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Electronic Components and Systems for European Leadership

MANTIS

Cyber Physical System based Proactive Collaborative Maintenance

D1.2 Consolidated State-of-the-Art of Sensor-based Proactive Maintenance Appendix 9:

Algorithms used to optimize maintenance strategies

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Abstract

In appendix 9, maintenance strategies and algorithms related to maintenance optimization are introduced and explained. Various maintenance strategies and their advantages and disadvantages are also discussed. As a specific use case, we show the strategies used in telecommunication network maintenance, and we show how the used maintenance strategies relate to the models presented.

Maintenance strategy optimization is one of the approaches that MANTIS can provide and improve upon.

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1 Introduction

Maintenance strategies are important for any equipment based industry. The aim of any maintenance operation is to reduce costs and increase availability of the equipment, either by limiting maintenance itself or to reduce equipment failure induced down time. Strategies range from run-to-failure to predictive or prognostic maintenance. Choosing and optimizing the most suitable strategy requires not only a comprehensive understanding of the whole operating model but also a device-level understanding of the equipment in use. Choosing the correct strategy also requires cost analysis. Further optimizing cost effectiveness of any chosen strategies requires further analysis.

Maintenance strategies were born from the needs of the airplane industry where a failure of a single component operating as part of a vast system of systems can lead to loss of life and asset.

2 Maintenance strategies

Maintenance strategies can be divided into four types of approaches: run-to-failure, preventive, condition-based maintenance and risk-based maintenance. Each of these strategies have their place in a complex operating model as do each of them have their advantages and disadvantages. All of the aforementioned strategies or approaches are part of reliability centred maintenance (RCM).

RCM was developed for the needs of airlines and air safety. RCM was developed as a result of research done by Nowlan and Heap and is still widely considered to be mostly valid even today despite originating from the late 70s.

An RCM program can be a mixture of all of these approaches for different equipment. Conducting a comprehensive failure modes, effects and criticality analysis or FMECA on the various pieces of equipment reveals which equipment can be considered non-critical and which are of higher criticality.

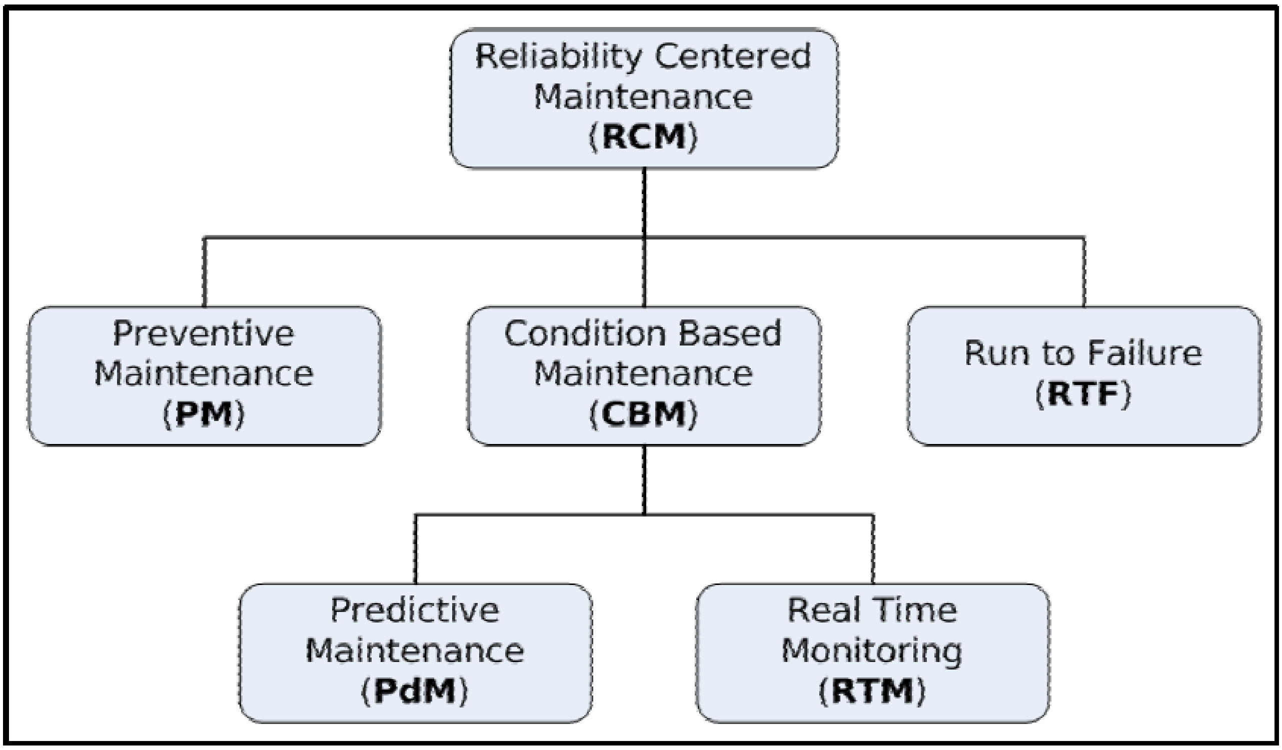

Figure 1 Maintenance approaches [1]

2.1 Corrective maintenance and Run-to-failure

Corrective Maintenance (CM) or reactive maintenance (RM) strategies are the low cost and low effort approach to maintenance. The principle behind these approaches is to only replace the asset when failures occur, regardless what is the state of the rest of the process. Failing assets are allowed to cause down-time. This is suitable for processes where the cost of other maintenance approaches far exceed the costs of possible downtime induced by a rundown failure of an asset. It is also cost-effective in scenarios where asset failure does not affect other assets in a meaningful way.

