IJSRD - International Journal for Scientific Research & Development| Vol. 1, Issue 2, 2013 | ISSN (online): 2321-0613

Guidelines to Understanding Design of Experiment and Reliability Prediction

Kevin Chauhan[1] **Prof. Nilesh Pancholi**[2]
[1]M.E.[CAD/CAM] student, [2] Faculty of Mechanical Department
[1,2]Department Mechanical engineering
[1,2]Indus Institute of Technology and Engineering (IITE), Ahmedabad, Gujarat

Abstract— This paper will focus on how to plan experiments effectively and how to analyse data correctly. Practical and correct methods for analysing data from life testing will also be provided. This paper gives an extensive overview of reliability issues, definitions and prediction methods currently used in the industry. It defines different methods and correlations between these methods in order to make reliability comparison statements from different manufacturers' in easy way that may use different prediction methods and databases for failure rates. The paper finds however such comparison very difficult and risky unless the conditions for the reliability statements are scrutinized and analysed in detail.

I. INTRODUCTION

Reliability engineering can be somewhat abstract in that it involves much statistics; yet it is engineering in its most practical form. Product reliability is seen as a testament to the robustness of the design as well as the integrity of the quality and manufacturing commitments of an organization. This paper explains the basic concepts of Design of Experiment and reliability.

The most effective way to improve product quality and reliability is to integrate them in the design and manufacturing process. In the development cycle the Design of Experiment (DOE) is a useful tool and use in early stage. It has been successfully adopted by many industries. The application of DOE is not limited to engineering. Many successful stories can be found in other areas. For example, it has been used to reduce administration costs, establish better advertisement strategies and improve the efficiency of the surgery processes.

Reliability is an area in which there are many misconceptions due to a misunderstanding or misuse of the basic language. It is therefore important to get an understanding of the basic concepts and terminology.

II. DESIGN OF EXPERIMENT

This section explains the basic concepts of the design of experiment and general guidance of DOE

A. DOE can do following:

1) *Comparisons:* When you have multiple design options, several materials or suppliers are available, you can design an experiment to choose the best one. For example, in the comparison of ten different suppliers that provide connectors, will the components have the same expected life? If they are different, how are they different and which is the best?

2) *Variable Screening:* If there are a large number of Variables that can affect the performance of a product or a system, but only a relatively small number of them are important; a screening method can be use to identify the important variables. For example, the warranty return is abnormally high after a new product is launched. DOE can be used to identify the troublemakers quickly and provide the guidelines for design modification to improve the reliability by follow-up experiment.

3) *Transfer Function Exploration:* Once an important variable have been identified as small, their effects on the system performance or response can be further explored. The relationship between the input variables and output response is called the transfer function. DOE can be applied to study the linear to design efficient experiments and quadratic effects of the variables and some of the interactions between the variables.

4) *System Optimization. :* For the system design the goal is to improve the system performance, such as to improve the efficiency, quality, and reliability. If the transfer function between variables and responses has been identified, the transfer function can be used for design optimization. DOE provides an intelligent sequential strategy to quickly move the experiment to a region containing the optimum settings of the variables.

5) *System Robustness:* In addition to optimizing the Response, it is important to make the system robust against "noise," such as environmental factors and uncontrolled factors. Robust design, one of the DOE techniques, can be used to achieve this goal.

B. General guidelines for DOE:

DOE is not only a collection of statistical techniques that enable an engineer to conduct better experiments and analyze data efficiently; it is also a philosophy. The following seven-step procedure should be followed

1) *Clarify and State Objective.* The objective of the experiment should be clearly stated. It is helpful to prepare a list of specific problems that are to be addressed by the experiment

2) *Choose Responses.* The experimental Outcomes is response. Based on the stated objectives an experiment may have multiple responses. The responses that have been chosen should be measurable.

3) *Choose Factors and Levels.* A factor is a variable that is going to be studied through the experiment in order to

understand its effect on the responses. Once a factor has been selected, the value range of the factor that will be used in the experiment should be determined. Values to be used within the range have two or more values. These values are referred to as levels or settings. When safety is involved especially Practical constraints of treatments must be considered. A cause-and effect diagram or a fishbone diagram can be utilized to help identify factors and determine factor levels.

