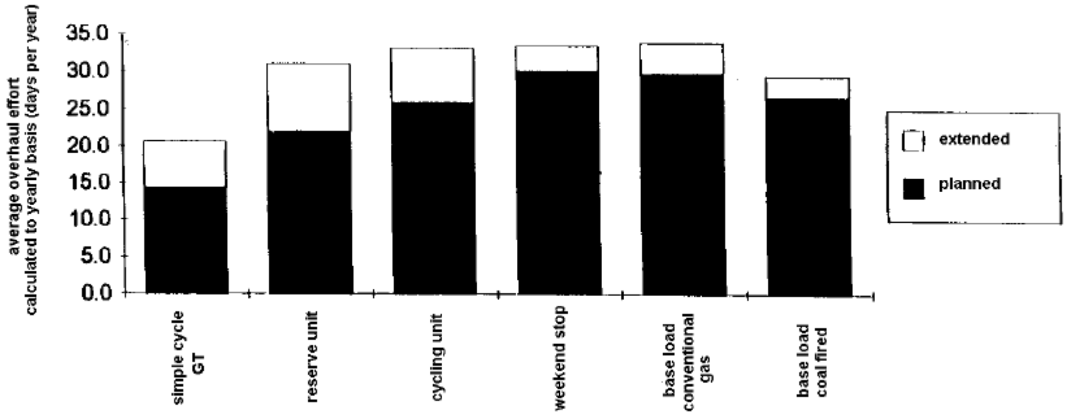
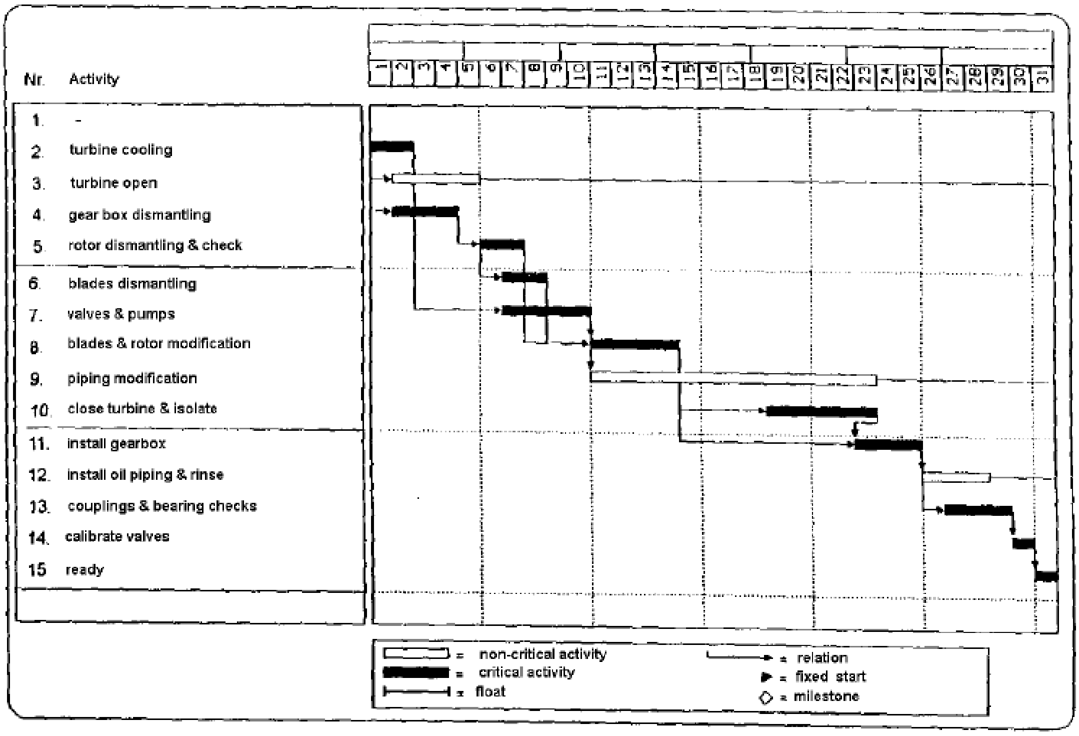


