

## RAM performance monitoring and MTBF demonstration on the SBB SA-NBS project

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**ABSTRACT:** In the framework of the Customer's (SBB/BLS) SA-NBS project including integrated trackside and integrated trainborne sub-systems (based on the application of ALSTOM's ERTMS/ETCS ATC solutions), an adequate RAM performance monitoring process has been planned, organised and executed in order to record all occurred trouble/incident events, to analyse them, to specify and to carry out adequate provisions.

The main target of this paper is to report the main elements of the applied RAM performance monitoring process based on the application of an adequate ALSTOM's FRACAS tool, which has been efficiently supported by Customer's ETCS hotline, event team and event Data Base.

The applied RAM performance monitoring process has allowed the organisation and the carrying out of the MTBF estimation for the overall fleet consisting of 11 different vehicle types and a total of 468 vehicles efficiently. MTBF estimation has been carried out for all LRUs, as well as for service relevant failures only, resulting in the spurious application of emergency and service brakes.

### 1 INTRODUCTION

Within the Customer's ambitious SA-NBS project including integrated trackside and integrated trainborne sub-systems, in total 468 vehicles, of 11 different vehicle types, have been retrofitted with ALSTOM's ERTMS/ETCS ATC solution.

In the invitation for tenders, the planning, organisation and application of an adequate RAM performance monitoring process and the execution of Reliability and Maintainability Demonstration Test (R&MDT), as a part of the RAM assurance Programme (RAMP), has been requested by the Customer. Hence, in the corresponding RAMPP (ALSTOM 2007a), prepared by the Main Suppliers, the requested RAM performance monitoring process (ALSTOM 2007b), as well as the R&MDT (ALSTOM 2007c) have been seriously planned, and later efficiently organized and successfully carried out during the SA-NBS system warranty period.

Bearing in mind that the MBDTs, including the MTTR demonstration, have been carried out as a part of the system acceptance test (Stamenković et al. 2008), only the MTBF demonstration has been requested in the operation phase of the fleet, during the system warranty period.

The documents (ALSTOM 2007b, c) are the result of a successful collaboration between the Customer and the Main Supplier.

In (ALSTOM 2007b), the most relevant elements of ALSTOM's FRACAS tool, but also the needed Customer's processes related to recording of trouble/incident events, maintenance of the event DB, daily and periodical reporting, decisions of event team, as well as the needed element related to existing Customer's processes for corrective maintenance are described in detail.

The main elements related to planning, organisation and execution of R&MDTs are given in (ALSTOM 2007c).

The present paper focuses on the presentation of the main results and the experience achieved within the SA-NBS project related to the application of the RAM performance monitoring process and the MTBF demonstration for the trainborne sub-system and its LRUs, while specific details related to trackside sub-system are addressed in (ALSTOM 2007b).

#### 1.1 Abbreviations and symbols

ATC	Automatic Train Control
BLS AG	BLS Lötschbergbahn AG (Railway company)

DB	Date Base
DMI	Driver Machine Interface
DRU	Diagnostic Recording Unit
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
FRA-CAS	Failure Reporting, Analysis and Corrective Action System
FRB	Failure Review Board
ISRDT	In Service Reliability Demonstration Test
LRU	Line Replaceable Unit
MBDT	Maintainability Demonstration Test (MBDT is used instead of MDT, which is reserved for 'Mean Down Time')
MTBF	Mean operating Time Between Failures
MTBF <sub>L1</sub>	Lower one-sided confidence limit on true MTBF
MTBF <sub>L2</sub> , MTBF <sub>U2</sub>	Lower und upper two-sided confidence limit on true MTBF
MTBSF	Mean operating Time Between Service (System) Failures
MTTR	Mean Time To Restoration/Recovery
NFF	No Fault Found
NBS	Neubaustrecke (New Swiss High Speed Line)
PPM	Performance Progress Meeting
r	Relevant failures occurred for the overall fleet during T*
RAM	Reliability, Availability and Maintainability
RAMP	RAM assurance Programme
RAMPP	RAM assurance Programme Plan
R&MDT	Reliability and Maintainability Demonstration Test
SA-NBS	Signalling and Automation Systems on New Swiss High Speed Line (Mattstetten-Rothrist)
SBB AG	Schweizerische Bundesbahnen AG (Swiss Federal Railway company)
T*	Accumulated operating test time
TRU	Train Recorder Unit
$\alpha$	Significance level: $100(1 - \alpha) \%$ is the confidence level at which confidence intervals and limits are calculated
$\chi^2_{\alpha}(v)$	The $\alpha$ fractile of the cumulative $\chi^2$ (chi-square) distribution with v degrees of freedom

