

# Methodology of maintainability and reliability prediction of technical objects

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## **ABSTRACT**

In recent times, an avalanche increase in the importance of reliability in the engineering design can be seen. The main reason is a permanent competition on the market and a competition for the customer resulting in increasing continually the efficiency of technological processes. The need to achieve a high level of reliability and maintainability is particularly important, where a safe and rapid transportation of people and goods is of high importance. The above-presented state of affairs has inspired the author to present a paper on the methodology and tools to support the estimation of maintainability and reliability of technical objects, together with practical examples.

**KEYWORDS:** maintainability and reliability prediction, parts stress analysis prediction, parts count analysis prediction, methods of prediction the reliability of technical objects

## **1. Importance of and technical objects reliability forecasting**

In recent times, an avalanche increase in the importance of reliability in the engineering design can be seen. The main reason is a permanent competition on the market and a competition for the customer resulting in increasing continually the efficiency of technological processes. The efficiency improvement is manifested by an increase in operating speed when optimizing the weight and size of the object. This action, combined with the multitude of technical measures, is a risk to human health and life and a destruction of the environment through the use of unreliable facilities and technical equipment. Such adverse effects can be addressed using methods of reliability and maintainability prediction of technical objects at the stage of designing

and manufacturing rather than during the same operation. Prediction methods, in particular, are applied in complex technical systems where it is very easy, each operated component may be damaged, causing damage to technical objects, which effects are difficult and dangerous to remove. The need to achieve a high level of reliability and maintainability is particularly important in the field where a safe and rapid transportation of people and goods is very significant.

## **2. Maintainability and reliability prediction methods for technical objects**

Achieving a high level of reliability and maintainability of a system is possible by determining its estimated reliability of the equipment used in order to obtain an

adequate level of system availability without later modifications when it is already in operation.

The Military Handbook 217 (MIL-HDBK 217), created to provide a standard assessment of the reliability of electronic systems and military equipment to enhance the reliability of the proposed equipment is widely used and recognized throughout the world. In this model, there are two ways to predict the reliability: reliability predicted based on the number of parts called Parts Count Prediction, and the prediction based on the analysis of exposure called Parts Stress Analysis Prediction. The method of Parts Count Prediction is used to predict the reliability of a product at the beginning of its development in order to obtain a preliminary assessment of reliability against reliability target or an indicator of availability. The system failure rate is calculated by summing the product of similar items and grouping them into different types of items. The number of elements in each group is then multiplied by the overall failure rate and the quality factor of the model specified in MIL-HDBK 217. At the end of the analysis, it is possible to add the following failure rates of all various parts to obtain the final failure rate. The method of Parts Count Prediction assumes that all components are in series and in the case of non series elements require a separate calculation of failure rates. Parts Stress Analysis Prediction is used in the phase of product development, before designing actual circuits and equipment for the production. It is similar to the Parts Count Prediction, in terms of failure rates of aggregation. However, using the Parts Stress Analysis Prediction method the failure rate for each element is calculated separately on the basis of specific stress levels. This method usually generates a lower failure rate than the Parts Count Prediction method.

The method of state-transition diagram enables the representation of collections of all the states, in which the analyzed system may be. Contrary to the block diagrams, this method provides a more accurate and more detailed representation of the system. This method results in the determination of the estimated indicators like the Availability, Mean Time to Repair and Mean Time between Failures of the system.

SR-332/TR-332 method can estimate the reliability of telecommunications equipment. This model is based on MIL-HDBK 217 as amended in 1985 in this way as to reflect the experience with the telecommunications equipment. In 1997, the SAIC bought the Bellcore model and changed its name to Telcordia.

The method of Handbook for Reliability Data for Electronic Components (HRD5) was developed by British Telecom and is used mainly in the UK. This method is similar to the standard Military Handbook 217 (MIL-HDBK 217) but does not include as many environmental variables and contains a reliable prediction model covering a wider range of electronic components, including telecommunications.

