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RELIABILITY ANALYSIS OF ELECTRONIC EQUIPAMENT BASED ON WARRANTY FAILURE DATABASE

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Abstract. *Nowadays, the great market competition makes that the companies look for high reliability and quality in the products. The decrease of the expenses with warranty makes possible its extension which is a great market differential. This objective can be accomplished with product reliability – based design and analysis. The objective of this work is to propose a method for reliability analysis based on warranty data and to validate the suggested method.*
The method consists on adapting the failure data, of any database, to develop a reliability analysis. To accomplish the analysis of the warranty data, the failure data are classified as suspended or complete, and an appropriate probability distribution is adjusted to evaluate the reliability of equipment or system. Starting from that data analysis it is possible to obtain seasonal relationships among faults, and between faults and production lots.
The application of the method is demonstrated through an example, involving the reliability analysis of a telecommunication equipment motherboard. The study follows the proposed model and, based on reliability estimative, it is possible to calculate the warranty cost and to propose possible product and data collection improvements, mainly in the warranty database, to improve the reliability analysis results.

Keywords: *reliability, electronic equipment, warranty.*

1. INTRODUCTION

Today’s demand for reliability on products and manufacturing processes with lower cost is continually growing, as well as demanding and well informed customers, especially in the electronic industry. Nowadays with the increase of competitiveness in the Brazilian market, electronics manufacturers are extending their warranty period in order to bring more customers to their brand. Therefore, it became necessary to develop methods to describe the field behavior of products and to predict their field reliability. The purpose of this paper is to develop a model of electronic system reliability analysis based on field failures data which can support warranty extension analysis.

The warranty claims over time occur according to a point process and depend on the reliability of the product and the sales over time. The failure data is incomplete and often grouped or aggregated. These facts raise several interesting and challenging problems for modeling and estimation, according to Karim et al. (2001) and Wang and Suzuki (2001).

The model developed in the paper can be applied to any product. It is based on the concept of using reliability data to predict the probability of a system to operate without failures for a pre-established period of time under specific conditions of usage. This analysis uses field warranty data from a manufacturer warranty database, which for a specific system means 12 months in service. To use this warranty data it is necessary to consider samples in which not all components have failed. A proportion of those components have survived the warranty period of time without failure and it is called censored data. Based on that data it is possible to obtain the reliability curve for this product and to predict which will be the probability of this system to fail at any time, including the warranty period. That method is based on the studies executed by Lu (1998) for automotive reliability prediction based on early failure warranty data.

The warranty period allocation for electronic equipment is an important subject, as proposed by Wu et al. (2006) and by Bai and Pham (2004). The methods for warranty estimate developed by those authors do not account for equipment reliability on their analysis being based on operational research concepts. Taking in view that the reliability is an important factor for warranty extension decision-making, the method developed in the present paper is applied on telecommunication equipment motherboard reliability and warranty costs analysis.

2. SYSTEM RELIABILITY ANALYSIS

The word reliability is widely used today; O’Connor (2002) says the simplest view of reliability is that in which a product is assessed against a specification or some attributes and when passed is then delivered to the customer. The customer, having accepted the product, also accepts that it might fail at some future time; this simple approach is coupled with warranty.

Whether failures occur or not and their exactly time of occurrence can seldom be determined with accuracy. Therefore, reliability can also be viewed as an aspect of engineering uncertainty, if a component or a system will work for a period of time is just a matter of probability. Reliability can also be expressed as the number of failures over a period of time.

Failures that have occurred at zero time are those which have passed the manufacturer quality system and failures that occurred during a certain time of usage are the reliability failures. Therefore, the main objectives of reliability engineering, in order of priority are:

1. To apply engineering knowledge and specialist techniques to prevent or to reduce the likelihood or frequency of failures.
2. To identify and to correct the cause of failures that occurred, despite the efforts to prevent them.
3. To apply methods for estimating the likely reliability of new designs.

The skills required to accomplish those tasks are the ability to understand and to anticipate the possible causes of failures and the knowledge to prevent them. It is also needed knowledge of the methods that can be used for analyzing designs and data. These skills are nothing more than good engineering knowledge and experience; reliability engineering is the first application of good engineering practice during the development of a new product.