## 2 RAM PERFORMANCE MONITORING

The objective of this paper is to describe the processes and, when applicable, resources, which have been put in place in order to monitor RAM performance of ALSTOM's SA-NBS System realised within the SA-NBS project.

Accordingly, the data collection, data processing and reporting are described.

As far as the trainborne subsystem is concerned the vehicles equipped within the SA-NBS project have been considered on the entire Swiss rail network; but a distinction has been made between failures occurring on or outside the NBS section.

It is pointed out that a number of process improvements will take place during the life-cycle of the project, constantly reflecting the status of the RAM monitoring organisation.

The description of the various processes, tools and resources found in this paper should not be understood as a commitment to deploy exactly those processes, tools and resources for the support period and beyond. In particular, some processes may become obsolete, some resources may be reallocated, facilities may be relocated, and current tools may be replaced.

This document is mainly addressing the processes for the trainborne sub-system.

Based on the RAM performance monitoring process the MTBF demonstration test has been organised during the warranty period.

### 2.1 Definitions

The following definitions will be used in the paper:

1. ALSTOM After Sales — is the organization which was in charge of warranty and maintenance management within ALSTOM Transport Information Solutions Operations worldwide.
2. SBB/BLS Service — refers to SBB/BLS hot line and responsibilities within the 1<sup>st</sup> level and 2<sup>nd</sup> level maintenance, defined in (Stamenković et al. 2008), of all SBB vehicles (within Passenger, Cargo or Infrastructure divisions) and BLS vehicles equipped within SA-NBS project.
3. Service specialist — a member of either SBB Service or BLS or ALSTOM Support, who is involved with the 1<sup>st</sup> line and/or 2<sup>nd</sup> line maintenance.
4. Materials administrator — a person in charge of managing inventory and ordering spare parts as appropriate.
5. Failure Review Board (FRB) — body made up of SBB/BLS Service and ALSTOM Support em-

ployees, which meets at regular intervals to review the failures of the elapsed period and to agree on failure responsibilities.

6. Event — an event is an occurrence of abnormal behaviour or malfunction which has been observed. It can be logged by the SBB/BLS Service, or by ALSTOM Support.
7. Assessment — this corresponds to the assessment by the SBB/BLS Service or ALSTOM Support following an event. This analysis may result in an NFF.
8. Intervention — an intervention is the action (replacement, permutation, crossing) undertaken by an SBB/BLS Service or an ALSTOM support technician following the observation of an event. All intervention forms issued have to be passed through the SBB/BLS maintenance manager.
9. Repair — is the maintenance action performed by a technician on a defective component following the dispatch of this component from the depot workshop to the repair unit. It follows the replacement of a part by a technician of SBB/BLS Service or ALSTOM support.

## 2.2 Data collection for the trainborne sub-system

The objective of the data collection process description is to define:

1. all mandatory inputs (data fields) that must be adhered to by the project in order to have a consistent view throughout project life and also with the aim to homogenise and standardise and to perform comparisons between projects; and
2. the certain «optional» fields, according to the customer requirements and the types of subsystems (trainborne, trackside, etc) within the project.

The data collection process refers to the following stages, shown in Figure 1:

- a. failure event;
- b. assessment;
- c. intervention; and
- d. repair.

The data originates from the SBB/BLS ETCS event DB which includes relevant information on faults/disturbances and/or their impacts on operation (emergency brake or delay for instance).

ETCS event DB supplies ALSTOM with daily and weekly reports providing the needed information for the event and the assessment phases.

Maintenance-related information is provided to ALSTOM through repair tickets (etiquettes) providing the intervention information, which is also used in the repair phase.

