Revista de Ciencias Tecnológicas (RECIT). Universidad Autónoma de Baja California ISSN 2594-1925
Volumen 7 (1): e324. Enero-Marzo, 2024. https://doi.org/10.37636/recit.v7n1e324

Review

Monitoring reliability of man-machine system of machining area using the Weibull distribution

Monitoreo de la confiabilidad del sistema hombre-máquina del área de mecanizado mediante la distribución de Weibull

Rosa María Amaya Toral[1], Manuel Baro Tijerina[2], Martha Patricia García-Martínez[1], Cinthia Judith Valdiviezo Castillo[1]

[1]Tecnológico Nacional de México Campus Chihuahua II, Ave. De las Industrias #11101, Chihuahua, Chihuahua, México, C.P. 31110.
[2]Tecnológico Nacional de México Campus Nuevo Casas Grandes,Tecnológico Ave #7100, Nuevo Casas Grandes, Chihuahua, México. C.P. 31700.

Corresponding author: Manuel Baro Tijerina, Tecnológico Nacional de México Campus Nuevo Casas Grandes, E.mail: mbaro@itsncg.edu.mx. ORCID: 0000-0003-1665-8379.

Submitted: September 1, 2023 **Accepted:** November 30, 2023 **Published:** January 1, 2024

Abstract. *- This publication presents the development of a method that seeks to monitor the parameters β (shape) and η (scale) for each component-subsystem combination following the Weibull distribution, necessary for the calculation of the reliability of the man-machine system in the machining area. This system defines the workshops of the metal-mechanic, with high-mix and low-volume batch production where conventional and Computerized Numerical Control (CNC) machines are involved, which share the manufacturing of parts that sometimes are unique, or their manufacturing period is short. The design of the man-machine system is based on the analysis of the failures of non-conforming parts in the machining area and on the failure rates, which the statistical model is developed for its evaluation, considering the 2-parameter Weibull distribution, and a redundant system with series-parallel configuration. The results obtained were based on the theoretical-practical, using mathematical and statistical models, as well as the Study Case. With the use of mathematical and statistical models, it is demonstrated that the probability of failure (risk) of the man-machine system is time-dependent and is generated by mechanical type stresses, which occur in the manufacture of parts.*

Keywords: Reliability; Machine-human; Weibull distribution; Exponential distribution.

Resumen. *- Esta publicación presenta el desarrollo de un método que busca monitorear los parámetros β (forma) y η (escala) para cada combinación componente-subsistema siguiendo la distribución de Weibull, necesarios para el cálculo de la confiabilidad del sistema hombre-máquina en el área de maquinado. Este sistema define los talleres de la metalmecánica, con producción por lotes de alta mezcla y bajo volumen donde intervienen máquinas convencionales y de Control Numérico Computarizado (CNC), que comparten la fabricación de piezas que en ocasiones son únicas, o su periodo de fabricación es corto. El diseño del sistema hombre-máquina se basa en el análisis de los fallos de piezas no conformes en el área de mecanizado y en las tasas de fallo, para cuya evaluación se desarrolla el modelo estadístico, considerando la distribución de Weibull de 2 parámetros, y un sistema redundante con configuración serie-paralelo. Los resultados obtenidos se basaron en el teórico-práctico, utilizando modelos matemáticos y estadísticos, así como el Caso de Estudio. Con el uso de modelos matemáticos y estadísticos, se demuestra que la probabilidad de falla (riesgo) del sistema hombre-máquina depende del tiempo y es generada por tensiones de tipo mecánico, que ocurren en la fabricación de las piezas.*

Palabras clave: Fiabilidad; Máquina-humano; Distribución de Weibull; Distribución exponencial.

ISSN: 2594-1925

1 Introduction

Consider a system that can be characterized as being in any of a previously specified set of states. Suppose that the system evolves or changes from one state to another over time according to a certain law of motion, and let X be the state of the system at time t [1]. If how the system evolved is not deterministic, but caused by some random mechanism, then X_t can be a random variable for each value of the index t. This collection of random variables is the definition of a stochastic process and serves as a model to represent the random evolution of a system over time [2]. In general, the random variables that make up a process are not independent of each other but are related to each other in some particular way [3]. A continuous random variable can take any value in an interval and it is represented by a set of real numbers. It is usually associated with measurements that generate physical quantities. The density function, the cumulative function, the complement function, the expected value of the average, the expected value of the variance, and the moments [4]. The random variable in the Weibull Distribution always takes values greater than or equal to 0 since it always represents time. The density function, the cumulative function, the expected value of the mean, and the variance are

$$f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}} \text{ when } \beta, \eta > 0 \text{ y } t \geq 0 \qquad (1)$$

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad (2)$$

$$\mu = \eta * \Gamma\left[1 + \frac{1}{\beta}\right] \qquad (3)$$

$$\sigma^2 = \eta^2 * \left\{\Gamma\left(1 + \frac{2}{\beta}\right) - \left[\Gamma\left(1 + \frac{1}{\beta}\right)\right]^2\right\} \qquad (4)$$

represented using the Weibull distribution. On the other hand, the variables that are generating the failures and that are not mechanical (human, procedural, administrative factors, etc.) or time-dependent, are represented by the Exponential distribution.