When a company increases the reliability of their products the costs of the project and the manufacturing system are also increased. The total cost of a product must also to consider the entire warranty time. When a business case of a new program is presented, all expenses and return of investments are considered, including all expenses in warranty during the life cycle of a product. Figure 1, according to O'Connor (2002) shows a commonly described representation of the theoretical cost-benefit relationship of effort expended on reliability. However, despite its intuitive appeal and frequent use in textbooks and teaching on quality and reliability programs, this scenario does not yet represent a real life situation. It is known that less than perfect reliability is the result of failures and each one with causes, and we should ask 'what is the cost of preventing or correcting the cause, compared with the cost of doing nothing?'

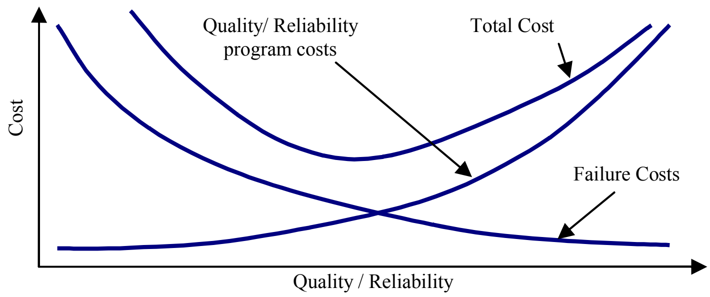

Figure 1. Reliability and Life Cycle Cost. (O' Connor, 2002)

When each potential failure mode is analyzed in this way, it is almost always visible that total costs continue to reduce as reliability is improved. Another way to put it is that all effort on an effective reliability program can be understood as an investment, usually with a payback over a short period of time. The only problem faced is that it is not always easy to quantify the effects of reliability program activities.

2.1 Reliability program tests

During the early design stages of a new product, several reliability tasks need to be performed as part of the design effort to improve its quality because they will be necessary in the future decisions. Many of these reliability tasks have been required by the customer and will need to be added to the new program by the manufacturer.

Deficiencies in this project stage will affect the product and certainly will cost much more to be corrected in the future design development phases of project or even after production has started.

According to Neubeck (2004), these tasks can be broken into two basic categories: component level analysis and system analysis. Component level analysis typically includes stress analysis and parts failure rate prediction. By performing stress analysis and part failure rate prediction several of the system level analysis is already performed. These include failure mode and effect analysis, fault tree analysis and system failure rate analysis. Figure 2 shows a typical reliability program tasks for a new product.

Concerns are often raised with the use of warranty data for reliability analysis, relating to the fact that the failure information extract from the warranty records is not consistent. First, the failure information recorded with a warranty claim is not 100% accurate. Second, the information is restricted to failure events that took place during the warranty period. Very little or sometimes no information is available for the products that have not experienced any concern with the component or system under analysis.

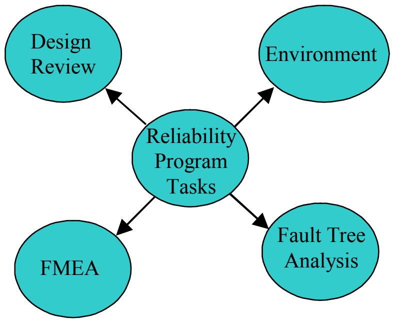

Figure 2. Typical Reliability Program Tasks. (Neubeck, 2004)

For a better result on all those analysis, it is important to have the knowledge of all root causes for every single failure occurrence. Only with an accurate analysis of component failure it is possible to make proper changes in the project in order to achieve good warranty results from the field, otherwise it will not bring any decent effectiveness to the system under analysis.

2.2. Failure mode and effects analysis (FMEA)

Failure mode and effects analysis is a powerful design analysis tool that is used to increase system reliability and it is commonly used during early stages of development, but it can also be used for products already in production. The main purpose of this tool is to identify potential failure modes and its effects resulting in reliability increase. The Fig. 3 shows, according to Martha de Souza (2003), the FMEA concept.