Figure 7.1 overhaul effort



Fiogure 7.2 Part of overhaul planning

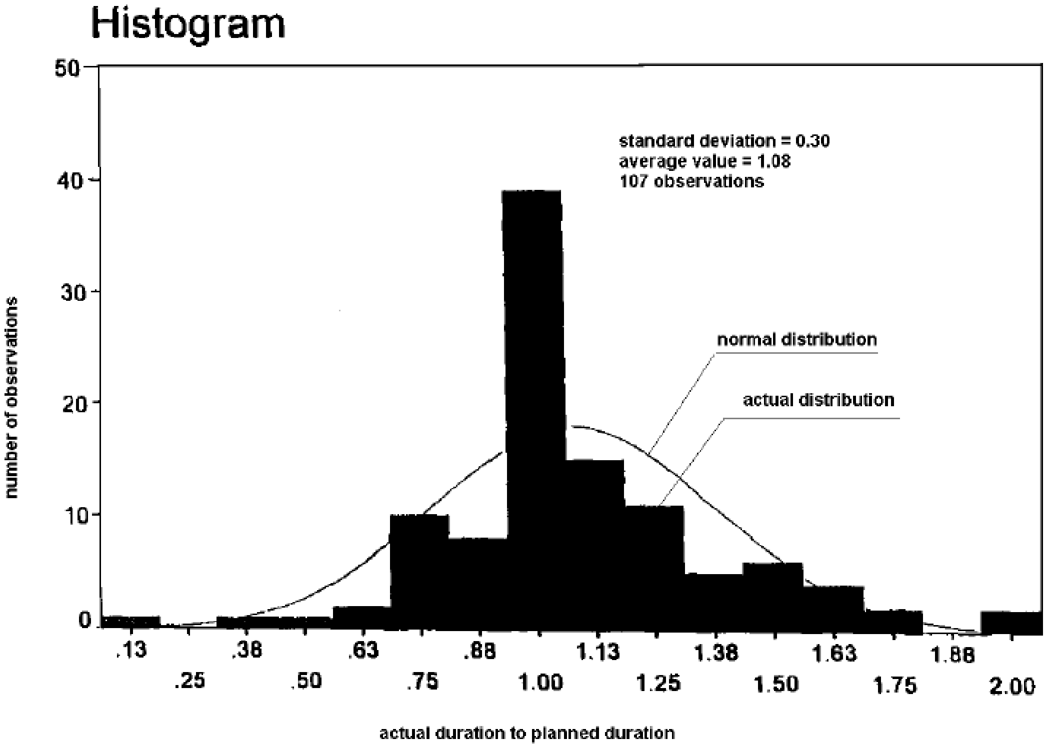


Figure 7.3 Variation of time to carry out overhaul actions

Both the spread in duration (figure 7.4) and the uncertainty in total costs of the revision can be calculated. Components that are dominant with regard to risks in costs and duration can be pinpointed. For those dominant components, measures can be applied and the difference in risk can be calculated.