The Process Failure Mode and Effects Analysis (FMEA) is used to analyze the failure mode of a technical object. This analysis can be modified by assigning a priority mode of failure to each object and in this case this method is called the Failure Mode, Effects and Criticality Analysis (FMECA). In this method, the estimation starts examining a technical object at the level of individual electronic and mechanical components, and ends at the level of the whole system.

The method of Highly Accelerated Life Testing (HALT) is used to increase the overall reliability of a product. Using this method, it is possible to specify the time required for the occurrence of a product failure by its carefully measured and controlled load, such as temperature and vibration. The actual time to failure of the product is estimated using a mathematical model. Although HALT can estimate the MTBF, its main function is to increase the reliability of a product.

Standard GJB/Z299B (299B China) is a standard for predicting the reliability of both civilian and military objects. It gives the ability to predict the level of environmental indicators, quality and mechanical properties. This allows, like MIL-HDBK 217, the reliability prediction analysis on the basis of the number of exposures and analysis of the test object.

The Handbook of Reliability Prediction Procedures for Mechanical Equipment (NSWC-07) is a standard commonly used to estimate the reliability of mechanical components. It uses several categories of models for different types of mechanical components to predict failure rates based on the mechanical fatigue of materials, resistance to temperature and other environmental parameters.

The method of Reliability Block Diagram (RBD) is a representative tool for plotting and calculations, used to model the system availability and reliability. It defines logical interactions in the system and each block diagram may represent a failure of a single element, subsystem, or other representative of the system. It is also used for the analysis of each element of a comprehensive system and its impact on the operation of the system.

Like the reliability of the system, the maintainability plays a large role in the design and subsequent operation of the system. The maintainability is the ability to maintain the facility or to restore the operating conditions of the state in which it can perform the required functions, provided that the operation is carried out under specified conditions and acc. to established procedures and measures.

The Military Handbook 472 (MIL-HDBK 472) is a commonly used method of estimating the maintainability of the system. It allows estimating the down time caused sometimes by the time of repairing in accordance with procedures outlined in the document (MIL-HDBK 472), and in particular determining the mean time to repair MTTR. To

determine the maintainability of the system it is necessary to take into account properly the tasks of system operation (known as elements' MTTR), which are sometimes defined as the implementation of various maintenance tasks. Knowing the amount of RI (called Replaceable Items) or a group of interchangeable parts (called group of RI's) of the analyzed system and their predicted failure rates it is possible to determine, for an individual component or group of components, the performance indicators of the system maintainability. For each of the analyzed elements of the RI the execution times of elementary MTTR process for each element are defined, where the sum of these times enables to determine the overall mean time to repair of the system.

### 3. Tools supporting the reliability and maintainability estimation of technical objects

During the reliability analysis of complex technical systems, it often becomes necessary to use computer tools to assist the calculation procedures. This allows for a substantial time saving and an increase in the accuracy of calculation. The most popular tools to support reliability analysis of technical objects are presented below.

#### 3.1. Package Item Toolkit of Toolkit Software Company

A powerful, developed tool to predict the reliability and maintainability is a package of technical objects Item's Toolkit Software. This software package is composed of many modules:

- Reliability Block/Network Diagram – a package to support the analysis of system reliability in terms of structure (reliability block diagram);
- Failure Mode Effect and Critical Analysis – a module equipped with a database of records based on MIL-HDBK-338. It enables to analyse the types, effects and the fault degree of technical objects based on internationally recognized studies: MIL-STD-1629 and BS 5760 Part 5;
- Fault Tree Analysis – a module supporting analysis using a Fault Tree;
- Event Tree Analysis (ETA) – a module supporting the analysis using an Event Tree;
- Markov Analysis – a module supporting the analysis using Markov chains and processes;
- MainTain – a maintainability prediction module to assist the technical objects in the document MIL-HDBK-472, Procedure V, Method A;

- Spare Cost – a module enables to determine the demand for parts and to optimise the number of parts in terms of operating costs. This module uses algorithms for military applications.