4) Choose Experimental design: According to the objective of the experiments, the analysts will need to select the number of factors, the number of level of factors, and an appropriate design type. For example, if the objective is to identify important factors from many potential factors, a screening design should be used. If the objective is to optimize the response, designs used to establish the factor-response function should be planned. In selecting design types, the available number of test samples should also be considered.

5) Perform the Experiment: A design matrix should be used as a guide for the experiment. This matrix describes the experiment in terms of the actual values of factors and the test sequence of factor combinations. For a hard-to-set factor, its value should be set first. Within each of this factor's settings, the combinations of other factors should be tested.

6) Analyze the Data: Statistical methods such as regression analysis and ANOVA (Analysis of Variance) are the tools for data analysis. Engineering knowledge should be integrated into the analysis process. Statistical methods cannot prove that a factor has a particular effect. They only provide guidelines for making decisions. Statistical techniques together with good engineering knowledge and common sense will usually lead to sound conclusions. Without common sense, pure statistical models may be misleading. For example, models created by smart Wall Street scientists did not avoid, and probably contributed to, the economic crisis in 2008.

7) Draw Conclusions and Make Recommendations: Once the data have been analyzed, practical conclusions and recommendations should be made. Graphical methods are often useful, particularly in presenting the results to others. Confirmation testing must be performed to validate the conclusion and recommendations.

III. RELIABLITY AND RELIABILITY PREDICTION

A. Reliability: Reliability is defined as the probability that a device will perform its required function under stated conditions for a specific period of time. Predicting with some degree of confidence is very dependent on correctly defining a number of parameters. For instance, choosing the distribution that matches the data is of primary importance. If a correct distribution is not chosen, the results will not be reliable.

B. Failure rate (λ)? Every product has a failure rate, λ which is the number of units failing per unit time. The fundamental first step in determining the reliability and life of a widget is to observe a representative set of samples, a "population" of widgets and record the failures over a certain time frame. The collected data will show a certain number of failures over an observed time period, it always has to be related to the observed population size. This is expressed by the failure rate.

$$FR = \frac{\text{Number of Failures (NF)}}{\text{Observation Time (OT) x Population Size (N)}}$$

NF- umber of Failures (during the overall time period, at a certain time / time interval Failures: - which type of failures? Failure mode? Which part? Repairable non repairable? Loading conditions environmental effects consistent?

OT- Observation Time (till a certain amount or all failed) hours - days - miles - cycles –

N- Population Size – overall number of units observed Selected test units - large population of units in field

C. What is MTBF, MTTF?

The equipment is going to be repaired and returned to service MTBF (mean operating time between failures) will applies; MTTF (mean time to failure) applies to parts that will be thrown away on failing. During the 'useful life period' assuming a constant failure rate, MTBF is the inverse of the failure rate and we can use the terms interchangeably.

$$MTBF = \frac{\text{Observation Time (OT) x Population size N}}{\text{Number of Failures (NF)}}$$

NF- umber of Failures (during the overall time period, at a certain time / time interval Failures: - which type of failures? Failure mode? Which part? Repairable non un repairable? Loading conditions environmental effects consistent?

OT- Observation Time (till a certain amount or all failed) Hours - days - miles - cycles –

N- Population Size – overall number of units observed selected test units - large population of units in field –

MTBF = 1 / FR

MTTF is the expectation of the time to failure

The general expression for MTTF is given by

$$E\{t\} = MTTF = \int_0^\infty Xf(X)dX = \int_0^\infty R(X)dX$$

Where R(t) denotes the reliability (performance).

When the failure rate is constant with time the times to failure are exponentially distributed. This leads to

$$\mathrm{MTTF} = \int_0^\infty \mathrm{R(X)d(X)} = \int_0^\infty \exp(-\lambda)\,\mathrm{dX} = 1/\lambda$$

MTTF is a measure used for non-repaired items.

MTTF is sometimes misunderstood to be the life of the product instead of the expectation of the times to failure. For example, if an item has an MTTF of 100 000 hours, it does not mean that the item will last that long. It means that, on the average, one of the items will fail for every 100 000 item-hours of operation. If the times to failure are exponentially distributed, then on average 63.2 % of the items will have failed after 100 000 hours of operation.