Run-to-failure (RTF) as the name implies, allows an asset to fail. Once failure occurs the asset is then either repaired or replaced completely. RTF is a part of the CM approach. In RTF costs of repairing or replacing the defective asset outweigh the cost of doing other maintenance related activities on it.

Optimizing CM is difficult as it is inherently cost-effective for non-critical equipment and as such equipment failures do not lead to any downtime or any non-negligible defects in the end-product. Equipment ranked as non-critical can be allowed to break down and replace or refurbish as needed.

2.2 Preventive maintenance

Preventive maintenance (PM) utilizes a scheduled or criteria based maintenance program. Sometimes called scheduled maintenance, PM tasks are carried out at a predetermined interval and are aimed at reducing the risk of failure and performance degradation of equipment. In the PM strategy, the equipment is taken offline, inspected and any necessary repairs are done. PM is probably the most common maintenance strategy in use despite being cost and man-labour intensive while the initial costs are relatively low.

In PM the replacement of a piece of equipment or the whole equipment can be determined for instance by time or through-put counter. Once a defined limit is approaching the equipment will be replaced or repaired regardless of whether it truly needs it or not.

Mean time to failure (MTTF) and mean time between failures (MTBF) play a vital role in PM planning. Each piece of equipment comes provided with a manufacturer assessed MTTF or MTBF, depending on whether the equipment in question is repairable or not. MTTF usually implies to a piece of equipment that ought to be replaced completely towards the end of the MTTF. MTBF implies that the equipment can be repaired.

Mean times are a tool for planning PM activities, however this does not take into consideration different failure rates such as infant mortality and bathtub. Both MTTF and MTBF assume that degradation is predictable and that the equipment is used in ideal conditions.

MTTF can be calculated for a set amount of samples, with observed failure times, using

$$MTTF = \int_0^\infty tf(t)dt = \int_0^\infty R(t)dt \quad (1)$$

where R is the reliability function and t is the any measurement of system usage that is a factor in system wear, can be operating hours, age, operational distance.

From observed operating times, the MTBF can be calculated using

$$MTBF(t) = \frac{t}{N(t)} \quad (2)$$

where t is the cumulative operating time and N(t) is the observed number of failures by time t.

Both calculations rely on history data and, more importantly, observed failures. This is why most of this information is obtained initially from the manufacturer of the asset. Obviously this time can be reassessed once the asset or similar assets in similar situations have been observed enough to accumulate history data.

2.3 Condition based maintenance

CBM can be further divided into two separate approaches. Both of which are inspecting the actual condition of the equipment but with different methods. Predictive maintenance relies on offline testing and history data for trending and real-time monitoring utilizes sensors to monitor the actual health of the equipment online.

2.3.1 Predictive maintenance

Predictive maintenance (PdM) strategy relies on offline testing of critical equipment. The test results are then trended and used to predict the need of the next test and possibility of future failures. Prediction by offline testing results in a rather limited data set and this has an adverse effect on the probability calculations when trying to predict the next course of action.

A useful tool for predictive and prognostic maintenance is estimating the remaining useful life (RUL) of an asset. RUL is a statistical estimation of the remaining operational time of a given asset based on the various information available from condition monitoring and other information sources. There are various types of models available on how to approach the subject. These are however not within the scope of this report. RUL is discussed more in detail in Appendix 8. [2]

2.3.2 Real-time monitoring

Real-time monitoring uses sensors and sensor-networks to measure the health of an equipment and using algorithms to predict problems. RTM is usually connected to some sort of computerized maintenance and monitoring system (CMMS). The real-time monitoring allows for more exact prediction based on much larger data sets. Automated real-time monitoring attached to a CMMS can dispatch work orders automatically when needed. Real-time trending based on large data sets yield more reliable prediction when possible faults may occur.

2.3.3 Health and Usage Monitoring (HUMS)

Health and Usage Monitoring is heavily used in aviation, and is now finding its way into other platforms where communication bandwidth is limited or not available at all. Monitoring data is collected continuously on-board, but real-time streaming is not possible. (In some military use-cases to avoid the risk of detection by signal emission.) Upon return, data is downloaded from the platform for offline analysis, but with a larger data set as opposed to Predictive Maintenance as described in par 2.3.1.

2.4 Risk-based maintenance

Risk-based maintenance (RbM) relies on risk evaluation of the equipment. The tasks themselves are carried out by integrating analysis, measurements and periodic tests to preventive maintenance. Risks can be analysed by assessing the probability of failure (PoF) and the consequences of failure CoF and plotting the values on a criticality/risk matrix. See figure.

