

Development and Application of Methods for Maintenance and Reinvestment Strategies for Improvement of Existing Transport Vehicles and Facilities by use of Barrier Modelling and Analysis.

Issued by

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September 2008

Abstract: *The transportation branches do experience an increasingly demand from the market for transport services. The increased demand challenges the branches both to develop and build new and more efficient vehicles, but also increase the utilization and cost effectiveness of the existing fleets. This means reduced and more cost effective maintenance to achieve increased availability and maintain an acceptable regularity to produce more transport capacity. The presentation will cover methods and examples from heavy transport, i.e. cargo and mass people transportation system.*

Key Words: *Maintenance, Risk, Availability, Regularity, Cost*

The analysis approach by barrier modelling has focus on the influence of the RAMS elements (Reliability, Availability, Maintainability and Safety) by implementation of different measures to reduce the maintenance burden and increase the transport production capacity, since the latter is the objective for the operator. The presentation will show how the method accounts for the risk and regularity implications by systematically analysis of the barrier structures, i.e. design, maintenance and operational barriers. The human factor issues may affect unintentionally all barrier types, meaning design by reinvestment and deletion/implementation/change of maintenance/operational procedures. Hence, this element is included in the analysis by MMI (Man/Machine Interface) and MTO (interaction between humans, technical and organisational factors).

1.INTRODUCTION

During the last decades increased competition in the market has moved many industry braches, as well as the transport and railway industry, to find potentials for unit production cost reductions. This has resulted in organisational changes, restructuring of companies, rationalization like staff reductions, increased staff rotation, etc. All these factors affect the maintenance performance in different ways. Traditional Maintenance was normally based principally on the staffs experience and the knowledge was maintained mainly through “learning by doing” from the seniors to the juniors, the “father-son” principle. As a result a generic maintenance program was normally developed and established based on experience and practice. Staff reduction, staff rotation and more frequent reorganisations for the management purpose to make the organisation more cost effective may

reduce the maintenance organisations ability to perform their existing maintenance practice and develop strategies for maintenance approach for existing and new vehicles. Consequently, the result may over time be reduced safety level, increased production loss and unit cost. However, this has increased the understanding that these single activities to reduce production cost need a focus on different management systems adapted to the new organisations and practice. This has moved the operators to find not only single analysis methods, but approaches to use the results from combination of methods to obtain improvement of maintenance management systems.

New technology developments are typically introduced to improve the product in the respect of operation and customers. To a less degree new technological improvements have developed opportunities to “smarter” maintenance for new vehicles and maintenance program development and reinvestments for existing vehicles. The latter is due to lack of approaches to systematically methods of maintenance program development. New technology does also give opportunities to improve existing vehicles in terms of reinvestments and “smarter” maintenance to increase availability, regularity and reduce maintenance unit cost.

This paper focus on experience of approaches to evaluate existing vehicles maintenance programs and development of maintenance programs for new developments.

2.DEVELOPMENT OF METHODS AND RAMS MANAGEMENT

To find a consistent approach for analysis method development the objective should be defined according to the operator's management system, e.g. management of operation and maintenance. There are different recognized methods available, but the challenge is to develop the methods specifically for the purpose to support the maintenance and operation management system. Below the analysis approach is based on the international standard IEC 60300-3-11: Application Guide – Reliability Centered Maintenance, This standard provides a method for establishing a preventive maintenance program which will efficiently and effectively allow the achievement of the required safety and availability levels of equipment and structures, which is intended to result in improved overall safety, availability and economy of operation.

RCM provides the use of a decision logic tree to identify applicable and effective preventive maintenance requirements for equipment and structures according to safety, operational and economic consequences of identifiable failures, and degeneration mechanism, responsible for those failures. The end result working through the decision logic is a judgment as to the necessity of performing a maintenance task. The IEC 60300-3-11 is further developed by including a barrier model to be able to more consistently analyse design, maintenance tasks and operational tasks. This concept meets the intention of the railway industry process standard for RAMS management.

RAMS is a process standard which enables the implementation of a consistent approach to the management of reliability, availability, maintainability and safety, denoted by the acronym RAMS.