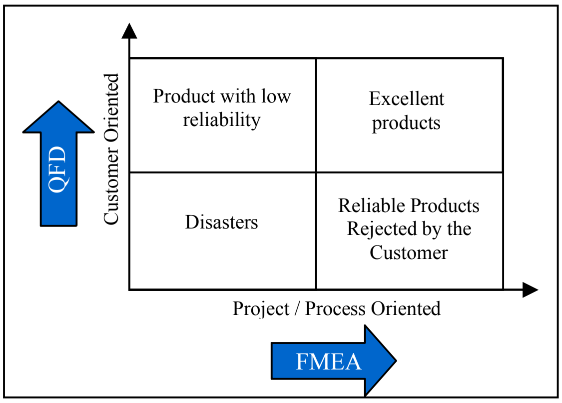

Figure 3. FMEA Concept. (Martha de Souza 2003)

Failure mode and effect analysis principle is to consider each failure mode of every component or system and to find out potential weakness and to correct them at the design stage. It is all based on the knowledge of technicians or in the lessons learned from similar components failures. Each one of these failure modes are classified in relation to the severity of their effects on the reliability of the product.

This classification considers three separated aspects for each failure mode. First, is the scale which considers the probability that a failure mode will occur. Second, is the scale which considers the severity of a failure mode effect. Third, is the scale which considers the chance of being detected either during production or during inspection and testing before reaching customer. The product of these numbers (occurrence, severity and detection) comes the risk priority number (RPN). These risk priority numbers are then used to assign priority for corrective actions. FMEA should start as soon as the project information is released and must be completed as more information becomes available.

2.3. Methods of design review

Even with great experience on product development, it is expected that some type of error occurs in a new project. These methods of design review were developed to help engineers to identify and to concentrate their attention on critical issues. Normally, these analysis shows that all critical issues are under control and the effort spent were only to show some deficiencies. However, by finding out such deficiencies in the early stages of project development one can cause a great gain to the program, because any change in the future causes cost increase and the plan to implement the corrective actions for such errors may go beyond start of production. Some of the main tools used to gain reliability applied on a project are: Quality function deployment (QFD) and failure rate prediction.

According to O'Connor (2002) QFD is a way of making the 'voice of the customer' heard throughout the organization. It goes beyond reliability, because it also considers items of customer perception such as touch, appearance, style, parts texture, etc. The QFD technique brings great advantages to the product development process such as reduction of the implementation timing, improvement of communication and share information within a cross-functional team charged to develop the new product. One can say that QFD keeps the focus on the customer and makes the link between customer requirements and product specifications, reduction of development cycles and finally improve customer's enthusiasm.

According to O'Connor (2002), an accurate prediction of the reliability of a new product, before it is launched to the market is highly desirable. Knowing such reliability in advance allows accurate forecast, support costs of development and warranty costs. On the other hand, this accurate reliability forecast implies some knowledge of the causes of failures and how they could be eliminated. In fact, reliability prediction can rarely be made with accuracy or confidence. One common representation of the reliability of component or system is the life history curve. This curve can be represented by three basic periods of failure performance, such as infant mortality (or early failures), random failures (or constant failure rate) and wear out failures (or end of life failures).

Early failures are the result of defects introduced during any phase of the manufacturing process or during assembly and in this case usually it is related with any kind of human error. Random failures are the failures of components under unexpected stress or load. Wear out failures are those related with long periods in service and associated with cumulative failure mechanisms, such as fatigue or corrosion, which may occur to the entire population in the field.

When the three basic period of failure are combined and represented on a graphic form, they form the life history or "bathtub" curve as shown in Fig. 4.

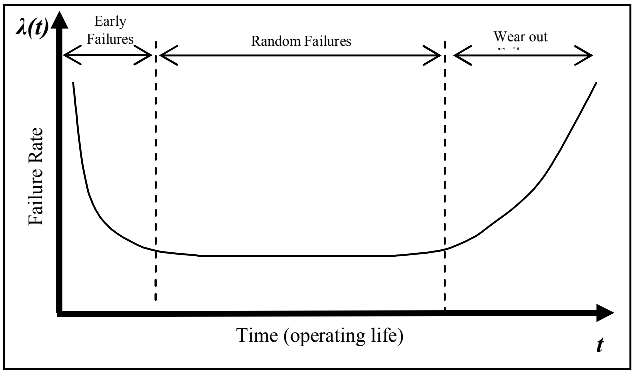

Figure 4. Reliability Bathtub Curve. (Neubeck, 2004)

According to O'Connor (2002) an accurate prediction of the reliability of a product requires the knowledge of all components, manufacturing process, expected environment where the product will be used and expected usage conditions. Reliability prediction based on past data can give good results for similar or little modified products, since we know that the underlying conditions which can affect future behavior will not change. However, it is not accurate to use it for new products.