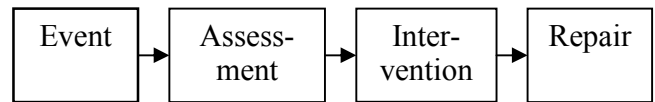


Figure 1. Data collection stages.

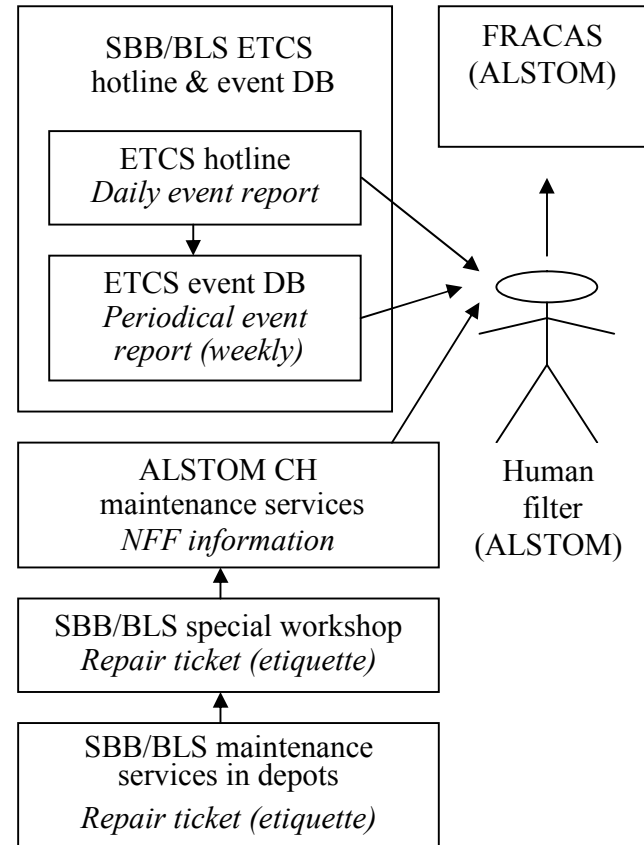


Figure 2. Origin of data for trainborne sub-system.

An ALSTOM operator will check the consistency of this information and will enter the resulting filtered information into FRACAS, as illustrated in Figure 2.

A macro function enables direct import of data into FRACAS by means of an EXCEL file. The data originating from SBB/BLS are compatible with the format defined jointly between the ALSTOM Service and the SBB Maintenance.

Filtering consists of resolving possible inconsistencies between the two sources of information (ETCS event DB and maintenance services). The process of filtering is overseen by the FRB. The decisions made by the operator must be traceable, so that an erroneous decision may be later reversed by the FRB.

### 2.2.1 Event

The event is recorded in the SBB/BLS ETCS event DB and the event notification is forwarded to ALSTOM support in the form of an event log, including the following mandatory inputs:

- a. event N° (ID) – in FRACAS;
- b. train operation N°;
- c. train/loco N°;
- d. date of event;
- e. event time;
- f. event location (track-km or station): the driver will specify what happened;
- g. event details (description of event, including environmental conditions if relevant) without interpretation;
- h. operational impact of the event (such as: emergency or service brake, delay, etc.) (SBB/BLS ETCS event DB); this is possible from the hotline event list;
- i. delay caused by events. There is a daily event journal which makes its way to the SBB/BLS ETCS event DB;
- j. immediate measures undertaken if any (SBB/BLS ETCS event DB);
- k. failure code/classification (DIN code); and
- l. software release.

### 2.2.2 *Assessment and intervention*

In case that an intervention is necessary to restore the system to normal operation, the intervention team has to provide the exact details of the intervention by filling in a standard form.

Inputs related to the assessment are:

- a. assessment by: SBB/ALSTOM/others;
- b. train/loco N°;
- c. location of assessment: depot, station line section ID;
- d. date;
- e. assessment description (NFF, non permanent failure, permanent failure, nonconformity);
- f. assessment details (relevant observations if the anomaly is observed; all useful relevant information for the entities in charge of the assessment);
- g. defect codes;
- h. failure cause description;
- i. men-hours for diagnosis;
- j. failure responsibility description (ALSTOM, SBB, third party, vandalism);
- k. in case ALSTOM After Sales involved (name/ phone number of operator);
- l. date & time train or system failure notified; and
- m. date & time train or system returned to service.