The exponential distribution is applied in reliability when the failure function is independent of time. This property of the exponential distribution is known as forgetfulness. The density function, the cumulative function, the expected value of the mean and variance are:

$$f(t) = \lambda\, e^{-\lambda t} \qquad \text{when } t \geq 0 \qquad (6)$$

$$F(t) = 1 - e^{-\lambda t} \qquad (7)$$

$$\mu = \frac{1}{\lambda} \qquad (8)$$

$$\sigma^2 = \frac{1}{\lambda^2} \qquad (9)$$

$$R(t) = e^{-\lambda t} \qquad (10)$$

In the machining work, when performing the analysis of the causes of non-conforming parts, some variables are generating failures due to the applied mechanical stress or strain, which due to tool wear varies over time. These variables are represented using the Weibull distribution. On

To evaluate the reliability of a random variable with a Weibull distribution, the following equation is used:

$$R(t) = \Pr(T \geq t) = \exp\left(-\frac{t}{\eta}\right)^{\beta} \qquad (5)$$

For the case where no failure times are available, it is proposed to use the method given in Piña [5]. The method allows estimating the parameters β and η of the Weibull distribution, from the observed or predicted principal stresses $\sigma 1$ (maximum) and $\sigma 2$ (minimum), thus allowing the calculation of the reliability R(t) for any desired stress value [5].

In the machining work, when performing the analysis of the causes of non-conforming parts, some variables are generating failures due to the applied mechanical stress or strength, which due to tool wear varies over time. These variables are

ISSN: 2594-1925

the other hand, the variables that are generating the failures and that are not of a mechanical nature (human, procedural, administrative factors, etc.) or time-dependent, are represented by the Exponential distribution [6].

Because the production process of parts in this type of machining shop is by high-mix, low-volume batches, the reliability of the man-machine system is affected by various products or part numbers, different types and characteristics of the material used, the various machines involved, as well as the different faults or defects that occur in the parts and produce scrap [7]. For this reason, reliability monitoring should be based on the causal factors of low reliability and the parameters of the distributions that describe the behavior of failures within the system components [8].

Some machining shops in the city of Chihuahua in the metal-mechanic sector have problems that do not allow them to meet delivery times by not completing production orders due to the presence of non-conforming parts in the scrap area. This generates high costs for them, in addition to the loss of their customers' confidence because they are not able to fulfill orders in due time and form. It was proposed to develop a method to monitor the reliability of the man-machine system, monitoring the parameters β (shape parameter) and η (scale parameter) of the component-subsystem combinations that follow a Weibull distribution [9].

This is to incorporate the monitoring information into the Series-Parallel statistical model, for the control and improvement of the reliability of the man-machine system, reducing the number of failures that generate scrap and can thus fulfill orders promptly. The monitoring of the changes in the Weibull parameters was done by monitoring the magnitudes of the stresses applied when manufacturing the parts [10].

2 Methodology

2.1 Man-machine system

The worker operates powered equipment, such as a tool or machine for production. This configuration is the most widely used in manufacturing systems. It involves combinations of one or more workers on one or more pieces of equipment; workers and machines combine to take advantage of their respective strengths and attributes [11].

2.2 Reliability

Suppose that T > 0 is a continuous random variable that records the failure time of a certain component that is in operation at time zero. We will denote by F(t) andf(t) the distribution and density function of this random variable. In reliability theory, it is of interest to know the probability that the component works correctly at least until any time t or the probability that it stops working at the next instant of time, given that the component has worked well until a certain time [12]. For this reason, the following two functions are defined: The reliability function is defined as R(t) = P (T > t), while the failure rate function is r(t) = f(t)/ (1 - F(t)). The reliability function is also called the survival function and the failure rate function is also known as the hazard function and is so called because a component that has survived to timet will fail in the interval (t, t + Δt] with conditional probability r(t) Δt + o(Δt), [13] in effect:

$$P\,(t < T \leq t + \Delta t \mid T > t) = \frac{P(t < T \leq t + \Delta t)}{P(t > t)} =$$

$$\frac{f(t)}{1-F(t)}\Delta t + o(\Delta t) = r(t)\,\Delta t + o(\Delta t)$$

$$r(t) = \frac{f(t)}{R(t)} = -\frac{d}{dt}\ln R(t)$$

Implying that the reliability function in terms of the hazard function is given by: R(t) = (- ∫t r(s)

ISSN: 2594-1925

ds) exp. In addition, the mean time to failure E(T) can be written in terms of the function R(t) as: $R(t) = \exp(-\int_0^t r(s)\, ds)$.

