# MARS : a software tool for Maintenance Assessment of Repairable Systems

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## Abstract

The aim of this talk is to present the software tool MARS (Maintenance Assessment of Repairable Systems), developed by EDF R&D and Grenoble University. MARS implements imperfect maintenance (virtual age) models and estimates jointly the effects of ageing and maintenance (preventive and/or corrective) efficiency on real data sets from field feedback.

## 1   Introduction

Throughout their operational life, industrial systems are subjected to preventive and corrective maintenances. Efficient maintenance allows extending the service life of an equipment, which is a crucial industrial issue. It is therefore important to build models of the effects of maintenance of complex repairable systems and develop methods to assess their efficiency. Basically, it is assumed that either maintenance is perfect (AGAN: As Good As New), or maintenance is minimal (ABAO: As Bad As Old). The reality is of course between these two extreme cases. This is called imperfect maintenance. A collaboration between Electricité de France (EDF) R&D and Grenoble University led to the development of a new software tool, which aims to implement these models and to estimate jointly the effects of ageing and maintenance (preventive and/or corrective). This software, called MARS (Maintenance Assessment of Repairable Systems), allows to apply these models to real and simulated data.

In a first step, we consider systems subjected to only Corrective Maintenance (CM), or repair. In a second step, we consider systems subjected to CM and Preventive Maintenance (PM).

## 2   Models for CM Only

Let $T_i, i \geq 1$, be the failure times of the system or equivalently the CM times. Let $X_i = T_i - T_{i-1}, i \geq 1$, be the inter-failure times, and $N_t$ be the number of failures up to time $t$. $\{N_t\}_{t \geq 0}$ is a point process with the following failure intensity:

$$\lambda_t = \lim_{\Delta t \to 0} \frac{1}{\Delta t} P(N_{t+\Delta t} - N_{t-} = 1 | \mathcal{H}_{t-}) \tag{1}$$

where $\mathcal{H}_t$ is the history of the failure process at time $t$.

Before the first maintenance, the failure intensity is the hazard rate of a new system. It is denoted $\lambda(t)$ and is called initial intensity. In the following, we assume that the first failure time has a Weibull distribution, i.e. the initial intensity is:

$$\lambda(t) = \alpha \beta t^{\beta-1} \tag{2}$$

where $\alpha$ and $\beta$ are two positive parameters. The position of $\beta$ with respect to 1 indicates if the system is wearing or not.

The CM models implemented in MARS are the ABAO, AGAN, $ARA_1$ and $ARA_\infty$ models (Doyen and Gaudoin 2004). In the next version, the Brown-Proschan model (Brown and Proschan 1983) will also be available.

The ARA models are virtual age models. These models consider that, after $i^{th}$ maintenance, the system is equivalent to a new one having survived without failure until an age $A_i$, with $A_i \leq T_i$. The virtual age at time $t$ is $A_{N_{t-}} + t - T_{N_{t-}}$. For instance, the $ARA_\infty$ model assumes that maintenance reduces the virtual age of the system of a quantity proportional to the virtual age just before the maintenance.

This quantity is denoted $\rho$ and characterizes maintenance efficiency. Thus, the failure intensity of the system is:

$$\lambda_t = \lambda(t - \rho \sum_{j=0}^{N_{t^-}-1} (1 - \rho)^j T_{N_{t^-}-j}) \tag{3}$$

Basic models are particular cases of the $\mathrm{ARA}_\infty$ model, according to the values of $\rho$:

- $\rho = 1$: perfect maintenance (AGAN),

- $\rho = 0$: minimal maintenance (ABAO),

- $0 < \rho < 1$: imperfect but efficient maintenance,

- $\rho < 0$: harmful maintenance.

## 3   Models for CM and PM

We assume now that the system is subjected to both corrective and preventive maintenance, and that PM are done at planned times $\tau_j, j \geq 1$. Let $\{K_t\}_{t\geq 0}$ be the counting process of both kinds of maintenance (PM and CM), $\{M_t\}_{t\geq 0}$ be the counting process of PM, $C_k, k \geq 1$, be the maintenance times (PM and CM) and $W_k$ be the inter-maintenance times, $W_k = C_k - C_{k-1}$ for $k \geq 1$ with $C_0 = 0$.