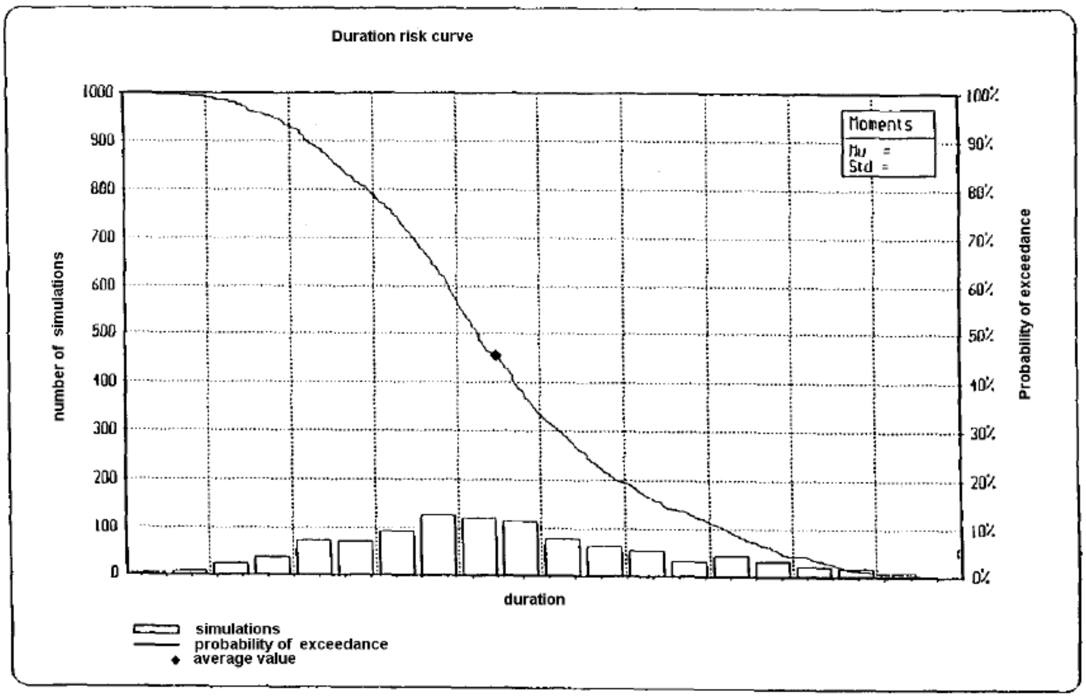


Figure 7.4 Risk duration curve

The quality of the analysis increases if the dominant unwanted events are estimated both from interviews and from databases. Quantification of the risk involved is relatively simple.

The collection of overhaul data is most useful if one restricts to data for activities on the critical path and dominant activities as far as concerning costs, etc. Collecting overhaul data differs from failure data with respect to EFOR: during an overhaul a extensive amount of work is done at the same time and at the same place while a lot of personnel is involved. This influences the way of collecting data as well as the depth of data collection.

8 Reliabilty Centered Maintenance

Reliability Centered maintenance (RCM) has been developed in the air industry and has proved to be successful in decreasing maintenance costs. Over recent years there is an increasing experience with RCM at power plants. By being a member of the Power Generation & Maintenance Experts network PGMON at VGB, it was learned that RCM may result in a a major amount of work to be carried out, but also at power plants RCM will lead to cost reduction. Many forms of streamlined RCM exist.

RCM should form the basis for a maintenance concept of equipment. Any RCM will start with a Failure Mode Effect analysis FMEA. This FMEA must show the qualitative relation between failures (prevented) and maintenance activities. The resulting maintenance concept as a next step must then be optimized.

NRG is experienced in RCM outside the E-production world also (ABB, Shell, DSM, etc.) and has used this experience in a systematic way for power plants on the Amer, IJmond, Purmerend and Almere locations. RCM necessitates a structured way of dealing with failure modes, consequences and measures to limit the chance of a occurrence of a failure and its effects. The best way is to use plant specific data and experience and to discuss it in groups of professionals from operations, maintenance etc. However if there is still little experience around (limited hours of operation), then generic events from other units should be used.

RCM gives management a tool to improve the existing maintenance concept and to control the costs and profits of suggested modifications. The (effects of the) resulting maintenance concept can and should be monitored.

Performing a good RCM is impossible without a good knowledge of the maintenance costs and costs of unavailability. Costs of unavailability have to be estimated, for example on the basis of a reliability analysis. Maintenance costs data have to be collected. Often there are already data present on the location. However, it is often necessary to analyze, screen and simplify these cost data.