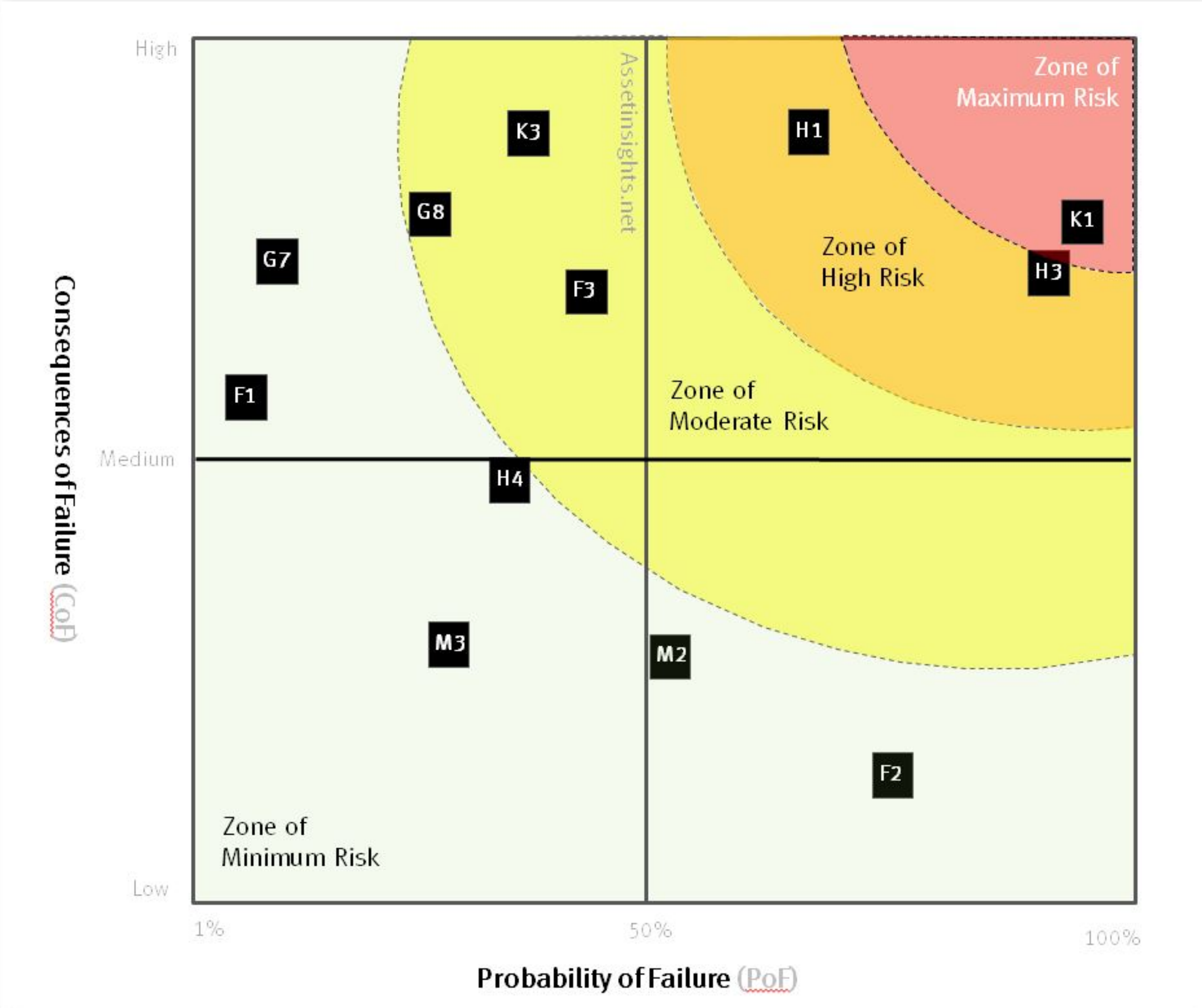

Figure 2 PoF and CoF in an RbM matrix [3]

The probability of failure changes over time depending on the type of the asset or equipment. Certain types can have for instance a high probability of failure at the beginning of its lifetime during the break-in period and then sharply dropping to low levels and through wear get progressively higher until reaching a wear-out phase. This is called the bathtub curve by Nowlan and Heap. They also outlined several other so-called age reliability patterns, from which infant mortality was the most common at 68%. The research was conducted in the 70s for United Airlines. [4]