An imperfect maintenance model has to be chosen for each kind of maintenance. In MARS, all the combinations between ABAO, AGAN, $\mathrm{ARA}_1$ and $\mathrm{ARA}_\infty$ models are implemented (Doyen and Gaudoin 2006). For instance, the $\mathrm{ARA}_\infty$-$\mathrm{ARA}_\infty$ model assumes that maintenance reduces the virtual age of the system of a quantity proportional to the virtual age just before the maintenance, but the proportional factor is different for PM and CM. If $\rho_p$ and $\rho_c$ denote respectively the PM and CM efficiencies, the failure intensity of the model is shown to be:

$$\lambda_t = \lambda(t - C_{K_{t^-}} + \sum_{j=1}^{K_{t^-}} (1 - \rho_p)^{M_t - M_{C_{j-1}}} (1 - \rho_c)^{N_t - N_{C_{j-1}}} W_j) \tag{4}$$

## 4   Parameters Estimation

The joint assessment of ageing and maintenance efficiency is done by estimating the parameters $\alpha$ and $\beta$ of the initial intensity, and the maintenance efficiency parameters $\rho$ or $\rho_p$ and $\rho_c$. In MARS, the maximum likelihood method is used. The estimates of $\theta = (\alpha, \beta, \rho_p, \rho_c)$ maximize the log-likelihood function:

$$L_t(\theta) = \sum_{i=1}^{N_t} \ln \lambda_{T_i} - \int_0^t \lambda_s \, ds \tag{5}$$

## 5   MARS software : Maintenance Assessment of Repairable Systems

MARS software has been developped in C++ using Qt libraries for graphics interfaces. It works on Windows and Linux platforms. When lauching Mars, the interface looks as in figure 1 after opening a project (Project/New Projet) and showing all windows (Edit/Show Data Window).

The window in the upper left corner is the **Data Window** which displays all the data sets available for analysis. The window in the bottom left corner is the **Data Monitoring Window**, which shows graphical descriptions of the chosen data set. The window in the upper right corner is the **Models Window**. It contains four tabs, described in the following : *Estimators*, *Indicators*, *Simulator* and *Validator*. The window in the bottom right corner is the **Model Monitoring Window** which displays indicators graphics : intensity, reliability, cumulative number of failures.

The **Data Window** is used to manipulate data sets. The data sets are organized in 2 classes: real data sets issued from field feedback and simulated data sets issued from MARS simulations. Each class is divided in 3 subclasses depending on the type of maintenances in the data set: only CM, only PM, and either CM and PM. When selecting a data set, the maintenance times appear in a table as shown
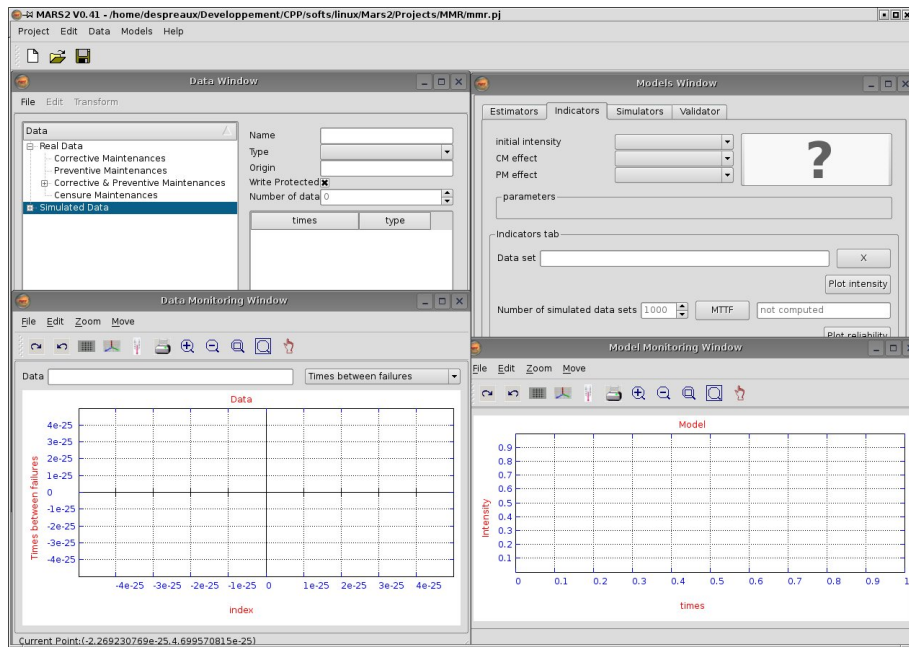
Figure 1: Mars Lauching

in figure 2. Some operations are enabled on data: importing or exporting in text or xml format (File menu), copying or removing data sets (Edit menu), translating or cutting data (Transform menu).