9 HILP events and Failure Mode Effect & Criticality FMECA analysis

HILP stands for High Impact Low Probability event. HILP events are very important considering production losses in a park of power plants. In the Netherlands yearly 1 or 2 events occur which can be considered as HILP.

It is not simple to defend against HILP events, because HILPs can occur at different components and due to different causes. The construction of a HILP chart, as carried out for an existing coal fired plant and a new combined cycle unit, makes that the HILP's can be fought and sometimes prevented. Use can be made of the FMECA method, while interviewing and working close together with the people of a plant. Any FMECA should give per component or process:

- what are possible unwanted events
- what are the consequences
- what are possible causes
- probability of the event and severity of the consequence
- the usual measures taken
- new measures that could be taken, if proven cost effective

The FMECA should be followed by the implementation of measures. Consider the analysis as a kind of homework: “did we do and can we show that we took all reasonable measures to prevent HILPs?” Countermeasures are not always that expensive, only for the expensive ones a cost benefit analysis may be necessary. Failure data are important in order to speed up HILP analyses. Together with interpretations of the team that performs the HILP analysis, the failure data can be seen as "paper experts" extending the memory of human expertise.

NRG has recently carried out an FMECA for all power plants of an electricity production company in the Netherlands (not the same company for which all plants were analysed with block diagrams) in order to rank new measures for improving the EFOR of the plants. Generic failure data in combination with plant specific data allowed ready ranking with regards to risk (probability, consequence), risk improvement and costs of the measures involved. Given a beamer, a spreadsheet, thorough preparation and expert knowledge in 1 room, in order to come to the basic results takes a very limited number of meetings!

10 Spare parts

The crux of spare parts is that the costs of spare parts are weighted against the costs of unavailability (waiting time) without the spare part.

In practice the optimum number of spare parts and the optimum strategy is not well known. The manufacturer recommends a number of spare parts, however the necessity will be a point of discussion between the manufacturer and the user/plant owner.

The profitability of spare parts to the user can well be calculated. NRG has developed computer codes for risk parts. For spare parts to be used for risk purposes, the optimum choice can made between one part or no spare part at all with an analytical model. This model uses a mean failure frequency and several parameters for costs and repair time. For parts that will be exchanged during overhauls and may be applied during crashes, a Monte Carlo simulation is the proper way to analyse. NRG carried out such analysis with the commercial SPAR computer code. SPAR, as is shown in figures 10.1 and 10.2, simulates the processes of failure, extraction, ordering, and repair of the spare part.