A number of standards are issued covering the area of maintenance, maintenance management and RAMS (acronym for Reliability, Availability, Maintainability and Safety). The standards includes more than maintenance issues, and are rather more like applications guides of a total management of the RAMS elements in the different lifecycles of the technical equipment also including the human factor elements. The standards are overall guidelines for an approach, or describing the intentions, to systematically evaluate all elements of concept and design for the purpose of operation. The methods, analytical approach and how the results should be applied in the different operational concepts must be established by the manufacturer and operator. This is the challenge and a key to success. In the following chapters we will describe some of our experience in such approaches.

Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS), EN 50126 was issued by CENELEC 2000-04-01.

The European Standard provides Railway Authorities and the railway support industry with a process which will enable the implementation of a consistent approach to the management of reliability, availability, maintainability and safety, RAMS.

The standard can be applied systematically throughout all phases of the lifecycle of a railway application, to develop railway specific RAMS requirements and to achieve compliance with these requirements. The systems-level approach facilitates assessment of the RAMS influence between elements of complex railway applications.

The approach defined in this standard is consistent with the application of quality management requirements contained within the ISO 9000 series of International standards.

The standard is a guideline which addresses lifecycle processes for railway applications and equipment to obtain a consistent and systematic approach for the use of analysis, safety targets, company strategies and RAM targets to demonstrate RAMS for a complete lifecycle. The standard do not specify analysis methods, targets or any specific solutions but is a guideline by recognition of typical RAMS tasks at the different stages or phases of the life cycle process. The influence of the different elements of RAMS can be illustrated as shown in fig. 2.1.

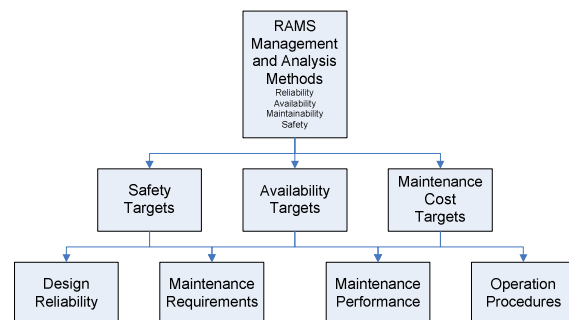


Fig 2.1 RAMS elements

For the lifecycle of the equipment it is necessary not only to demonstrate the safety, operational availability and cost in the design phase but also demonstrate the requirements to maintain the technical equipment and meet the RAMS targets throughout the operational phase.

The results of the analyses are qualified for the operator to manage and control the different criticalities in his operation and maintenance. The challenge is to establish necessary analysis methods/techniques to identify critical functions, measures to reduce the criticality and control the safety of the operation, and a method of continuous surveillance of the assets performance and change management throughout the operational phase. The

operators also have their own business targets to follow up which may lead to different change processes of the equipment or use. These change processes should be demonstrated not to jeopardise the safety of the operation.

The method could not be supported by a single analysis method itself, but is a combination of several practised methods used in several industry branches, like Hazard analysis, FMEA (Failure Mode and Effect Analysis), HAZOP (Hazard and Operability Analysis), Fault/event Tree analysis, Cause analysis, Man-Machine analysis, RCM (Reliability Centred Maintenance), etc. Qualification of the results and determination of indicators for continuously surveillance and change management is a major activity for the preparation of the operator's management system. For this process the standard EN 50126 is a guideline to apply a systematic approach.

For analysis of maintenance task, and maintenance strategy the CEI/IEC 60300-3-11 "Application guide RCM" is used. This standard is a specific method description and is mainly based on the MSG-3 "Maintenance Program Development" developed in the aircraft industry and first issued in 1979. The method covers the area of RCM and is a top down approach identifying critical systems and functions that should be controlled by maintenance or operational procedures in the operational phase. The top down approach is found as a practicable method to re-analyse existing vehicles and facilities since the main objectives of this approach is to more carefully ensure that all relevant critical functions on system level are identified and to eliminate unnecessary assessments and to expedite the detailed RCM analysis.

3. ANALYSIS METHOD APPROACH

The government regulatory and the branch expectation were to establish methods to achieve more predictive processes by control and management of the RAMS elements to achieve and maintain an acceptable safety level throughout the operational phase with optimal operational capability and competitive maintenance and operational cost. The challenge is to find methods of analysis where the results can be adapted and visualised in a way that these could be used in the operator's management system in the operational phase. The approach was to establish acceptance criteria's, identify critical functions, barriers and design/operational principles that had reasonable conditions for the operator to be implemented in a functional management system. This approach could be adapted to implement a method to re-analyse and optimize existing maintenance programs with the purpose of reduce maintenance cost, more evenly distribute the maintenance burden, a program for improved more

flexible planning and increased availability for operation.