The quality of the information used is very important for an accurate reliability prediction of the component or system under analysis. It is always necessary to be alert with warranty data, because all failures reported have occurred during the warranty period. Very little or no information is readily available for the products that have not experienced any failure within the warranty period.

As a result, from the statistics point of view, warranty data from electronic products warranty database must be considered as censored data, as shown in Fig. 5. According to Dodson and Nolan (1995) censored data set includes information on failed components and surviving components.

According to Campean et al. (2000), field failure data extracted from warranty databases are considered to be randomly censored, typically with unknown censoring time. A way to overcome these difficulties with statistical analysis of this type of data consists of using additional information and assumptions about the censoring process.

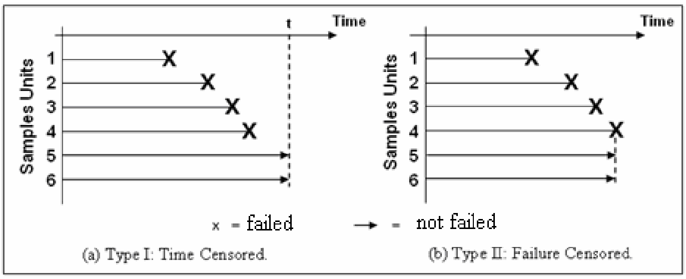

Figure 5. Censored Data (Krishnamoorthi, 1992)

3. RELIABILITY ANALYSIS METHOD

The method proposed for equipment reliability analysis based on failures reported during warranty period is presented in the flowchart in Fig. 6.

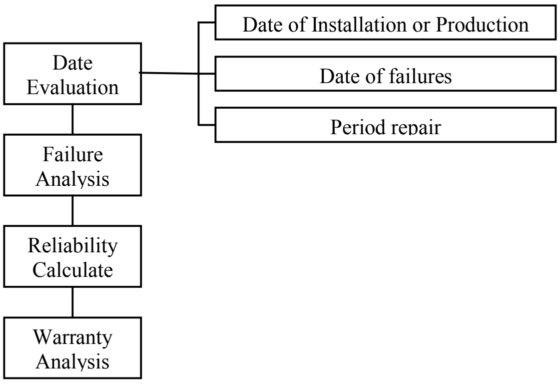

Figure 6. Reliability Analysis Method Flowchart.

The first step in the proposed method involves the evaluation of the first failure for each sold product in a given period of time, usually set equal to or greater than the pre-defined warranty period.

Based on the failures reports provided by the technical assistance department that is responsible by repairs during warranty period under analysis, a time to failure database can be developed. Those reports present the equipment installation date and the date where the costumers reported the equipment first failure.

Considering that as soon as the equipment fails the customer will notify the manufacturer, the difference between that date and the installation date represents the time to failure. Usually those reports present the repaired component(s) and the equipment time to repair.

The next step in the methodology requires the organization of the time to failure database in failure data and censored data as for reliability analysis.

Field information for electronic equipment frequently appears in terms of units produced in a certain period with the resulting returns for that production lot in the subsequent time period. This information can be arranged in a diagonal chart as displayed in Fig. 7. For electronic equipment the failures are usually monthly reported and the warranty analysis will provide, for a given production lot, the monthly reported number of failures, until the end of the warranty period.

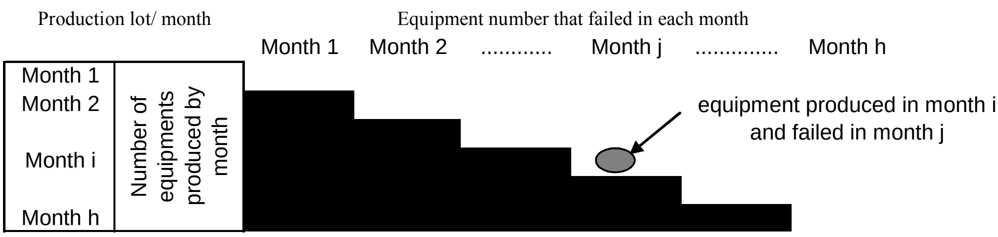

Figure 7. Production lots and registered failures relationship for months.