2.3 Reliability for serial systems

Consider a system of n components placed in series as shown in Figure 1. We will assume that each of these components works independently of the other. It is intuitively clear that such a system as a whole work if every component is in good condition [14]. We are interested in finding the reliability and failure rate functions of such a system. Note that the failure time T of such a system is the smallest failure time of each of the components, i.e., T =min {T1, Tn}. Thus, physical schemes of this type help to justify asking the question of finding the probability distribution of the minimum of *n* independent random variables, which, for time-dependent homogeneous systems, is the Weibull distribution [15].

Figure 1. Serial system representation.

The reliability and failure rate functions for series systems are presented below. We will denote by R1 (t), Rn (t) the reliability functions of each component in the system, and the failure rate functions will be r1(t), rn(t).

The reliability and failure rate functions of the series system are:

$$R(t) = R_1(t) * R_2(t) * \cdots R_n(t) \qquad (11)$$

$$r(t) = r_1(t) + r_2(t) + \cdots\ r_n(t) \qquad (12)$$

2.4 Reliability for Parallel Systems

In a system of n components placed in parallel, each of these components operates independently of the other, as shown in Figure 2. Such types of systems work as a whole if at least one of the components is in good condition. Systems of this type are used when it is desired to maintain a high level of operational reliability, such as aircraft flight systems, or nuclear reactor management systems. The failure time T of such a system is the largest failure time of the components, i.e., T = max {T1, ... , Tn}, where the event ($T \leq t$) is equivalent to all components failing before time t. The reliability function of the parallel system is:

$$R(t) = 1 - ((1 - R_1(t)) * (1 - R_2(t)) * \cdots (1 - R_n(t))) \qquad (13)$$

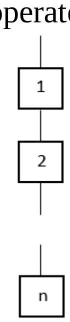

Figure 2. Parallel System.

ISSN: 2594-1925

2.5 Weibull distribution

The Weibull distribution is used in Reliability Engineering for failure time data and is useful to determine the probability that a part will fail after a certain time t. It is described by 2 or 3 parameters: shape (β), scale (η), and location (γ), which are present in the probability density function (pdf), where the failure time is given by:

$$f(t) = \frac{\beta}{\eta}\left(\frac{T-\gamma}{\eta}\right)^{\beta-1} * e^{-\left(\frac{T-\gamma}{\eta}\right)^{\beta}} \text{ (3 parameters)} \quad \text{o}$$

$$f(t) = \frac{\beta}{\eta}\left(\frac{T}{\eta}\right)^{\beta-1} * e^{-\left(\frac{T}{\eta}\right)^{\beta}} \text{ (2 parameters)}$$

2.6 Properties of the Weibull Distribution

The Weibull reliability function starts at β =1 since it is assumed that at the beginning of the mission, all the equipment is in good condition, and as time goes by the reliability decreases. For values of β less than 1 the reliability function decreases asymptotically. Like the density function, for values of β =1, the reliability function assumes the exponential form. The properties of the Weibull distribution are:

For β = 1 the curve decreases monotonically faster than for 0 < β <1.

2.7 Parameters of the Weibull distribution

It is useful first to know the effect of the different parameters of the Weibull distribution to be able to act:

Effect of the shape parameter. The shape parameter describes the way the data are distributed. A shape of β =3 approximates a normal curve. A low shape value, e.g., β =1, gives a curve with skewness to the right. A high shape value, e.g., β =10, gives a curve with skewness to the left.

Effect of the scale parameter. The scale, or characteristic life, is the 63.2 failure percentile of the data. The scale defines the position of the Weibull curve concerning the threshold value, which is similar to the way the mean defines the position of a normal curve.

Effect of the threshold value parameter. The threshold value parameter describes a shift of the distribution away from 0. A negative threshold value shifts the distribution to the left, while a positive threshold value shifts the distribution to the right [16].