#### 3.2. Reliasoft Software

The company ReliaSoft, as opposed to the software outlined above, does not offer a single package to assist the analysis of reliability. The software consists of separate programs integrally acting independently:

- Xfmea – software supporting the analysis, data management and preparation of reports to analyze the types and effects of a fault (FMEA);
- BlockSim – a package enabling the analysis of the reliability structure of RBD (Reliability Block Diagram) and Fault Tree analysis of the FTA;
- Weibull++ - data management software that enables the damage and estimates the reliability of the measurement system;
- Lambda Predict – a program that allows the estimation of reliability factors of both the technical facilities and mechanical studies using recognized, methods such as MIL-HDBK-217 (MIL 217), NSWC-07 (NSWC Mechanical), SR-332/TR-332 (Telcordia), GJB/Z299B (China 299B) and HRD5;
- Alta – a program that allows the estimation of reliability factors with the use of accelerated testing (QALT);
- MPC – maintainability prediction program to help technical objects, in particular the technical systems used in aviation.

#### 3.3. Relex Reliability Studio Package of the Relex Software Company

Another software package supporting the analysis of the reliability of technical objects is the Relex Reliability Studio package. This package in its full commercial version has the following modules:

- Fracas – a system for reporting and analysing failures and corrective actions (Failure Reporting Analysis and Corrective Action System). The program allows support processes to manage the businesses through the optimization of production costs and to improve quality;
- FMEA/FMECA – a program to help analyze the types and effects of failures and to analyse types and effects of the degree of failures. The software uses standard MIL-STD-1629, SAE ARP5580;
- Human Factors Risk Analysis – support software derived from the analysis of a human factor. The most commonly used in industries where a large proportion of errors is attributable to human factors;

- Life Cycle Cost – software for life cycle cost analysis of the "life cycle" from product's inception to the end of its use;
- OpSim – software for simulation and optimization of systems for reliability. It provides information about the activities of maintenance, spare parts store and schedule repair process;
- Reliability Block Diagram (RBD) – software for analyzing the reliability block diagram;
- Weibull – software for the examination of the failure data using Weibull technique;
- Maintainability prediction - assistance software for maintainability prediction of technical objects in the document MIL-HDBK-472, Procedure V, Method A. This allows the estimation of maintainability measures of the system;
- Markov – software to support analysis using Markov chains and processes;
- Reliability Prediction – assistance software for reliability prediction using multiple standards such as MIL-HDBK-217 (MIL 217), NSWC-07 (NSWC Mechanical), SR-332/TR-332 (Telcordia), GJB / Z 299B (China 299B), and HRD5 PRISMPlus library.

### 3.4. Reliability Workbench Package of Isograph Ltd. Software Company

The Reliability Workbench software package of Isograph Ltd. possesses, like the rest of the software environment described above, the modules to support the reliability analysis:

- FMECA – a module that allows analyzing the types, effects and the degree of failures of technical objects;
- Fault Tree + – a graphical module for the assessment of risk with the use of reliability tree analysis and event tree;
- RBD – an analysis of systems using a block-reliability structure. It allows analysing complex systems for the estimation of fundamental measures of reliability;
- MTTR – a module to assist the analysis of systems maintainability;
- Prediction modules – modules supporting reliability prediction using multiple standards such as MIL-

HDBK-217 (MIL 217), NSWC-07 (NSWC Mechanical), SR-332/TR-332 (Telcordia), GJB / Z 299B (China 299B) and HRD5.

## 4. Practical example of reliability estimation of electronic components using the ReliaSoft software

In this chapter, the paper presents a practical example of estimating the reliability of electronic components using the software, ReliaSoft's Lambda Predict. The material is a part of a larger study on methods for estimating the reliability and maintainability of mechanical and electronic components. The reliability analysis was conducted on the example of an induction loop used in the toll collection process. A toll collection loop diagram is shown in Figure 1.

