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Savunma Sektöründeki Sistemlerin Arızalar Arası Ortalama Süre Analizi

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Anahtar Kelimeler
Güvenilirlik
AAOS Analizi,
Güvenilirlik Analizi,
Entegre Lojistik Destek.

Öz: Yüksek teknolojili çalışma ortamları için Güvenilirlik Analizi, tasarım aşamasında MIL-HDBK-217F ve Telcordia SR-332 veya kullanım aşamasında saha verileriyle Weibull Dağıtımı gibi birçok farklı metodolojiye göre yapılmaktadır. Bu makalenin amacı, daha doğru Arızalar Arası Ortalama Süre (AAOS) değerleri için bir metodoloji elde etmek amacıyla AAOS hesaplama yöntemlerini karşılaştırmaktır. Bu makalede; Savunma Sanayiinde kullanılan sistemler için MIL-HDBK-217F standardı ve Weibull Dağılımı baz alınarak hesaplanan AAOS değerleri karşılaştırılmıştır. Çalışmanın sonuç kısmında; sonuçlar incelenmiş olup daha güvenilir AAOS değerleri için MIL-HDBK-217F standardını daha iyi hale getirecek bir düzeltme katsayısının bulunabileceği önerilmektedir.

MTBF Analysis of Systems in Defense Industry

Keywords
Reliability,
MTBF Analysis,
Reliability Analysis,
Integrated Logistics Support.

Abstract: For high technology working environment Reliability Analysis is implemented according to various methodologies such as MIL-HDBK-217F and Telcordia SR-332 in design phase or Weibull Distribution with field data in usage phase. This paper aims to compare Mean Time Between Failure (MTBF) calculation methods in order to establish a more accurate methodology for MTBF values. In this article; MTBF values calculated based on MIL-HDBK-217F standard and Weibull Distribution are compared for the systems used Defense Industry. In the conclusion of the article; the results are examined and as a result, it is recommended that a correction coefficient could enhance the accuracy of MTBF values derived from the MIL-HDBK-217F standard.

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1. Introduction

Integrated Logistics Support (ILS) represents a methodology that emerged with the aim of providing supportability features throughout the design and development processes of a system or product. The concept of ILS encompasses support at all maintenance and repair levels of systems. The processes within the Integrated Logistics Support methodology are fundamentally defined as 12 Integrated Logistics Support Elements. These ILS Elements are Maintenance Plan, Manpower and Personnel, Supply Support, Support Equipment, Technical Data, Training and Training Support, Computer Resource Support, Facilities, Packaging, Handling, Storage, and Transportation (PHST), Design Interface, Continuous Engineering, and Product Support Management.

This article focuses on the Design Interface concept within these ILS Elements. The Design Interface element covers how long a system will be in use before a failure, how much time it will take to repair in case of a failure, and the development of maintainability methodologies. For instance, after designing the system, the design engineer shares design documents to the ILS engineer for conducting the Mean Time Between Failures (MTBF) analysis. The ILS engineer performs the analysis considering factors such as the operating temperature and environmental conditions of the system in order to compare with the user's requirements. If the analysis indicates that the obtained value does not meet the user's requirements, the ILS engineer gives feedback the designer about this issue and requests a revision in the design. The designer may improve the design by switching higher quality level components or inserting redundancy blocks to the design. The Design Interface is implemented effectively by this process.

Reliability, Availability, and Maintainability Analysis (RAM) based on Military Standards (namely MIL-HDBK-338B Electronic Reliability Design Handbook and MIL-HDBK-217F Reliability Prediction of Electronic Equipment) are commonly conducted in order to ensure the impact of ILS elements on design. RAM analysis is comprehensive, bottom-up (part-component-device-system) analysis that rely heavily on statistical methods and are based on failure and maintenance data. MIL-HDBK-338B Electronic Reliability Design Handbook is written for reliability engineers and provides guidance. According to MIL-HDBK-338B, Reliability has two definitions: Firstly, Reliability is the duration or probability of failure-free performance under stated conditions. Reliability also can be defined as the probability that an item can perform its intended function for a specified interval under stated conditions. In addition, availability is a measure of the degree to which an item is in an operable and committable state at the start of a mission when the mission is called for at an unknown time. Lastly, maintainability is the relative ease and economy of time and resources with which an item can be retained in, or restored to, a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair.