The intervention data are entered in the FRACAS system of ALSTOM and, in case of hardware or software change, in ALSTOM's configuration management tool, ADVITIUM.

It should be noted that, within FRACAS, from one event, it is possible to generate several assessments

and, from a given assessment, it is possible to generate one or more interventions.

LRUs will be recorded at the intervention level. If two tasks are performed leading to two LRU replacements (for instance), then in FRACAS two interventions will be opened for one assessment. In case of two different assessments, two assessments will be opened for a given event.

FRACAS can be used to perform searches and thus to evidence trends, based on correlations such as the frequency of a given LRU being the failure cause on a given train type, or the correlations between certain events and time of day and location.

Inputs relating to an intervention are:

- a. activity description: replacement, repair, check, interchanging two modules;
- b. intervention by (SBB, ALSTOM, others);
- c. intervention time (duration in hours);
- d. intervention location (which workshop);
- e. intervention detail (what has been performed to return the train/line to operational status);
- f. intervention result (successful or not); and
- g. in case of part replacement: (a) part description; (b) part identifier; (c) software version of removed part; and (d) software version of refitted part.

Part of the information is used in the FRACAS database to better identify and classify failure categories and for data processing (failure rates per failure code/failure class).

For each event, such a form is created by the SBB service team additionally to the event log record. However, only in cases of new failures or failures with significant impact on the operation will those detailed intervention forms be forwarded to ALSTOM.

SBB Service is in charge of issuing the intervention form/repair ticket (etiquette). These documents have been created specifically for the purpose of meeting the requirements identified by the SBB and ALSTOM project teams. The information therein is equally used for FRACAS, anomaly identification and tracing, as well as configuration management.

### 2.2.3 *Repair*

In the case that parts have been shipped for repair, the material administrator and the repair site have to provide the exact shipment details and a repair report by filling in a standard form, which will be entered in the corresponding SBB database and in parallel in the FRACAS system of ALSTOM and, in case of HW- or SW-change, in the configuration management tools.

Mandatory inputs relating to repair are of two kinds: repair logistics and repair properties.

Repair logistics information includes the following:

- a. site shipping date;
- b. sent by;
- c. sent to;
- d. description of requested repair; and
- e. tracking number.

Information related to repair properties includes the following:

- a. reception date;
- b. repair date;
- c. shipping date;
- d. description of repair performed;
- e. repair detail (fully detailed description of the maintenance action);
- f. function of repaired component;
- g. failure cause;
- h. tracking number; and
- i. person in charge of repair: name and phone number.

### 2.3 *FRACAS data entry process*

Data entry into FRACAS is performed by the local ALSTOM Support organization for most of the entries, except for repair data.

The process is broken down in 5 different steps:

- a. event capture;
- b. investigation data entry;
- c. intervention data entry;
- d. logistic repair data entry; and
- e. repair office data entry.

### 2.4 *FRACAS tool*

The characteristics of the FRACAS tool as well as the DB structure are described in this section.

The main functionalities of ALSTOM Transport's FRACAS tools are the following:

- a. support of capture of event/investigation/ intervention;
- b. support of repair logistics;
- c. support of monthly entry of counters (km, traction hours, powered-up hours, etc.);
- d. support of modifications and their applicability/ applied status;
- e. support of visualisation/analysis of the captured data via indicators;

- f. multilingual: German, French, Italian, English, Spanish, Dutch, and Portuguese;
- g. synchronisation of compressed data; and
- h. it is local DB encrypted & secured.

#### 2.4.1 *FRACAS DBs*

Figure 3 illustrates the FRACAS DB structure: two local DBs (in France and Switzerland respectively) communicate via the central FRACAS DB.

In the context of SA-NBS, ALSTOM Support refers to the local team (part of ALSTOM After Sales) which manages warranty and would manage help desk and emergency service in the framework of a technical support contract with SBB.