The potentials by re-analysing existing maintenance program was based on experience with maintenance program developments in the industry and technological developments for the last two decades showing;

- Railway vehicles, rolling stock, have been subject to major technological improvements the last two decades.
- Modern maintenance program philosophy and analysis methods have not been considered and used to a significant extent.
- Maintenance programs are still based on manufacturers experience, the operator is not directly involved in the maintenance program development process.
- Maintenance program development takes to a less degree considerations to opportunities with new technology.
- Components removal for overhaul, called "hard time", is still widely used.
- Condition based, "on condition" is less evaluated and inspection criteria are not developed to a sufficient degree.

The approach of the analysis of existing maintenance programs is based on a conceptual barrier model which is added to the RCM method IEC 60300-3-11, see fig. 3.1a In the model a critical function is defined as a function active during normal operation, see fig 3.1b. A barrier is defined as an implemented measure to reduce the probability of a single failure to develop to an undesirable event, meaning consequence for safety, availability/regularity or significant cost. Implemented measures may be technical design as redundancy, back-up systems, etc., or maintenance tasks/ operational procedures.

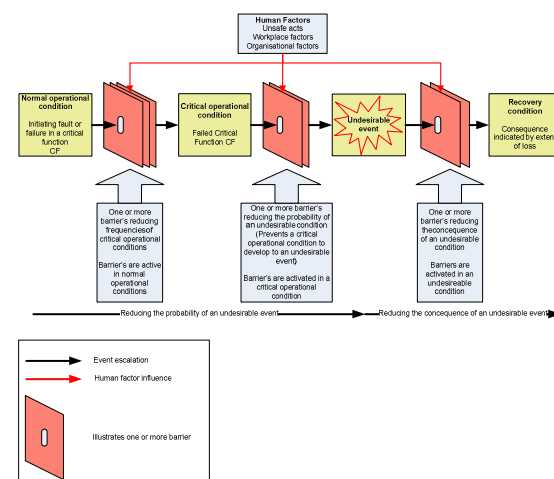


Fig. 3.1a Conceptual model, barriers

The barrier model is added to systematically identify all barriers implemented to preserve a critical function. The critical function is identified by the different maintenance tasks. Further, the barrier model is used to analyse the total barrier chain for the function for the purpose to develop and improve existing barriers, implement new barriers or remove barriers/maintenance tasks that do not contribute to preservation of the actual function.

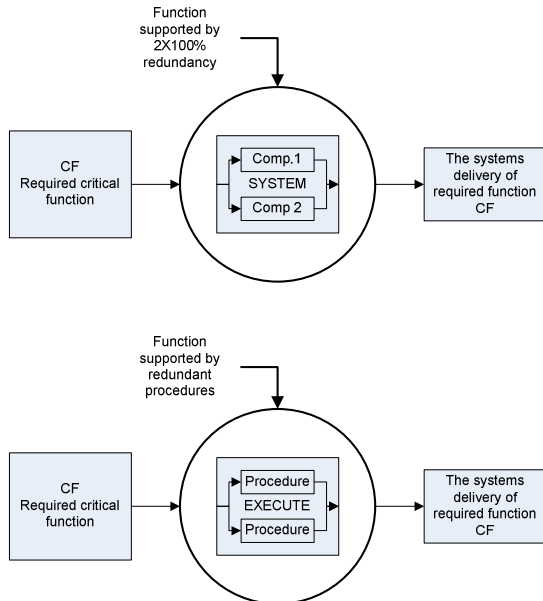


Fig 3.1b Critical Functions

Re-analysing existing maintenance programs starts with the existing maintenance activity followed by the analytical steps;

Existing maintenance program;

- Maintenance task level, identify the function the task preserves
- Classify the function according to significance for safety, availability/regularity or maintenance cost.
- Systemize the operators (and industry) experience

Barrier analyses

- Identification of existing barriers, barrier chain (design, maintenance tasks, operational procedures), fig 3.2.
- Analyze the maintenance significance for the total barrier chain.

IEC 60300-3-11 Reliability Centred Maintenance

- Analyze the function according to RCM decision logic, fig 3.3.
- Develop maintenance strategy.

