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OPTIMIZATION OF RELIABILITY AND USABILITY OF FUNCTIONAL TESTS OF THE PRODUCTION PROCESS IN THE COMPANY "TUCUMÃ SEM CASCA DE CABLE MODEMS"

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ABSTRACT

The test jigs are responsible for functional tests are complex and high performance equipment used in the electronics industry to validate the functionality of analog, digital devices or any other products of the electro-electronic industry in the industrial hub of Manaus. In the analyzed process, these gigas are arranged following a configuration in parallel with each other, and in series with the rest of the assembly line and the effect of a failure in this kind of configuration is critical, because the simplest failures can impact the production process generating several types of waste and, consequently, financial losses for the company. This work aims to study the behavior of the equipment of a production process of Cable Modems and Set Top Boxes, analyze the failures that occur during the process and guide the study of its reliability in order to allow the maintenance management to make decisions on how to handle the equipment, aiming to reduce failure rates and use appropriate maintenance practices to allow the maximization of reliability.

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INTRODUCTION

Given the current scenario of economic market instability and in view of a generation of more demanding consumers who seek better cost-benefit, companies can not leave room for errors and doubts. Regardless of the type of product or service offered, it is essential that deliveries are made within the deadline set by the customer and with guaranteed quality, so it is necessary that production processes have greater productivity and efficiency, considering less time and costs during production. From this, it is necessary that the execution and the results of the tests obtained are, in fact, reliable, in order to reduce the production time with tests and retests, ensuring the quality of the products, consequently, increasing productivity. In this context, the test stations installed in companies require the use of structured and objective maintenance techniques that can ensure greater equipment efficiency, maximum functional availability for operations and adequate maintenance costs. Therefore, the concepts of Reliability and Reliability Centered Maintenance, along with the evolution of Maintenance concepts, constitute a very useful tool in a real production environment. In electro-electronic industries (IEE), the above mentioned concepts are daily used in the routine of their processes, once in this kind of industry the production usually occurs with the serial disposition of machines, equipments and people. This type of arrangement, although common, significantly reduces the reliability of the process, because a simple failure, whether a real failure or a false failure, can cause the most diverse hindrances, from compromising the reliability of the following stations to line stoppages, generating significant financial losses. In a more specific way, the false failures are more critical during the tests, if compared to a real failure, because besides generating undue costs of rework, loss of productivity and efficiency, they also severely reduce the reliability of the test stations once they point out a failure situation in a functional product that should be approved. Therefore, this study is motivated by the opportunity to make improvements in a test station for electrical and electronic products, so that the efficiency and reliability of this station is significantly increased.

BIBLIOGRAPHIC REVIEW

Production Systems: According to FAVARETTO (2003), as of the need for more accelerated growth, especially with the Industrial Revolution, men like Ford and Taylor revolutionized the productive systems with mass production, standardization of components, and Scientific Management. Production systems can be defined as the interrelationship between activities and resources for the production of goods or the provision of a service, its fundamental constituent elements are the inputs and resources, the conversion process and the control subsystem (MOREIRA, 2009). In a more detailed way, CARDIAL et al (2017) corroborates by defining a production system as the ability that an organization has to join input resources such as raw materials, information among others, perform a certain transformation in these resources and have as a result products or services that add value to the company. Regarding the types of productive systems, they can be classified by the flow of resources to be transformed through the processes and their production volume (MOREIRA, 2009). Following this context, TUBINO (2017) determines that mass production systems are those employed in the large-scale production of standardized products. Still in this scenario, DAVIS et al (2001) classify manufacturing systems into three major types, each dependent on the volume of items to be produced, these being: design processes; intermittent process; and in-line flow processes (subdivided into continuous process and assembly line). Design process is defined as a project-oriented process, generally involving the manufacturing of a unique, exclusive product (DAVIS et al, 2001). Examples of this type of production include the production of a movie and the construction of a building. The authors also state that the intermittent process is characterized by producing the same product several times, usually in specified batch sizes, and at the end of production, other products take its place for the production of another batch.

Regarding line flow processes, these can be divided into two classes (DAVIS et al, 2001):

a) Assembly line: these are known as mass production process and their main attributes are mass production, but with low variety, large production volumes and little variety. Examples of this type of process are the electro-electronic and automotive industries.
b) Continuous process: distinguished by production in large quantities and very little or no variety, inseparable products, and constant flow due to the characteristics of the operation. It presents high fixed costs and low variable costs. As an example we cite petrochemical and power generation industries.

Losses in Production Processes

The most effective way to achieve a high level of performance in an organization is to reduce production inefficiencies because they harm the results and have a direct impact on the work environment (COSTA JUNIOR, 2008). In this sense, MARQUES and MELLO (2013) define losses as anything other than the minimum amount of equipment, materials, parts and workers (working time) that are absolutely essential to production.

Knowing these concepts, it is possible to deduce that to annul losses and waste in the production process, it is necessary that they be detected. Using the concepts determined by the Toyota Production System methodology, one can list seven types of losses that prevail in production processes:

a) Overproduction losses: occurs when the production of items is greater than the demand.
b) Waiting losses: According to Ferreira et al (2011) waiting losses are resources that are left waiting for certain activities to be performed. In other words, it occurs when there are delays in processing, such as interruption of equipment operation or capacity bottlenecks. Antunes (1995 apud Kayser, 2001) defined that the central causes that lead to the increase of waiting losses are setup time, lack of synchronization and unforeseen failures.

Table 1. Causes and effects of production loss by waiting

Causes	Effects
Set up time	Long changeover times for devices and tools
Lack of synchronization	Non-uniform production rhythm
Unforeseen Failures	Delay in the delivery of raw material, equipment breakdown and/or work accidents

Source: Adapted from Antunes, (2021).

c) Motion losses: This type of loss is related to expendable operator movements and can be avoided through motion and time studies (MARQUES and MELLO, 2013), as well as proper operator training.
d) Excessive stock losses: JUNIOR (2009) claims that inventories can be considered as the result and the final impact of several losses and wastes, representing waste of investments and space. MARQUES AND MELLO (2013) state that it is fundamental to identify and eliminate the causes that generate the need for inventories so that this type of waste can be reduced.
e) Losses by transport: For Karpinski (2009) losses in transport are associated with excessive and/or inadequate handling due to poor scheduling of activities or even an inefficient layout. MARQUES AND MELLO (2013) corroborate when they state that transportation does not add value to the product and is a cost element, so it becomes relevant the elimination of unnecessary movements.
f) Processing losses: According to MARQUES AND MELLO (2013) this type of loss is related to dispensable activities during processing. The exclusion of these should provide greater agility in the process.
g) Losses for manufacturing defective products: According to (ABREU, 2002) losses for manufacturing defective products refer to losses for manufacturing defective products or performing faulty activities. That is, the products or services performed that do not meet the client's quality specifications.

Based on the above concepts, it can be seen that at least three types of failures can be avoided if there is an efficient preventive maintenance program.

Quality Concepts: The definition of quality is discussed by several authors over decades and despite being considered as something abstract, the concepts presented suggest the same understanding. For example, FEIGENBAUM (1961) conceptualizes quality as the total composition of marketing, engineering, production and maintenance characteristics of a product or service, through which the same product or service in use will meet the customer's expectations. For JURAN (1974) quality is the level of satisfaction achieved by a given product, in meeting the user's objectives, during its use, called suitability for use. DEMING (1990) states that quality is the statistical control of the process (variability reduction). FAGLIATO and DUARTE (2009) define quality as the ability of an item to perform its required function in a certain period of time or in a predetermined period. In short, quality is the correct performance of the criteria of a project with the least variability possible during its execution. (MOREIRA, 2012) considers quality as something fundamental since it aims above all to meet the needs of customers or users, to the extent that it is they who make the products remain on the market. The benefits of offering quality products are essential for its recognition in the market, ensuring that the company survives the competitive market due to the excellent quality of the final product and the appreciation and appreciation of customers (CAMPOS, 2004).

Reliability: Reliability and risk analysis consists in the systematic examination of an industrial facility in order to identify the risks present in the system through the recognition of potentially dangerous occurrences and their consequences (MARTINS, 2013). Following this context, LAFRAIA (2014) conceptualizes reliability as the probability that a functioning component or system, within specified design limits, will not fail during its expected lifetime.

Reliability History: The concept of reliability began to be introduced more than 50 years ago (FAGLIATO and DUARTE, 2009). The authors state that this concept gained technological significance after World War I, where comparisons were made in aircraft with one, two or four engines. In the late 1950s and early 1960s, Americans kept their focus on intercontinental missile development and space research, these developments were driven by the Cold War. Reliability was boosted in 1963 by the race to send the first manned mission to the moon, given the risks involved. Also in that year, the first association of reliability engineers was created in the U.S., as well as the first journal published in the IEEE (Transactions on Reability). In the 1970s, reliability research focused on the study of risks associated with the construction of Nuclear Power Plants. These applications associated with Production Engineering were listed by (FLOGLIATTO, 2009 p. 4) in the following areas: risk and safety analysis, quality, maintenance optimization, environmental protection and product design. In this decade the first books specifically focused on systems reliability appeared, by SMITH (1976) and KAPUR AND LAMBERSON (1977), which are used as reference today. During these two decades, with the nuclear and aerospace industries as the main motivation, techniques for reliability assessment were proposed, including the Fault Tree and the introduction of the maintainability concept. In the 1980s, LAFRAIA (2014) states that it was observed that countries that had the latest technology began to use reliability analysis techniques in several engineering sectors and in the electro-energy sector. Meanwhile, in Brazil, the practical use of reliability in the electrical, telecommunications, weapons and nuclear sectors occurred.

Basic Concepts: The following will present essential concepts for the study of reliability, of which their understanding is intrinsic to the understanding of this research. These concepts are based on the Technical Standard 5462/94 on Reliability and Maintainability (ABNT, 1994) and scholars in the area, such as LAFRAIA (2014).

Reliability: As already mentioned, reliability is the probability that an item, component or system will perform the function for which it was designed during a predefined period of time, under certain environmental and operational conditions, operating equally to the initial instant. It is important to note that reliability should not be considered synonymous with quality. Although they are interconnected, product quality is associated with the degree of customer satisfaction, while reliability is associated with how long the product is able to perform its function without failure (MARTINS, 2013).

Maintainability: According to NBR 5462, it is the ability of an item to be maintained or put back in a condition to perform its required functions, under pre-established conditions of use, being maintained under predetermined conditions and using standard resources and procedures. In short, it is the time interval during which an item performs its function at the specified failure rate, or until the occurrence of a non-repairable failure.

Availability: It is the ability of an item to be in a position to perform a certain function at a given instant or time interval.

Item: Any part, component, device, subsystem, functional unit, equipment, or system that can be considered individually and can be tested individually.

Component: It is the basic unit of a system. This item can fail only once and is considered a repairable system when it can be repaired by replacing the failed components.

Function: Each and every activity that the item performs, from an operational point of view.

Fault: It is understood as the end of an item's ability to perform the required function. Equipment failures can represent great economic and human losses, presenting, in many cases, significant compromises to the institutional image of companies (NUNES, 2001). The Chernobyl and Gulf of Mexico tragedies are examples of the consequences of failures in which there were financial, social and environmental losses.

Functional Failure: Inability of any item to achieve the expected performance.

Cause of the failure: Circumstances that induce or activate a failure mechanism, that is, the reasons why failures occur.

Failure Mode: Set of effects by which a failure is observed. A failure mode describes the way in which a product or process could not present the desired performance for its function, such as fatigue, collapse, breakage, deterioration, loss, vibration, burning, among others (LEAL, 2008). PILLAY and WANG (2003) also state that the cause of failure refers to the cause for each failure mode, such as: incorrect material, corrosion, assembly error, excessive heat or cold, poor maintenance, impurity in the material, misalignment, etc.

Service life: Time interval during which an item performs its function at the specified failure rate, or until a nonrepairable failure occurs.

Reliability Centered Maintenance: The term maintenance has military origin and in the military area whose meaning is to maintain, in combat units, the personnel and the material in constant volume (NUNES, 2001). The Brazilian Association of Technical Standards - ABNT, in standard TB-116 of 1975, defined maintenance as the set of all actions necessary for an item to be preserved or restored so that it can remain in accordance with a specified condition. In its 1994 revised version, named NBR-5462, maintenance is conceptualized as the combination of all technical and administrative actions, including supervisory ones, intended to maintain or restore an item to a state in which it can perform a required function (ABNT, 1994). Slack et al. (1997) noted that 'maintenance' is the term used to address the way in which organizations try to prevent failure by taking care of their physical facilities. This approach emphasizes failure prevention and recovery, an important area of maintenance (NUNES, 2001). An efficient maintenance program brings equipment in good condition for a longer period of use, while ineffective or non-existent maintenance makes equipment poorly maintained and consequently increases its vulnerability to failure. (NUNES, 2001) states that since failures are not foreseen, they imply in the non-availability of equipment for maintenance and compromise the production schedule and, consequently, the delivery deadline. Reliability centered maintenance (MCC) is the type of maintenance in which failure modes, severities, effects and possibilities of occurrence are studied and classified (LAFRAIA, 2014). Considering the concepts presented previously, it is noted that the main difference is that while ordinary maintenance focuses on equipment, MCC acts on function.

The IEC60300-3-11 standard shows that the objectives of MCC can be listed as:

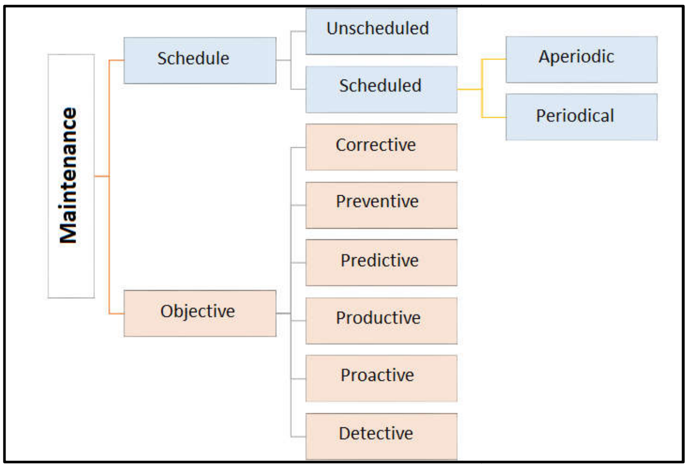
a) Preserve the functions of the equipment with the required safety;
b) Optimize availability;
c) Minimize life cycle cost;
d) Act according to failure modes;
e) Perform only activities that need to be done;
f) Act according to the effects and consequences of failure;
g) Document the reasons for the choice of activities.