#### 2.4.2 *RAM data processing flow*

Figure 4 illustrates the flow of RAM data and their processing to issue the periodical RAM reports:

1. A record is opened within the FRACAS DB as soon as an event occurred;
2. This record is closed when either the LRU is declared as healthy after detailed analysis or when the LRU is sent back to SBB after repair;
3. In the mean time, the repair site is maintaining a local repair database and a consistency check is performed by the RAM team together with the product line managers before issuing the RAM figures;
4. The RAM figures have been presented during the PPMs, in place on a bi-weekly basis since December 2005 up to the end of December 2007; and
5. Since January 2008, these meetings will no more take place; and the RAM figures have been presented through the RAM reports, on a bi-monthly basis.

### 2.5 *Customer's ETCS hotline and SBB OCP help desk*

In the first phase, a single SBB & BLS ETCS hotline has been established in order to record only ETCS relevant events, registered and reported by drivers, relating to SBB and BLS trains retrofitted with ALSTOM's trainborne sub-system.

In the second phase, the activities of the SBB & BLS ETCS hotline have been transferred/delegated to SBB OCP help desk, dealing with all events relating to SBB passenger trains and only with ETCS relevant events for SBB-Cargo (OCP is contacted only for ETCS relevant events) and BLS trains, which are reported by BLS periodically, because nowadays, BLS record ETCS relevant events separately for their trains.

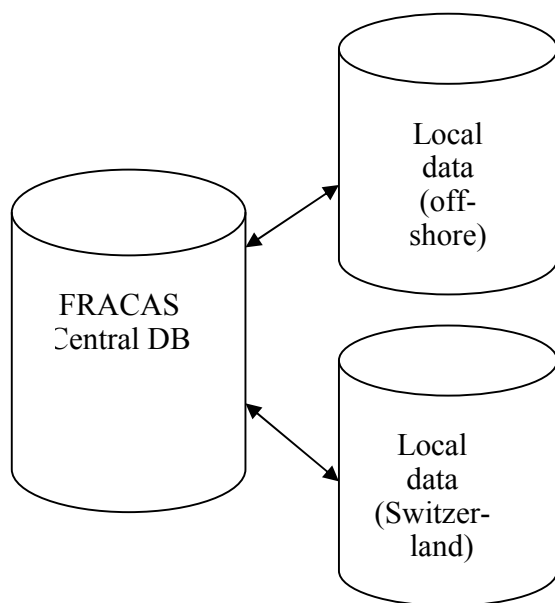


Figure 3. FRACAS DB structure.

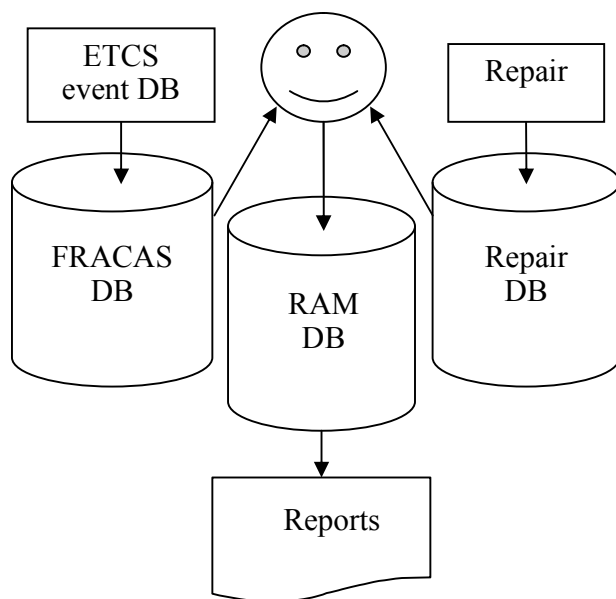


Figure 4. RAM data processing flow.