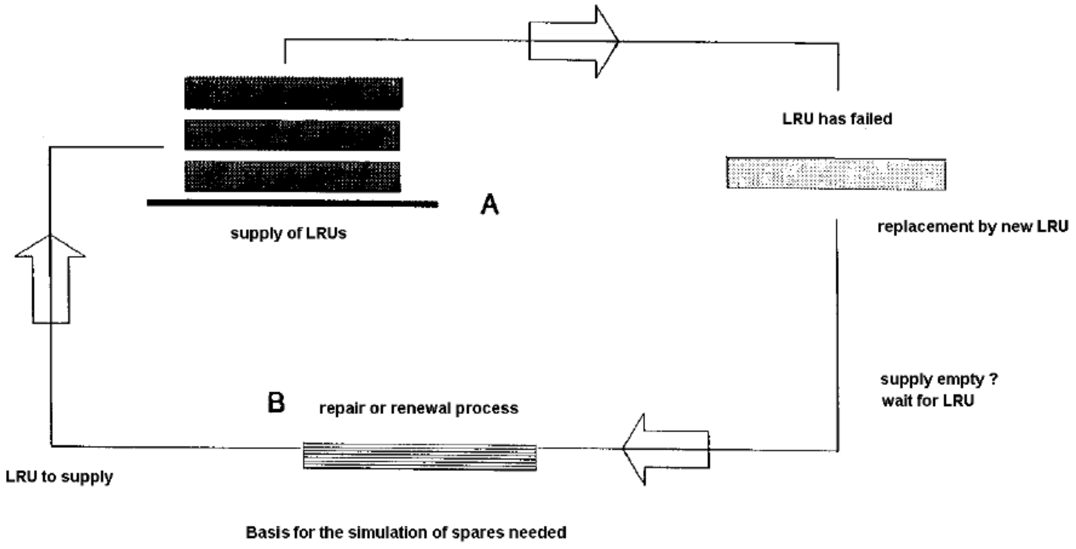


Figure 10.1 Principle of spare parts simulation

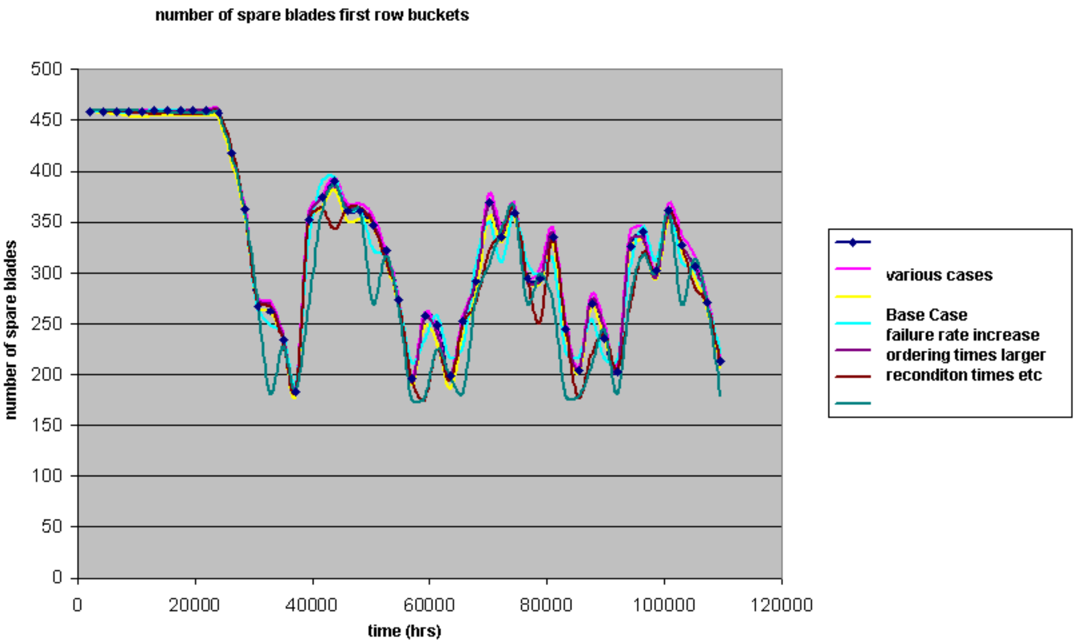


Figure 10.2 Result of spare parts simulation

For a specific type of gasturbine, this analysis resulted in optimum costs depending on the number of gasturbines in a pool and the initial set of spare blades. Also optimization of the strategy itself for spare blades is important:

- spare parts in stock?
- using a pool of spare parts with other users/the manufacturer?
- using a crash stock of the manufacturer?
- deliberately ordering as late as possible to get state of the art spares?
- deliberately ordering as early as possible to prevent that spare parts are no longer available?

11 Structural Reliability

Structural reliability involves the construction of a model for failure probability (e.g. failure by creep), based on the actual properties of the material as well as process parameters, taking into account the spread in properties and measured values. Such a model gives the failure rate as a function of time opposed to deterministically calculated lifetime. Based on such a model, life cycle management is feasible, including what-if analyses for:

- What will happen if we increase temperature?
- What to do in case of decreasing wall thickness?

As a next step, decision trees allow to underpin choices between maintenance strategies (maintenance based on calender or operating hours, maintenance depending on the state of the component (condition based maintenance) and/or maintenance only when failures occur). The effects of the decisions can be calculated and reasoned. Failure data should be used to test the lifetime models.