The strategies for MCC management may be different given the reality of each company. The following are maintenance classifications, so that the concepts are clarified. MOSS (1985) observed that MCC is structured with the fundamental principle that every maintenance task must be justified and the justification criterion corresponds to safety, availability and economy in postponing or preventing a specific failure mode. For NUNES (2001), this criterion comprises the main characteristic of the MCC application, because from this, the most adequate maintenance tasks are established to guarantee the operational performance of the installation.

Table 2. Compares the differences in characteristics between MCC and traditional maintenance

Characteristic	Traditional Maintenance	MCC
Focus	Equipment	Function
Objective	Maintaining the equipment	Preserve
Acting	Component	System
Activities	What can be done	What must be done
Data	Little emphasis	A lot of emphasis
Documentation	Reduced	Mandatory and systematic
Methodology	Empirical	Structured
Combat	Equipment Deterioration	Consequence of failures
Standardization	No	Yes
Prioritization	Non-existent	By function

Maintenance Classification: Usually maintenance activities have been classified according to the form of programming and the objective of the tasks performed (SIQUEIRA, 2014). The flowchart in Figure 1 exemplifies the divisions and subdivisions considered in these aspects.



Source: Adapted from (SIQUEIRA, 2014).

Figure 1. Maintenance Classification Flowchart

Below the classifications will be detailed according to the studies of SIQUEIRA (2014), LAFRAIA (2014), AZEVEDO (2007), SWANSON (2001).

Scheduling Classification: Scheduling refers to activities that are carried out according to predefined time criteria and conditions, or that are performed as needed. They are divided into:

a) Scheduled maintenance are performed obeying time criteria. They can also be subdivided into periodic (performed in fixed time intervals) or aperiodic (variable intervals or depending on the opportunities).
b) Non-scheduled maintenance: They are carried out under pre-defined conditions or by necessity.

Classification as to objectives

In this category, maintenance is classified according to the user's attitude towards failures. The most common are:

a) Reactive or Corrective Maintenance: In this type of maintenance there is correction of already existing failures, including actions to return a system from a failure state to an availability state. It is noteworthy that these actions are not planned, because this type of maintenance occurs when it is not desired;
b) Preventive Maintenance: The objective of this type is to prevent and avoid the consequences of failures, keeping the system in a state of availability. It includes planned actions such as cleaning, lubrication, calibration, etc. This type of maintenance causes reduction in maintenance costs and gains in equipment efficiency, since they tend to stop only at scheduled times, avoiding unexpected stops (AZEVEDO, 2007). For SWANSON (2001) the advantages of using preventive maintenance are the decrease in the probability of failure and the increase in the life cycle of the equipment, while the disadvantage is the stop of the equipment, at scheduled times, to perform maintenance.
c) Predictive Maintenance: It is the predictive maintenance or anticipation of failures. Here, parameters are measured that indicate an imminent failure in which there is time to be corrected in advance. SWANSON (2001) states that in this type of maintenance, the wear and tear of the equipment is monitored and mapped, intervening before it fails;
d) Proactive Maintenance: experience is used to optimize the process and the design of new equipment;
e) Productive Maintenance: aims to ensure the best use and highest productivity of equipment, and;
f) Detective Maintenance: identifies failures that already occur, but have not been noticed.

Cable Modems: Cable Modem (CM) is an equipment that interfaces an internal data network - usually in Ethernet standard - with a coaxial network. This type of equipment receives and sends data in two ways:

a) Downstream direction (Internet to user): the data is modulated and placed in a typical 6 MHz television channel;
b) Upstream direction (user to the Internet): the data is transmitted between 5 and 42 MHz.

Through the Cable Modem Termination System (CMTS) (Figure 2), located in the local cable TV operator's network, the traffic is routed to the Internet backbone through an Internet Service Provider (ISP) (Unsupported source type (ElectronicSource) for source NAS11). From this communication between CMTS and CM it is possible to establish a communication bridge between the installed data network equipment responsible for interconnecting with other networks and the subscriber's internal network, thus creating a large comprehensive local network (LEON, 2014).

Source: Author (2021)

Figure 2. Cable Modem Models

MATERIALS AND METHODS

Materials: This chapter will describe the steps, processes and techniques used to develop this dissertation. In order to carry out this research, software programs were used that allow for reliability calculations and graphical generation; failure data collection and root cause analysis were also used.

Reliability Software: According to Willis (2000), there is software on the market for calculating the reliability of simple and complex systems. These include AVSIM; BLOCKSIM; CARE; MEADEP; RAPTOR; RELEX; PAR and TIGER. The author makes a comparison considering several purposes in order to enable engineers to make a decision for selection and acquisition of the most appropriate software for their work. Due to the familiarity and ease of access to the usage instructions, the software chosen for use in this work were Weibull++ version 6.0 and BlockSim version 6.0 from Reliasoft.

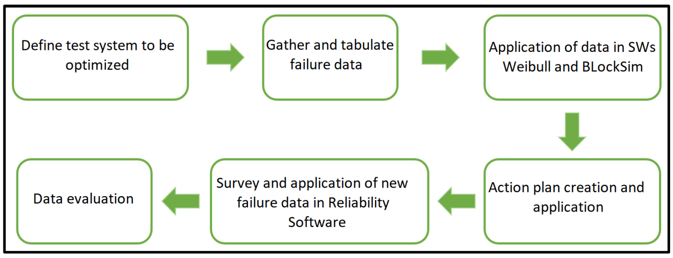
METHODOLOGY

In order to visualize the real impact of the problems, compare performances between test stations, and find the value of the reliability of the system as a whole, a methodology was defined to achieve the desired results.

The methodology consists of:

a) Choose a test system for a production line;
b) Characterize the problem;
c) Collect the failure data for reliability calculation;
d) Tabulate and treat the data;
e) Apply the data in Weibull and BlockSim software;
f) Calculate the reliability of the components and the system studied with the help of the software;
g) Evaluate the results shown in the software;
h) Create an action plan in order to improve performance, i.e., reduce the failure rate and thus increase reliability;
i) Collect the new failure data to calculate the new reliability after the application of the actions;
j) Evaluate the results and verify whether a new action plan is required.

The methodology is shown in simplified form in the flow chart below:



Source: Authors, (2022).

Figure 3. Flowchart of the methodology used for reliability optimization

Procedure followed for data treatment in the chosen software: The procedure followed for processing the data in the given software, according to the methodology and flow proposed by Pallerosi (2001), can be listed as follows:

a) Entering the data into the spreadsheet;
b) Selecting the appropriate distribution and parameter estimation method, and then process the calculation;
c) Processing the calculations by clicking on the icon corresponding to the parameter calculation;
d) Using the Quick Calculator Pad (QCP) software to obtain the corresponding calculations;
e) Obtaining the reliability plots as a function of time, reliability, failure rate and PDF.

Research Location: The factory assumes a Make to Stock (MTS) manufacturing strategy, where products are manufactured based on demand forecasts and sent to stock, awaiting release for shipment according to orders received and planning. This is followed by a master production plan, on a weekly basis, and a production forecast plan with a 6-month horizon. This six-month plan serves as a reference for the acquisition of raw materials, which are kept in stock in loco, and may also be stored at the supplier or in outsourced warehouses. As for sales, the finished products are sent to stock, which is located in a compartment of the factory itself. It is worth mentioning that even following the production planning, it is possible that situations may occur in which a short-term change in the orders of a certain product is necessary, leading to a short-term change in the production plan, aiming to meet this variation. This type of short-term variation in the production plan can occur due to the lack of some necessary input, for internal quality reasons, supplier capacity, or any reason that has an impact on a global level, such as a pandemic and financial reasons, for example. In relation to inputs, the company has its main suppliers located in Manaus. These supply the printed circuit boards already with the components assembled, the plastic parts such as Top Covers and Bottom Covers, and packaging. The suppliers of the accessories are divided: a percentage comes from some factories in Manaus, another percentage is acquired from other factories abroad, mostly of Asian origin. The product portfolio varies according to the customers' needs (which are already pre-determined). The customers propose the necessary configurations and the Korean developers design both the product and the production process. Then, the production lines are configured for each product model in order to ensure the ability to meet the production and sales plan, to be efficient in the use of manpower, and to meet the established quality targets. Only one type of model is produced on each line, and the line remains active for this model until the end of production (EOL) of the model, and then this line is reconfigured to assemble products with different specifications. The time for the changeover to occur is long, on average 2 years, and after this period the model is no longer produced for reasons of technological development.

Cable Modem Production Stages

The steps that make up the process flow adopted in the factory are presented, in macro form, in the diagram of Figure 3.1. This flow is similar to that used by competitor companies, both in the PIM and in other countries (effect of globalization and the progress of companies in the PIM).

As such, each stage fulfills the role and has the following characteristics:

a) Preparation of the individual packaging (offline): preparation, offline, of the individual box with its respective accessories such as cables, power supplies, etc.
b) Bottom Assembly: assembly of the PCBA on the Bottom cover.
c) Antenna Mounting: mounting the 4 antennas and the Led Lens.
d) Thermal Pad Assembly: Thermal Pad assembly and antenna adjustment.
e) Attachment of the label: Attachment of the label with the serial number and initialization of the board in the Manufacturing Executive Systems (MES) of the factory.
f) Top Cover assembly: assembling and screwing the Top Cover and attaching the wifi labels.
g) Functional tests (parallel configuration): we have 8 functional test jigs, each connected to a personal computer (PC). The PC sends commands to the connected device and waits for a response. This response is compared to an acceptable range. If the responses are all positive, the PC injects the client software (Default Setting) and the device is released into the system for the next station.
h) Default Setting Check: this is a test performed to confirm that the Default Setting was performed, in other words, if the device really has the client's software. If everything is correct, the warranty label is attached.
i) Packaging in the individual box: this is the step of packaging the device in the individual box. The equipment is wrapped in bubble wrap and stored in the box along with the manual,

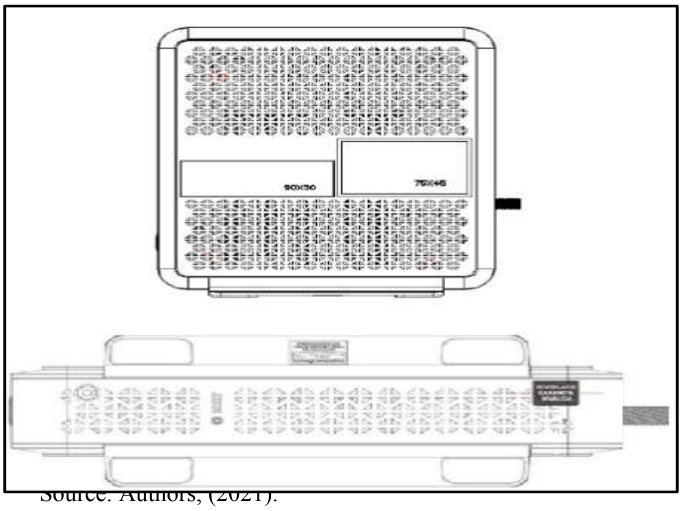
power supply, cables, and other accessories that make up the box. In addition, a label is generated for the box and attached to it.

j) Packing in the collective box: five individual boxes are packed in a collective box, called Carton Box. According to the individual boxes, a collective box label called "Carton Label" is generated.

k) Palletizing: all Carton ID's generated in the previous step are read and a pallet label is generated with a serial number according to the sequence, called Pallet ID. The collective boxes are organized in a determined quantity and belong only to that Pallet ID.

The work will focus on the functional testing stage, since these are the stations with the most rework, the most reprocessing (or retesting) and, therefore, produce the most information and allow the greatest gain in case of efficiency improvements.

Problem description and scope limitation: The sequence of test commands in the functional test station of a CB device follows a well-defined logic, obeying the technical characteristics of the product, specifications and quality requirements imposed by the developer and by the client itself. This logical sequence is described, for the problem being studied, in Table 3. The table lists the commands sent to the device for the product's functional tests, identified by test codes.



Source: Authors, (2021).

Figure 4. Side and top section of Cable Modem device

Source: Authors, (2021).

Figure 5. Image of a Cable Modem device

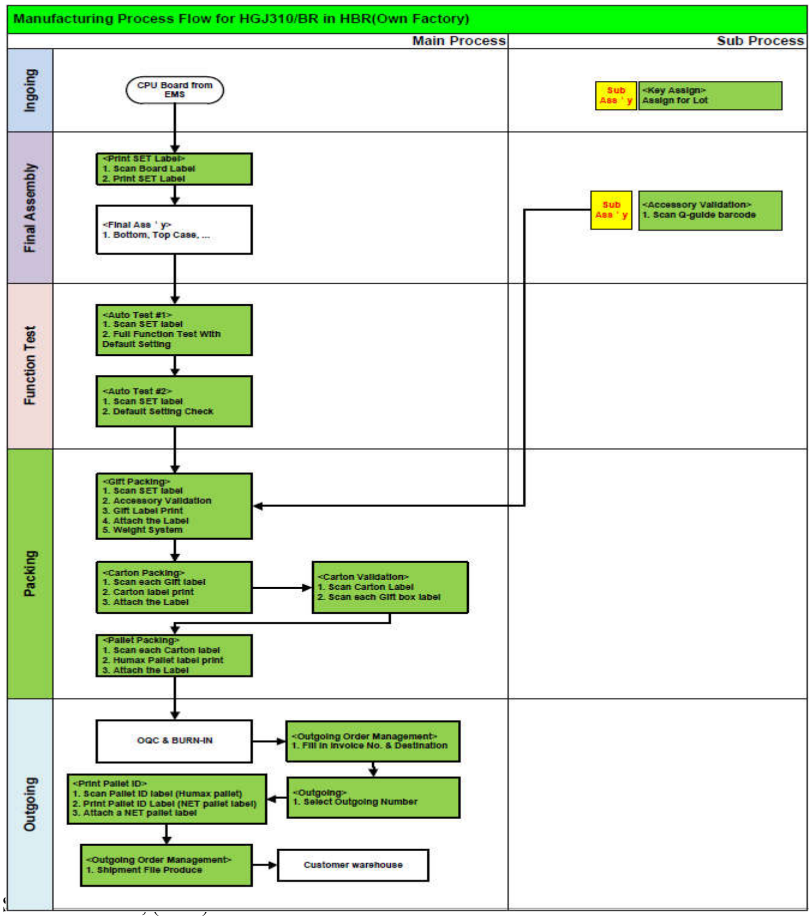
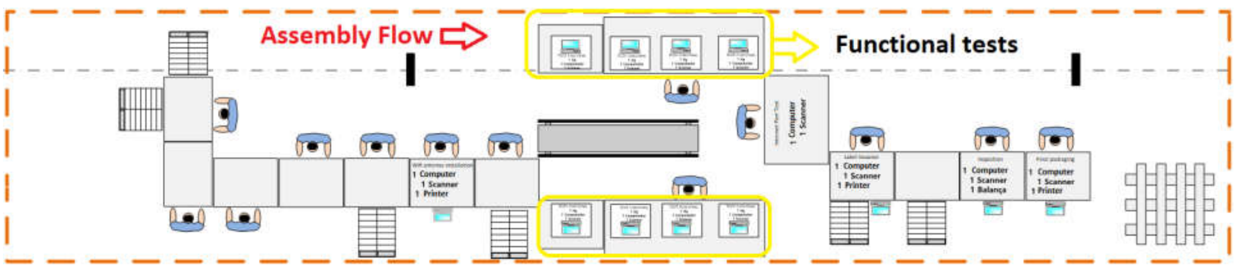