This article specifically has a focus on Reliability Analysis, and Mean Time Between Failures (MTBF) which is the fundamental parameter in Reliability Analysis. According to MIL-HDBK-338B, MTBF is a basic measure of reliability for repairable items. The mean number of life units during which all parts of the item perform within their specified limits, during a particular measurement interval under stated conditions. Reliability Analysis is done based on the data gathering from design phase and usage phase in field. The results of Reliability Analysis are used for spare parts planning, maintenance cost and many Integrated Logistic Support issues.

In the first section, the calculation methods for MTBF are explained according to MIL-HDBK-217F which is one of the military standards giving information on reliability prediction procedures and Weibull Methodology.

The flow of the work in the rest of the paper is as follows. In the second section, the MTBF values for two defense industry systems are calculated using the Weibull and MIL-HDBK-217F methodologies. The subsequent section presents the results obtained from these calculations. Mean Time Between Failure (MTBF) values are obtained according to MIL-HDBK-217F standard and Weibull Distribution for comparison. The final section provides recommendations based on the results obtained.

2. Material and Method

2.1. Literature Review

For literature review, articles covering studies, analyses, and methodologies on Reliability Analyses focusing on Mean Time Between Failure from 1995 to the present have been examined. The content of these articles explores studies conducted in various sectors.

M. Kimura et al. (1995) predicted the reliability of a software system during arbitrary testing periods. The paper introduced a method of software reliability prediction that leverages software failure-occurrence time data and employs software reliability growth models represented by a nonhomogeneous Poisson process (NHPP) [1].

Wang H. and Pham H. (1996) addressed the challenges associated with evaluating the Mean Time Between Failures, availability and reliability for complex large-scale systems. The paper explored the combination of Monte Carlo technique and Bayes method [2].

Angus J. E. (1988) presented a method for finding out a methodology for Mean Time Between Failure in k-out-of-n: G parallel system with unlimited repair (There are enough repairmen to repair simultaneously any number of failed units) and exponential failure and repair times of the failed unit [3].

Crocker J. et al. (1998) suggested a new alternative measure, called Maintenance Free Operating Period, to MTBF and Failure Rate since MTBF has main disadvantage; namely being impossible to predict MTBF if failure rate distribution is not exponential [4].

Elerath J. G. (2000) recommended to analyze hazard rate with using Weibull distribution instead of analyzing MTBF using with exponential distribution for disk drive industry [5].

Jia Y. et al. (2002) presented approach to analyze the time between failures for machining centers (MC). By applying likelihood function, the authors fit the Weibull distribution to model the TBF of MCs. Additionally, the study is conducted Goodness-of-fit tests employing Hollander's method, providing that the time between MC failures adheres to the Weibull distribution [6].

Mondro M. J. (2002) described a simple technique for estimating a mean time between operational failure (MTBF) that was measured at periodic intervals. This type of maintenance was appropriate in high perceptions, after the missionaries' assignments are over. This approach could greatly simplify MTBF analysis for large systems. This article provided the equations and limited the possible errors in this estimate [7].

Carlson J. et al. (2004) investigated the reliability of mobile robots used in hazardous environments, revealing a MTBF of 24 hours and availability of 54%, with the control system being the most common source of failures [8].

Sharma R.K. and Kumar S. (2007) presented the importance of RAM (Reliability, Availability, Maintainability) analysis, using a Markovian approach to model system behavior and estimate reliability and maintainability at different mission times. The results have proven beneficial for plant personnel, leading to significant improvements in system performance through the adoption of appropriate maintenance policies and strategies [9].

Juang Y.S. at al. (2008), this article presented a genetic algorithm-based optimization formula aimed at improving design efficiency in industrial system, with a focus on balancing system availability, reliability and cost [10].

Krasich M. (2009) determined that one item has “estimated, calculated, averaged” MTBF’s or MTTF’s since these terms are dependent on various factors such as application stresses, the other items of the system, usage period, stress level etc. [11].

Zhai J. et al. (2013) studied the Mean Time Between Failure, the failure and repair rate and the availability value for Building Cooling Heating and Power (BCHP) System. Combination of the state-space method and Markov model’s probabilistic analysis was used for this study [12].