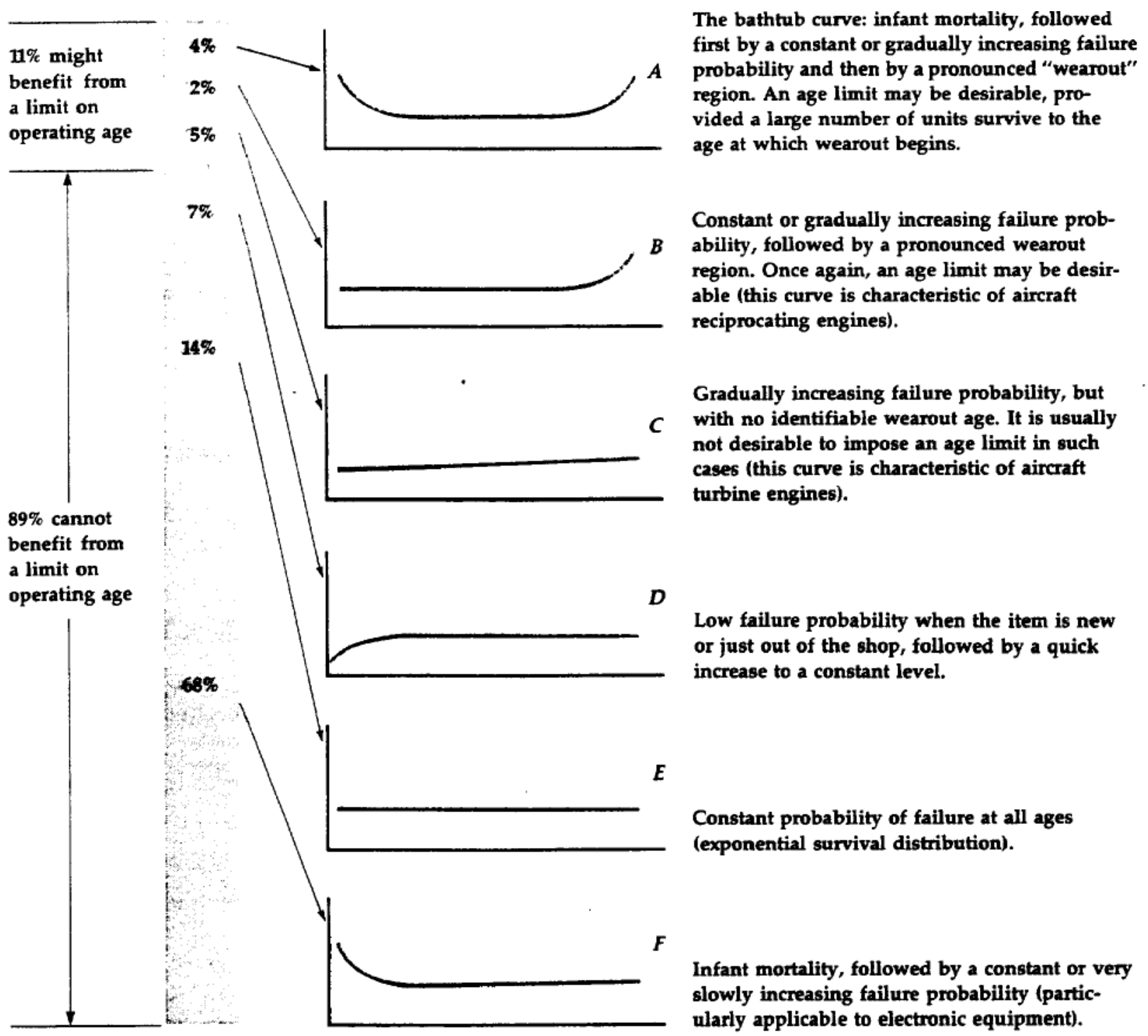

Figure 3 Various reliability patterns identified by Nowlan and Heap [4]

Consequences of failure can be established through criticality analysis. Ranking of consequences can be for instance a multi-tiered approach, a simple low-medium-high ranking or a numerical value. They can also be divided into different types such as legal, physical, social or financial. A consequence can contain characteristics of one or all of these types.

After evaluating CoF and PoF the risks can be ranked and based on their rankings, inspection plans and mitigation measures can be outlined. Occasionally the RbM evaluation will need to be reassessed. See figure for the evaluation framework diagram.

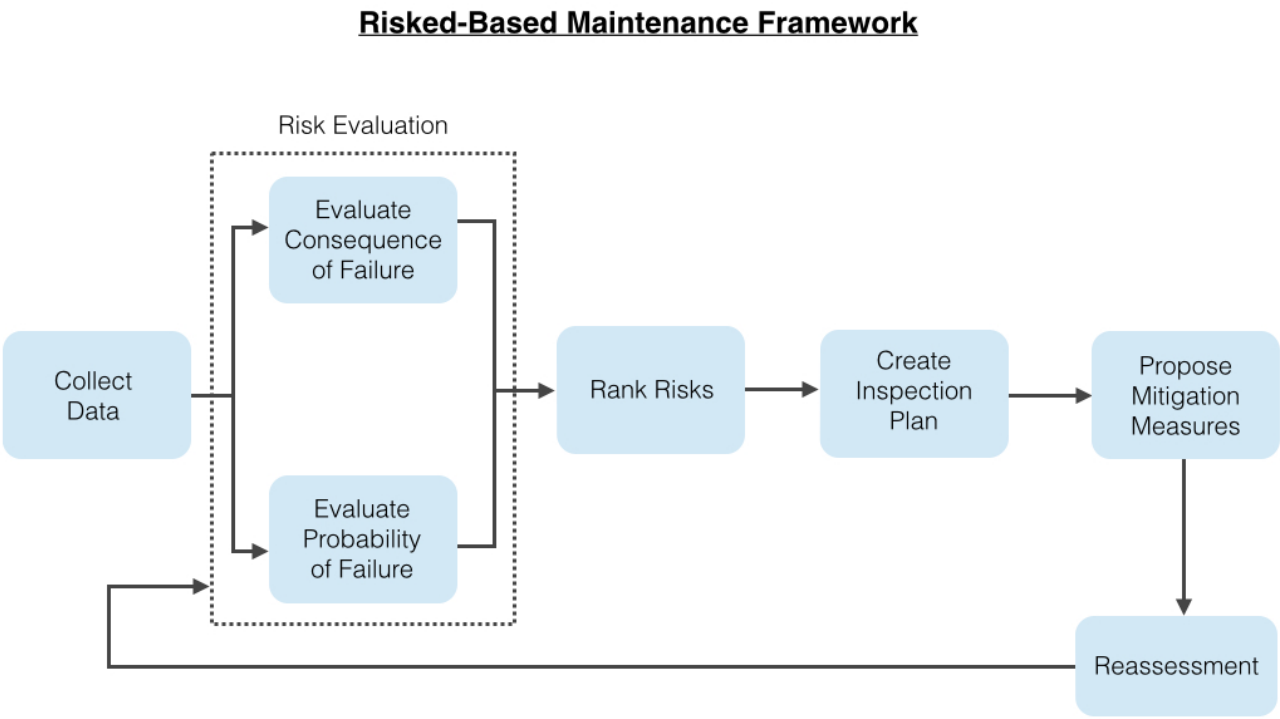

Figure 4 The framework of a risk-based maintenance evaluation [5]

3 Algorithms

Failure rate is a simple algorithm that can be used to define the reliability of an asset. It is rather rudimentary but does provide some insight. It can be calculated as:

$$FAILURE\ RATE = \frac{FAILURES}{OBSERVATION\ TIME} \qquad (3)$$

Where failures are the amount of failures observed during a set observation time.

Over time several maintenance optimization models have been developed for various different applications. Usually applying an existing mathematical approach to maintenance tasks, costs and timing. Some take inspiration from nature, such as genetic algorithms and the ant colony models. These models are listed chronologically and described shortly in table 1. A few of these will looked in more detail within this document.

