Reliability & Maintenace Field Data Analysis (FDA) New Vision

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1. Purposes

Colected field and test data are the most reliable source of failure rates and maintenance information. They are available in support systems servicing a number of equipment units and registering the equipment failures, for example - in communication network support systems (telephone, computers, transport, electric, etc.),

If a sufficient amount of data about the system failures and maintenance is collected during a certain period, this data allows doing some important conclusions and evaluations concerning the system operation and maintenance:

- Mean Time Between Failures (MTBF) and its confidence limits.
- Mean Time To Repair completion (MTTR) and its change for the period.
- Failure and repair time distributions.
- MTBF growth or fall during the considered period.
- Confidence probability that the applied MTBF growth model complies with field data.
- The most compliant growth model for the system from the available ones.
- Conclusions whether the system MTBF matches given requirements on the base of truncated test or field data under given error risk.
- Accelerated MTBF test planning and evaluation.
- Most frequent failure modes and their causes analysis
- Scheduled and actual preventive maintenance
- Effectiveness of different Preventive Maintenance (PM) policies, optimal PM strategy.

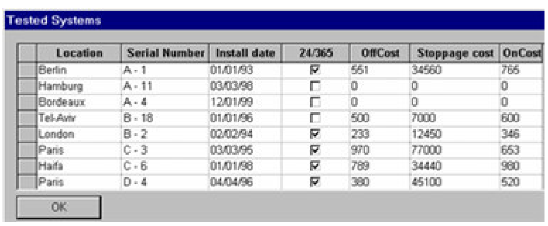
Having these data the system user or developer can control its state and detect all negative and positive changes in its reliability and maintainability.

We discuss below data collection and some of these analyses on example of BQR FDA software.

2. Data collection

User needs a simple and convenient interface for failure and repair registration containing at least the following data:

- *Common Equipment data*: system serial number, installation place and date, OFF cost, Stoppage cost and ON cost.



Tested Systems

Location	Serial Number	Install date	24/365	OffCost	Stoppage cost	OnCost
Berlin	A - 1	01/01/93	☑	551	34560	765
Hamburg	A - 11	03/03/98	☐	0	0	0
Bordeaux	A - 4	12/01/99	☐	0	0	0
Tel-Aviv	B - 18	01/01/96	☐	500	7000	600
London	B - 2	02/02/94	☑	233	12450	346
Paris	C - 3	03/03/95	☑	970	77000	653
Haifa	C - 6	01/01/98	☑	789	34440	980
Paris	D - 4	04/04/96	☑	380	45100	520

OK

Fig1: Interface for failure and repair registration

Off cost - means all cost connected with the system turning off.

Stoppage cost - is the damage caused by the system down time for a time unit (say, a day).

On cost - the same for the system turning on.

- Equipment structure and components: the system configuration tree showing which sub blocks contains each assembly

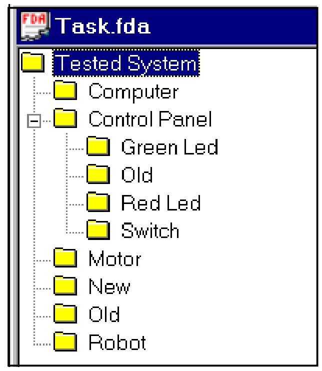
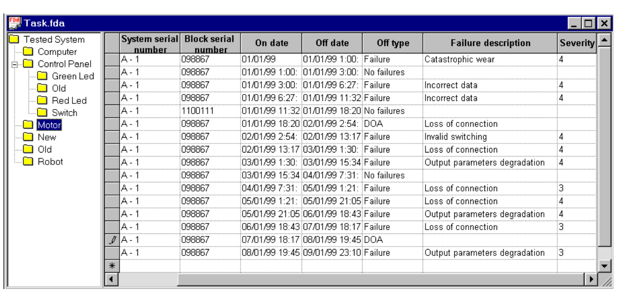


Fig2: System configuration tree

The tree should include only the blocks which the failures will be registered as important causes of the system failures. For all these blocks MTBF and MTTR parameters can be evaluated as a result of registered failures and repairs. The tree shows only nominal units, not physical. It is not changed after a fail block replacement with spare.

The tree is used to show operation and maintenance records related to the selected by user block. If the root block is selected, all records are shown.