D. Reliability prediction

Reliability prediction is the process used to estimate the constant failure rate during the useful life of a product. This however is not possible because predictions assume that:

- The design is perfect, the stresses known, everything is within ratings at all times, so that only random failures occur
- Every failure of every part will cause the equipment to fail.
- The database is valid

a) Need of Reliability Prediction

A commitment to product quality and reliability is necessary in today's very competitive products market. And the companies don't meet the Customers high expectations for the reliability of the products they buy, lose. The main advantages of reliable products of your company are when the products you sell operate reliably, your costs shrink, your reputation grows, and your business exuberant. The most successful companies meet these market demands for quality by using design for reliability principles: integrate reliability considerations into the entire product design process, right from the start. This way reliability is designed into the product, not patched on later, when problems arise. The companies find results in fewer design changes and iterations for practice design for reliability, lower manufacturing costs, lower warranty and service costs, more profit, and, most importantly, happy customers. To predict product failure rates reliability prediction is important element of the design for reliability process.

b) Reliability Prediction usage

To evaluating product reliability, reliability predictions provide a quantitative basis. This information can be used to guide your design decisions throughout the development cycle.

– *Feasibility Study*: a reliability prediction can give you an idea of the feasibility of the design as far as reliability is concerned when an initial design concept is proposed, these early stage predictions are based on limited design information, and thus are approximate at best, they can give direction to your design decisions; many of these early design decisions may be critical to the success of the product. In addition, it can really pay to discover potential problems early on paper, before time and money is spent on detailed design and development.

You will usually start with a reliability requirement, which may be given by your customer, or dictated by competitive products. You might have a requirement of a 20,000 hour MTBF for a product. If your predicted value is 3,500 hours, the current design concept may not be feasible; at this point you can modify the design concept, or revise the requirement. If your predicted value is 50,000 hours, this can give you confidence in your design concept, at least as far as reliability is concerned.

– *Compare Design Alternatives*: You will make many decisions on design alternatives as your design moves through the early stages into more detailed design. The other factors of reliability predictions, along with performance and cost, can be used as a basis for your decisions. For example you may be able to implement a given circuit function in a number of ways, all performing and costing about the same; it would stand out if one alternative is estimated to be much more reliable than the others.

– *Find Likely Problem Spots*: Reliability predictions can help to identify likely problem areas. You will go over your parts lists, do stress analysis, and note part quality levels; this detailed examination can expose overstressed parts and misapplied parts as part of the prediction process. The predicted failure rates will point parts, or part groups, which are high contributors to the product failure rate.

– *Trade-Off System Design Factors*: For a successful design some factors that determine the overall value of a product; functional performance, cost, size, weight, reliability. The design process will involve many trade-offs among these factors; reliability predictions can offer a quantitative measure of reliability to guide your trade-off decisions.

– *Track Reliability Improvement*: The evidence can offer of by reliability predictions to improving reliability.

c) Reliability improvement

You can improve reliability by using the following ideas

– *Reduce Part Count*: Reducing part count will increase reliability. You can use innovative design ideas, and more highly integrated functional parts, to reduce the number of parts.

– *Part Selection*: For the product quality and reliability of the components is very important.

– *De-rating*: De-rating, or operating the part at levels below its ratings can increase reliability part failure rate decrease as applied stress levels decrease.

– *Burn-In*: Burn-in is operation in your factory, at elevated temperature, to accelerate the rate of infant mortality failures; burn-in allows you to weed out failure prone devices in your factory, rather than in the field. Note that burn-in can be done at the part, board, or system level.

– *Redundancy*: Product reliability may also be enhanced by using redundant design techniques.

d) Reliability Prediction

There are various reliability prediction techniques, depending on your knowledge of the details of your design. An early estimate can be made by comparing your product with products of similar function, of known reliability; as the many differences in design details between the products are not accounted for. More accurate methods become available as more details of your design are known. To predict the failure rates of parts based on various part parameters by utilizing part failure rate, such as technology, complexity, package type, quality level, and stress levels.

Two of the better known failure rate prediction methods are MIL-HDBK-217, and Bellcore.