The main activities of OCP help desk relating to SA-NBS ETCS trainborne sub-system are:

1. recording of ETCS events according to driver messages (telephone, GSM-R, etc.) and BLS-information;
2. filtering of delay files (all trains having more than 3 minutes delay) and recording of train delays caused by ETCS events;

3. supporting drivers by resolving some of the problems, and to communicate with the other involved parties, such as signaller, train management and/or train owner;
4. generating of orders for the recording of the train data needed for some event analyses (according the request of the SA-NBS event team); and
5. preparing of daily event reports including SA-NBS ETCS events list and caused train delays, which have been sent to different interest groups, such as ETCS event team, the Main Supplier's FRACAS, etc.

Daily event list, train delays and daily reports have been stored also in ETCS event DB.

## 2.6 SA-NBS ETCS event team

SA-NBS ETCS event team has been constituted from the Customer's and the Main Supplier's specialists.

The event team has been dealing daily with categorising and analysing of ETCS daily event reports from the previous day.

At the beginning all events have been analysed in detail, but later only the most important ones remained for analysis. The Main Supplier has been obliged to carry out the needed analysis for a few most important events and to present analysis results within a specified time (usually one week).

The results of the Main Supplier's event analyses have been considered by the event team, and accepted analyses stored in ETCS event DB.

For the relevant problems that have repeatedly occurred, the event team has initiated the events clustering in order to solve the problems.

## 2.7 SBB/BLS ETCS event DB

Management activities of the Customer's ETCS event DB have been based on the Customer's ETCS hotline daily reports, events analyses of the event team, and some additional information.

The main ETCS event DB management activities are:

1. clarification requests to drivers;
2. trouble source allocation;
3. status controlling of orders for the recording train and other data;
4. classification of the events based on the event team analysis reports and decisions; and
5. the preparation of the weekly reports.

The manager of the Customer's ETCS event DB has prepared weekly reports, which include:

1. all events;

2. technical events only (excluding events caused by faulty handling, etc.); and
3. train delays — which have also been considered by the Main Supplier's FRACAS.

## 2.8 Performance progress meetings (PPMs)

At the beginning, regular hardware reliability progress meetings have been organised between the Customer and the Main Supplier to discuss and resolve reliability weaknesses that have occurred in the field. Later, these meetings have been further extended to software problems, and finally they have been defined as PPMs considering all relevant operational, functional and RAM performances.

These meetings have been organised on the project management level in order to discuss and to agree with some important decisions and with the needed mitigation activities, related to the number of problems due to design weakness, software versions weakness, communication on subsystem and system level (e.g. train — Radio Block Centre), installation and construction, etc.

With its diversified activities, the PPMs have covered in the same time the role of the FRB.

The PPMs have been organised on a two weeks basis. The main subject of the meeting agenda were:

1. failure field statistic;
2. the list of reliability critical items and Pareto diagrams for the critical items, with distribution of failure causes (such as: NFF, external problems, manufacturing, software update, hardware, under investigation, etc);
3. reliability growth;
4. software stability;
5. different functional, operating, constructive, loading, environmental and other problems;
6. problem analysis and proposed provisions to solve the problems (mitigation action plan); and
7. the whole fleet delay prediction.

## 3 IN SERVICE RELIABILITY DEMONSTRATION TEST (ISRDT) — MTBF ESTIMATION

The objective of ISRDT has been to demonstrate the MTBF contractual target achievement during system operation by means of field data.

The following aspects of ISRDT have been considered:

1. failure recording;
2. types of failures;
3. period of observation;

4. capture of operating time;
5. statistical estimation of MTBF;
6. pass/fail criteria; etc.

### 3.1 Periods of observation

The failures have been recorded from the beginning of the revenue service.

For the purpose of ISRDT, a 12-month moving time period has been selected, from 01.01.2007 to 31.12.2007, under the following additional conditions:

1. If achievement of targets has been demonstrated successfully, no further reliability test will need to be carried out.
2. If achievement of targets has not been demonstrated successfully, additional tests will be conducted every month, over the next 12-months period, until the targets have been achieved.
3. If by the end of the demonstration period (not later than December 31, 2009), some targets have still not been achieved, the Customer and the Main Supplier will meet to discuss remedies and action plans. Clearly, action plans will be undertaken much earlier if early results evidence a wide discrepancy between the targeted and the achieved reliability.