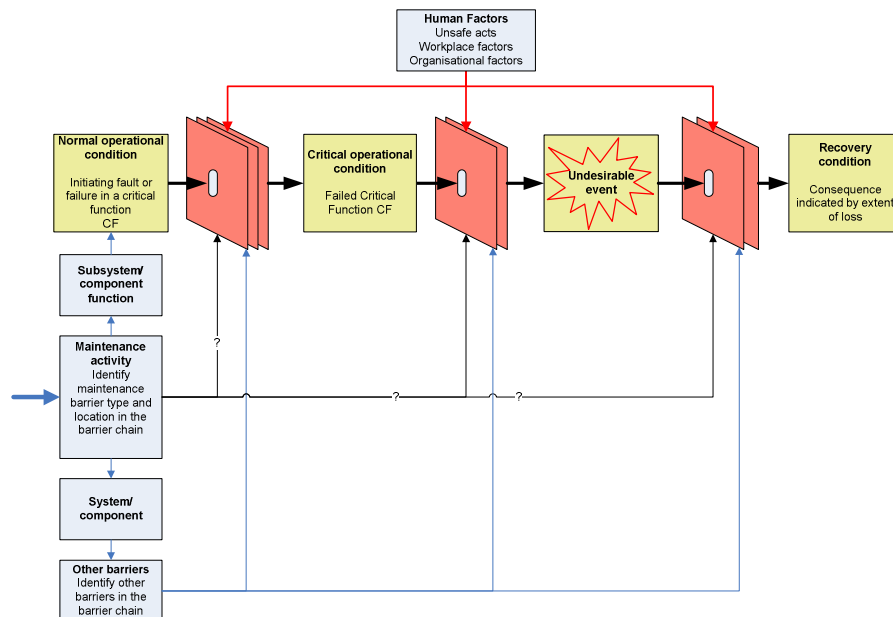


Fig. 3.2 Re-analyzing existing maintenance program

When the barriers preserving a specific function are identified the decision logic, see fig.3.3 is applied to analyse the technical system delivering the function. The decision logic is based on the principles of IEC 60300-11.

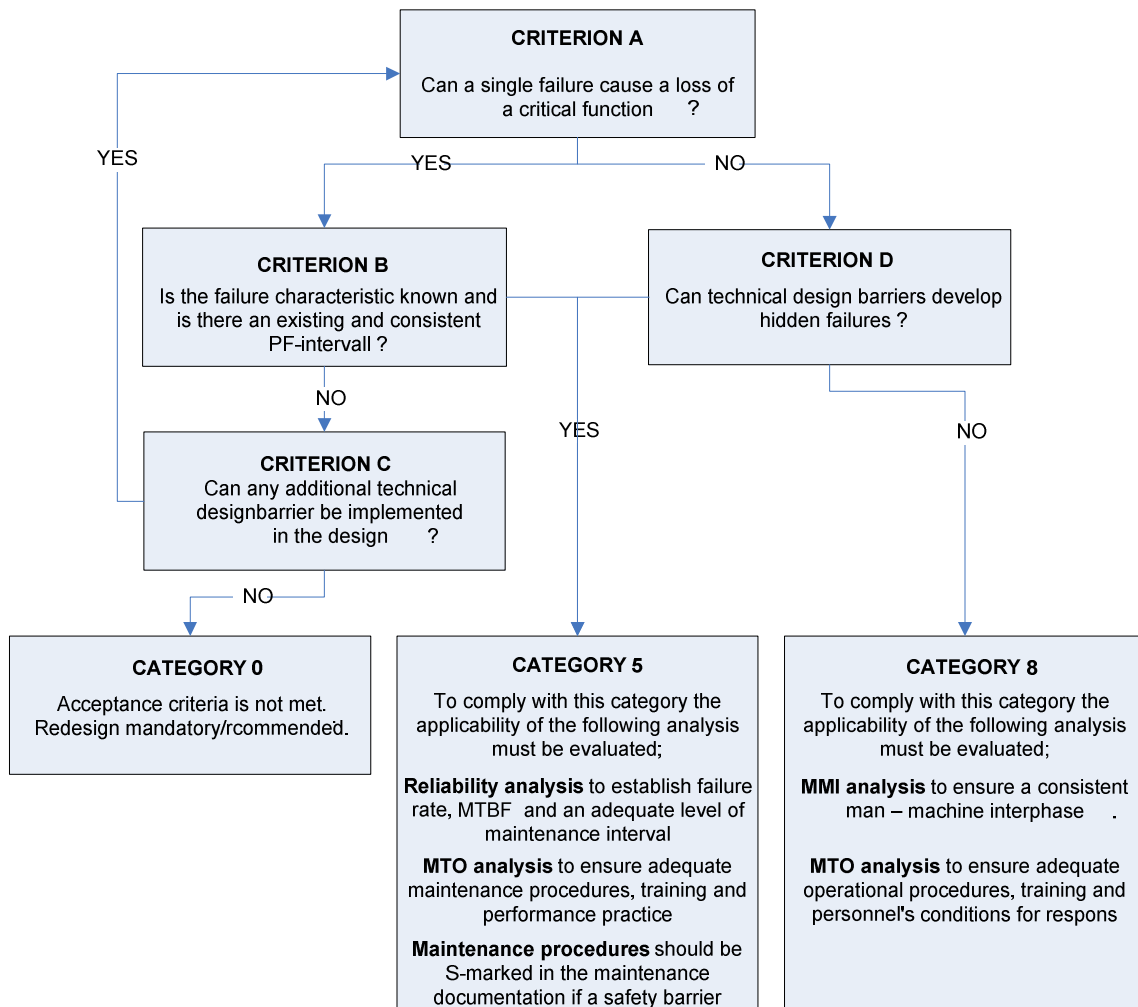
The acceptance criteria's are formulated as criteria's for acceptance of design, if not criteria for design (Criteria A) is met; criteria's for acceptance of maintenance and/or operational procedures must be validated. If these are not met, redesign is recommended or mandatory if risk is implicated. This