IV. RELIABILITY STANDARDS

MIL-HDBK-217-MIL-HDBK-217 is the original standard for reliability calculations. It provides reliability math models for nearly every conceivable type of electronic device. Used by both commercial companies and the defense industry, *MILHDBK- 217* provides detailed reliability equations. *MIL-HDBK-217,* which is updated regularly, is currently at Revision F Notice 2. This standard uses a series of models for various categories of electronic, electrical and electro-mechanical components to predict failure rates which are affected by environmental conditions, quality levels, stress conditions and various other parameters. These models are fully detailed *in MIL-HDBK-217.*

A. Bellcore-The Bellcore reliability standard, Reliability Prediction Procedure for Electronic Equipment, TR-332, Issue 5, Dec. 95, is a very popular standard for commercial companies. It was originally developed at AT&T Bell Laboratories, and was based on MIL-HDBK-217. Bell Labs modified the equations from MIL-HDBK-217 to provide results which better represented what their equipment was experiencing in the field. They also added the ability to take into account burn-in testing, as well as field and laboratory testing. Bell Communications Research, formed in the divestiture of the former Bell System on January 1, 1984, is now the controlling organization of the Bellcore reliability standard

B. Mechanical- The Handbook of Reliability Prediction Procedures for Mechanical Equipment, NSWC-94/L07, provides models for various types of mechanical devices including springs, bearings, seals, motors, brakes, clutches, and much more. This latest issue date of this mechanical standard is March 1994.

V. EXPONENTIAL DISTRIBUTION

The exponential distribution is used to model the failure behavior of items having a constant failure rate.

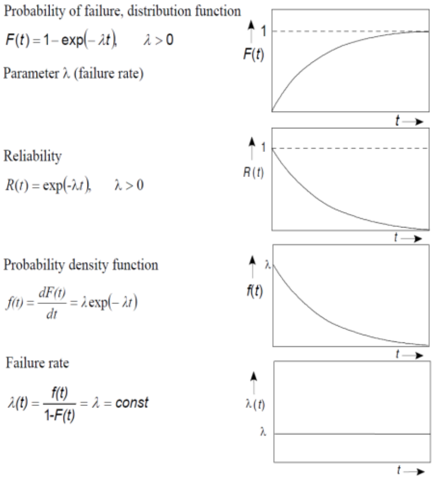

Figure. 1. Graphs of various parameters

VI. RELATIONSHIP BETWEEN MEASURES

	$F(t)$	$R(t)$	$f(t)$	$\lambda(t)$	
$F(t) =$	$F(t)$	$1 - R(t)$	$\int_0^t f(x)dx$	$1 - \exp\left(-\int_0^t \lambda(x)dx\right)$	Probability of failure
$R(t) =$	$1\text{-}F(t)$	$R(t)$	$\int_t^\infty f(x)dx$	$\exp\left(-\int_0^t \lambda(x)dx\right)$	Reliability
$f(t) =$	$\frac{dF(t)}{dt}$	$\frac{dR(t)}{dt}$	$f(t)$	$\lambda(t)\exp\left(-\int_0^t \lambda(x)dx\right)$	Probability density function
$\lambda(t) =$	$\frac{\frac{dF(t)}{dt}}{1 - F(t)}$	$\frac{d(\ln R(t))}{dt}$	$\frac{f(t)}{\int_t^\infty f(x)dx}$	$\lambda(t)$	Failure rate

VII. CONCLUSION

This paper will focus on how to plan experiments effectively and how to analyze data correctly. In this paper, simple examples were used for the basic concepts in DOE. Guidelines for conducting DOE were given. Practical and correct methods for analyzing data from life testing will also be provided. Design of Experiments (DOE) is one of the most useful statistical tools in product design and testing. However, with the basic knowledge of this paper, readers should be able to learn most of them easily.

This paper has briefly looked at reliability engineering, its terms and formulae, and how to predict reliability and demonstrate it with tests and field data. Failure rate predictions are useful for several important activities in the design and operation of equipment. These include assessment of whether reliability goals can be reached, identification of potential design weaknesses, evaluation of alternative designs and life-cycle costs, the provision of data for system reliability and availability analysis, logistic support strategy planning and to establish objectives for reliability tests.

REFERENCES

[1] Huairui guo & adamantios, mettas - 2011 Design of experiments and data analysis Annual reliability and maintainability symposium, 2011

[2] European power supply manufactures association reliability guidelines to understanding reliability prediction (visit the epsma website at www.Epsma.Org) revision date: 24 june 2005

[3] Amoroso reliability associates Reliability report mean-time-between-failure (MTBF) prediction Amoroso reliability associates, amoroso island, inc,188 jefferson street, suite 232, newark, nj 07105, 1-888-579-1166

[4] How to determine the MTBF of gearboxes Dr. Gerhard G. Antony Neugart USA LP Paper for 07 AGMA FTM.