This matrix format allows the transformation of the production and warranty return data into the standard reliability data form of failure and suspension so that it can easily be analyzed with traditional life data analysis method. For each time period in which a number of products are manufactured, there will be a certain number of returns of failures in subsequent time periods while part of the population that was produced will continue to operate in the following time periods.

At the end of the analysis period, all of the units that where produced and have not failed in the defined analysis period are considered to be suspensions. This process is repeated for each production lot prior to reliability analysis.

For reliability analysis a probability distribution must be selected to represent the time to failure database. As for electronic equipment reliability analysis the exponential distribution is usually used once it represents random failures, typically observed in electronic equipment (Department of Defense, 1991).

The exponential probability function is presented in Eq. (1).

$$F(t) = 1 - e^{-\lambda . t} \tag{1}$$

where *F(t)* is the probability of failure at time t and λ is the distribution parameter, named failure rate.

The probability distribution parameter is calculated based on the database prepared on step 2 using the maximum likelihood method. The main goal of the method is to define the parameter λ for which the likelihood function, expressed in Eq. (2), is maximized.

$$\ln(L) = \sum_{i=1}^{Me} N_i . \ln\left[\lambda e^{-\lambda T_i}\right] - \sum_{j=1}^{S} N_j^{'} T_j^{'} \tag{2}$$

where:
L: exponential distribution likelihood function.
Me: number of groups of months (time-to-failure) data points
N_i: number of failures in the ith month data groups
T_i: the time (month) of ith group of time to failure data
S: number of groups of suspended data points
$N_j^{'}$: the number of suspension in the j^{th} group of suspension data points.
T'_j: the time of suspension in the j^{th} group of suspension data points.
λ: failure rate (parameter to be estimated)

The method last step aims to predict the number of failures during the warranty period. Once the product reliability function is estimated, the warranty period is chosen and the failure product probability is calculated as:

$$F(t_{WARRANTY}) = 1 - R(t_{WARRANTY}) \tag{3}$$

where:
$t_{WARRANTY}$: warranty period

Based on the failure probability estimate and considering an average monthly production lot, the manufactures can calculate the expected cost of repair of warranty returns using Eq. (4).

$$Cost = F(t_{WARRANTY}).C_{REPAIR}.P_{LOT} \tag{4}$$

where:
Cost: total cost of repair associated with a production lot.
P_{LOT}: average number of products in a lot
C_{REPAIR}: unit cost of repair

The manufacturer can use those cost to define a possible strategy for warranty extension.

4. ANALOGIC TELECOMMUNICATION EQUIPMENT RELIABILITY ANALYSIS

The reliability analysis model proposed in the previous section is used to estimate the reliability of an analogic telecommunication equipment motherboard.

The equipment is capable of dialing 4 lines and up to 20 extensions. The equipment is controlled by a microprocessor that commands a communication matrix. The equipment has a great number of circuits supporting its main functions.

Taking in view the number of electronic components compounding the equipment, it can be classified as a complex electronic system.

As for reliability analysis a time to failure database corresponding to 24 production months is furnished by the manufacturer.

4.1. Reliability analysis

The number of motherboards produced into each of the 24 months production lots are presented on Tab. 1. Considering the analysis period of 24 months, in the same table, for a given production lot, the total number of reported failure units is presented. For the first 12 months, the manufacturer has also consolidated the failures occurred during the one year warranty period.

Table 1.Percentage of failure in equipments during analysis period.

Production month	Total of units produced	fails	% of fails in study period	Number of failures in warranty period	% of fails in warranty period
1	699	48	6,87	40	5,72
2	1863	66	3,54	57	3,06
3	1214	53	4,37	47	3,87
4	1582	44	2,78	31	1,96
5	1075	41	3,81	33	3,07
6	1347	62	4,60	53	3,93
7	1277	33	2,58	25	1,96
8	1333	105	7,88	81	6,08
9	300	25	8,33	18	6,00
10	272	17	6,25	17	6,25
11	364	15	4,12	15	4,12
12	727	49	6,74	48	6,60
13	1236	55	4,45	54	4,37
14	1260	56	4,44	27	2,14
15	854	27	3,16		
16	1262	42	3,33		
17	894	45	5,03		
18	1495	48	3,21		
19	1460	38	2,60		
20	1534	18	1,17		
21	0	0	-		
22	680	3	0,44		
23	1100	3	0,27		
24	216	0	0,00		
Average			3,59		4,21

According to those data, the average number of failed units in a monthly production lot is equal to 3,59% of the production units. The average percentage of failures in the warranty period corresponds to 4,21% of units produced in a monthly lot.