facilitates an evaluation of the design and the measures the operator need to control to maintain an operation of the equipment. Further, the acceptance criteria's is formulated in a decision flow chart to facilitate the analysis.

The acceptance criteria's are qualitative and are used to evaluate the design solution and requirements to control the risk through measures in design, operational or maintenance procedures. Detailed analysis of failure frequencies, probabilities of potential failure detection, failure development, etc.

are comprised by maintenance measures where maintenance is significant to preserve critical functions with consequence for safety, operation or maintenance cost.

It should be noted that human factors may impact any barrier in the barrier chain unintentionally meaning that critical functions with maintenance or operational procedures as the last barrier should be paid attention to ensure a sufficient level of quality performance of the maintenance and operational personnel.



NOTES:

Category 0: Redesign required/recommended. The design does not meet the acceptance criteria. The criticality is unacceptable. Consequently, redesign is imperative (if a safety barrier) or recommended to conform to the acceptance criteria.

Category 5; The design alone does not conform to the acceptance criteria. Acceptable means of control measures must be implemented. The criticality may be reduced with potential failure detection by

maintenance procedures (single or hidden failures). To control by maintenance procedures the probability of failures shall be estimated to establish maintenance/conditional control intervals.

Systems with safety functions which are not active during normal operation shall be considered as systems where an initial event is the first failure and the function on demand system is the second failure. These systems shall be analysed as

functions with hidden failures shall have maintenance actions to prevent failure on functional demand.

Category 8;

Fig 3.1 Decision logic diagram based on IEC 60300-3-11.

4.EXAMPLES AND EXPERIENCE FROM RE-ANALYSIS PROJECTS

Experience from reanalysis of railway vehicles, rolling stock, has shown significant potentials in the

Distribution of maintenance burden/cost reduction

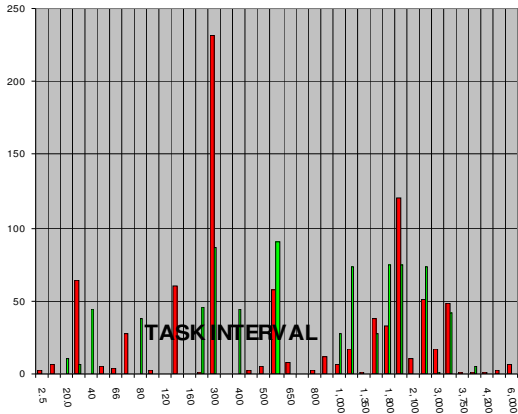


Fig 4.1 Maintenance task distribution

The main contributors to the analysis results are within the following areas;

- Development of inspection criteria or means of detection to reveal a potential failure