- Failures and corrective maintenance (CM) data for the tree blocks:

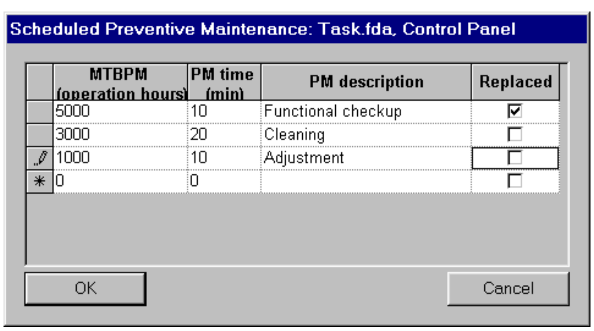


System serial number	Block serial number	On date	Off date	Off type	Failure description	Severity
A - 1	098867	01/01/99	01/01/99 1:00:	Failure	Catastrophic wear	4
A - 1	098867	01/01/99 1:00:	01/01/99 3:00:	No failures		
A - 1	098867	01/01/99 3:00:	01/01/99 6:27:	Failure	Incorrect data	4
A - 1	098867	01/01/99 6:27:	01/01/99 11:32	Failure	Incorrect data	4
A - 1	1100111	01/01/99 11:32	01/01/99 18:20	No failures		
A - 1	098867	01/01/99 18:20	02/01/99 2:54:	DOA	Loss of connection	
A - 1	098867	02/01/99 2:54:	02/01/99 13:17	Failure	Invalid switching	4
A - 1	098867	02/01/99 13:17	03/01/99 1:30:	Failure	Loss of connection	4
A - 1	098867	03/01/99 1:30:	03/01/99 15:34	Failure	Output parameters degradation	4
A - 1	098867	03/01/99 15:34	04/01/99 7:31:	No failures		
A - 1	098867	04/01/99 7:31:	05/01/99 1:21:	Failure	Loss of connection	3
A - 1	098867	05/01/99 1:21:	05/01/99 21:05	Failure	Loss of connection	4
A - 1	098867	05/01/99 21:05	06/01/99 18:43	Failure	Output parameters degradation	4
A - 1	098867	06/01/99 18:43	07/01/99 18:17	Failure	Loss of connection	3
A - 1	098867	07/01/99 18:17	08/01/99 19:45	DOA		
A - 1	098867	08/01/99 19:45	09/01/99 23:10	Failure	Output parameters degradation	3

Fig3: Failures and corrective maintenance (CM) data

Each record represents an operation session, for example - the system operation during a workday. **On date** means current turning on date (and time, if it is essential), **off date** - current turning off time instant by all causes, not only failures (for example - end of workday).
Off type is the turning off cause including failures with different **severity**.
System and blocks **serial numbers** identify **physical** units currently operating. User can choose records for a certain physical system and physical block to simplify data input and check out.
All shown records may be **sorted** by system and block serial numbers and by On date to present full view of performed actions for each unit until the current moment.
Serial numbers are used to calculate operation time for a physical unit between failures as the sum of differences Off date - On date for all the unit records after the previous failure in Off type field until the next failure in the same field.
New records for a unit with On date are inputted in the log end.
When the unit is turned off, user must input Off date in the last existing (uncompleted) record for the same system and block serial number. For each physical unit the program does not allow inputting new record, if there is an uncompleted record for the same unit without Off date.
Serial numbers can be also used to control each block **reliability dynamics** (decreasing and increasing) after different changes in operation and maintenance conditions and perhaps in design. Particularly they are used for reliability growth analysis for a selected nominal block. MTBF growth models require to separate operation time and failure data by physical tested units.
Failure description is used for qualitative analysis of failure causes and enhancement decisions and also for data separation by different failure modes.
Severity is used to define possible failure damage for different failure modes. This is an additional selection key and analytical factor.

- *Scheduled Preventive maintenance (SPM)*:

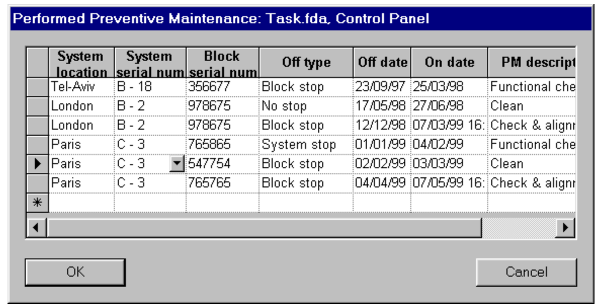

Scheduled Preventive Maintenance: Task.fda, Control Panel

MTBPM (operation hours)	PM time (min)	PM description	Replaced
5000	10	Functional checkup	☑
3000	20	Cleaning	☐
1000	10	Adjustment	☐
0	0		☐