Memon H.H. and Alam M.M. (2016) predicted the failure rate and RAM (Reliability, Availability, Maintainability) of IGBT Triggering System in the marine environment by using MIL-STD 217 and MIL-HDBK 472 and by defining the values of different parameters which includes stress factor, quality factor, temperature factor etc. These results have been able to utilized by the designers and Integrated Logistics Support engineers for the input of resource requirements and life cycle cost analysis [13].

Ferreira F.J.T. E (2016) provided insights into the key considerations surrounding the reliability and operation of high-efficiency motors. By presenting a comprehensive perspective, the advantages, drawbacks, and limitations associated with high-efficiency industrial motors are examined [14].

Liu Y. et al. (2022) Black's mean time to failure (MTTF) equation was applied to predict electromigration life in electronics. It was an empirical equation and at least three datasets have been tested under two temperatures and two temperatures. Cost and time could be saved effectively with reliability tests to predict the electromigration life of electronic products [15].

Duer S. et al. (2023) considered the time between failures as a function of maintainability and the dependability of the Wind Farm as a function of service life [16].

2.2. MTBF Analysis Methodologies

2.2.1 Weibull

One of the key methods discussed in this article used for reliability analysis is Weibull Analysis. According to the book named Practical Weibull Analysis Techniques - Fifth Edition by James A. McLinn; lots of methodologies for Weibull analysis have been investigated. The major advantage of Weibull distribution is that it is widely applicable to lots of reliability, maintainability, test and quality issues. Moreover, the Weibull distribution has widely applicable to analyze Mean Time to Failure and Cycles to Failure.

Weibull formula can be stated commonly as Reliability plus unreliability; which totals equals to 1.0.

$$R(t) + F(t) = 1.0 \tag{1}$$

We may express "F(t) the unreliability function" by using Weibull distribution as following:

$$F(t) = 1 - e^{-(\frac{t-\gamma}{\eta})^{\beta}} \quad (2)$$

This formula can be also seen as:

$$F(t) = 1 - e^{-(\frac{t-\gamma}{\eta-\gamma})^{\beta}} \quad (3)$$

This alternative formula shows that the offset has an impact on the characteristic life, η.
"f(t) the probability density function" is the time derivative of the "F(t) the unreliability function". This is:

$$f(t) = \beta\eta^{-\beta}t^{\beta-1}e^{-(\frac{t-\gamma}{\eta})^{\beta}} \quad (4)$$

β , η and γ are commonly used for standard Weibull parameters.
β (Beta): Shape parameter. The shape of the time to failure distribution is shown by using β.
η (Eta): Scale parameter where 63.2% of the test units fail.
γ (Gamma): Location parameter where the time to failure distribution actually begins. This value can be positive or negative.

It can be shown Equation 5 that relation between η (characteristic life) and the mean depends on β(Beta) by using the Gamma function. This is:

$$Mean = MTBF = \eta\Gamma(1 + 1/\beta) \quad (5)$$

Γ (The Gamma Function) depends on the value of 1 + 1/ β and these values can be found from special Gamma Function table. In general this correction value can be seen as a little correction to the value of η (eta). Usually this correction value varies between 0.88 and 1.00. And also this correction value can be greater than 1.0 when β is less than 1.0.

2.2.2 MIL-HDBK-217F

The another method explored here is MIL-HDBK-217F. MIL-HDK-217F aims to establish and maintain general methods for analyzing the inherent reliability for the electronic systems in military industry.
This handbook contains two types of method for reliability predictions; namely "Part Stress Analysis" and "Parts Count" methods.

The Part Stress Analysis Method is applied at the later design phase when the detail information is gained. This method also results in lower and close failure rate of system. On the other hand; the Parts Count Method needs less information and is applicable in earlier design phase. This method also results in higher failure rate of system.
Part failure rate model of The Part Stress Analysis is difference from part to part. A typical example of the model for discrete semiconductors:

$$\lambda p = \lambda b \prod T \prod A \prod R \prod S \prod C \prod Q \prod E \quad (6)$$

λp : part failure rate,
λb : the base failure rate,
∏E : the environment factor,
∏T : the temperature factor,
∏Q : the part quality factor,
∏S : the stress factor.