ReliaSoft's software allows creating a System Hierarchy panel of the analyzed system. For example, the panel of the analyzed induction loop diagram shown in Figure 2. When working in the System Hierarchy panel in Lambda Predict, we should be aware of how the following terms are used:

- Systems are analyzed according to one of the reliability prediction standards supported by the Lambda Predict (e.g. MIL-HDBK-217F, Telcordia SR-332 Issue 2, etc.). Such systems are made up of blocks and components.
- A block represents a group of blocks and/or components in the next lower level of the system configuration. The Lambda Predict uses the block properties (based on the applicable reliability prediction standard) together with the calculations for the blocks and components in the next lower level to determine the failure rate, MTBF and other results for the subassembly that the block represents.
- A component represents an individual item (such as a fuse, capacitor, valve, spring, etc.) with properties based on the applicable reliability prediction standard that is used to calculate the item's failure rate, MTBF and other results. Components always represent the lowest level within a branch of the hierarchy. In other words, it is not possible to place another block or component below an existing component.

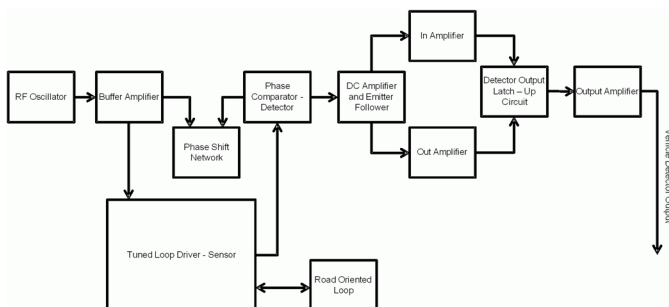


Fig. 1. Toll collection loop diagram

Source: [own work]

We can build a hierarchical system configuration using the blocks and components that are available for the current standard (e.g. MIL-HDBK-217F, Telcordia SR-332 Issue 2, etc.). In general, blocks are used to represent groups of items within a multilevel system configuration (e.g.



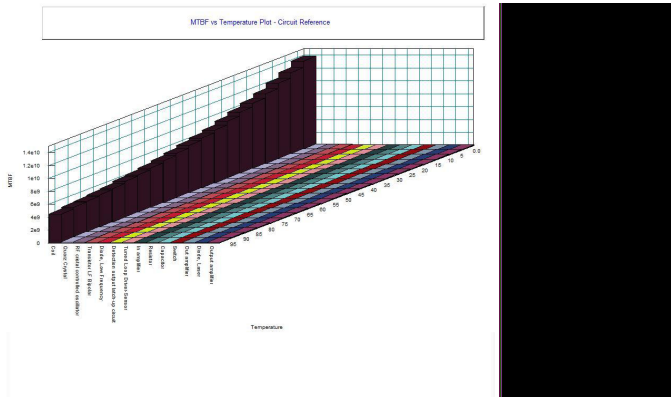


Fig. 2. System Hierarchy panel of the analyzed system in the Lambda Predict  
Source: [own work]

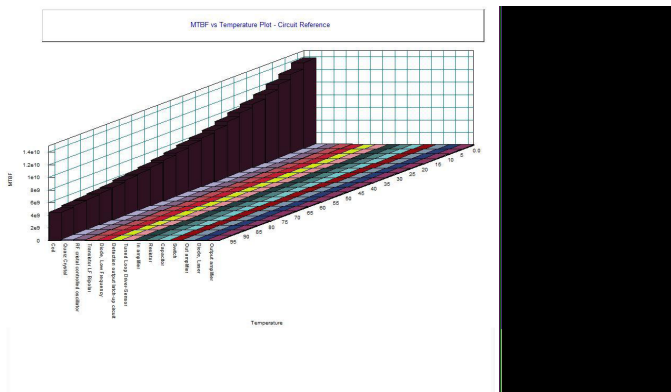


Fig. 3. The Pi Factor view of the analyzed System Hierarchy panel in the Lambda Predict  
Source: [own work]

- The Pi Factor view displays the item properties based on the Pi factor(s) that they contribute to. Pi factors account for the effects of various factors such as environment, stress, quality, etc. on the part's expected failure rate, which is the product of the part's base failure rate and each Pi factor (or acceleration factor) that quantifies the effect of a particular factor's variance from baseline. This means that all Pi factors for a part operating under baseline conditions will be equal to 1, while if the part is operating under conditions other than baseline, one or more Pi factors will be greater than or smaller than 1.
- The Tab view displays the item properties grouped on separate tabs, rather than in a hierarchical tree structure.
- The Grid view displays each item property as a column.