OK Cancel

Fig4: Planned PM task list

This is the planned PM task list for each physical unit of the currently selected block in the tree.
MTBPM - planned operation time between preventive maintenance actions
PM time (min) - duration of the PM action
PM description - the sequence of maintenance operations which must be performed
Replaced - if marked, the unit must be replaced during the action or before it by another normal unit of the same block.
Actual performed Preventive maintenance (PPM):


Performed Preventive Maintenance: Task.fda, Control Panel

System location	System serial num	Block serial num	Off type	Off date	On date	PM descript
Tel-Aviv	B - 18	356677	Block stop	23/09/97	25/03/98	Functional che
London	B - 2	978675	No stop	17/05/98	27/06/98	Clean
London	B - 2	978675	Block stop	12/12/98	07/03/99 16:	Check & alignr
Paris	C - 3	765865	System stop	01/01/99	04/02/99	Functional che
Paris	C - 3	547754	Block stop	02/02/99	03/03/99	Clean
Paris	C - 3	765765	Block stop	04/04/99	07/05/99 16:	Check & alignr

OK Cancel

Fig5: Performed Preventive maintenance

Off type - No stop (the action was performed during operation), Block stop - the block was stopped during the system operation, System stop - entire system was stopped to perform the PM action. Different off types cause different PM cost and productivity damage.
Rest fields has the same meaning as for corrective maintenance data.

3. Analyses

3.1 MTBF and MTTR

Mean Time Between Failures (MTBF) estimation for a nominal or physical unit is calculated as total operation time (Off date - On date) of all records related to this unit divided by total number of failures contained in these records (Off type = Failure). MTBF may be estimated also for each severity. For this purpose only failures with this severity are included in total number of failures.
MTBF confidence limits are calculated using the standard methods for different supposed failure time distribution, see for example MIL - HDBK - 338 - 1A, paragraph 8.3.2.5. [1].

Mean Time To Repair completion (MTTR) estimation may be calculated using maintenance time. This value may be obtained as the difference between On date in the record **after** failure and Off date in the **failure** record. The program selects all failure records (with Off type = Failure) for the considered unit and next records and calculate maintenance time for all those pares. Then the average value of the maintenance time results presents MTTR. Confidence intervals for MTTR can be obtained by the same way as for MTBF.

3.2 MTBF growth or fall during a time.

The input data for this analysis for a selected nominal block are the arrays of each physical unit age for each failure number. The unit age is its total operation time until the considered failure. The age is accumulated from operation time values between failures. Then the MTBF growth rate is estimated according to a chosen model. Most often the Duane model is used [1; para 8.5.4]. One

can apply maximum likelihood estimations proposed by Crow [2].
To view growth trend and compliance between the field data and Duane model the program calculates modeled and observed instantaneous MTBF values for each accumulated test time and shows them on the following graph:

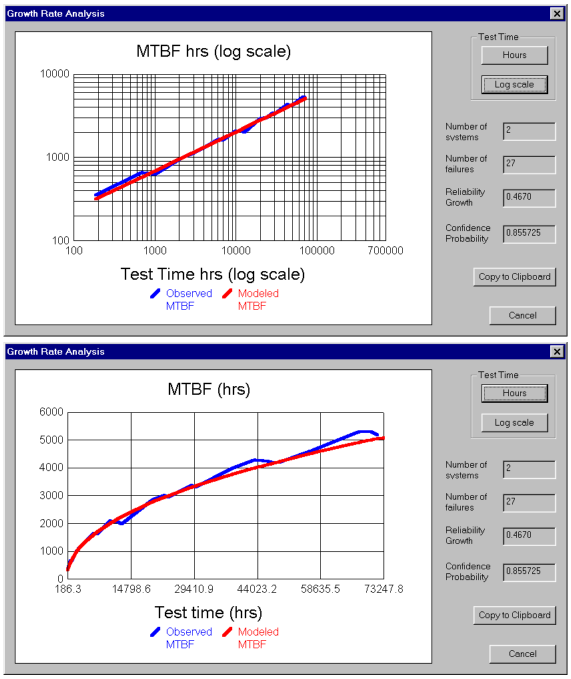
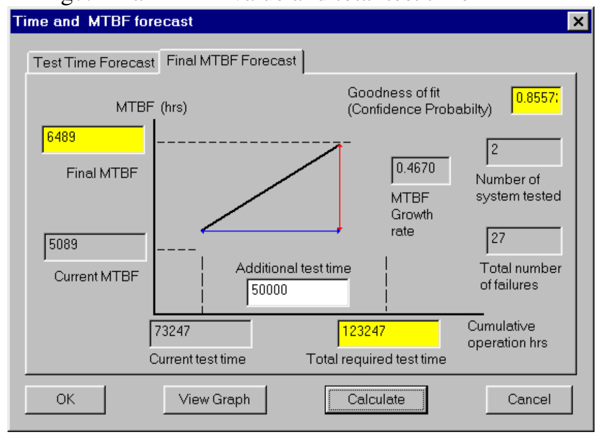