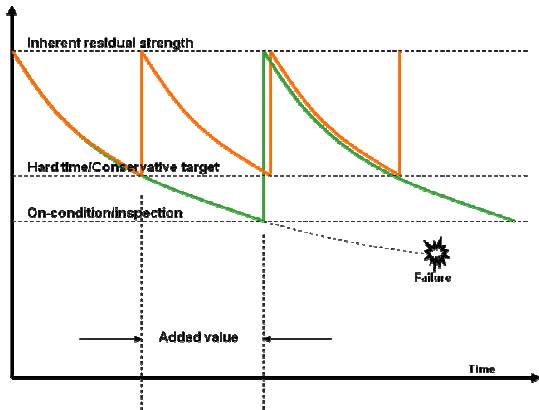


Fig 4.2 Hard time versus on-condition/inspection

area of reducing maintenance cost, less downtime for maintenance increasing the availability for operation, better distribution of the ~~The designed burden forms~~ to the accept improved regularity during operation by implementing procedures for operation. Fig. 4.1 shows some results of maintenance task distribution and cost reduction from an actual re-analysis project with this objective. Red columns indicate the existing maintenance program. Green columns indicate the new maintenance program.

development. Replaces the traditional remove for overhaul interval (Hard-time interval) allowing the operator to utilize the system/components lifetime. See fig. 4.2. Such solutions may add investments to obtain acceptable means of detection and should be demonstrated cost effective.

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- Implement means of failure detection and determination of a P-F interval (time from potential failure (P) to functional failure (F). Timely detection and knowledge of remaining time to functional failure opens a possibility to plan repair to an ordinary maintenance opportunity. See fig. 4.3 and 4.4.
- Implementation of frequent damage source detection. Inspection criteria and repair action for overheat, overpressure, overvoltage, foreign object impacts, exposure for corrosive environment, etc. Extending the lifetime of systems and components. See fig. 4.4.

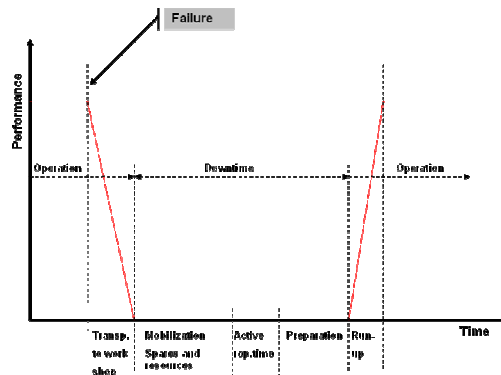


Fig. 4.3 P-F interval and maintenance planning

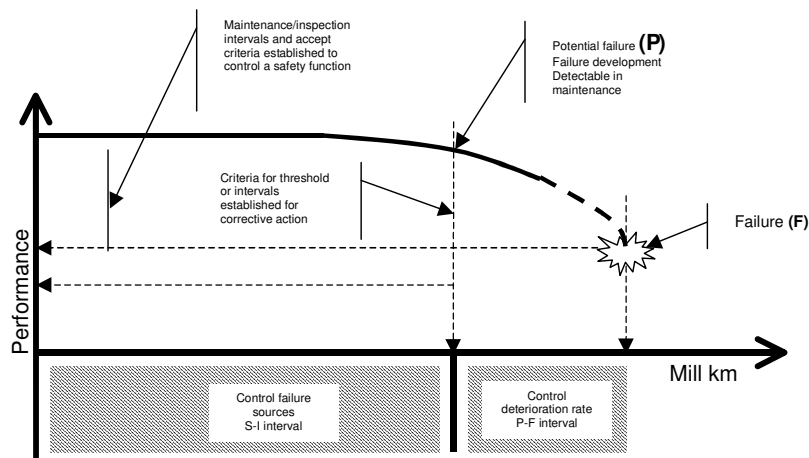


Fig.4.4 Damage source detection and P-F interval

Experience from re-analysis of maintenance programs by application of the RCM method IEC 60300-3-11 and the use of barrier modelling has shown through a number of projects that a maintenance burden/cost reduction potentially may be reduced in the area of 15 – 35% on vehicle level (Rolling Stock) and improve the availability with 5 - 15%. However, the method is selective, meaning that the analysis may be applied on a selected system level by systems predicted as a significant contribution to meet targets for improved operational availability and level of maintenance burden/cost. And these targets can be met ensuring that operational regularity is kept at existing or improved level and acceptable risk level maintained or improved. As a closing remark, it should be noted that the analysis approach is not only applicable for railway vehicles or rolling stock, but also facilities and other industry branches.

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