Table 1 Several different maintenance optimization models described [6]

Maintenance optimization models	Reference author(s); year	Short description
Block replacement model	BARLOW et al.; 1960	Introduced for optimization of replacement times in PM of one-unit systems. The equipment is replaced at failure and exchanged at a pre-specified time, respectively.
Age replacement model	BARLOW et al.; 1960	Introduced for optimization of replacement times in PM of one-unit systems. The equipment is replaced at a failure or when it has reached a predetermined age. The method has benefits for system availability, but is not cost-effective from the replacement decision point of view.
Minimal repair model	BARLOW et al.; 1960	The model advocates on performing minimal repairs in order to restore the system. There are limitations regarding the distinction between critical components.
Opportunity replacement model	JORGENSON et al.; 1967	In this model there are two classes of components failure of a component from one class triggers opportunities for preventive replacement of components from the other class.
RBR (rule-based reasoning)	BUCHANAN et al.; 1969	RBR optimization comprise a knowledge-base and a set of rules the system use to diagnose or predict a fault. Extracting, validating, and verifying the rule base is essential since one faulty rule may wreck the complete result and make the results unreliable.
PHM (proportional hazard model)	COX; 1972	In this model, the unique effect of a unit increases in a covariate is multiplicative with respect to the hazard rate. The model is limited to the cases where the replacement of the faulty component is considered to bring the system to its original state.
CBR (case-based reasoning)	SCHANK et al.; 1977	CBR is based on the idea to apply old knowledge of problem solving to solve new problems, using a cognitive model of learning from experience. When a new failure occurs, it is compared with the existing case library and similar cases are retrieved. In complex systems CBR cycle could become progressively time and resources consuming.
PAR (proportional age reduction)	MALIK; 1979	The maintenance effect is assumed to reduce the age of the system with respect to the rate of occurrence of failures, and the stress acts multiplicatively on the baseline cumulative intensity.
Pareto optimum	KOSKI; 1984	The concept has been introduced as the solution for multi-objective optimization problems. The weighting of the maintenance objectives depends on the consequences of failure, economy, and reliability.
Ant colony optimization	COLORNI et al.; 1991	The collective behaviour emerging from the interaction of the different search threads has proved effective in solving combinatorial optimization problems.
Optimal interval for PM/ replacement using an age-based/ diagnostic-based renewal strategy	LEGAT et al.; 1996	The method is useful for engineering systems with Weibull life distributions and for a reasonable range of the cost factor (ratio of unit corrective to unit preventive maintenance costs).
Optimal maintenance schedule	VATN et al.; 1996	Used for the components of a production system, taking into account safety, health and environment objectives, maintenance costs and costs of lost production.

Age reduction	DEDOPOULOS et al.; 1998	It determines the optimal number of PM interventions within a specified time, the extent of these activities by means of the age reduction of the system and the expected profit.
PAS (proportional age setback)	MARTORELL et al.; 1999	The model considers that the maintenance activity reduces proportionally the age that the component has immediately before it performs maintenance.
Joint optimization of PM and replacement policies	HSU; 1999	Used for queue-like production system with minimal repair at failures it provides long-run expected profit per unit time for a given maintenance and replacement policy.
PM optimization to multi-state systems	LEVITIN et al.; 1999	The architecture of algorithms is developed to identify the optimal sequence of maintenance actions to provide system functioning with the desired level of reliability during its time by minimum maintenance costs.
Risk-based maintenance optimization using a Bayesian approach	APELAND et al.; 2000	Used to present probabilistic frameworks for the maintenance optimization, with the help of Bayesian approaches to risk and risk analysis.
Optimal number and period of time for periodic PM	PARK et al.; 2000	Used to minimize the costs of PM of the systems subject to slow degradation. Each PM relieves stress temporarily and hence slows the rate of system degradation, while the system keeps its hazard rate monotonically increasing.
Incorporate GAs (genetic algorithms) in planning periodical PM	TSAI et al.; 2001	Introduced for systems with deteriorated components. The degraded behaviour of components was modelled with a dynamic reliability equation while the effect of PM to reliability and failure rate of components was formulated based on age reduction model.
PM policy with the critical reliability level	ZHAO; 2003	Developed to avoid the problem posed by degradation systems with imperfect PM effect when using conventional PM policies, the model is based on the law that there is the same number of faults in the interval between PM cycles, with the same degradation ratio.
Determination of PM schedules to optimize one measure of the system performance	BARTHOLOMEWBIGGS et al.; 2006	The method treats the number of PM as a continuous optimization variable, with the global minimization of a non-smooth performance function. The method optimizes, through proper PM timing, a measure of system performance, such as minimizing the mean cost over a lifetime, or maximizing the lifetime per unit-cost.
Optimum frequency to perform PM	DUARTE et al.; 2006	The model computes the interval of time between two close PM interventions for each component, minimizing the costs, with the total immobilization periods not exceeding a predetermined value.
Integrate the effect of CM while planning for the PM	SAMROUT et al.; 2009	The method does not consider the CM actions as minimal repairs or replacements, like many of the PM optimization before it. The PHM was used as a modelling tool.
Proposed framework to establish PM plans with safety constraints	VATN et al.; 2010	The authors envisaged a framework for maintenance optimization which shifted the decision tool in maintenance policies with high safety impact, from the maintenance / logistic department to safety department of the organization.

3.1 Genetic algorithms

Genetic algorithms have been proposed as a method to optimize maintenance strategies from cost and asset availability aspects. Genetic algorithms are inspired by natural selection and species evolution. According to Lapa et al. genetic algorithms have been successfully applied to various design and optimization challenges. [7]

According to Alhamad et al. genetic algorithms could be applied to preventive maintenance scheduling in their article on the Advances in Operations Research journal. Defining a genetic algorithm begins from creating a population or collection of chromosomes where each chromosome consists of a number of genes. Each chromosome represents a proposed solution to the given problem. Mutation and crossover operators are applied to two chromosomes to generate new chromosome generations. Crossover combines the parent chromosomes to produce a new chromosome offspring. The offspring chromosome can take the best characteristics from the parents to produce a better solution. Mutation operators can alter one or more of the genetic values to produce altered chromosomes and can produce better solutions. After each generation, the resulting chromosomes, be it a crossover or a mutation, must have its fitness evaluated. The fitness in this means the quality of the solution. [8]

A genetic algorithm has three aspects: The definition of the objective function, definition and implementation of the genetic representation of the chromosomes and the definition and implementation of the genetic crossover and mutation operators. [8] See figure 5 for a flowchart of a genetic algorithm.