3. Study case introduction

Case Study in a Machining Workshop, which starts with theprocess of collecting and analyzing the scrap generated, the evaluation of its reliability, and the identification of the worst reliability, as well as the monitoring of parameters. Research hypotheses were proposed and, to test them, different probabilistic and statistical tools were implemented. The direction of this research was guided by the testing of four issues that are shown below:

In the man-machine system there are activities whose risk or probability of failure depends on time and/or the failure is generated by mechanical stresses (friction, wear, etc.); that is, thedamage accumulates over time.

In the man-machine system, there are activities whose risk or probability of failure is constant and does not depend on time, of which it is possible to determine their mean and variance.

ISSN: 2594-1925

It is possible to combine activities and determine the reliability of each combination, in a series-parallel system, to determine the partial and total reliability of the system.

It is possible to monitor the parameters of each component-subsystem combination of the man-machine system, incorporating them into the series-parallel statistical model, due to its configuration, and detect the worst reliability.

3.1 Study Case

A machining shop in the metal-mechanical sector, located in the city of Chihuahua, whose production system is batch, high-mix-low volume, has semi-automated CNC machines for themanufacture of parts. The company has some problems that do not allow them to meet deliverytimes, because they cannot complete production orders due to the presence of nonconformingparts in the scrap area, which generates high costs, in addition to the loss of confidence of its customers. The workshop wants to improve its reliability, reducing the number of failures that generate scrap and thus be able to fulfill orders promptly.

3.2 Data Analysis

To test the hypotheses formulated and taking as reference the data from the machining shop, the following was carried out: Classification of faults or defects that occur in the manufacture of parts. Information was collected on the types of failures or defects that occurred in the manufacture of parts in the machining shop, from April 27 to June 2, 2021 [17]. These failures were classified by their origin (failure mechanism), using the Cluster Analysis Technique, developed through brainstorming generated by a work team made up of 2 operators, 1 maintenance technician, and a production supervisor. Table 1 shows the resulting classification of the type of failure byits origin.

Table 1. Classification of failure type by origin. Own design.

ORIGIN OF THE FAULTS					
Mechanic	**Mechanic Error**	**Human Error**	**Thermal Treatments**	**Material**	**Improvements**
3	22	1	43	26	42
4	23	2	49	30	45
5	24	10	50	33	
6	25	16	51	34	
7	28	17	52	58	
8	29	27	53		
9	31	32	55		
11	35	36	56		
12	37	39	57		
13	38	44			
14	40	54			
15	41				
18	46				
19	47				
20	48				
21					

ISSN: 2594-1925

In Table 1, the failure origins resulting from the analysis were identified as follows: mechanical, human error, heat treatments, material, and unforeseen events. Table 2 shows the frequency of failures by origin.

Table 2. Frequency table of failures by origin.

ORIGIN	NUMBER OF FAILURES	% RELATIVE	% ACCUMULATED
MECHANIC	31	53.45%	53.45%
HUMAN ERROR	11	18.97%	72.42%
THERMAL TREATMENTS	9	15.51%	87.93%
MATERIAL	5	8.62%	96.55%
IMPROVEMENTS	2	3.45%	100%
Total	**58**	**100%**	

Table 2 shows that one of the origins with the highest number of failures is the mechanical type, with 31 out of a total of 58 (53.54%). Figure 3 shows the Pareto Diagram of the origin of the type of failure, using the data from Table 2.

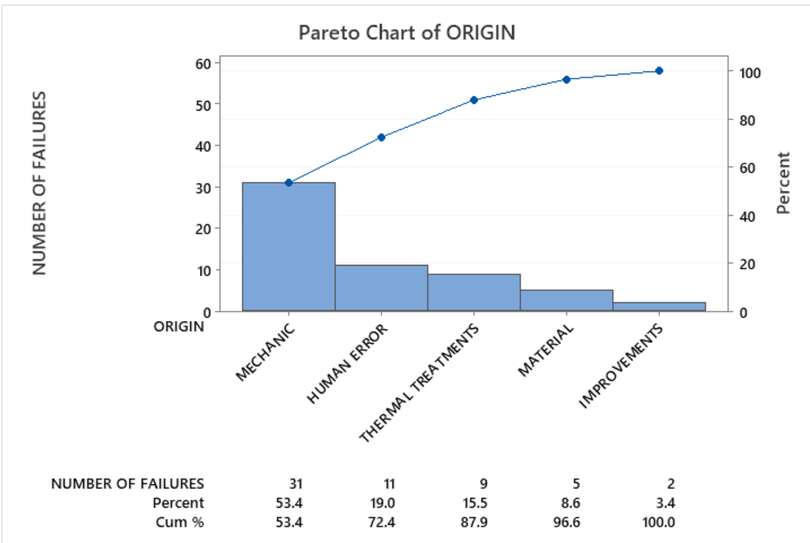

Figure 3. Frequency table of faults by origin.