Figure 6. Flowchart - Flow of the manufacturing process

Table 3. List of test items needed for validating the functionality of a Cable Modem

Teste Code	Test name	Duration	Read Value
A139	INITIALIZE TEST SYSTEM 1st	0,0	V_5.83
A143	TEST START STATION_SL	1,0	V_5.83
A419	SW_Version(Factory SW)	1,2	BRGCAI 0.3.9.a566_1582184356
G264	LED_GREEN ALL ON	1,8	
H213	ETHERNET1_LINK_SPEED	0,6	1000
H214	ETHERNET2_LINK_SPEED	0,6	1000
G260	LED TEST_ROI #1	3397	9
A415	SW_Version(Release Loader)	0,6	2.7.0alpha4
G235	LED_RED ALL OFF	1,3	
H228	ETHERNET3_LINK_SPEED	0,6	1000
G254	LED_RED ALL ON	2,2	
H229	ETHERNET4_LINK_SPEED	0,6	1000
H120	NAND BAD BLOCK COUNT	0,6	00000004
G261	LED TEST_ROI #2	2455	4
A320	Default Application CRC	1,2	ea8b863e
G118	KEY_WPS	44,3	00800000
G138	KEY_HW RESET	3,0	01000000
H245	CHECK USB1(2.0) Device Detection	0,6	
H322	Change CM High Split Path	1,6	
A533	CM_Package_Manufacturer_Certificate	1,2	
A534	CM_Package_Root_CA	0,9	
A423	Compare Serial Number	1,2	14013585850080908992
A424	Compare 1st Mac Address	0,6	C85D38180FE3
A431	Compare 2nd Mac Address	0,6	C85D38180FE4
A435	Compare 3rd Mac Address	2,0	C85D38180FE5
A436	Compare 4th Mac Address	1,5	C85D38180FE6
A449	Compare 5th MAC ADDRESS	0,6	C85D38180FE7
A450	Compare 6th MAC ADDRESS	1,5	C85D38180FE8
A451	Compare 7th MAC ADDRESS	1,5	C85D38180FF0
Q824	DOS_CMD1	1,1	
H488	WiFi_TX_On_ANT1_5G	1,1	
A016	DELAY0	10,2	
H484	WiFi_TX_On_ANT1_2.4G	1,1	
A022	DELAY6	10,2	
H501	WIFI_ANT1_RSSI_READ_2.4G	2,4	C85D38180FF0
A023	DELAY7	10,2	
1103	Reserved	0,6	high
A024	DELAY8	10,2	
H482	WiFi_TX_On_ANT0_2.4G	1,1	
H486 -	WiFi_TX_On_ANT0_5G	1,4	
H497	WIFI_ANT0_RSSI_READ_2.4G	2,4	C85D38180FF0
H498	WIFI_ANT0_RSSI_READ_5G	2,4	C85D38180FE8
H504	WIFI_ANT2_RSSI_READ_5G	2,4	C85D38180FE8
A079	PRINTER_PORT_OUT_1		
A080	PRINTER_PORT_OUT_2		
A081	PRINTER_PORT_OUT_3		
A082	PRINTER_PORT_OUT_4		
H241	VOIP BOARD PORT0	8,1	
H242	VOIP BOARD PORT1	6,8	
A135	INITIALIZE TEST SYSTEM 3rd	0,0	V_5.83
A162	TEST START (BIST MODE)	0,8	factory(1)
A007	WIFI_GET_5G_SSID (Before Default)	2,7	CLARO_5G181880
A303	Default Check Parameter setting_1	0,3	false(2)
A304	Default Check Parameter setting_2	0,3	true(1)
A312	Default Parameter setting for User	0,3	IpAddress: 192.168.0.1
A315	Check Default (Serial Number)	0,3	14013585850080909097
A316	Check Default (Application Version)	0,3	BRGCAI 1.0.10
A319	Check Default (5G SSID)	0,3	disabled(0)
A366	Check Default (Fusing Mode)	0,3	SecureBoot Enabled

Source: Authors, (2022).



Source: Authors, (2022).

Figure 7. Final assembly line layout

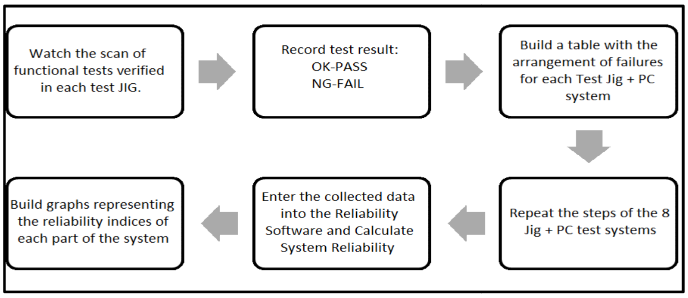
The other columns of the table inform the description of the item to be checked, an example of the value read from the device for each item, and the duration, which is the average time required to perform the check, in seconds.The figure illustrates some important points of the organization of the assembly line under study:

a) Physical arrangement of the 13 workstations;
b) Identification of the 2 test stations in yellow (to be studied);
c) Direction of product assembly;

At the end, each unit produced is ready for sale to the end customer.

Data Collection and Problem Modeling: In order to identify opportunities to improve the efficiency of functional test Jigs, a final assembly line and a model were defined as the object of this study, being a DOCSIS 3.1, Cable Modem, Gateway (Wi-Fi Router) type device. The sequence that will be followed in this study is:

a) Survey of the current situation of reliability and failure disposition: for the experimentation of the defined product, with data collection of failures and approvals that were recorded in each PC that performs a functional test. The flowchart Figure 8 describes the steps of this step: Evaluation of the verified items; of the Device Under Tests (DUT) device responses; station reliability and productivity.



Source: Authors, (2022).

Figure 8. Flowchart for collecting activity times on the production line

RESULTS AND DISCUSSIONS

Modeling and Simulation - Main Offenders: In this chapter, we will move on to the analysis of the main offenders. The idea is to verify whether reliability is within the acceptable parameter and, if not, to identify the impacting symptoms and their possible causes. With this information, a list of actions is created in order to optimize the process and prevent the symptoms from recurring with the same frequency. If positive results are achieved, the actions are entered into a preventive maintenance checklist. In this chapter, we will survey and identify the reasons for functional test failures and act on the main offenders, according to the Pareto principle.

Pareto Principle: table 4, we can see the causes of the JIG01 failures.

Table 4. Faults in Jig 01

Jig ID	Test Time	Sequence	Test Result	Defect
JIG01	20200302 083606	2	NG	RJ45 TEST
JIG01	20200302 083911	3	NG	RJ45 TEST
JIG01	20200302 085814	11	NG	CHECK BATTERY
JIG01	20200302 090701	39	NG	CHECK USB1(2.0) Device Detection
JIG01	20200302 090757	41	NG	RJ45 TEST
JIG01	20200302 092303	70	NG	CHECK USB1(2.0) Device Detection
JIG01	20200302 092605	74	NG	CHECK BATTERY
JIG01	20200302 092742	76	NG	WiFi_TX_On_ANT1_2.4G
JIG01	20200302 093351	82	NG	RJ45 TEST
JIG01	20200302 101509	151	NG	CHECK BATTERY

Source: Authors, (2022).

If we separate the main offenders for Jig 1, we have the following distribution visualized in Table 5.

Table 5. Distribution of defects of Jig 01.

RJ45 TEST	4
CHECK BATTERY	3
CHECK USB1(2.0) Device Detection	2
WiFi_TX_On_ANT1_2.4G	1

Source: Authors, (2022).

In other words, if we focus on solving the problems related to RJ45 symptoms, we will solve 40% of the downtime and production losses in Jig 01.

About the other jigs, the main offenders can be seen in tables 06, 07, 08, 09, 10, 11 and 12:

Table 6. JIG02 offenders

Jig 2 – Defect	Qtd
RJ45 TEST	5
CHECK BATTERY	3
CHECK USB1(2.0) Device Detection	3
LED_GREEN ALL ON	2
SW_Version(Release Loader)	1
Compare 1st Mac Address	1

Source: Authors, (2022).

Table 7. JIG03 Offenders

Jig 3 - Defect	Qtd
RJ45 TEST	3
CHECK BATTERY	2
KEY_WPS	1
Compare 1st Mac Address	1
VOIP BOARD PORT0	1

Source: Authors, (2022).

Table 8. JIG04 Offenders

Jig 4 - Defect	Qtd
RJ45 TEST	2
CHECK BATTERY	1
WiFi_TX_On_ANT0_2.4G	1
CHECK USB1(2.0) Device Detection	1

Source: Authors, (2022).

Table 9. JIG05 Offenders

Jig 5 - Defect	Qtd
RJ45 TEST	2
CHECK BATTERY	1
WiFi_TX_On_ANT0_2.4G	1

Source: Authors, (2022).

Table 1011. JIG06 Offenders

Jig 6 - Defect	Qtd
RJ45 TEST	7
CHECK BATTERY	6
CHECK USB1(2.0) Device Detection	5
WiFi_TX_On_ANT0_2.4G	4
Compare 1st Mac Address	3
WIFI_ANT1_RSSI_READ_2.4G	3
VOIP BOARD PORT1	1
LED_GREEN ALL ON	1
KEY_HW RESET	1
SW_Version(Factory SW)	1
Compare Serial Number	1

Source: Authors, (2022).

Table 11. JIG07 Offenders

Jig 7 - Defect	Qtd
RJ45 TEST	5
CHECK BATTERY	5
WiFi_TX_On_ANT0_2.4G	4
KEY_WPS	3
CHECK USB1(2.0) Device Detection	3
WIFI_ANT0_RSSI_READ_2.4G	3

Source: Authors, (2022).

Table 12. JIG08 Offenders

Jig 8 - Defect	Qtd
RJ45 TEST	6
CHECK BATTERY	5
CHECK USB1(2.0) Device Detection	4
VOIP BOARD PORT1	2
KEY_HW RESET	1
Compare Serial Number	1

Source: Authors, (2022).

Action Plan: It can be seen that there are problems that are repeated in all jigs. Therefore, if actions are taken specifically on these items, there will be improvements in the whole process.

This is the case for the items below:

1. RJ45 TEST
2. CHECK BATTERY
3. CHECK USB1(2.0) Device Detection

The following is a step-by-step improvement approach taken for the CHECK BATTERY problem using the LEAN A3 design tool:

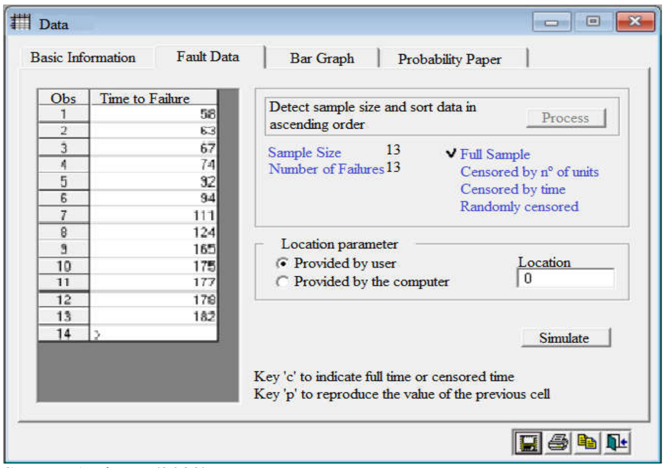
1. Clarify the problem;
2. Present conditions and problem statement;
3. Goal;
4. Root cause analysis
5. Countermeasures;
6. Results of the activity;
7. Evaluated results;
8. Lessons learned and standardization;

Fault Disposition - Final Situation: The data below was extracted from tests performed on May 18, 2021, after several maintenance actions and improvements applied to the process. In Table 13 below is the distribution of only the failures for Jig 01. In Figure 9 we can see the data from table 13 inserted in ProConf software:

Table 13. JIG01 failures after improvement actions

Jig ID	Test Time	Sequence	Test Result
JIG01	20210518 101057	58	NG
JIG01	20210518 102146	63	NG
JIG01	20210518 102826	67	NG
JIG01	20210518 104506	74	NG
JIG01	20210518 113455	92	NG
JIG01	20210518 113751	94	NG
JIG01	20210518 131903	111	NG
JIG01	20210518 135513	124	NG
JIG01	20210518 153215	165	NG
JIG01	20210518 155641	175	NG
JIG01	20210518 160340	177	NG
JIG01	20210518 161950	178	NG
JIG01	20210518 162813	182	NG

Source: Authors, (2022).



Source: Authors, (2022).