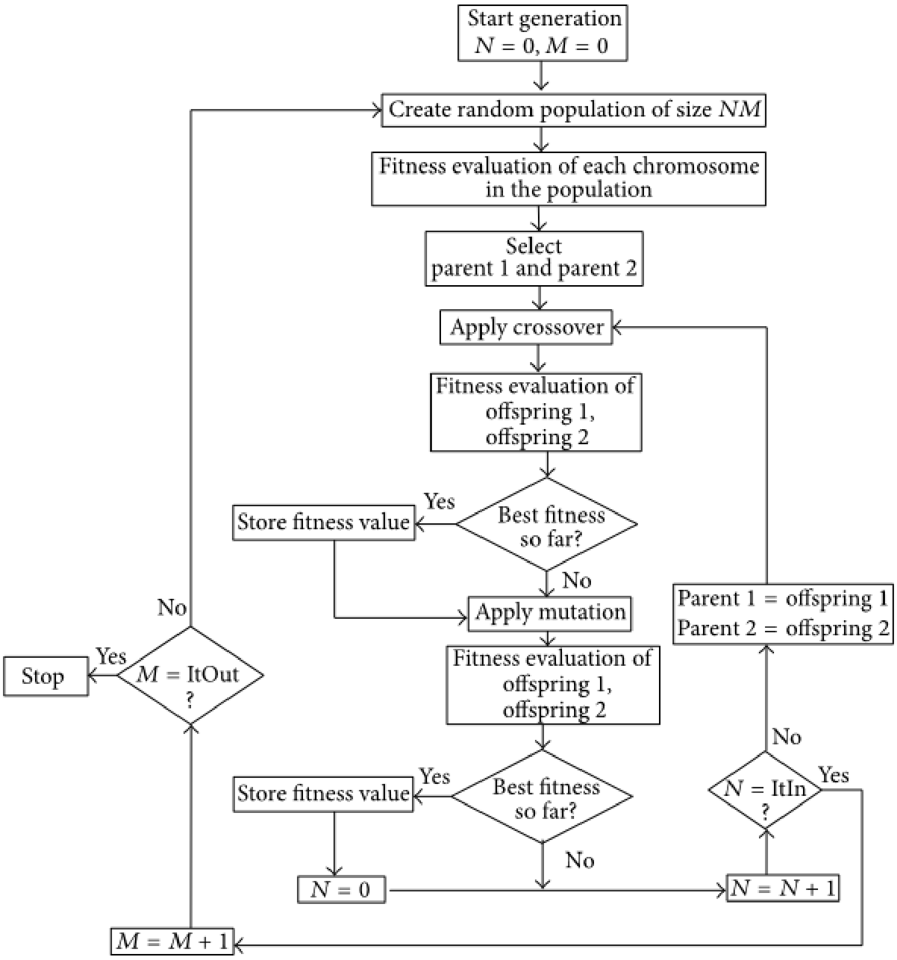

Figure 5 A flow chart of a genetic algorithm [8]

3.2 Ant colony optimization algorithms

Ant colony optimization (ACO) algorithms, much like genetic algorithms, are inspired by naturally phenomenon. As the name implies ACO is based on observing ant colony movements and their optimized pathfinding tendencies. ACO□s principle idea is to find how a supposed ant colony would be able to find the shortest path. In ACO the basic idea is to watch a supposed colony of ants find a path to a solution to a problem and use that path as best solution. In nature the path selection relies on pheromone secretions left by the ant colonies that other ants then sense and use to follow. As the pheromone lasts a limited time due to evaporation and dilution, the less used paths lose their pheromone attraction and only the path with the strongest pheromone trail attracts the majority of ants. This has been observed by placing an obstacle between an ant path and a source of food. At first the ants go around the obstacle at random. Over time however the shortest route prevails and the ant movements become predictable as the least used routes lose their pheromone trail and thus do not attract the ant colony. This is illustrated in figure 6.

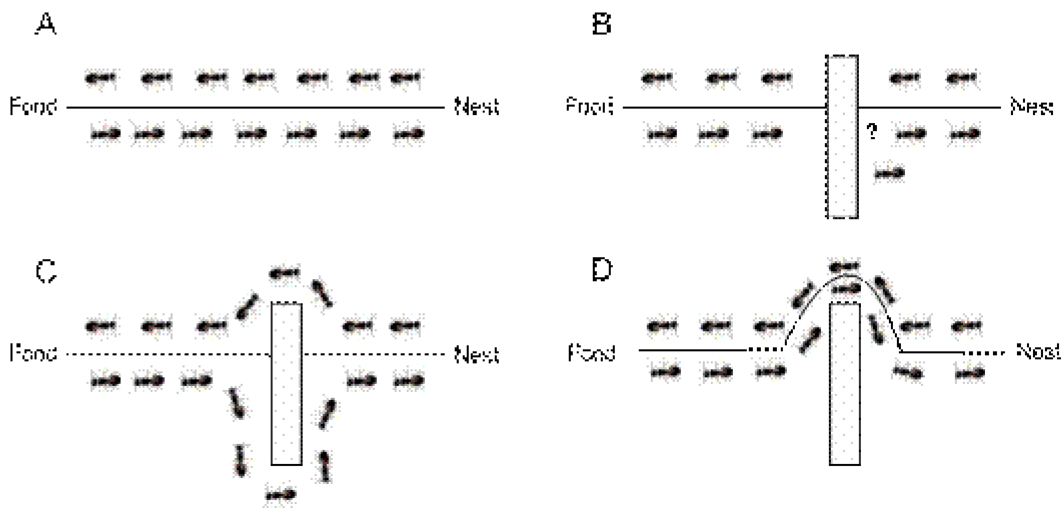

Figure 6 Ants choosing the shortest path around a an obstacle between the nest and a source of food [9]