Lambda Predict's ability to analyze multiple systems within each project allows performing "what-if" analyses for comparison purposes. For example, we can change the ambient temperature of the analyzed system, at which it operates. The analyzed system of an inductive loop is in

specific weather conditions. "What-if" analyses allow on the relationship analyzed the elements of the environmental changes in which the system operates. MTBF vs ambient temperature and Failure Rate vs ambient temperature are presented below for the analyzed system of inductive loop.

## 5. Applications

The method of estimating the reliability of technical objects, presented in this paper, to a large extent contributes to achieving a high level of technical reliability of the planned objects, particularly in times of high competition on the market and of competing for customers resulting in increasing continually the efficiency of technological processes. The use of computer tools in the form of reliability software can significantly shorten the analysis time both in the modelling phase and in the way of calculating. The

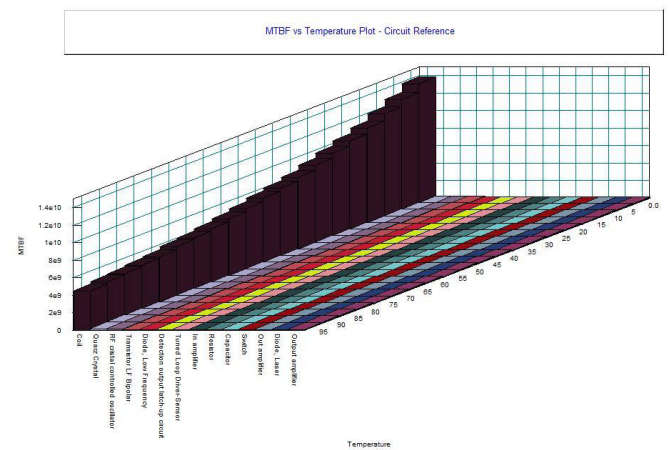


Fig. 4. MTBF vs. ambient temperature  
Source: [own work]

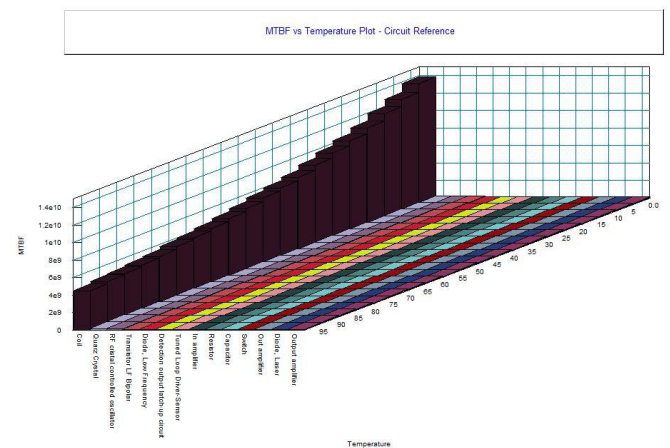


Fig. 5. Failure rate vs. ambient temperature  
Source: [own work]

material presented on the software indicated the author's opinion concerning the most important features of individual programs for the possibility of including the information exchange between packages. The estimation method presented in the paper and the software supporting the process of reliability analysis has been partly used by the author in a comprehensive study on the reliability analysis of technical objects involved in the process of charging on national roads. The aim of the study is to determine the work schedule of the required level of reliability, as defined in fundamental technical requirements for the design, construction and operation of highways developed by the General Directorate for National Roads.

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