To plot graphical descriptions of a selected data set, drag and drop the data from the Data Window to the line edit component next to Data of the Data Monitoring Window and select the curve to plot, times between failures or cumulative number of failures (as in figure 2). Basic operations such as zooming and moving are enabled on the drawing area.
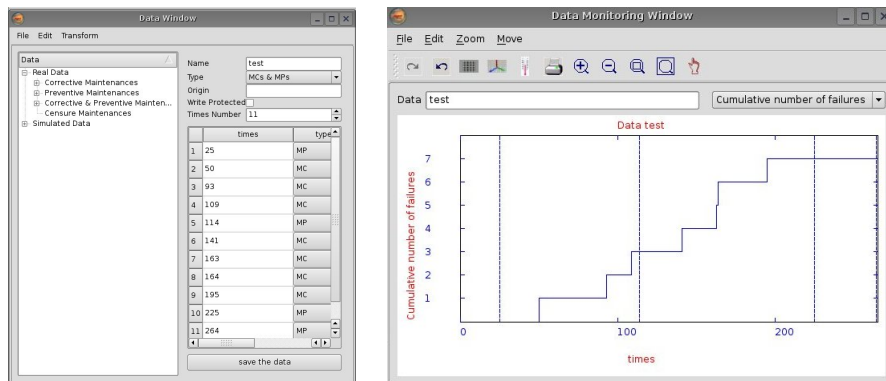


Figure 2: Data Window and plot of the observed cumulative number of failures

The **Models Window** performs the analysis of one or several data sets with a given model. First, drag and drop the data set from the Data Window to the list box component of the *Estimators tab* of the Models Window. Then, select a model. Click on the **Estimate Parameters** button in order to estimate the model parameters by the maximum likelihood method (see figure 3). MARS uses a simple or multiple BFGS algorithm in order to maximize the log-likelihood (5).

With a click on the ≫ button, the *Indicators tab* is selected and the model and data set analyzed from

the estimator tab are also selected in the indicator tab. Then, click on the **Plot Intensity** button to plot the estimated intensity in the Model Monitoring Window, as in figure 3. The *Indicators tab* enables also to compute several reliability indicators : the predicted MTTF value, the estimated reliability function (see figure 4) and the predicted future cumulative number of failures.
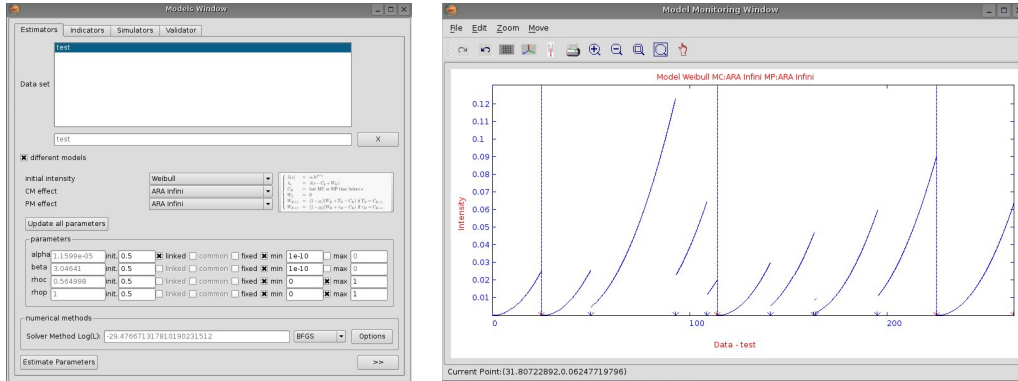


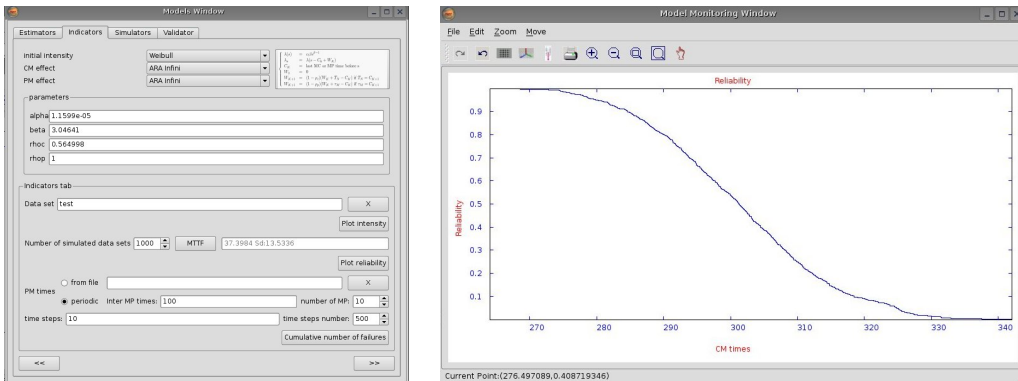Figure 3: Parameters Estimation and plot of the estimated intensity



Figure 4: Indicators tab and plot of the estimated reliability

To simulate data from a model, select the *Simulator tab*. Then, choose the appropriate model, fill the simulation parameters and click on the **Simulate data** button. Then, a data set is generated and added to the data sets of the Data Window in the Simulated Data class. The graphical descriptions of the simulated data set are directly shown in the Data Monitoring Window.

The last tab *Validator* is used to validate the estimation procedure and to assess its quality. The bias and variance of the estimators are assessed by means of intensive simulations.

## References

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