In order to apply The Part Count Method part quantities, quality level and application environment information are needed.

$$\lambda = \sum_{i=1}^{i=n} N_i \, (\lambda_g \prod_Q)_i \quad (7)$$

λ : total system failure rate (failures per 106 hours)
λg : the failure rate of the ith part (failures per 106 hours)
∏Q : the part quality factor of the ith part
Ni : the quantity of the ith part
n : the number of diffent parts in the system.

Drake G. and Corradi G. (2020) determined that in general the probability of failure of electronic components and systems during their useful lifetime tends to have an exponential distribution unit [19].
As a result; after calculating failure rate according to MIL-HDBK-217F, MTBF is calculated based on exponential distribution with the following formula.

$$\mathrm{MTBF} = 1/\lambda \tag{8}$$

3. Results

MTBF analysis conducted within the scope of reliability analysis, as mentioned in the previous sections, are commonly performed during the design phase using the MIL-HDBK-217F methodology. The calculation of the MTBF value depends on the environmental conditions in which the system is used, the duty cycle of the subsystems during their missions, the operation and maintenance plans of the system, and the design and quality levels of the components that make up the system. Before the design phase, a reliability target or requirement is determined based on the system's availability ratio or reliability data from existing systems.

The MTBF value of the system can be improved throughout the project with activities such as design revisions, quality improvements, and preventive maintenance. The predicted MTBF value obtained during the design phase serves as input for the work of design teams. The Part Stress Analysis method within MIL-STD-217F was used in calculating the predicted MTBF. During this analysis, reliability block diagrams of the systems were created and the systems of duty cycles, quality levels, operating temperatures, and stress factors of the components were imported to analysis.

It is important to verify MTBF values based on predictions during the design phase with data collected during tests and field use. Because examined systems in the projects are used in the Non-Disclosure Agreements, limited information sharing about the systems and system components was provided in the article. These systems are mission-critical systems used in national defense, operating 7/24 under challenging environmental conditions. These systems consist of varies electronic components like resistors, capacitors and connectors. According to user requirements, these systems are subjected to heavy environmental conditions tests. These repairable systems are expected to operate in very short time. Due to Non-Disclosure Agreements, detailed information about these systems cannot be provided.
The failure data of the systems have been recorded for users since the delivery date. Users report faults through Customer Relationship Management (CRM) and Failure Management System when they occur. The responsible ILS support teams and their field teams intervene, resolve the failures, and track them through the Failure Management System. In this context, the data for the systems covered in the article were collected through CRM and Failure Management, as detailed in the following sections.

- Failure Number
- Part Number
- Part Description
- Serial Number
- Failure Description
- Start Date of Usage
- Start Date of Failure
- End Date of Failure
- Time to Failure (Hours)

The dataset collected for the two systems with the mentioned sections was used to calculate the field MTBF value using the Weibull distribution. In order to perform this calculation, the relevant Weibull parameters were first obtained. Using the parameters obtained in accordance with the Weibull formulation, the MTBF value was then calculated.

MTBFs of two systems in defense industry were calculated according to Weibull and MIL-HDBK-217F. When calculating according to Weibull, the field data gathered from delivery time to analyze time was used. When calculating according to MIL- HDBK-217F, the prediction data was used as described previous sections. The results of the analysis can be seen from Table-1.

Table 1. The results of the analysis

	Inputs*			Outputs	
Part Number	Failure Numbers For Field MTBF Calculation	Start Date of Usage	End Date of Failure	Predicted MTBF (MIL-HDBK-217F)	Field MTBF (Weibull)
System-1	190	2018	2023	3208 Hours	14452 Hours
System-2	150	2018	2023	10806 Hours	19998 Hours

* Due to Non-Disclosure Agreements, detailed information about these systems (Part Description, Serial Number, Failure Description, Start Date of Failure, Time to Failure) cannot be provided.

According to the results of the analysis, Field MTBF values which are empirical information for systems are higher than Predicted MTBF values. It can be stated that Field MTBF Calculation method may represent more accurate values for these systems compared to theoretical Predicted MTBF.

4. Discussion and Conclusion

The activities of Integrated Logistics Support (ILS) are carried out to manage all supportability criteria that a system will require throughout its lifecycle under a comprehensive view, ensuring cost effective use and directing the design accordingly. This article, focusing on reliability analysis within the discipline of design interface, addresses ILS activities that play a critical role in developing systems with reliable performance that are both cost-effective and aligned with user expectations.