According to the proposed method, for a given production lot, a monthly based reported failure database must be prepared. Table 2 presents an example of that database for the lot produced during month 2.

The matrix that relates the monthly reported number of failure units for a given production lot can be developed. For the case under analysis the matrix have 24 lines (corresponding to the number production lots) and 24 columns (corresponding to the period of 24 months considered in the analysis). The first five columns and lines of that matrix are presented on Tab. 3.

The equipment reliability analysis is performed using the exponential distribution. The failure rate (λ) is calculated using the maximum likelihood method. For that analysis the software Weibull 6++ (ReliaSoft Corporation, 2000) was used.

The reliability is expressed, which curve is presented in Fig. 8, as:

$$R(t) = e^{-0,0026.t}, \lambda = 0,0026 \text{ failures/month}$$

where t is the motherboard operational time, expressed in months.

Table 2. Example of Production lot and reported failures

Month of production	Failure month	Equipment number that failed
Month 2	2	3
	3	5
	4	13
	5	10
	6	6
	7	2
	8	4
	9	2
	10	8
	11	2
	12	6
	13	6
	14	3
	15	1
	16	1
	17	2
	18	1
	19	1
	20	2
	21	0
	22	0
	23	0
	24	0
	25	1

Table 3. Monthly Production lot and reported failures in the analysis period.

		Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Month 1	699	0	1	3	6	6	7
Month 2	1863		3	5	13	10	6
Month 3	1214			1	6	11	8
Month 4	1582				0	2	5
Month 5	1075					0	2
Month 6	1347						0

In the reliability curve it is also presented the 90% confidence bound for the equipment reliability.

Based on the reliability analysis and, considering the warranty period of 12 months, the reliability is:

$$R(12) = e^{-0,0026x12} = 0,9693$$

The reliability analysis indicates that 3% of the units of a given production lot will present some failure until the end of the warranty period. The predicted percentage of failures is smaller than average failure percentage calculated for warranty period. This difference can be explained by the great dispersion of the number of failures during the warranty period for the first 12 monthly production lots. Furthermore, the reliability analysis is developed considering 24 production lots and according to the data presented on Tab. 2, the last production lots presented a small number of failures in comparison with the first 12 production lots. The reduction of number of failures affects the reliability analysis, increasing that estimate for the warranty period.

Once the equipment reliability is estimated, a warranty repair cost analysis can be executed to evaluate the possibility of warranty period extension, as presented on Tab. 4.

The analysis is executed according to the following steps.

i) Evaluate the failure probability for the proposed warranty period ($t_{WARRANTY}$) by Eq. (3).

$$F(t_{WARRANTY}) = 1 - R(t_{WARRANTY})$$

ii) Estimate the number of failure equipment during warranty period for a production lot

$$\textit{Expected Number failures} = F(t_{WARRANTY}).(\textit{Production lot size}) \qquad (4)$$

iii) Evaluate the expected warranty cost for a production lot

Cost = (*Expected Number failures*). C_{REPAIR} (5)

iv) Compute the average warranty cost per production unit

$$Average \quad Warranty \quad Cost = \frac{\sum_{i=1}^{k} Cost}{\sum_{i=1}^{k} (\Pr oduction \quad lot \quad size)} \tag{6}$$

k: number of production lot.

The cost of repair is set equal to R$ 20,00.

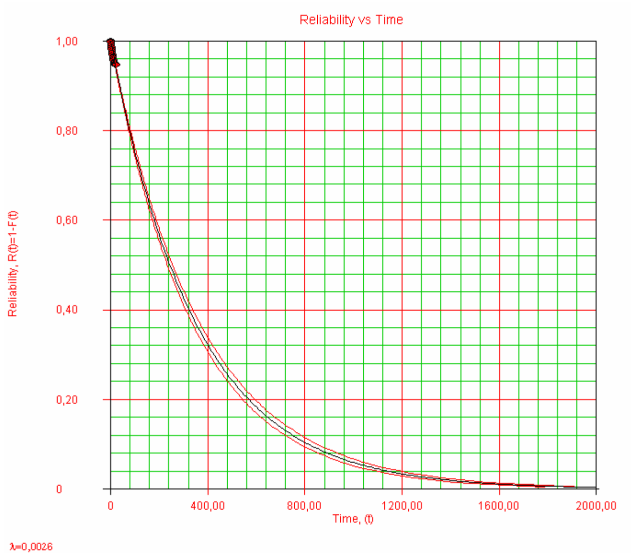

Figure 8. Electronic System Reliability by warranty data.