Regular reporting including reliability relevant aspects have been given within regular PPM reports.

At the end of ISRDT a final report has to be prepared by the Main Supplier and reviewed and approved by the Customer.

### 3.2 Capture of operating hours

At the beginning, it has been considered to use vehicle DRU data to retrieve the operating time of the train-borne ETCS, but this solution has been shown to be extremely time-consuming, requiring special resources. Hence, a more pragmatic solution has been applied, by estimating the average operating time per year for each of the 11 types of vehicles, considering different operating profiles (cc. 6800 operating hours per year). Vehicles equipped with ALSTOM train-borne ETCS within the SA-NBS project shall be considered on the overall Swiss (standard gauge) rail network.

Failure data (at event, investigation, intervention or repair stage) can be completed by information gathered by SBB or ALSTOM, as the case may be, according to the procedures and responsibilities relevant for RAM performance monitoring. In particular, ALSTOM, SBB and, when applicable, BLS will fill

in the same intervention form and send it to the ALSTOM configuration manager. Part replacement information will be collected by ALSTOM at the 3<sup>rd</sup> level of maintenance.

### 3.3 Statistical estimation of MTBF

The following requirements have been defined:

1. Significant failure — Failure involving automatic application of an Emergency Brake (EB) with  $MTBSF(EB) = 12$  operating years;
2. Major failure — Failure requiring application of a Service Brake (SB), with  $MTBSF(SB) = 2$  operating years; and
3. Predicted MTBF of all LRUs have to be satisfied.

As a reminder, by relevant failure is meant a failure caused by a technical failure of one of the subsystems. Excluded are failures caused by:

1. vandalism;
2. force majeure;
3. improper use of equipment;
4. maintenance by SBB not in compliance with equipment maintenance manual procedures; and
5. operation not in compliance with the operations plan.

#### 3.3.1 The MTBF estimation method

The MTBF estimation method, the notation and definitions applied in (IEC 2001) are used.

When during the accumulated operating test time  $T^*$ ,  $r$  relevant failures have occurred for the overall fleet, and the failed items are replaced with healthy/operating ones, then for a given confidence level  $(1 - \alpha)$ , the lower  $MTBF_{L2}$  and the upper  $MTBF_{U2}$  two-sided confidence limits of the confidence interval for the unknown parameter MTBF are given by Equation 1

$$\begin{aligned} MTBF_{L2} &= 2T^* / \chi^2_{1-\alpha/2}(2r+2) \\ MTBF_{U2} &= 2T^* / \chi^2_{\alpha/2}(2r) \end{aligned} \quad (1)$$

so that

$$MTBF_{L2} < MTBF < MTBF_{U2}. \quad (2)$$

If no failures are observed, then only the lower one-sided confidence limit on the MTBF can be used, defined by Equation 3

$$MTBF > MTBF_{L1} = 2T^* / \chi^2_{1-\alpha}(2r+2), \quad (3)$$

where  $MTBF_{L1}$  is used to denote the lower one-sided confidence limit.

All estimation have been made with confidence level  $(1 - \alpha) = 0.6$ .

#### 3.3.2 Pass/fail condition

The test will be considered passed, or equivalently the reliability target will be deemed to be achieved if and only if the following condition obtains:

$$MTBF_{target} < MTBF_{Li}, \quad (4)$$

with  $i$  being either 1 or 2.

#### 3.3.3 Failure field statistic

The Main Supplier has been obliged to analyse all failures systematically in order to identify weaknesses and to propose appropriate corrective actions.

The FRACAS data have been used for the calculation of the following reliability indices:

1. Apparent MTBF ( $MTBF_{app}$ ) considering all interventions (i.e. each replacement of one LRU, independent on the fact whether this LRU fails or not (also NFF)); and
2. Effective MTBF ( $MTBF_{eff}$ ) excluding NFF cases – based as the maximum likelihood point estimate value of MTBF ( $MTBF_{eff} = T^*/k$ ) and upper and lower boundaries of the unknown parameter MTBF with the confidence level of 60%.

#### 3.3.4 Results

Apparent and effective MTBF values have been estimated based on the 90 days and 365 days moving period (rolling window) failure field statistic.