Figure 9. Results in ProConf software of JIG01 failures

Below, we have the Bar Graphs of Frequency, Failure Rate, Reliability, Cumulative Failure Density, all as a function of t: sequencein figures 10 to 13 the Grapf 5.5:

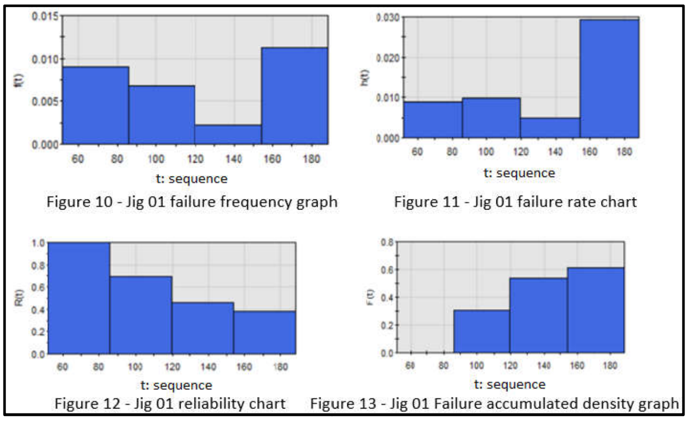


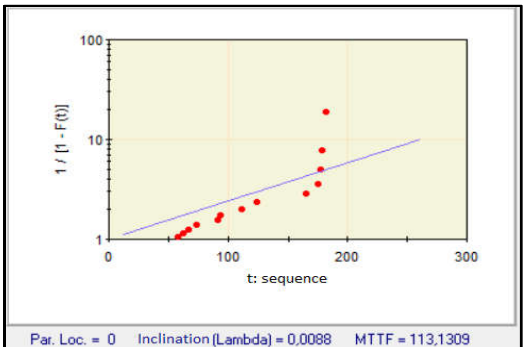
Figure 10 - Jig 01 failure frequency graph

Figure 11 - Jig 01 failure rate chart

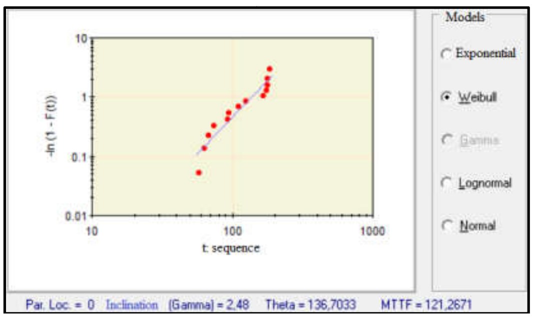
Figure 12 - Jig 01 reliability chart

Figure 13 - Jig 01 Failure accumulated density graph

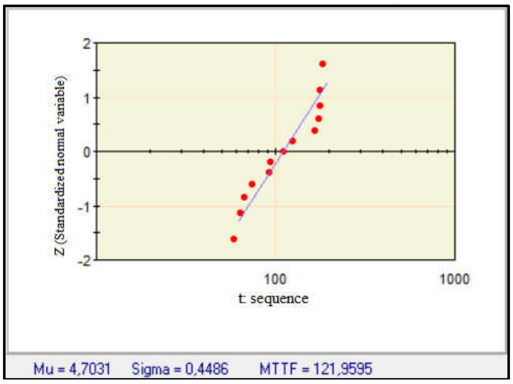
Graph 5.5 shows the Probability Paper for the distribution for Jig 1 according to the Exponential, Weibull, Lognormal, and Normal models:



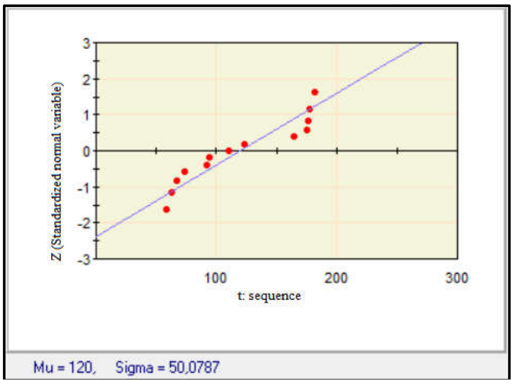
Graph 5.5 - JIG01 Exponential Model



Graph 5.6 - JIG01 Weibull Model



Graph 5.7. JIG01 LogNormal Model



Graph 5.8 - JIG01 Normal Model

In Table 14 below is the distribution of only the failures for Jig02:Entering the data from Table 14 into the ProConf software gives us the layout of Figure 5.2:

Table 14 - JIG02 Fault Distribution

Jig ID	Test Time	Duration	Test Result
JIG02	20210518 074127	1	NG
JIG02	20210518 090603	38	NG
JIG02	20210518 101258	61	NG
JIG02	20210518 101501	62	NG
JIG02	20210518 101557	63	NG
JIG02	20210518 101746	64	NG
JIG02	20210518 102101	66	NG
JIG02	20210518 104817	79	NG
JIG02	20210518 111039	87	NG
JIG02	20210518 112052	91	NG
JIG02	20210518 130536	111	NG
JIG02	20210518 133209	123	NG
JIG02	20210518 142850	147	NG
JIG02	20210518 144646	154	NG
JIG02	20210518 145025	156	NG
JIG02	20210518 150037	161	NG
JIG02	20210518 150453	163	NG
JIG02	20210518 152804	173	NG
JIG02	20210518 153448	176	NG
JIG02	20210518 153923	178	NG

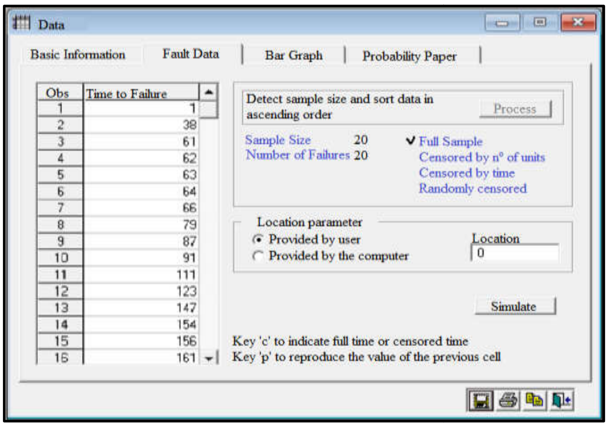
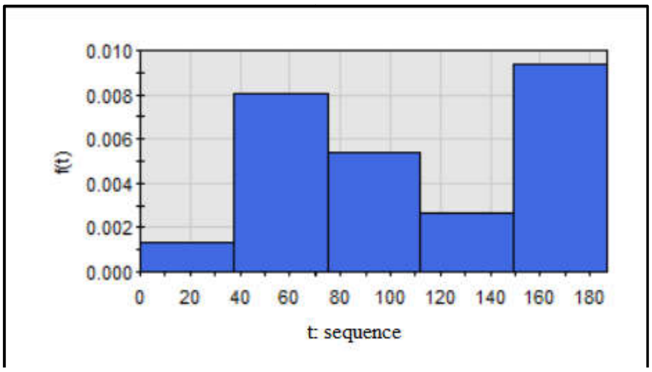
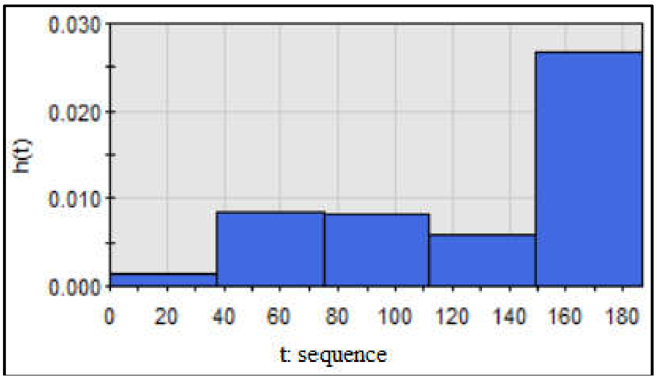


Figure 10. JIG02 ProConf Software Results

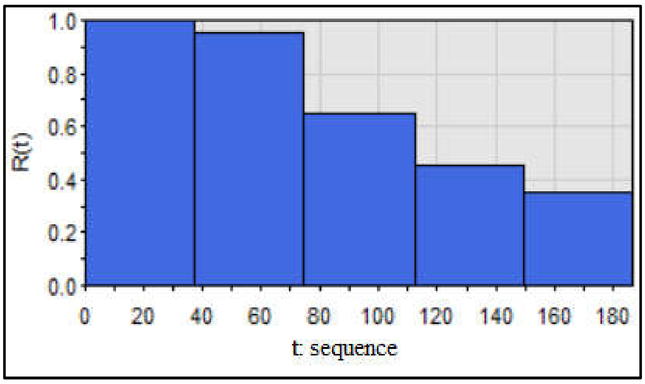
Below are the Bar Graphs of Frequency, Failure Rate, Reliability, Cumulative Failure Density, all as a function of t: sequence:



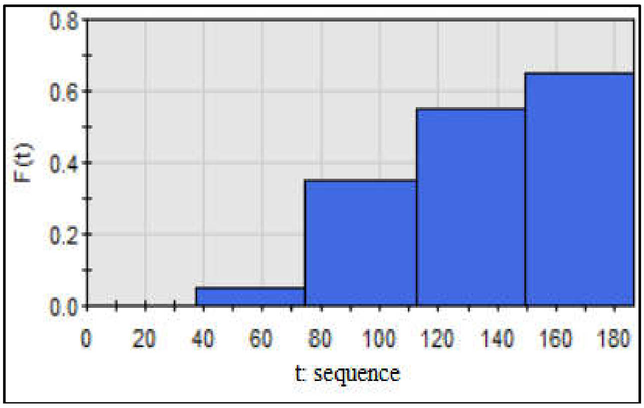
Graph 5.9. JIG02 Frequency



Graph 5.10. JIG02 Failure Rate

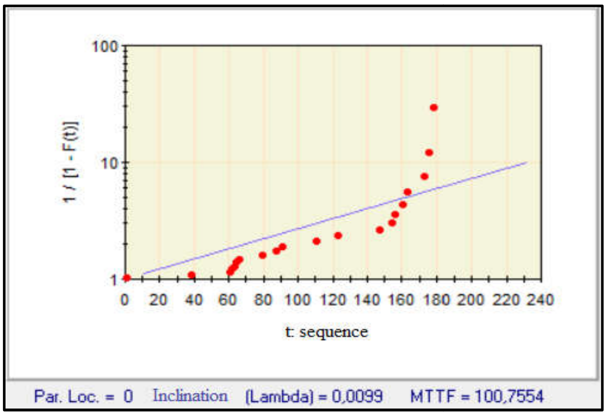


Graph 5.11 - JIG02 Reliability

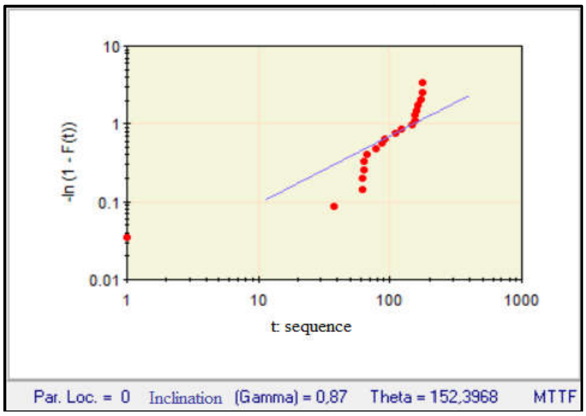


Graph 5.12 - JIG02 Cumulative Failure Density

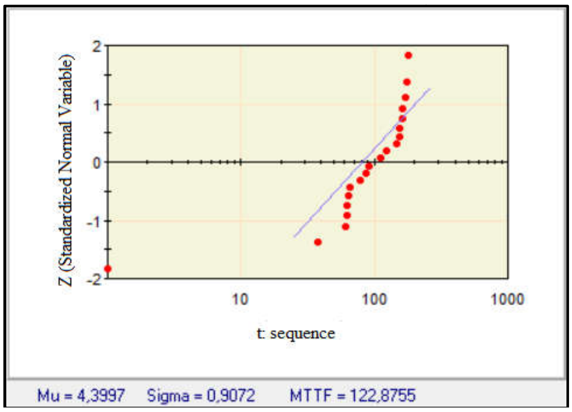
Accumulated Failure Density: Below, we have the Probability Paper for the distribution referring to Jig 02 according to the Exponential, Weibull, Lognormal, and Normal models:



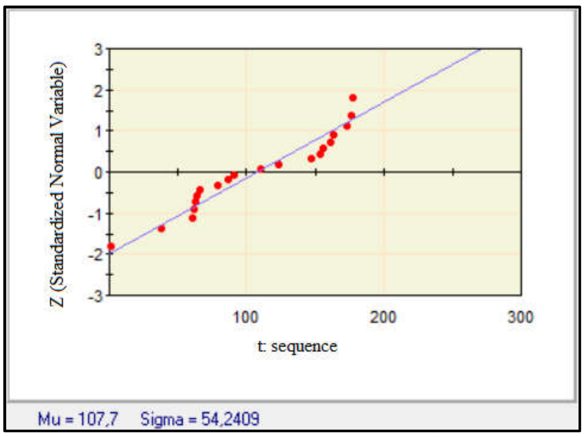
Graph 5.13. JIG02 Exponential Model



Graph 5.14 - JIG02 Wilbull Model



Graph 5.15 - JIG02 LogNormal Model



Graph 5.16 - JIG02 Normal Model

In the Table 15 below is the distribution of only the failures for Jig03:

Table 15. JIG03 Fault Distribution

Jig ID	Test Time	Duration	Test Result
JIG03	20210518 083443	20	NG
JIG03	20210518 105231	77	NG
JIG03	20210518 130605	107	NG
JIG03	20210518 132156	115	NG
JIG03	20210518 153320	169	NG
JIG03	20210518 163516	189	NG
JIG03	20210518 163744	190	NG

Entering the data from Table 15 into the ProConf software gives us the following layout:

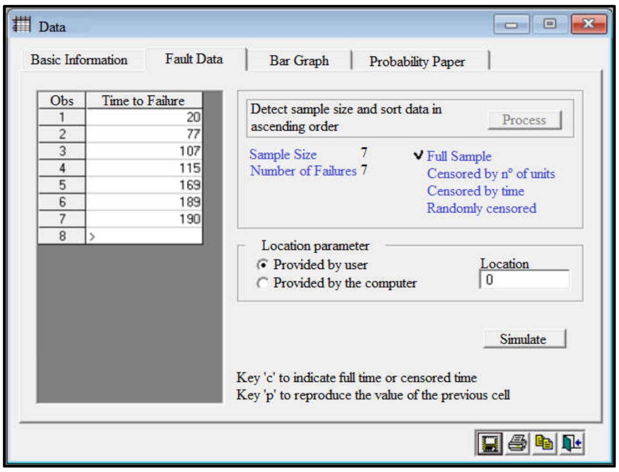
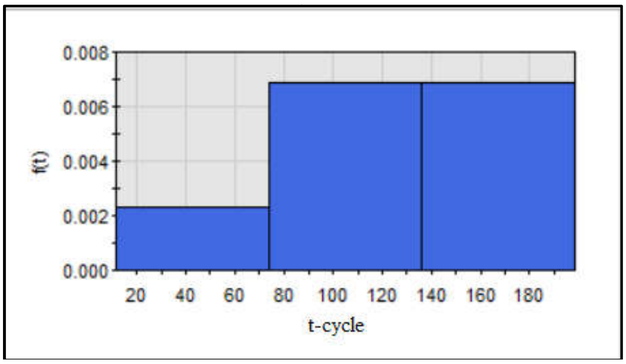
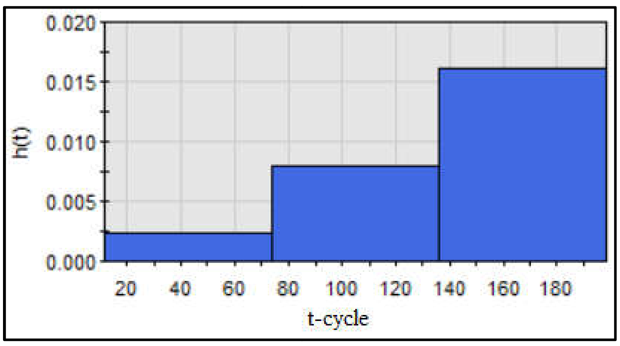