One of the fundamental parameters used in reliability analysis is MTBF. In this context, the article calculates MTBF data for defense industry systems using two different methods; field MTBF obtained from the Weibull distribution and predicted MTBF obtained from MIL-HDBK-217F. The resulting MTBF values are compared.

Field MTBF was obtained much bigger than predicted MTBF. This big difference was not expected. Because the predicted MTBF is used for estimating spare parts, planning periodic maintenance schedules, planning maintenance labor cost and other Integrated Logistic Support issues. Therefore; the predicted MTBF value is expected to be close to field MTBF value. Probably there can be a correlation between predicted and field MTBF values. In order to find out this kind of correlation, lots of data of systems must be gathered and analyzed. Obtaining accurate data in the reliability discipline is a process that takes many years. Comparing predicted MTBF and field MTBF values is an ongoing controversial.

References

[1] Kimura, M., Yamada, S., Osaki, S., 1995. Statistical Software Reliability Prediction and Its Applicability Based on Mean Time between Failures, Mathematical and Computer Modelling, 149-155.

[2] Wang, H., Pham, H., 1996. Survey of Reliability and Availability Evaluation of Complex Networks Using Monte Carlo Techniques, Microelectronics Reliability, 187-209.

[3] Angus, J.E., 1988. On Computing MTBF for a k-out-of-n: G Repairable System, IEEE Transactions on Reliability, 312-313.

[4] Kumar, U.D., Knezevic, J., Crocker J., 1999. Maintenance free operating period – an alternative measure to MTBF and failure rate for specifying reliability, Reliability Engineering and System Safety, 127-131.

[5] Elerath, J. G., 2000. Specifying Reliability in the Disk Drive Industry: No More MTBF's. Annual, Reliability and Maintainability Symposium, 198-199.

[6] Dai, Y., Zhou, Y., Jia, Y., 2002. Distribution of time between failures of machining center based on type I censored data, Reliability Engineering and System Safety, 377–379.

[7] Mondro, M. J., 2002. Approximation of Mean Time Between Failure When a System has Periodic Maintenance, IEEE Transactions on Reliability, 166-167.

[8] Carlson, J., Murphy, R. R., Nelson, A., 2004. Follow-up Analysis of Mobile Robot Failures, IEEE International Conference on Robotics 8 Automation, 4987-4994.

[9] Sharma, R.K., Kumar, S., 2008. Performance modeling in critical engineering systems using RAM analysis, Reliability Engineering and System Safety, 913–919.

[10] Juang, Y., Lin, S., Kao, H., 2008. A knowledge management system for series-parallel availability optimization and design, Expert Systems with Applications, 181–193.

[11] Krasich, M., 2009. How to Estimate and Use MTTF/MTBF Would the Real MTBF Please Stand Up?, Annual Reliability and Maintainability Symposium, 353-359.

[12] Wang, J., Fu, C, Yang, K., Zhang, X., Shi, G., Zhai, J., 2013. Reliability and availability analysis of redundant BCHP (building cooling, heating and power) system, Energy, 531-540.

[13] Memon, H.H., Alam, M.M., 2016. Reliability, Maintainability, Availability and Failure rate Analysis of IGBT Triggering System Designed for Marine Environment, 13th International Bhurban Conference on Applied Sciences & Technology, 295-299.

[14] Ferreira, F.J.T.E, 2016. Reliability and Operation of High-Efficiency Induction Motors, IEEE Transactions on Industry Applications, 4628-4637.

[15] Liu,Y., Gusak, A., Jing, S., Tu, K.N., 2022. Fast prediction of electromigration lifetime with modified mean-time-to-failure equation, Materials Letters, 325p.

[16] Duer, S. Woźniak, M., Paś, J., Zajkowski, K., Bernatowicz, D., Ostrowski, A., Budniak, Z., 2023. Reliability Testing of Wind Farm Devices Based on the Mean Time between Failures (MTBF), Energies, 1659p.

[17] McLinn, J.A, 2010. Practical Weibull Analysis Techniques, Fifth Edition.

[18] MIL-217 Military Handbook, 1991. Reliability Prediction of Electronic Equipment, Department of Defense, Washington DC.

[19] Drake, G., Corradi, G., 2020. A Reliability Analysis of the Mu2e Calorimeter Front End Amplifier Board, The Mu2e Project, 1-59.