3.3 Man-machine system model, for the identification of the combinations present in the failures of non-conforming parts for scrap.

The man-machine system is made up of the component-subsystem combinations and the subsystems that participated in the failures during the period analyzed. As a reference to identify the component-subsystem combinations that participated in the man-machine system, Figure 4 is presented. There are 24 possible component-subsystem combinations possibleto occur in a certain period. Only those combinations that have contributed to the generation of failures are considered for the reliability assessment, using the corresponding Weibull or exponential distribution, depending on the origin of the failure.

ISSN: 2594-1925

3.4 Component-subsystem combinations are present in failures

The times to failure generated by a certain component-subsystem combination together form a data distribution, either Weibull or Exponential, with their corresponding parameters.

Table 3. Combinations are present in the scrap.

COMBINATION	DESCRIPTION	WEIBULL/ EXPONENTIAL PARAMETERS		
		β	η	1/λ
1,1	MACHINE MAINTENANCE/SETUP	1	3.1667	
1,6	MACHINE-SUPPLIER	1	9.5	
2,1	TOOL MAINTENANCE/SETUP	1	9.5	
3,1	PROCESS//OPERATION-MAINTENANCE/SET UP	1.0688	3.1268	

Considering the parameters in Table 3, these are used to evaluate the reliability of each component-subsystem combination of the subsystems and the system. As can be seen, all participating combinations were analyzed with the Weibull distribution, since only failures of mechanical origin were involved.

3.5 Evaluation of the Reliability of the Subsystems and the Man-Machine System

Considering Equation 11 (series configuration) the reliability of each subsystem participating in the failures was evaluated. Considering Equation 13 (parallel configuration) the reliability of the man-machine system was evaluated. Table 5 shows the values of the reliability of the subsystems that were present in the scrap and the reliability of the man-machine system during the reviewed period, for 5 periods of time considered within the 9.5 hr. shift.

Table 4. Reliability of the combinations presents in the scrap from January 25 to 30, 2021, for 5 time periods.

PERIODS (hr.)	RELIABILITY OF THE SUBSYSTEMS (Rij) AND THE SYSTEM RS			
	R1	R2	R3	RS
1	0.6563	0.9	0.645	0.9878
3	0.2827	0.7292	0.2683	0.8579
5	0.1218	0.5907	0.1116	0.6807
7	0.0524	0.4786	0.0464	0.5289
9	0.0226	0.3877	0.0193	0.4131

Table 4 shows that 7 hours after the start of the shift, in subsystem 1 (machine), the probability of not having failures for scrap was 5.24%, while in subsystem 2 (tool) it was 47.86% and in subsystem 3 (process/operation) it was 4.64%, being the worst reliability of subsystem 3.86% and in subsystem 3 (process/operation) it was 4.64%, the worst reliability being that of subsystem 3. Concerning the reliability of the man-machine system, it showed a probability of 52.89% that no failures for

ISSN: 2594-1925

scrap would occur in 7 hours after thestart of the shift.

3.6 Component-subsystem combinations are present in failures

The times to failure, generated by a certain component-subsystem combination, together form a data distribution, either Weibull or Exponential, with their corresponding parameters. Table 5 shows the component-subsystem combinations that were present in the failure analysis.

Table 5. Combinations are present in the scrap.

COMBINATION	DESCRIPTION	WEIBULL/EXPONENTIAL PARAMETERS		
		β	η	1/λ
1,1	Machine-Manto/set up	3.4615	7.9737	
1,6	Machine-Supplier	2.1839	7.1972	
2,1	Tool-Manto/set up	1.5263	5.3284	
3,1	Process/Operation-Manto/set up	1.9091	2.3472	
3,3	Process/Operation-Institutional Condition/Attitude			9.5

As can be seen in Table 5, four of the five combinations were analyzed with the Weibull distribution, because they involve aspects of mechanical origin. The last combination was analyzed with the Exponential distribution because it involves aspects of human error origin. The Weibull ++ software was used to calculate the parameters of both the Weibull and Exponential distributions.

3.7 Evaluation of the reliability of the component-subsystem combinations

Considering thestatistical model to evaluate the reliability with each of the Weibull and Exponential distributionsof Equations 5 and 10 respectively, the reliabilities of each combination were evaluated. Table7 shows the values of the reliabilities of each component-subsystem combination that were present in the scrap, during the analyzed period, for 5 time periods considered within the 9.5 hr shift.

Table 6. Reliability of the combinations present in the scrap.