Figure 11. ProConf JIG03 software results

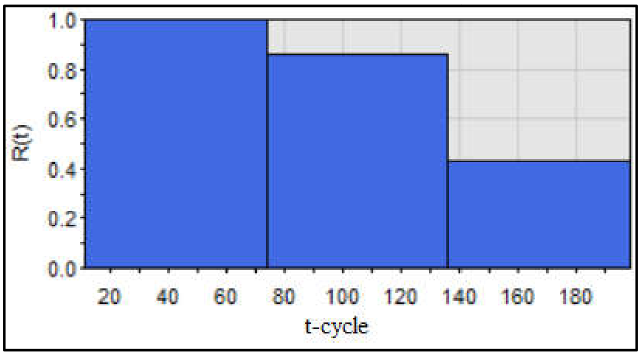
Below are the Bar Graphs of Frequency, Failure Rate, Reliability, Cumulative Failure Density, all as a function of t: sequence:



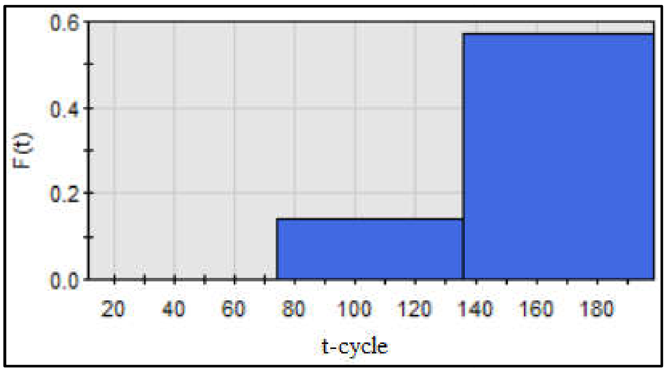
Graph 5.17 - JIG03 Frequency



Graph 5.18 - JIG03 Failure Rate

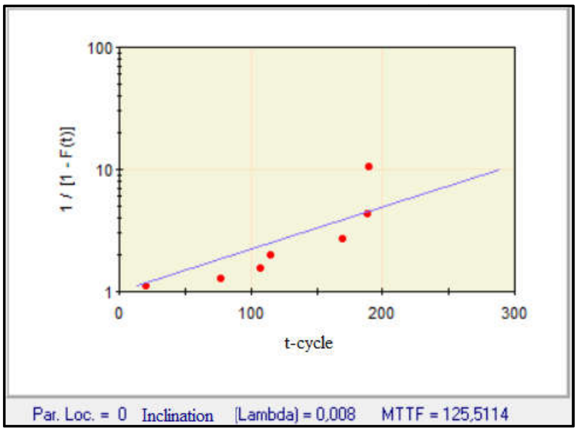


Graph 5.19 - JIG03 Reliability

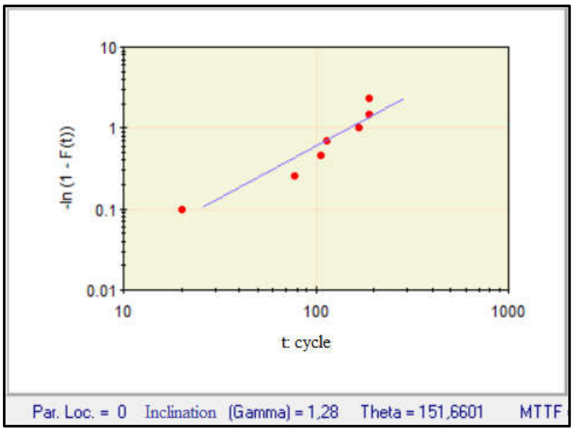


Graph 5.20 - Cumulative Failure Density

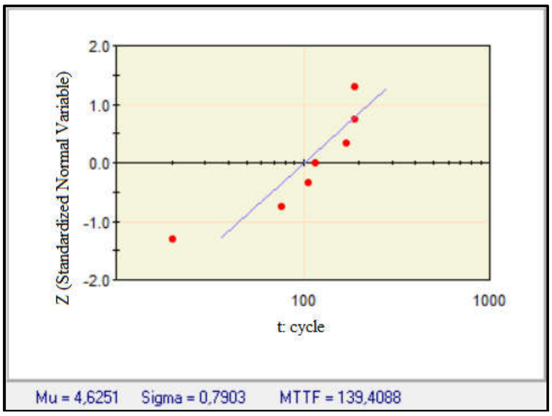
Below is the Probability Paper for the distribution for Jig 03 according to the Exponential, Weibull, Lognormal, and Normal models:



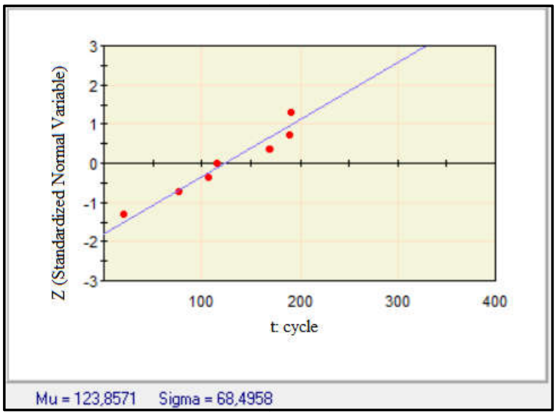
Graph 5.21 - JIG03 Exponential Model



Graph 5.22 - JIG03 Weibull Model



Graph 5.23 - JIG03 LogNormal Model



Graph 5.24 - JIG03 Normal Model

In the table below is the distribution of only the failures for Jig04:

Table 16. Results JIG04

Jig ID	Test Time	Duration	Test Result
JIG04	20210518 094951	53	NG
JIG04	20210518 100306	56	NG
JIG04	20210518 104704	75	NG
JIG04	20210518 111022	84	NG
JIG04	20210518 113342	96	NG
JIG04	20210518 133641	122	NG
JIG04	20210518 140710	135	NG
JIG04	20210518 150648	161	NG
JIG04	20210518 151330	163	NG
JIG04	20210518 153550	173	NG
JIG04	20210518 162022	187	NG

Entering the data from Table 16 into the ProConf software gives us the following layout:

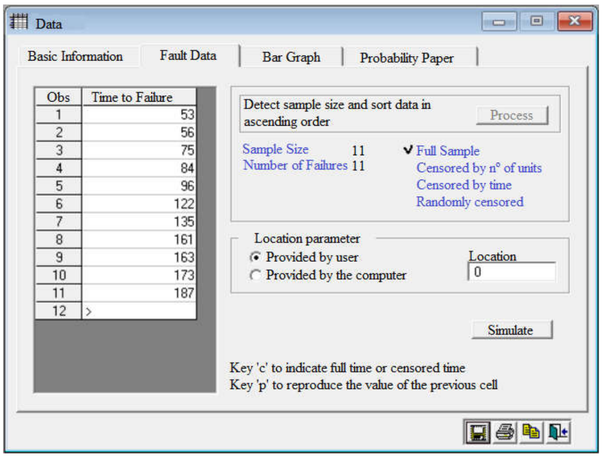
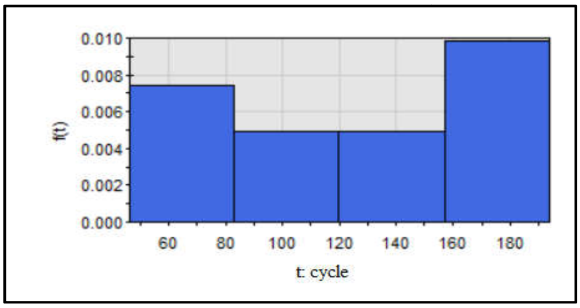
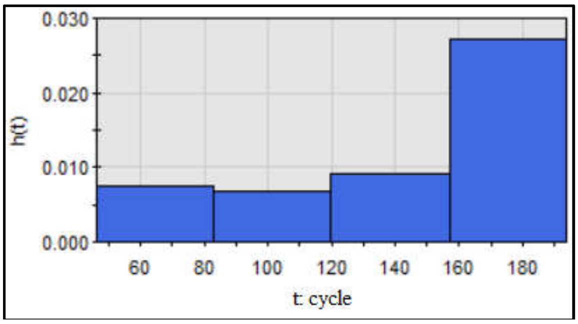


Figure 12. Results in ProConf JIG04 software

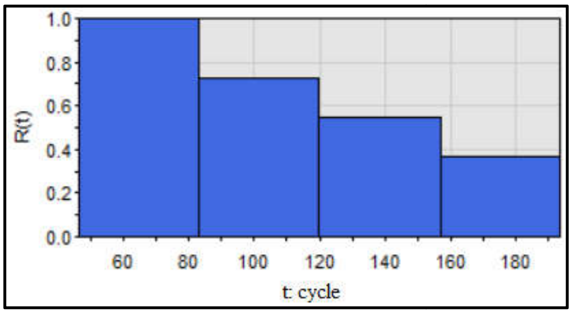
Below are the Bar Graphs of Frequency, Failure Rate, Reliability, Cumulative Failure Density, all as a function of t: sequence:



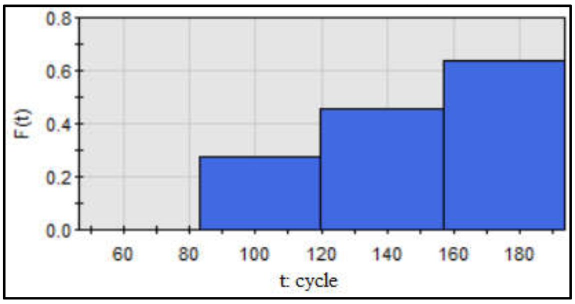
Graph 5.25 - JIG04 Frequency



Graph 5.26 - JIG03 Failure Rate

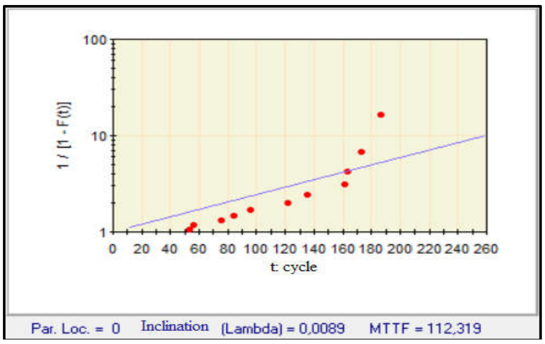


Graph 5.27 - JIG03 Reliability

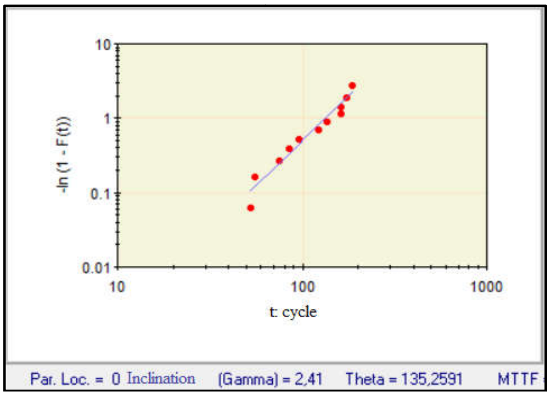


Graph 5.28 - JIG03 Accumulated Density

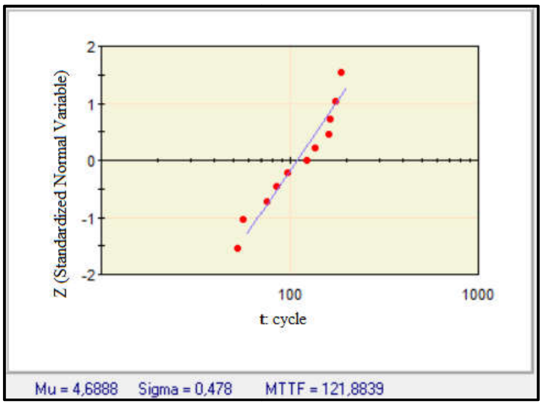
Below, we have the Probability Paper for the distribution for Jig 04 according to the Exponential, Weibull, Lognormal, and Normal models:



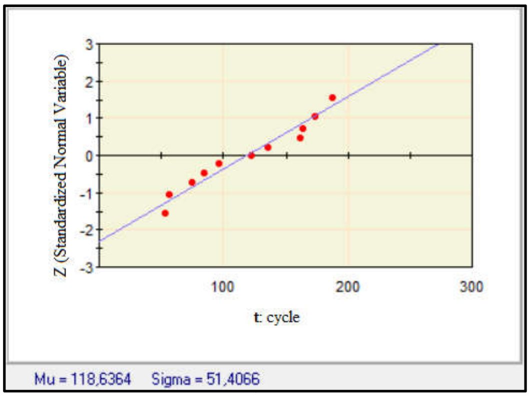
Graph 5.29 - JIG04 Exponential Model



Graph 5.30 - JIG04 Weibul Model



Graph 5.31 - JIG04 LogNormal Model



Graph 5.32 - Jig04 Normal Model

In the table below is the distribution of only the failures for Jig05:

Table 17 - Results JIG04

Jig ID	Test Time	Sequence	Test Result
JIG05	20210518 075504	5	NG
JIG05	20210518 091932	38	NG
JIG05	20210518 105136	75	NG
JIG05	20210518 110317	79	NG
JIG05	20210518 133020	118	NG
JIG05	20210518 135303	128	NG
JIG05	20210518 135455	129	NG
JIG05	20210518 142037	140	NG
JIG05	20210518 143953	149	NG
JIG05	20210518 150227	160	NG
JIG05	20210518 151920	168	NG

Entering the data from Table 17 into the ProConf software gives us the following layout:

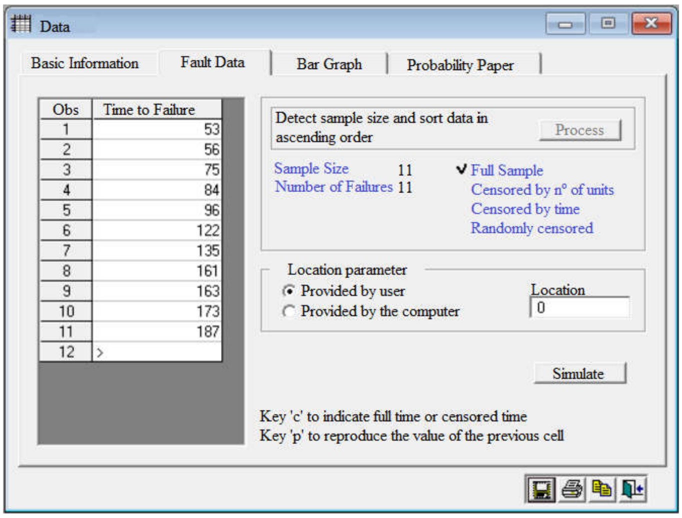
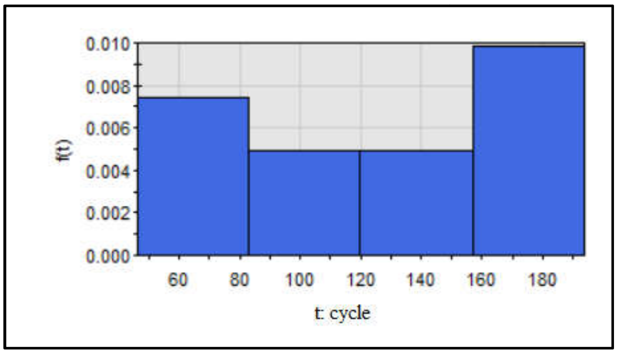
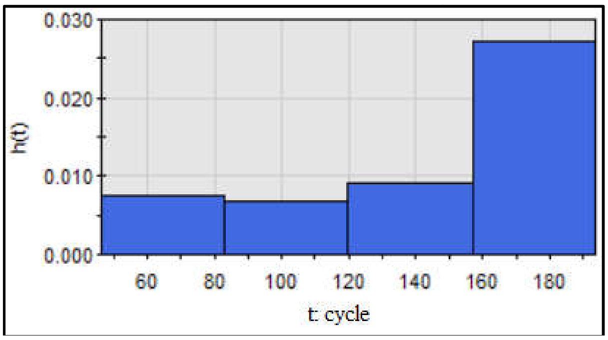


Figure 13. Results in ProConf JIG04 software

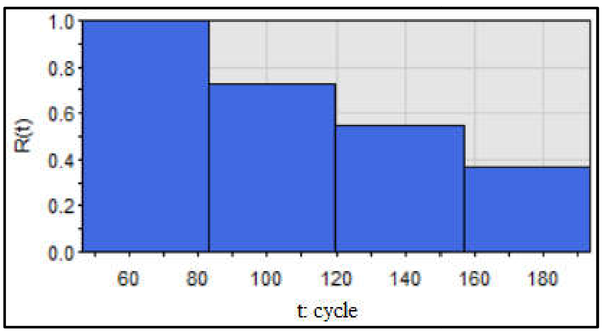
Below are the Bar Graphs of Frequency, Failure Rate, Reliability, Cumulative Failure Density, all as a function of t: sequence:



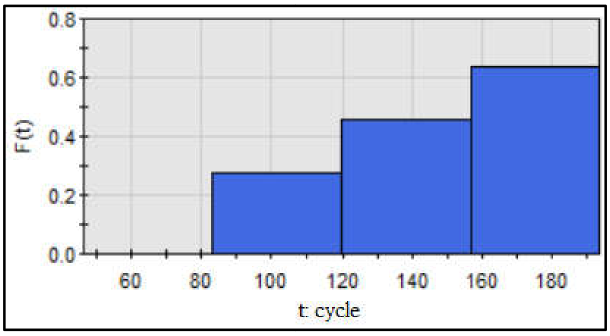
Graph 5.25 - JIG04 Frequency



Graph 5.26 - JIG03 Failure Rate

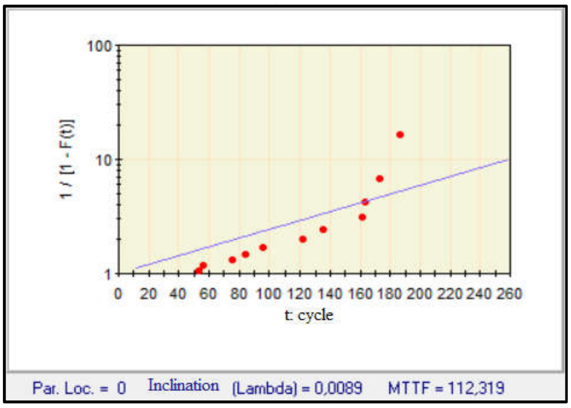


Graph 5.27 - JIG03 Reliability

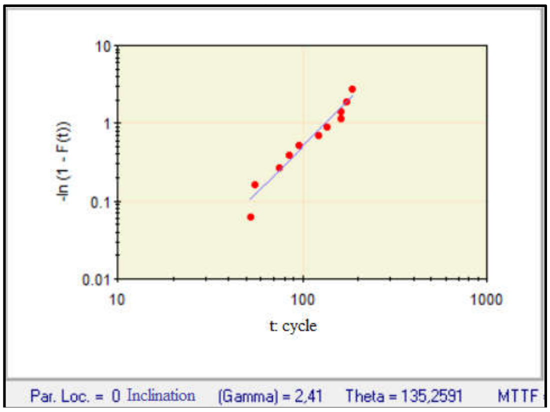


Graph 5.28 - JIG03 Accumulated Density

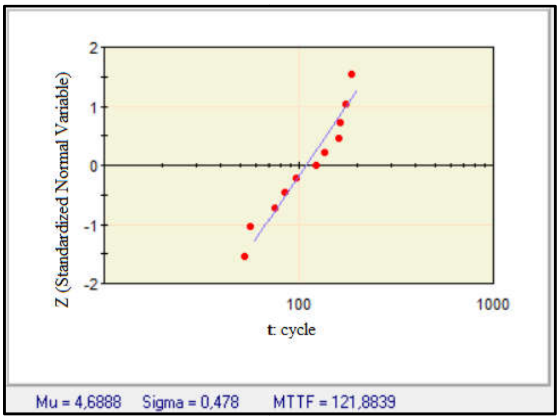
Below, we have the Probability Paper for the distribution for Jig 04 according to the Exponential, Weibull, Lognormal, and Normal models:



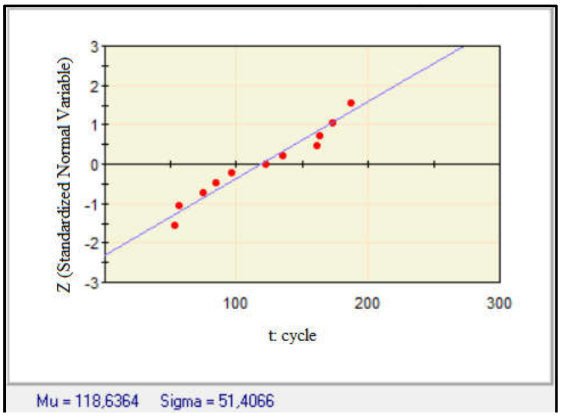
Graph 5.29 - JIG04 Exponential Model



Graph 5.30 - JIG04 Weibul Model



Graph 5.31 - JIG04 LogNormal Model



Graph 5.32 - Jig04 Normal Model

In the table below is the distribution of only the failures for Jig05:

Table 18. JIG 05

Jig ID	Test Time	Sequence	Test Result
JIG05	20210518 075504	5	NG
JIG05	20210518 091932	38	NG
JIG05	20210518 105136	75	NG
JIG05	20210518 110317	79	NG
JIG05	20210518 133020	118	NG
JIG05	20210518 135303	128	NG
JIG05	20210518 135455	129	NG
JIG05	20210518 142037	140	NG
JIG05	20210518 143953	149	NG
JIG05	20210518 150227	160	NG
JIG05	20210518 151920	168	NG

Entering the data from Table 18 into the ProConf software gives us the following layout:

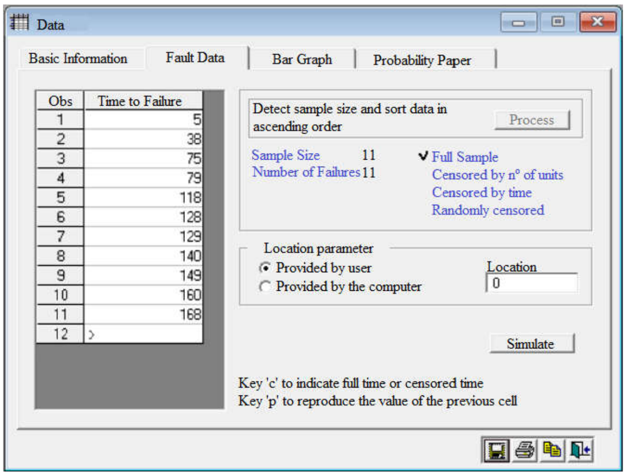
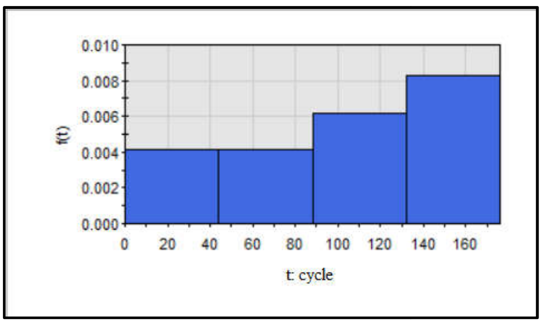
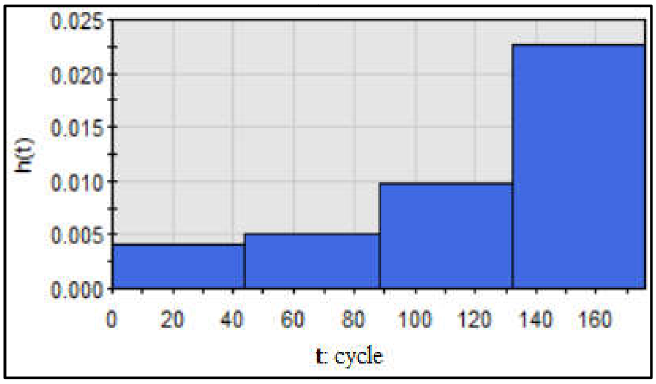


Figure 14. Results in Sample Size and Location parameter

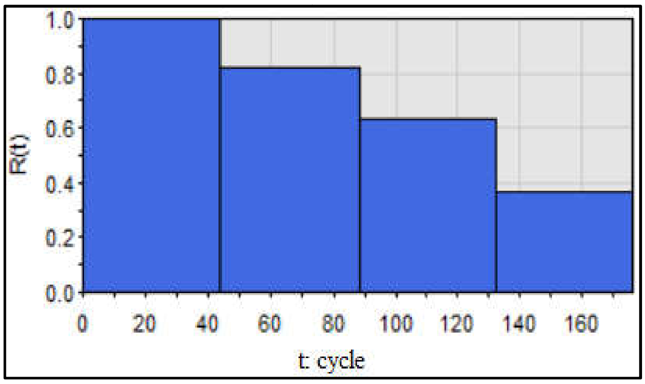
Below, we have the Bar Graphs of Frequency, Failure Rate, Reliability, Cumulative Failure Density, all as a function of t: sequence:



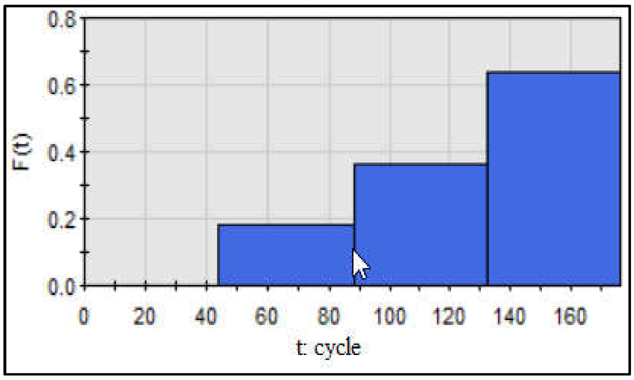
Frequency



Failure Rate

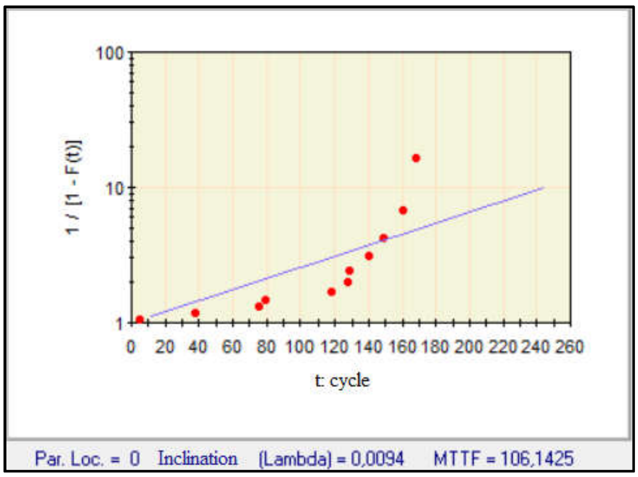


Reliability Accumulated

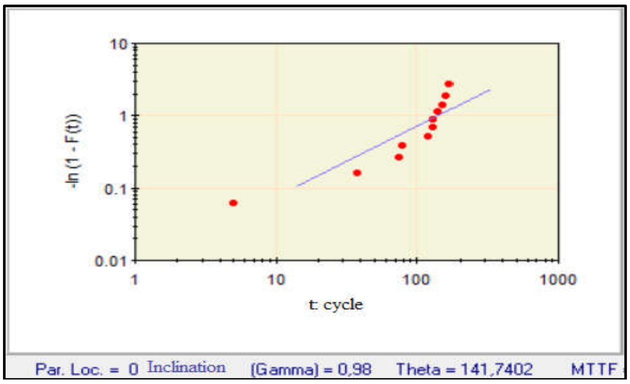


Failure Density

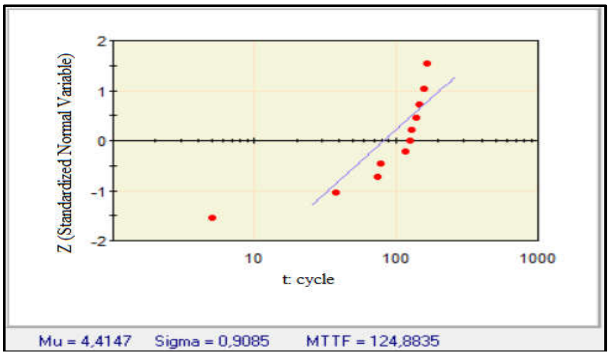
Below, we have the Probability Paper for the distribution for Jig 05 according to the Exponential, Weibull, Lognormal, and Normal models:



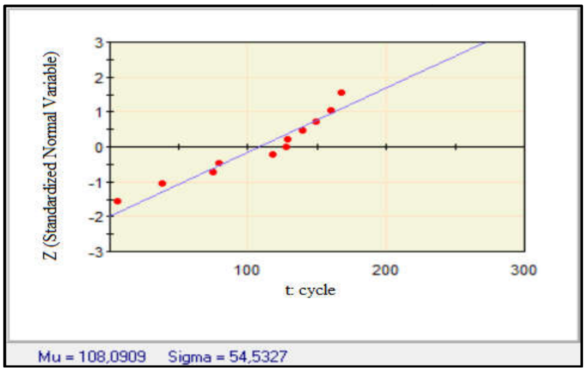
Exponential Model



Weibull Model



Lognormal Model



Normal Model

In the Table 19 below is the distribution of only the failures for Jig06:

Table 19. JIG 06

Jig ID	Test Time	Duration	Test Result
JIG06	20210518 081009	8	NG
JIG06	20210518 090340	33	NG
JIG06	20210518 093032	42	NG
JIG06	20210518 094606	49	NG
JIG06	20210518 100256	52	NG
JIG06	20210518 100948	55	NG
JIG06	20210518 102604	63	NG
JIG06	20210518 105842	78	NG
JIG06	20210518 110306	80	NG
JIG06	20210518 140448	135	NG
JIG06	20210518 142847	147	NG
JIG06	20210518 144938	158	NG
JIG06	20210518 145219	160	NG
JIG06	20210518 152716	177	NG
JIG06	20210518 153426	181	NG
JIG06	20210518 154859	189	NG
JIG06	20210518 162529	199	NG
JIG06	20210518 165059	210	NG

Entering the data from **Table 19** into the **ProConf**software gives us the following layout:

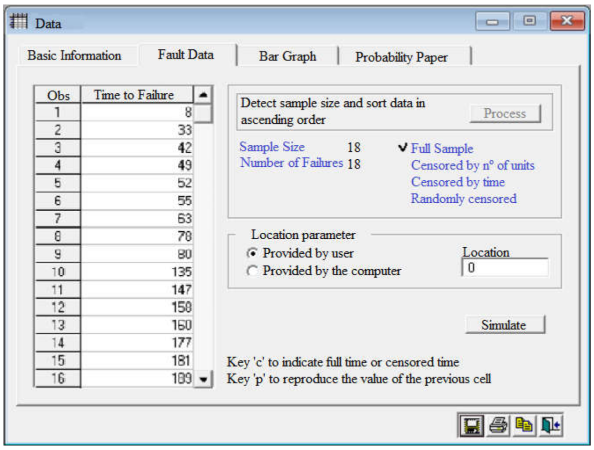
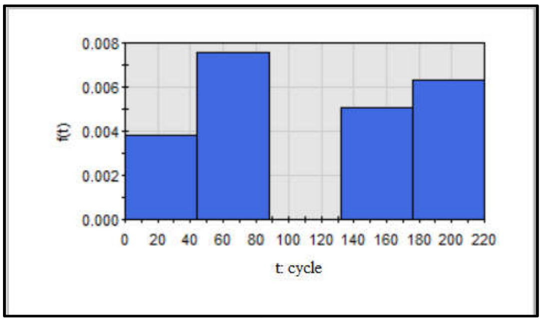
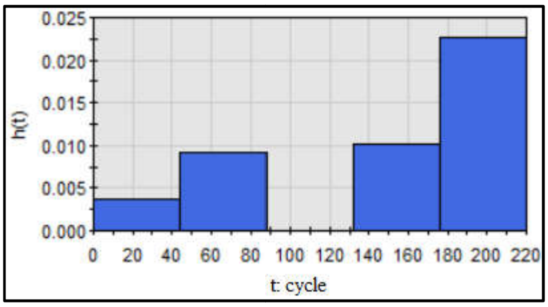


Figure 15. Results in Sample Size and Location parameter

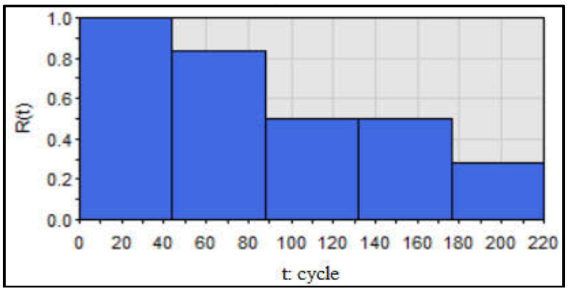
Below, we have the Bar Graphs of Frequency, Failure Rate, Reliability, Cumulative Failure Density, all as a function of t: sequence:



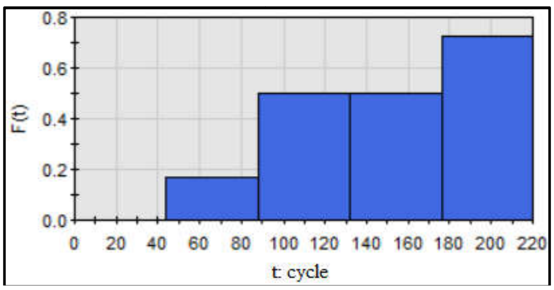
Frequency



Failure Rate

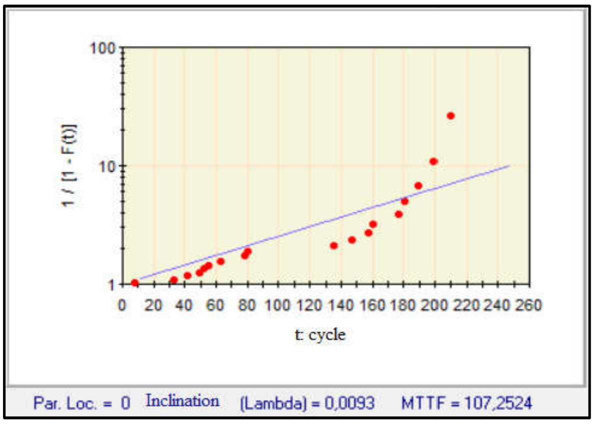


ReliabilityCumulative

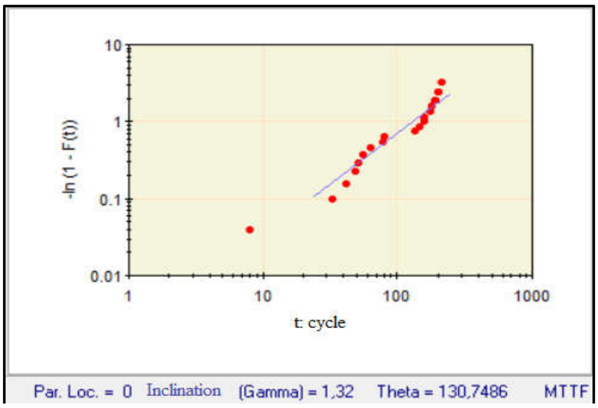


Failure Density

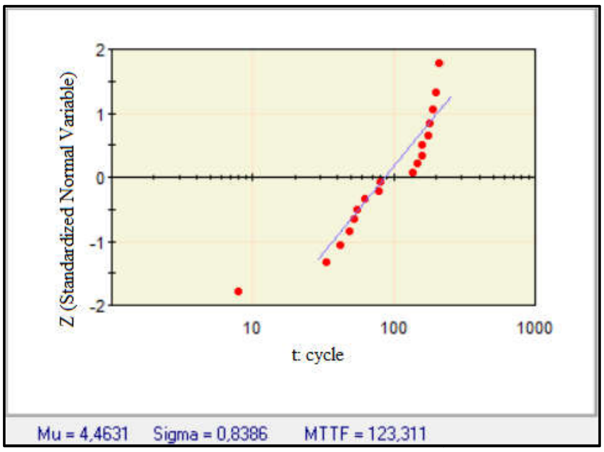
Below, we have the Probability Paper for the distribution for Jig 06 according to the Exponential, Weibull, Lognormal, and Normal models:



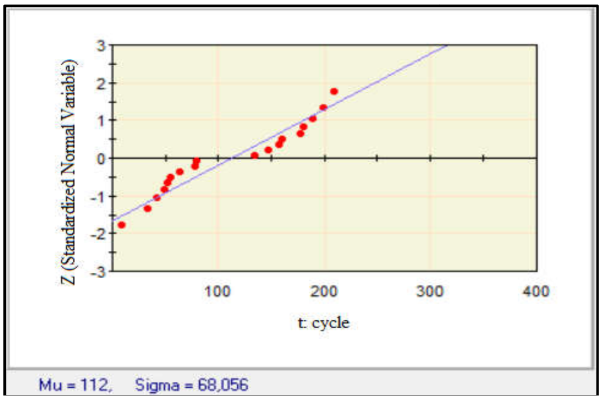
Exponential Model



Weibull Model



Lognormal Model



Normal Model

Table 20 shows the distribution of only the failures for Jig07:

Table 20. JIG 07

Jig ID	Test Time	Duration	Test Result
JIG07	20210518 074234	1	NG
JIG07	20210518 075147	4	NG
JIG07	20210518 080559	7	NG
JIG07	20210518 081357	10	NG
JIG07	20210518 081742	12	NG
JIG07	20210518 082609	16	NG
JIG07	20210518 084346	25	NG
JIG07	20210518 091043	38	NG
JIG07	20210518 093313	45	NG
JIG07	20210518 093609	47	NG
JIG07	20210518 094707	52	NG
JIG07	20210518 102429	65	NG
JIG07	20210518 113723	98	NG
JIG07	20210518 131157	114	NG
JIG07	20210518 141051	139	NG
JIG07	20210518 141706	142	NG
JIG07	20210518 143727	152	NG
JIG07	20210518 144508	156	NG
JIG07	20210518 145947	164	NG
JIG07	20210518 151331	171	NG
JIG07	20210518 153715	183	NG
JIG07	20210518 155022	190	NG
JIG07	20210518 160242	196	NG
JIG07	20210518 160331	197	NG
JIG07	20210518 160404	198	NG
JIG07	20210518 162521	201	NG
JIG07	20210518 162650	202	NG

Source: Authors (2022)

Entering the data from Table 20 into the ProConf software gives us the following layout:

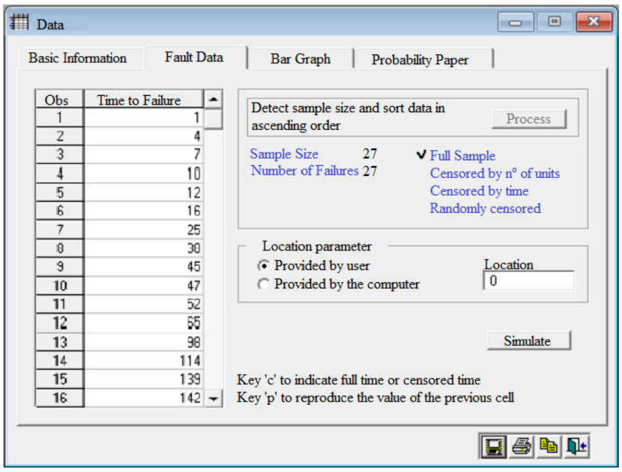
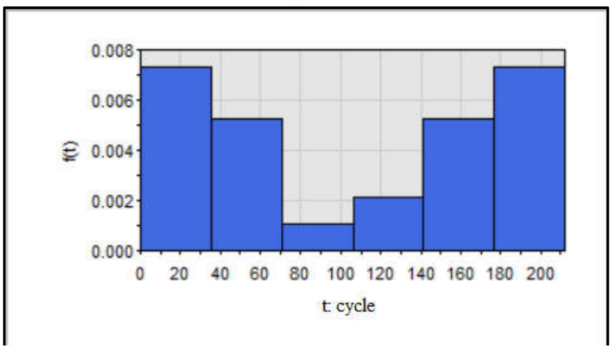
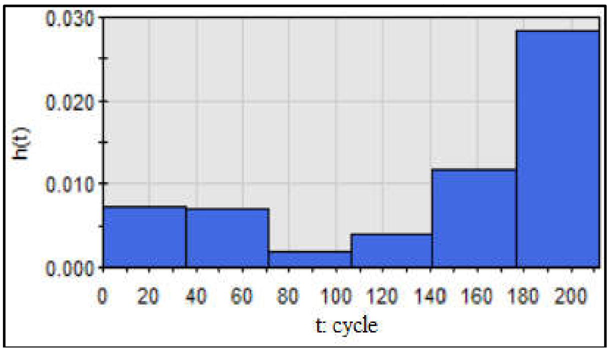


Figure 16 - Results in Sample Size and Location parameter

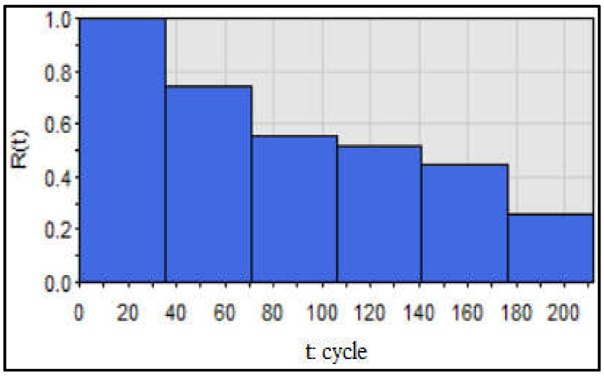
Below, we have the Bar Graphs of Frequency, Failure Rate, Reliability, Cumulative Density of Failure, all as a function of t: sequence:



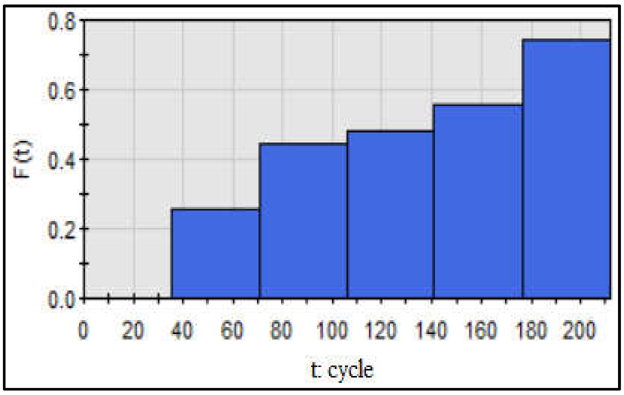
Frequency



Failure Rate

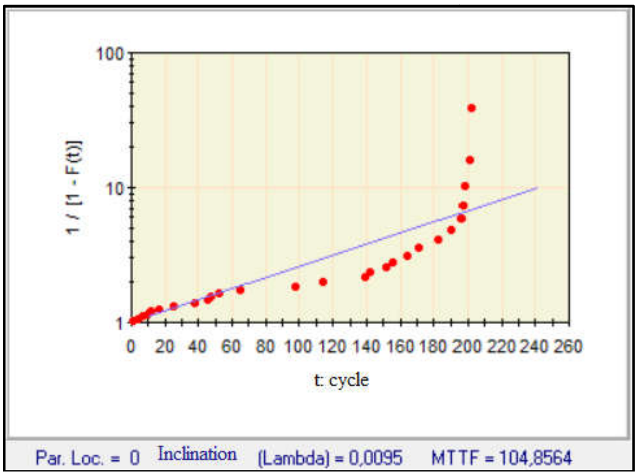


Reliability Cumulative

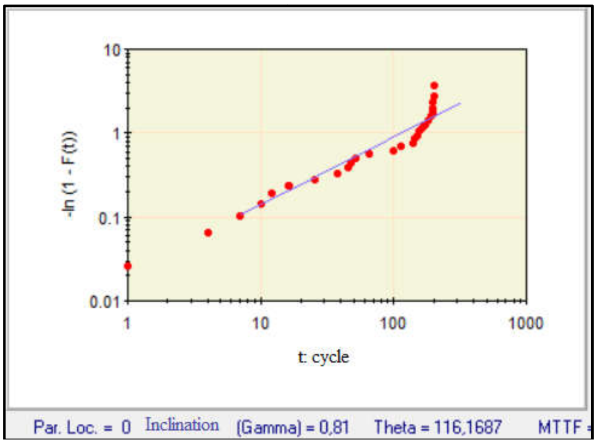


Failure Density

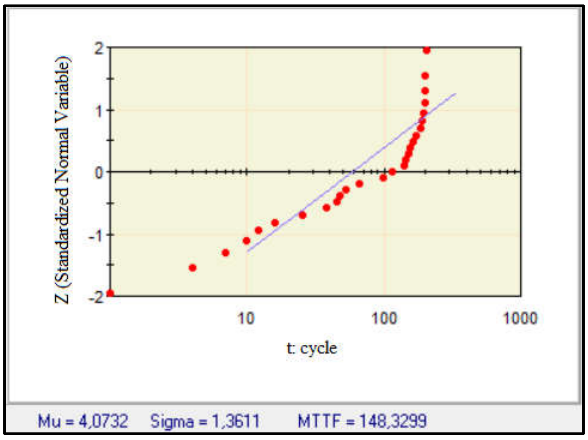
Below, we have the Probability Paper for the distribution for Jig 07 according to the Exponential, Weibull, Lognormal, and Normal models:



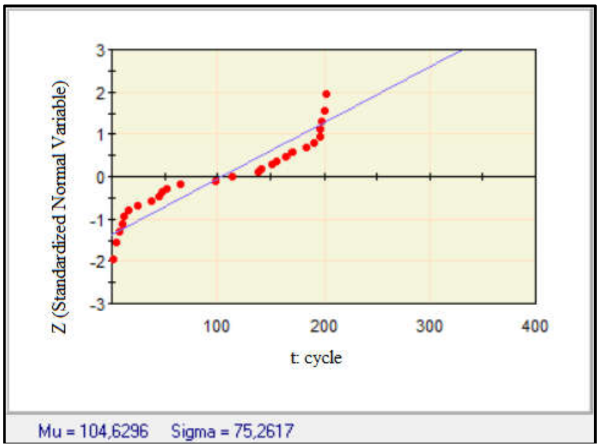
Exponential Model



Weibull Model



Lognormal Model



Normal Model

In the table below is the distribution of only the failures for Jig08:

Table 21. JIG 08

Jig ID	Test Time	Duration	Test Result
JIG08	20210518 080614	8	NG
JIG08	20210518 081848	14	NG
JIG08	20210518 090738	38	NG
JIG08	20210518 094246	51	NG
JIG08	20210518 101821	63	NG
JIG08	20210518 140154	137	NG
JIG08	20210518 142547	148	NG
JIG08	20210518 145503	163	NG
JIG08	20210518 150111	166	NG
JIG08	20210518 150821	170	NG
JIG08	20210518 155846	195	NG
JIG08	20210518 162939	203	NG
JIG08	20210518 164101	208	NG
JIG08	20210518 164239	209	NG

Entering the data from Table 21 into the ProConf software gives us the following layout:

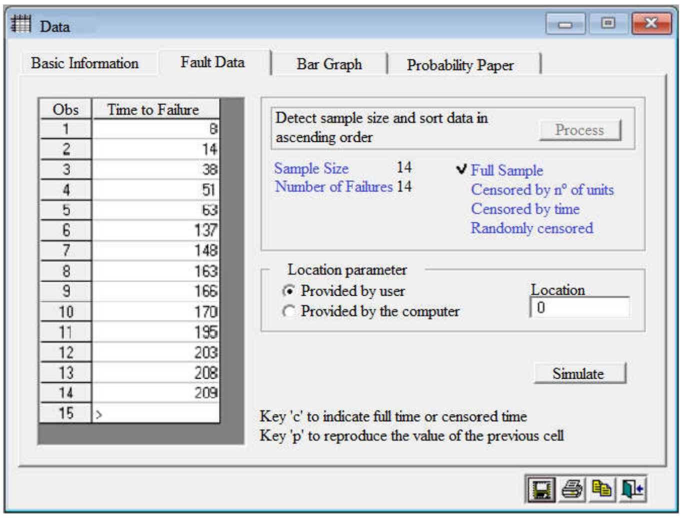
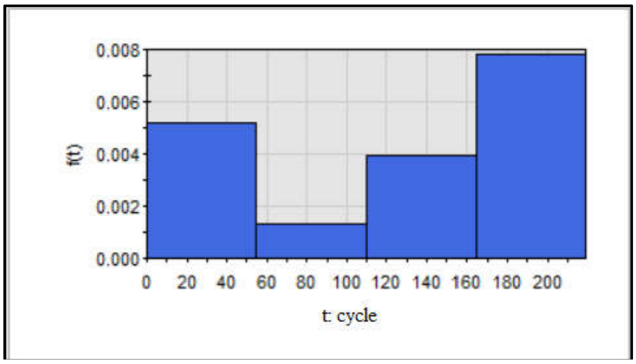
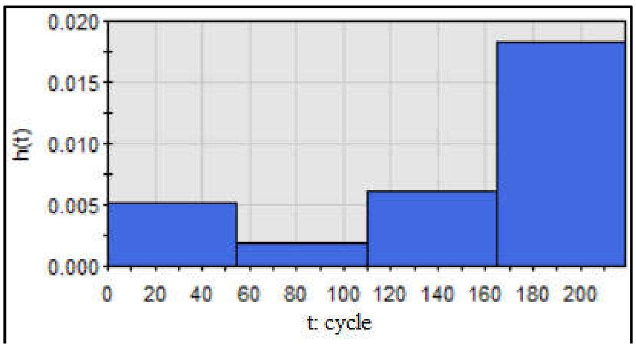


Figure 17. Results in Sample Size and Location parameter

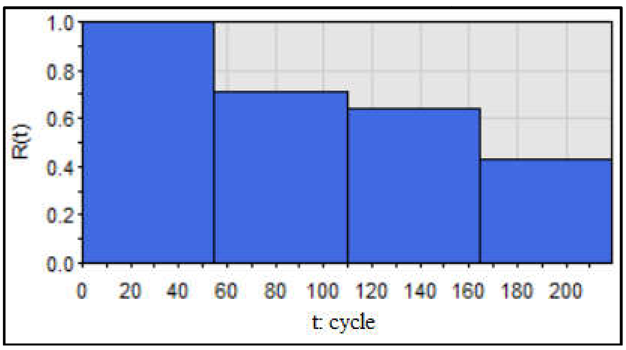
Below, we have the Bar Graphs of Frequency, Failure Rate, Reliability, Cumulative Density of Failure, all as a function of t: sequence:



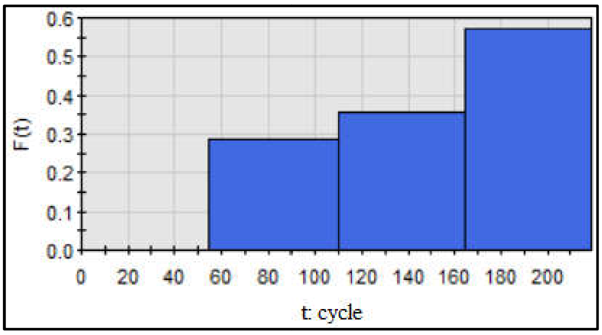
Frequency



Failure Rate

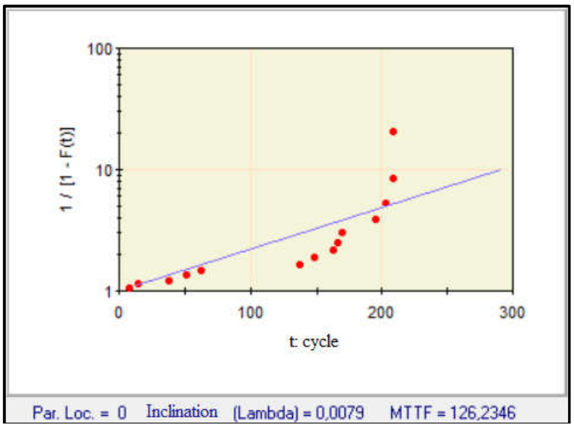


Reliability Cumulative

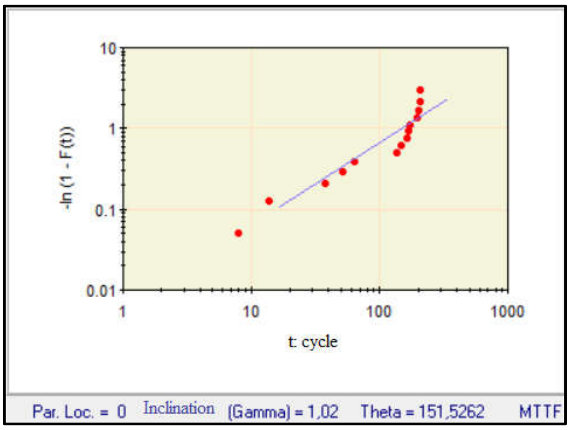


Failure Density

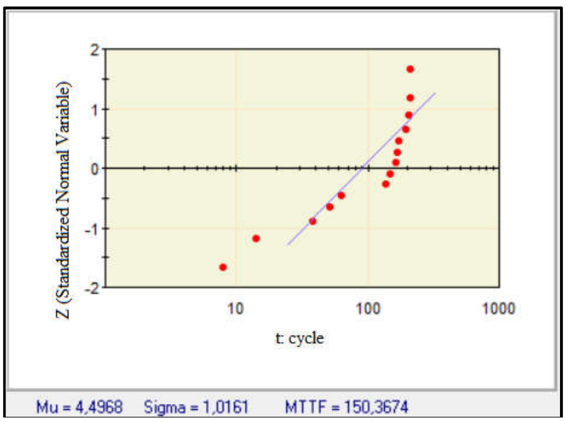
Below, we have the Probability Paper for the distribution for Jig 08 according to the Exponential, Weibull, Lognormal, and Normal models:



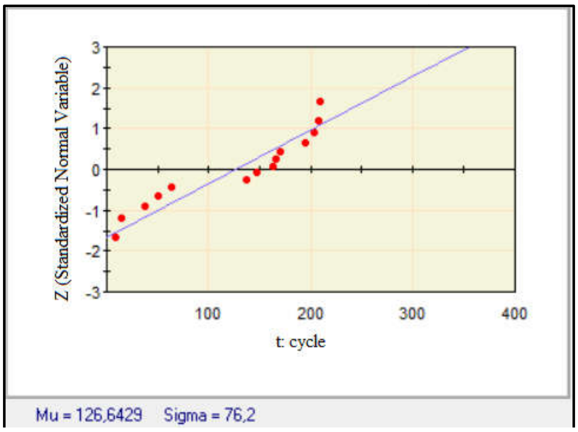
Exponential Model



Weibull Model



Lognormal Model



Normal Model

CONCLUSION

This study allowed us to present an analysis using reliability concepts. The main idea is to obtain the machine failure data and estimate the behavior of the line according to the new high-volume process concept. Using this criterion, we were able to determine how capable the line was of achieving the expected results and what improvements would be needed to achieve the objectives. Thus, after collecting the data from each equipment and the tests to define the probability function that fitted the failure data of each one, we estimated the reliability of each equipment and of the line, as can be seen in the research.Therefore, as immediate suggestions for improvement we have: 1. adjust the line according to the number of equivalent parallel units to achieve the proposed reliability; 2. reinforce the maintenance budget including spare parts, calibrations, refurbishments, insufficient analysis and maintenance management; 3. reinforce technical skills in maintenance management and problem solving; 4. implement RCM concept in the plant. 5. Make investments to renovate machines to have better reliability and low maintenance costs. A solution based on N.E.P.U. makes the project very expensive. Also, the line concept does not support the implementation of new machine units. A good option would be to make investments for new technologies that are able to guarantee the desired performance with a good level of reliability. Making investments for refurbishments, predictive maintenance and calibrations can improve the performance of the line and the machines as well. On the management side, it is very important to involve the maintenance team to do studies to find the root cause of failures and support the maintenance tasks with solutions that prevent the process and machines from malfunctioning. Using tools like FMEA, FRACAS, FMECA are a good way to find solutions. The main idea is to invest in the optimization of the currently adopted maintenance practices, which means using more tools for root cause analysis of failures and feed back the conclusions to the maintenance plans, i.e. review them more often in order to tackle the causes of failures and not the effects, and furthermore improve the training of the maintenance staff on the technical knowledge of the equipment, such as calibrations and complex maintenance. Moreover, from the management point of view, reinforce the Maintenance Engineering culture and make studies to implement the RCM Methodology as soon as possible for an improvement in the maintenance management. One point should be reinforced and refers to the quality of the acquired data. Some equipment showed a shortage of data during the observed time because there was not enough record to determine the correct failure distribution. And this would have a high impact on the conclusions and recommendations of this study.

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