Table 4. Warranty Costs Analysis

Production month	Total of units	Warranty Costs			
		1 year	2 year	5 year	8 year
1	699	R$ 429,65	R$ 846,01	R$ 2.019,58	R$ 3.089,51
2	1863	R$ 1.145,12	R$ 2.254,82	R$ 5.382,66	R$ 8.234,27
3	1214	R$ 746,20	R$ 1.469,32	R$ 3.507,54	R$ 5.365,76
4	1582	R$ 972,40	R$ 1.914,72	R$ 4.570,78	R$ 6.992,28
5	1075	R$ 660,76	R$ 1.301,09	R$ 3.105,93	R$ 4.751,39
6	1347	R$ 827,95	R$ 1.630,29	R$ 3.891,81	R$ 5.953,61
7	1277	R$ 784,93	R$ 1.545,57	R$ 3.689,56	R$ 5.644,21
8	1333	R$ 819,35	R$ 1.613,35	R$ 3.851,36	R$ 5.891,73
9	300	R$ 184,40	R$ 363,09	R$ 866,77	R$ 1.325,97
10	272	R$ 167,19	R$ 329,21	R$ 785,87	R$ 1.202,21
11	364	R$ 223,74	R$ 440,55	R$ 1.051,68	R$ 1.608,84
12	727	R$ 446,86	R$ 879,90	R$ 2.100,48	R$ 3.213,27
13	1236	R$ 759,72	R$ 1.495,95	R$ 3.571,10	R$ 5.463,00
14	1260	R$ 774,48	R$ 1.525,00	R$ 3.640,44	R$ 5.569,07
15	854	R$ 524,92	R$ 1.033,61	R$ 2.467,41	R$ 3.774,59
16	1262	R$ 775,71	R$ 1.527,42	R$ 3.646,22	R$ 5.577,91
17	894	R$ 549,51	R$ 1.082,02	R$ 2.582,98	R$ 3.951,39
18	1495	R$ 918,92	R$ 1.809,42	R$ 4.319,42	R$ 6.607,75
19	1460	R$ 897,41	R$ 1.767,06	R$ 4.218,29	R$ 6.453,05
20	1534	R$ 942,89	R$ 1.856,62	R$ 4.432,10	R$ 6.780,13
21	0	R$ 0,00	R$ 0,00	R$ 0,00	R$ 0,00
22	680	R$ 417,97	R$ 823,01	R$ 1.964,68	R$ 3.005,53
23	1100	R$ 676,13	R$ 1.331,35	R$ 3.178,17	R$ 4.861,89
24	216	R$ 132,77	R$ 261,43	R$ 624,08	R$ 954,70
25	0	R$ 0,00	R$ 0,00	R$ 0,00	R$ 0,00
Warranty cost medium per unit		R$ 0,61	R$ 1,21	R$ 2,89	R$ 4,42

If the warranty period is extended to two years, the average warranty cost would double. This average warranty cost represents the amount of the equipment selling price that will be used to cover warranty cost due to failures reported during warranty period.

For longer warranty periods there is a great increase in the average warranty costs because of the failure probability increase.

5. CONCLUSION

The methods used in this paper for warranty data analysis are only part of a reliability program. Warranty data information is with no doubt the best source of information from the field, reflecting the product performance and capturing the appropriate usage and environmental stresses. In the past many companies increased their profit by selling spare parts for their low reliability products. Today electronic systems are more reliable and reliability became a point to be considered when purchasing a product. The extension of their warranty period is just one way to show to the customers how reliable a product is.

The proposed reliability-based method for complex electronic equipment analysis aims to define the equipment reliability based on failure data reported during warranty period. The method is based on four main steps, including a very important step where the failure database is evaluate and the data classified as suspended or complete to prepare the reliability analysis.

The method is used to define the reliability of a telecommunication equipment motherboard, based on a 24 months failure database. The predicted probability of failure during the warranty period is close to the failure percentage observed by the manufacturer.

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8. RESPONSABILITY NOTICE

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