PERIODS (hr.)	RELIABILITY OF COMPONENT-SUBSYSTEM COMBINATIONS r_{ij}				
	$r_{1,1}$	$r_{1,6}$	$r_{2,1}$	$r_{3,1}$	$r_{3,3}$
1	0.6478	0.7382	0.7509	0.4433	0.9
3	0.2718	0.4023	0.4232	0.0871	0.7292
5	0.1141	0.2193	0.2387	0.0171	0.5907
7	0.0478	0.1195	0.1346	0.0037	0.4786
9	0.02	0.0651	0.0759	0.0006	0.3877

Table 6 shows that the component-subsystem combinations with the lowest

ISSN: 2594-1925

reliability value were 3.1 and 1.1, referring to Process/Operation-Maintenance/Set up and Machine-Maintenance/Set up, respectively, with Maintenance/Set up being the component in common.

3.8 Evaluation of the reliability of the subsystems and the man-machine system

Considering Equation 11, which considers a series configuration, the reliability of each subsystem participating in the failures was evaluated. Considering Equation 13 (parallelconfiguration) the reliability of the man-machine system was evaluated. Table 8 shows thevalues of the reliability of the subsystems that were present in the scrap and the reliability of the man-machine system, during the period reviewed, for 5 periods of time considered withinthe 9.5 hrs. shift.

Table 7. Reliability of subsystems and system, present in the scrap.

	SUBSYSTEM RELIABILITY (Rij) AND SYSTEM RELIABILITY RS			
PERIODS (hr.)	R1	R2	R3	RS
1	0.4782	0.7509	0.3990	0.9219
3	0.1094	0.4234	0.0635	0.5191
5	0.025	0.2387	0.0101	0.2653
7	0.0057	0.1346	0.0016	0.1409
9	0.0013	0.0759	0.0002	0.0773

Table 7 shows that 7 hours after the start of the shift, in subsystem 1 (machine), the probability of not having failures for scrap was 0.57%, while in subsystem 2 (tool) it was 13.46% and in subsystem 3 (process/operation) it was 0.16%. The worst reliability was that of subsystem 3. Concerning the reliability of the man-machine system, it showed a probabilityof 14.09% that no scrap failures would occur in 7 hours after the start of the shift.

4. Results

For the verification of the research, these were based in a theoretical-practical way, using mathematical and statistical models, as well as the Case Study. The procedure performed is described below. In the man-machine system, there are activities whose risk or probability of failure depends on time, and/or the failure is generated by mechanical efforts (by friction, wear, etc.), that is, the damage accumulates over time. time. For the evaluation of the reliability of the man-machine system, the Weibull distribution is used, since this distribution is appropriate when the variables that generate the failure are based on mechanical efforts, whose damage accumulates over time. To prove that in the man-machine system, there are activities whose probability of failure depends on time, and are due to mechanical stress, Table 8 is presented.

ISSN: 2594-1925

Table 8. Activities of the man-machine system are dependent on time and mechanical effort.

Activities	Time-dependent	Mechanical stresses
Cut		The pressure of the cutting tool against the metal of the workpiece.
Drilling	The cutting tool removes material in the form of chips from the workpiece and the sharpness of the tool suffers wear over time.	The material is cut by rotating a drill bit, which removes chips from the material, making a hole.
Turning		The cutting tool approaches the workpiece radially, which, when rotating, is provided with the cutting motion.
Milling		The rotary motion of a tool for cutting, feeding, or depth.
Grinding		The grinding wheel wears the workpiece as it advances towards the grinding wheel, by abrasive means.

Table 8 describes 5 activities carried out in the Machining Workshop that depend on the edge of the tool. When the cutting tool is installed new or just sharpened, after some time of machining parts and it loses its edge, it makes the efficiency of the cut depend on time. In addition, the failure is generated by efforts of the mechanical type, since the activity is carried out by the pressure of the cutting tool against the metal of the piece; therefore, the analysis used is the Weibull.

In the man-machine system, there are activities whose risk or probability of failure is constant and does not depend on time, from which it is possible to determine their mean and variance. With the use of mathematical and statistical models, it is shown that the probability of failure (risk) of the system may not be a function of time (Exponential). For the evaluation of the reliability of the man-machine system, the Exponential distribution is used, since this distribution is appropriate when the variables that generate the failure are not based on time. To prove that in the man-machine system, there are activities whose probability of failure does not depend on time, Table 9 is presented.

Table 9. Failures in the man-machine system are not dependent on time.