Fig6: Instantaneous MTBF values for each accumulated test time

The chart is outputted in linear (Hours button) and logarithmic (Log scale button) axes.
There are some fields in the graph form with most important data:
Number of systems - number of physical units (serial numbers) presenting the selected nominal block in test log.
Number of failures - total number of the block observed failures
Reliability Growth - MTBF growth rate estimation. If this value is negative, it means MTBF fall rate and the trend line decreases.
Confidence Probability (CP) - the probability that the observed test (field) data fits the Duane Model.
To calculate CP the accumulated test time is divided into some intervals and for each interval the difference between the observed O and estimated E number of failures is defined. The CP is calculated as Hi - square statistic, i.e. the sum $(O - E)^2/E$ by all intervals.
CP is the goodness of fit degree between the test data and Duane model. Having a CP requirements you can decide if the model is appropriate for the block MTBF growth estimation.

The program allows predicting the block MTBF after an additional test time using the preliminarily estimated MTBF growth rate

Fig7: Final MTBF value and total test time



User should input the desired additional test time and click Calculate button. He gets Final MTBF value and total test time as the sum of the current and the additional one.

Clicking View graph button he will get also prediction graph:

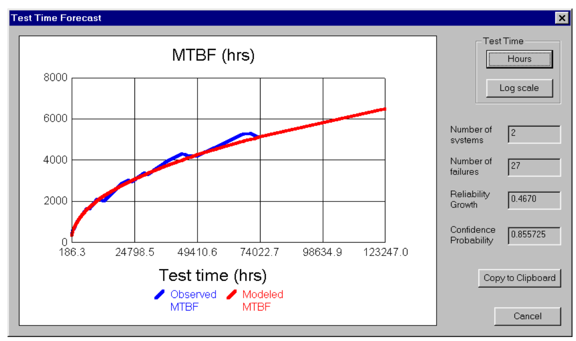


Fig8: MTBF prediction graph

The last 50,000 hours of total test time on this chart present **planned** period having no observed points.

3.3 Identifying failure and repair time distribution

Observed failure or repair time values from test log can be the good base to pick up an appropriate distribution for a block or system to use it then for RAM analysis and preventive maintenance optimization. Theoretical methods here are well known, the problem is to make this process easy and visual for user by means of corresponding software.
In BQR FDA package the collected in test log (described above) failure and repair times for each failure are imported by CARE-STAT program and shown by failure numbers:

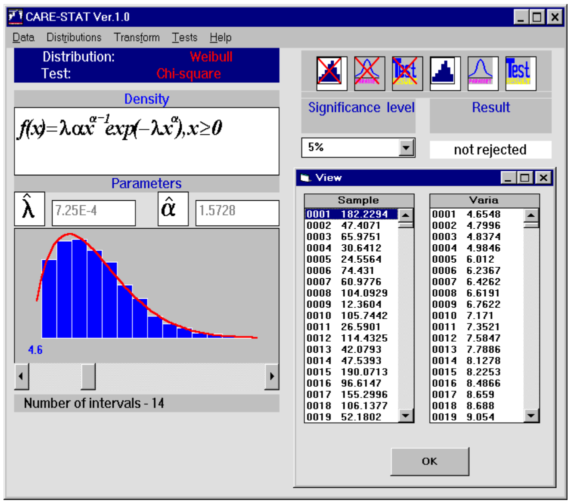


Fig9: Failure and repair times for each failure are imported by CARE-STAT program

View section presents observed operational time between failures (**Sample** column) and the same range sorted by the time increasing (**Varia** column). On the left side the observed density function is shown - the fraction of failures contained in each time interval. Number of intervals user can adjust visually using this histogram. He selects one of available standard distribution (in this example - Weibull) to test its compliance with the observed data. The tested theoretical density function expression appears above the histogram. User selects also one of available test types (here - Hi-square). The results of testing are presented as parameters' estimations calculated with observed data and the test conclusion (rejected, not rejected) by a selected significance level (here - 5%).