RAM performance monitoring has been started with the progressive train commissioning (from beginning of September 2004).

The comparison of requested, predicted and estimated MTBF values, the list of reliability critical items, actual reliability problems, the needed analyses and adequate provisions have been presented in standardised reliability reports and discussed intensively during bi-weekly PPMs, which have been organised on the project management level.

For each of the 11 vehicle types the total accumulated operating time per year has been estimated. Based on this estimation and the configuration of the trainborne sub-system, a total accumulated operating time per year has been calculated for each LRU. The total of 468 vehicles realise about 3,076,158 operating hours per year.

The main items of the trainborne sub-system are: European Vital Computer assembled with 17 different LRUs; Odometry sub-system (including radar and accelerometer as LRUs); Driver Machine Interface (DMI) sub-system (consisting of ERTMS DMI and Voice DMI as LRUs); Cab Radio (consisting of Data



rack, Voice rack, and Antenna Coupling Unit as LRUs); GSM-R/GPS antenna; GSM-R/Analog antenna; Train Recorder Unit (TRU); Eurobalise antenna, etc.

Predicted MTBF (MTBFpr) of the LRUs of the trainborne sub-system have been obtained using different software packages, which are based on the use of the old (MIL 1995), part stress method or the new (IEC 2004), considering the impact of heat management.

Determination of the predicted MTBF for significant and major failures has been based on detailed reliability and availability modelling of the relevant trainborne sub-system vital safety-relevant functionalities, so that their failure results in the category either significant or major, and the use of predicted values of the needed LRUs.

The final results are shown in Figure 5 and Table 1.

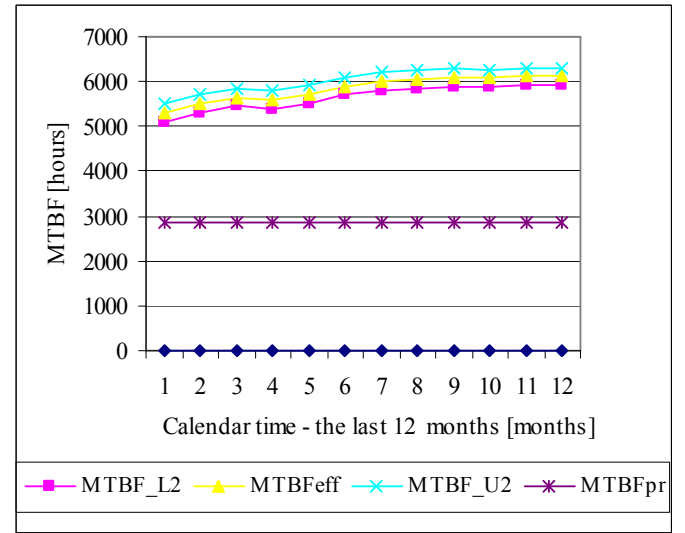


Figure 5. MTBF value of the trainborne subsystem during a 12 months moving period (rolling window).

Table 1. Requested, predicted and effective MTBF values of the trainborne sub-system for three failure categories.

Failure category	Requested (*) MTBFreq [years]	Predicted MTBFpr [years]	Effective MTBFeff [years]
Significant	15	13.26	16.92
Major	2	10	3.22
Maintenance	Not defined	0.327	0.613

(\*) MTBFreq as a part of RAM requirements specification

#### 4 CONCLUSIONS

The RAM performance monitoring process applied by the SA-NBS project has been described in detail.

Due to the joint efforts of the ETCS hotline (later OCP help desk), the ETCS event team, the ETCS event DB and PPMs, as well as the efforts of the design, manufacture, test and maintenance teams, etc. the numbers of software and hardware weaknesses have been identified, analysed and adequate provisions have been carried out to obtain a reliable trainborne sub-system.

The MTBF estimation based on the results of field failure statistic carried out for the fleet consisting of 468 vehicles during more than 3 years, has demonstrated that the requested MTBF values for the significant und major failure categories are satisfied.

The achieved results have initiated the project dealing with systematising and improving performance monitoring processes for all new signalling and automation products.

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