Activities	Not time-dependent
Process errors due to unfamiliarity with new processes and equipment	They occur per event and can be quantified.
Non-compliance with requirements by subcontracted suppliers	
Insufficient power capacity to keep machinery running	
Use of incorrect material due to carelessness	
Different finishes due to operator carelessness	

Table 9 describes 5 failures that occur in the man-machine system, caused by human error and unforeseen events, which do not depend on time and can be quantified to obtain the probability of failure; then the analysis to use is Exponential. Table 2 shows that the origin of human error type, has a frequency of 11, out of a total of 58, contributing 18.97%. Figure 3 shows the origin

ISSN: 2594-1925

of the type of failure, where failures of human-error origin are identified, together with failures of mechanical origin, as vital causes, contributing 72.5%. For reliability monitoring, the parameters of the Weibull and/or Exponential distributions were used, based on the occurrence of failures, according to the data recorded during 2 different periods of the year 2021. Table 3 shows the parameters of the component-subsystem combinations that were present in the failure analysis for the period from January 25 to 30, 2021, while Table 6 shows the parameters of the component-subsystem combinations that were present in the failure analysis for the period from May 17 to 28, 2021. Combinations 1,1;1,6; 2,1 and 3,1 contributed to the failures during the 2 periods analyzed, which involved machine-maintenance/set up; machine-supplier; tool-maintenance/set up, as well as process/operation-maintenance/set up. These combinations were considered to be mechanical in origin and time-dependent. Combination 3.3 occurred only during the last period analyzed and involved process/operation-institutional conditions/attitude.

This combination was considered to be of human error origin and not time-dependent. To evaluate the reliability of the combinations of both periods, the statistical models corresponding to the Weibull (Equation 5) and Exponential (Equation 10) distribution were used, depending on the origin of the failures. Table 4 presents the values of the reliabilities of each component-subsystem combination that was present in the scrap in the period from January 25 to 30, 2021, for 5 time periods considered within the 9.5 hrs. shift, while Table 6 presents the values of the reliabilities of each component-subsystem combination that was present in the scrap in the period from May 17 to 28, 2021, for 5 time periods considered within the 9.5 hours shift. For the 2 periods analyzed, the worst reliabilities were those of the combinations 3,1 and 1,1, referring to Process/Operation-Maintenance/Set up and Machine-Maintenance/Set up.

To evaluate the reliability of the subsystems and the man-machine system for both periods, the statistical model for a serial configuration was used (Equation 11). Table 5 shows the values of the reliability of the subsystems and the system for the period from January 25 to 30, 2021, for 5 time periods considered within the 9.5 hours shift, while Table 7 shows the values of the reliability of the subsystems and the system for the period from May 17 to 28, 2021. Table 5 shows that 7 hours after starting the shift, in subsystem 1 (machine), the probability of not having failures for scrap was 5.24%, while in subsystem 2 (tool) it was 47.86%, and in subsystem 3 (process/operation) it was 4.64%, with the worst reliability in subsystem 3. Table 8 shows that 7 hours after starting the shift, in subsystem 1 (machine), the probability of not having failures for scrap was 0.57%, while in subsystem 2 (tool) it was 13.46% and in subsystem 3 (process/operation) it was 0.16%. The worst reliabilities were those of subsystem 3 for the 2 periods analyzed, referring to the Process/Operation.

5. Conclusions

With the verification of hypothesis 1, it can be concluded that, with the use of mathematical and statistical models, it is demonstrated that the probability of failure (risk) of the man-machine system is time-dependent and is generated by mechanical type stresses, which occur in the manufacture of parts; the failures of mechanical origin presented in Table 2 and Figure 3, are an example of this. The man-machine system, as it participates in the failures that occur in the machining area, presents a risk rate or probability of failure that grows steadily. The Weibull distribution used to evaluate its reliability, represents the damage in an additive way, with a growth rate at a constant rate, through its shape

ISSN: 2594-1925

parameter β. This parameter remains constant and is also representative of the process variation and reliability that the data represents. The man-machine system is a dynamic process, so the location parameter γ of the Weibull distributionis not considered, only the parameters β and η. Failures of human error origin actively participate in the failures of the machining area due to the nature of the study, since it is a workshop that produces high-mix, low-volume batches, where operators, technicians, programmers, etc., make voluntary and involuntary errors when making changes to the process/operation, machines, tools and materials, produced by the frequent changes in the number of parts to be manufactured. For the above, on the man-machine system, there is a riskor probability of failure, which is not dependent on time, being of human error origin, reason enough for which the Exponential distribution is used for the evaluation of the reliability of the man-machine system. Mixing production batches, varying the type of material and/or the type of tool to be used, is when wear on the cutting tool can occur and this is what happens in reality in machining workshops, since large batches of the same part are generally not produced. It is also advisableto use a measuring tool that allows one to appreciate the wear on the cutting edge of the cutting tool, such as a microscopic optical comparator since with the vernier or the micrometer it is not always possible to appreciate the variation in the cutting edge of the tool.