Computationally an ant in an ACO algorithm is a simple computational agent that iteratively constructs a solution for a problem. In each of the iterations an ant transitions probabilistically from state x to state y. The probability depends on two values, the attractiveness of the move and the trail level of the movie. Attractiveness is some heuristic that indication the desirability of the move. Trail level indicates how proficient the move has been in the past. Trail level is the amount of pheromone deposited for that transition. This transitional probability can be calculated as follows:

$$p_{xy}^{k} = \frac{(\tau_{xy}^{\alpha})(\eta_{xy}^{\beta})}{\sum_{z \in \mathrm{allowed}_x} (\tau_{xz}^{\alpha})(\eta_{xz}^{\beta})} \quad (4)$$

Where τ_{xy} is the amount of pheromone deposited for transition from state $x$to y, 0 ≤ α is a parameter to control the influence of τ_{xy}, η_{xy} is the desirability of state transition xy (a priori knowledge, typically $1/d_{xy}$, where d is the distance) and β≥ 1 is a parameter to control the influence of η_{xy}. τ_{xz} and η_{xz} represent the attractiveness and trail level for the other possible state transitions.

From a maintenance point of view, ACO has been mostly utilized in for example nuclear power plant and vehicle fleet maintenance scheduling and other complex maintenance planning situations. In addition ACO has been used in complementing and enhancing edge detection in computer vision based solutions.

4 Maintenance Optimization in telecommunication

In telecommunication, one of the major factors that change during the lifetime of a system is the traffic - which depends on the users. Unlike for a production plant - where maintenance has to focus mainly to the asset conditions - in telecommunication, besides the equipment management, the service should also be be monitored for detecting the degradation in the quality of the service (QoS). A decrease in QoS may also result from a change in customer traffic, even when the equipment is working optimally.

The International Organization for Standardization (ISO) developed an international network management model known as the FCAPS model [11]. This model identifies five key areas that make up the backbone of network management. The term itself is an acronym that stands for Fault, Configuration, Accounting, Performance and Security. For the different areas, different maintenance optimization strategies are used.

Fault management

For fault management usually both preventive and condition based maintenance is used. Notifications and continuous monitoring detects failures, and protection mechanisms are triggered to handle the failure.

Protection mechanisms are proactive maintenance used for services that require high availability. Based on MTTF and MTTR values the availability of a telecommunication network can be calculated. In some cases the outage caused by repair time (MTTR) is not acceptable. There are two types of preventive maintenance mechanisms used to increase network availability [12]:

- Restoration, and
- Protection.

Restoration uses the available resources in the network to handle the device outage locally. As no resources are allocated for restoration, service degradation may occur.
Protection means proactive maintenance as resources are allocated in advance to be immediately used when a failure occurs in the protected service. The resources dedicated to protection can be allocated as:

- Shared protection, or
- Dedicated protection.

In case of shared protection, multiple resources are protected by one reserved resource. Service degradation may occur in case of multiple simultaneous failures. In case of dedicated protection (or 1:1 protection) the spare resources are dedicated. The latter of course represents the most expensive solution.

Configuration Management

The goals of configuration management include gathering and storing configurations from network devices, to simplify the configuration of the device, to track changes that are made to the configuration, to configure ('provision') circuits or paths through non-switched networks and to plan for future expansion and scaling.

Configuration management is concerned with monitoring system configuration information, and any changes that take place. This area is especially important, since many network issues arise as a direct result of changes made to configuration files, updated software versions, or changes to system hardware. A proper configuration management strategy involves tracking all changes made to network hardware and software, which falls into the category of both preventive and condition-based maintenance.

Providing for change is difficult, as is predicting what changes the future holds. Three types of maintenance are recognized:

1. Corrective maintenance is change involving bug fixes which are either scheduled to be made or are emergency patches, such as incorrect algorithms.

2. Adaptive maintenance is change that is required because some enhancement is needed or an underlying assumption has changed, such as the addition of new hardware.

3. Perfective maintenance is change that is required to make the application more amenable and robust to change for the future, such as making the software more modular, since it is known that change will occur.

Current configuration maintenance addresses corrective and adaptive maintenance through notions such as change requests, change control boards, and life-cycle state transitions. Assistance for perfective maintenance will come with improvements in software engineering techniques.

Administration/Accounting management

The goal is to gather usage statistics for users. Accounting management is concerned with tracking network utilization information, such that individual users, departments, or business units can be appropriately billed or charged for accounting purposes. For non-billed networks, "administration" replaces "accounting". The goals of administration are to administer the set of authorized users by establishing users, passwords, and permissions, and to administer the operations of the equipment such as by performing software backup and synchronization.

Although administration and accounting management involves different subsystems, the related maintenance operations are similar to the case of configuration management.

Performance management

Performance management is focused on ensuring that network performance remains at acceptable levels. It enables the manager to prepare the network for the future, as well as to determine the efficiency of the current network in providing the services. The network performance addresses the Quality of Service parameters, namely the throughput, network response times, packet loss rates, link utilization, percentage utilization, error rates and so forth.

Different standardization bodies (ITU-T, IETF, IEEE) defined methods for monitoring the performance of the network, and they also provide tools for verification and localization.