The following parameters are available for user selection:
Theoretical distributions: Normal, Lognormal, Exponential, Wiebull, Uniform, Betta, Gamma, Coshi, Laplas, Pareto, Railigh, Gumbel (maximum), Gumbel (minimum), Chi-square, Fisher's, Student's.
Tests: Chi - square, Kolmogorov - Smirnov, W - square, Wilky - Shapiro
Significance levels: 10%, 5%, 1%.

3.4 MTBF demonstration tests.

Collected in test log data can be used to accept or reject a declared MTBF value. For those conclusions in addition to failure time data the following parameters should be taken:

- Demonstrated MTBF
- Unacceptable MTBF
- Consumer's risk - the error probability by MTBF acceptation.
- Producer's risk - the error probability by MTBF rejection

Each demonstration test should be planned so that it will provide the risks will not exceed the specified values.
The detailed test planning and evaluating is presented in MIL-STD-781 and MIL-HDBK-781 for truncated tests under **normal** loading with fixed time, fixed number of failures and for sequential tests.

BQR developed planning and evaluation methods for **accelerated** test under **overloading.** It allows significant reduction of the test time. This method uses Arrhenius - Pick model and can be applied for electronic equipment. It contains the following steps:

a. Permitted stress is defined:
For a small lot of samples the different levels of work temperature and humidity are consequently examined while the physical state features (at work and at possible failure) are the same as under the normal work conditions. The maximal temperature and humidity satisfying this requirement is the highest permitted stress. The stresses used for the accelerated test must be lower, then this level.

b. A standard fixed time plan is chosen from MIL-STD-781. It defines:

- t - test time under normal temperature
- a - accepted number of failures
- r - rejected number of failures (r = a+1)

c. Preliminary expected acceleration factor A and total test time ta is defined for different stress temperature and expected value of Activation energy.

d. The accelerated test is planned to be performed with 2 groups of samples j = 1, 2 simultaneously for taj1 and taj2 hours of total test time under 2 different stress temperatures T1 < T2 and the same humidity H1 = H2. Total test duration taj1 and taj2 for each group are preliminary determined for expected value of Activation energy so that each of them will be correspond (regarding time acceleration) to **half** of the required total test time under normal conditions t.
In this case the mean number of failures observed is the same for both of stresses and estimation accuracy will be the highest possible.
Failure time tij is registered, i = 1,2,..rj - failure number. After each or some new failures the Activation Energy value Ea, acceleration factor AFj and predetermined total test time taj for each group are estimated more precisely.
The test for each group j is stopped when predetermined test time taj is reached or total number of failures r1 + r2 exceeds a.

e. MTBF estimation and confidence limits are calculated after test using obtained acceleration factors values. Preliminary calculations shows that du to acceleration total test time may be reduced by some times comparing with standard truncated tests.

3.5. Preventive maintenance optimization.

If failure time distribution is **not exponential**, the efficiency of preventive repair may be considered.
Preventive repair has the following advantage. When failure rates of some blocks begin to increase according to their failure time distribution function, the system failure frequency is also increases. This causes often

system stopping for corrective maintenance. The maintenance cost raises because of often disassembles and assembles and also stoppage damage.

If to plan preventive maintenance so that to do replacement or repair of different 'old' blocks simultaneously, the total number of the system stops may be reduced.

But we replace some blocks before failure and so the total number of used spares or repairs for each block may increase. Though the number of system repairs will be less because of combining different blocks repair.

PM optimization problem may be formulated by the following way: choose the groups of blocks repaired together and PM schedule to provide minimal maintenance cost and system stoppage damage.

The maintenance groups (MG) are selected from the blocks having near failure rate increasing time moment in their distribution curve. Preliminarily for each block should be performed distribution analysis as described above (see 3.3).

Then for each MG the time between preventive maintenance (TBPM) is optimized to provide declared above purpose. To do this the Reliability Block Diagram module is used calculating down time and its damage for all blocks' hierarchy including the system.

4. References:

1. MIL - HDBK - 338 - 1A . Electronic reliability design handbook US DOD, 12 October 88

2. Crow, L.H., "On tracking Reliability Growth", Proceedings 1975 Annual Reliability & Maintainability Symposium, pp 438 - 443.

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Mr. Bot has more than 25 years of experience in RAMS and ILS. He was the RAM/ILS manager of many defense and commercial projects of more that US500 Million Dollars. He has written articles for leading magazines, conducting seminars and gives lectures worldwide.

From 1989 he is the president of BQR, a leading consulting and software developing firm. Previous employment as a Reliability and ILS Engineer: freelance adviser (1984-1989), Tadiran Telecommunication (1980-1984) and IDF (1970-1980).