6. Author acknowledgments

Rosa Ma. Amaya Toral: Conceptualización; Recursos; Ideas; Metodología; Análisis formal; Investigación; Recursos; Análisis de datos; Borrador original. *Manuel Baro Tijerina:* Conceptualización; Ideas; Investigación; Análisis de datos; Escritura. *Martha P. García Martínez:* Conceptualización; Ideas; Metodología; Análisis formal; Investigación; Análisis de datos; Escritura; Borrador original; Revisión y edición; Administración de proyecto. *Judith Valdiviezo Castillo:* Conceptualización; Ideas; Metodología; Análisis formal; Investigación; Análisis de datos; Escritura; Borrador original; Revisión y edición; Administración de proyecto.

References

[1] D. Morin, "The Hamiltonian method," Introduction to Classical Mechanics, With Problems and Solutions, no. October, 2008.

[2] J. C. Pardo, "A brief introduction to self-similar processes," Department of Mathematical Sciences, University of …, vol. 1, no. d, pp. 1-20, 2007.

[3] M. Baro-Tijerina, M. Piña-monarrez, and B. Villa-covarrubias, "Weibull Stress / Strength Analysis with Non-Constant Shape Parameter," 2017, pp. 1-6.

[4] R. L. Anjum and S. Mumford, Powers, Probability and Statistics, vol. 417. 2020. https://doi.org/10.1007/978-3-030-28722-1_8

[5] M. R. Piña-Monarrez, "Weibull stress distribution for static mechanical stress and its stress/strength analysis," Qual Reliab Eng Int, vol. 34, no. 2, pp. 229-244, 2018, https://doi.org/10.1002/qre.2251

[6] M. W. Fu and J. L. Wang, "Size effects in multi-scale materials processing and manufacturing," Int J Mach Tools Manuf, vol. 167, no. May, 2021, https://doi.org/10.1016/j.ijmachtools.2021.103755

[7] I. Gödri, "Improving Delivery Performance in High-Mix Low-Volume Manufacturing by Model-Based and Data-Driven Methods," Applied Sciences (Switzerland), vol. 12, no. 11, 2022, https://doi.org/10.3390/app12115618

[8] E. Zio, "Some Challenges and Opportunities in Reliability Engineering To cite this version: HAL Id: hal-01550063," IEEE transactions on Reliability, vol. 65, no. 4, pp. 1749-1782, 2016. https://doi.org/10.1109/TR.2016.2591504

[9] Z. S. Yea and M. Xie, "Stochastic modeling and analysis of degradation for highly reliable products," Appl Stoch Models Bus Ind, vol. 31, no. 1, pp. 16-32, 2015, https://doi.org/10.1002/asmb.2063

[10] R. M. Amaya-Toral et al., "Human-Machine Systems Reliability: A Series-Parallel Approach for Evaluation and Improvement in the Field of Machine Tools," Applied Sciences (Switzerland), vol. 12, no. 3, 2022, https://doi.org/10.3390/app12031681

ISSN: 2594-1925

[11] L. Rainie and J. Anderson, "The Future of Jobs and Jobs Training," Pew Research Center, no. May, pp. 1-95, 2017.

[12] H. Pham, Handbook of Engineering Statistics Springer Handbook of Engineering Statistics, vol. 21, no. 4. 1956.

[13] P. Baredar, V. Khare, and S. Nema, "Reliability assessment of biogas power plant," in Design and Optimization of Biogas Energy Systems, 2020, pp. 187-229. https://doi.org/10.1016/B978-0-12-822718-3.00005-8

[14] Erich Gamma, Design Pattersns. 2006. https://doi.org/10.1007/978-1-4302-0096-3_10

[15] P. Vassiliou and A. Mettas, "Understanding accelerated life-testing analysis," Annual Reliability and Maintainability Symposium, Tutorial Notes, pp. 1-21, 2001.

[16] B. Yaniktepe, O. Kara, I. Aladag, and C. Ozturk, "Comparison of eight methods of Weibull distribution for determining the best-fit distribution parameters with wind data measured from the met-mast," Environmental Science and Pollution Research, pp. 0-18, 2022, https://doi.org/10.1007/s11356-022-22777-4

[17] J. Brier and lia dwi jayanti, Research Methodology, vol. 21, no. 1. 2020.

ISSN: 2594-1925