The basic monitoring capabilities in the network are the passive monitors, which continuously gather information through the implementation of a network monitoring system which in most of the cases builds on the SNMP protocol [10]. Collecting passively performance related data makes possible condition based maintenance. Analysing passively monitoring data network health can be monitored, and trends can be detected which may indicate capacity or reliability issues before they affect the service. Based on passively monitored data, performance related KPIs are calculated which can be used for real-time monitoring. The network monitoring toolset also provides active monitoring tools as well, which can be used either for verification or as part of a proactive network management strategy.

Security management

Security management is the process of controlling access to assets in the network, of gathering security related information and of ensuring that gathered security-related information is analysed regularly. Data security can be achieved mainly with authentication and encryption.

From maintenance point of view, security management is very important and both preventive and reactive maintenance should be used in a well-defined way. Best practices are described in the ITIL recommendations [8].

The proactive security maintenance ensures that all devices are running up-to-date software (including the operating system), and all patches are applied in time.

The condition based security maintenance periodically analyses the security related logs and identifies possible security related issues. If a security related issue is suspected, immediate action is required. As a proactive security measure an increased security level can be applied immediately but the detected security related issues should be handled by security experts.

For all network maintenance related strategies best practices have been established, that define the maintenance process. These best practices are defined in Information Technology Infrastructure Library (ITIL) [13]. The Information Technology Infrastructure Library (ITIL) can be explained as a series of documents that are used to aid the implementation of an Information Technology Service Management structure. This framework defines and outlines how service management should be applied within an organisation.

5 Conclusions

There are various approaches to maintenance optimization and some powerful algorithms to be applied. They can be applied to multiple maintenance strategies. A powerful and comprehensive platform would bring these optimization techniques closer to those involved in maintenance planning. Some of the tools that could be used for maintenance optimization require a lot of historical data to be accumulated before the algorithms produce viable solutions. A platform that consumes data from various sources and different locations where similar assets are deployed, could provide enough information that could be applied to maintenance plans in locations that are new.

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Appendix 1 List of relevant standards related to WP4 tasks 4.4 and 4.5

Standard Organization	Number	Title	Publishing Year
PSK	6201	Maintenance. Terms and definitions	2011
PSK	7501	Key performance indicators of maintenance for use in process industry	2010
SFS	13306	Maintenance. Maintenance terminology	2010
SFS	15341	Maintenance. Maintenance Key Performance Indicators	2007
DIN	31051	Fundamentals of maintenance. (Grundlagen der Instandhaltung)	2012
BSI	1325	Value Management. Vocabulary. Terms and definitions	2014

BSI	1325-1	Value management, value analysis, functional analysis vocabulary. Value analysis and functional analysis	1997
BSI	13269	Maintenance. Guideline on preparation of maintenance contracts	2006
BSI	13306	Maintenance terminology	2001
BSI	13460	Maintenance. Documentation for maintenance	2009
BSI	15341	Maintenance. Maintenance key performance indicators	2007
BSI	55000	Asset management. Overview, principles and terminology	2014
BSI	55001	Asset management. Management systems. Requirements	2014
BSI	55002	Asset management. Management systems. Guidelines for the application of ISO 55001	2014
UNI	10144	Classification of maintenance services	2006
UNI	10145	Definition of evaluation factors of services maintenance firms	2007
UNI	10146	Criteria to prepare a contract for supplying maintenance finalized services	2007
UNI	10147	Maintenance - Additional terms and definitions to EN 13306	2003
UNI	10148	Maintenance - Management of a maintenance contract	2007
UNI	10224	Maintenance - Process, sub-processes and main activities - Fundamental principles	2007
UNI	10366	Maintenance - Design criteria of maintenance	2007
UNI	10449	Maintenance - Criteria to prepare and to manage the permit to work	2008
UNI	10584	Maintenance. Systems of information of maintenance	1997
UNI	10652	Maintenance - Appraisal and evaluation of the goods condition	2009
UNI	10749-1	Maintenance - Guidelines for management of maintenance materials - General aspects and organizational problems	2003
UNI	10749-2	Maintenance - Guidelines for management of maintenance materials - Criteria for classification, codification, standardization and support	2003
UNI	10749-3	Maintenance – Guide-lines for management of maintenance materials - Criteria for the choice of materials to be managed	2003
UNI	10749-4	Maintenance - Guidelines for management of maintenance materials - Criteria for operational management	2003
UNI	10749-5	Maintenance - Guidelines for management of maintenance materials - Criteria for purchasing, tests and final check	2003
UNI	10749-6	Maintenance - Guidelines for management of maintenance materials - Administration criteria	2003
UNI	10992	Maintenance budget for manufacturers and suppliers of products and services - Guidelines for the definition, approval, management and check	2002
UNI	11063	Maintenance - Definitions of ordinary and extraordinary	2003

		maintenance	
IEC	60300-3-16	Dependability management - Part 3-16: Application guide - Guidelines for specification of maintenance support services	2008
TAPPI	10685	Maintenance - Criteria to prepare a maintenance global service	2007
CEN	EN 16646:2014	Maintenance - Maintenance within physical asset management	2014
CENELEC	EN 60300-3-14	Dependability management - Part 3-14: Application guide - Maintenance and maintenance support	2004
CENELEC	EN 60300-3-16	Dependability management - Part 3-16: Application guide - Guidelines for specification of maintenance support services	2008
PSK	7502	Key performance indicators of logistics. Material function	2002
NF	NF X 60-212	Maintenance - Handbook of instructions maintenance - Definitions and general principles for the wording and layout	1983
NF	NF X60-000	Maintenance function	2002
VDI	2893	Selection and formation of indicators for maintenance	2006
ITU-T	L.25	Optical fibre cable network maintenance	2015
ITU-T	M series	Telecommunication management, including TMN and network maintenance	