Revista Iberoamericana para la Investigación y el Desarrollo Educativo
ISSN 2007 - 7467

https://doi.org/10.23913/ride.v12i24.1217

Artículos científicos

Metodología para medir la confiabilidad en líneas de ensamble

Methodology to Measure Reliability in Assembly Lines

Metodologia para medir a confiabilidade em linhas de montagem

Gilberto Orrantia Daniel
Tecnológico Nacional de México, Instituto Tecnológico de Hermosillo, México
gilberto.orrantiad@hermosillo.tecnm.mx
https://orcid.org/0000-0002-7191-0656

Jaime Sánchez Leal
The University of Texas at El Paso, Estados Unidos
jsanchez21@utep.edu
https://orcid.org/0000-0002-6324-2379

Jorge de la Riva Rodríguez
Tecnológico Nacional de México, Instituto Tecnológico de Ciudad Juárez, México
jorge.dr@cdjuarez.tecnm.mx
https://orcid.org/0000-0001-8402-0065

Rosa María Reyes Martínez
Tecnológico Nacional de México, Instituto Tecnológico de Ciudad Juárez, México
rosyreyes2001@yahoo.com
https://orcid.org/0000-0003-4950-5045

Ericka Berenice Herrera Ríos
Tecnológico Nacional de México, Instituto Tecnológico de Ciudad Juárez, México
ericka.hr@itcj.edu.mx
https://orcid.org/0000-0002-6964-5830

Resumen

La medición es un aspecto clave para evaluar el resultado de cualquier proceso. Las líneas de ensamble deben medirse considerando la confiabilidad tanto del producto como del proceso de producción. El propósito de este estudio fue desarrollar una metodología que permitiera conocer el estado de una línea de ensamble y que integrara un modelo de medición para obtener un índice de confiabilidad para una línea de este tipo de la industria automotriz. Los dos productos resultantes de este estudio fueron la metodología con su estructura en etapas y el modelo matemático. La metodología está compuesta de cinco etapas y el modelo de cuatro elementos. La confiabilidad pudo ser calculada para una línea de ensamble de la industria automotriz haciendo uso de la media de la distribución de mejor ajuste. Lo anterior permitió detectar el índice que más afectó a la confiabilidad general. El índice que más afectó al valor de confiabilidad general fue el de disponibilidad con 75.55 %, seguido del índice de eficiencia con 87.25 %, continuando con el índice de calidad con 90.15 % y, por último, con el menor efecto, está el índice de capacidad de entrega con 97.75 %.

Palabras clave: calidad, capacidad de entrega, confiabilidad, disponibilidad, eficiencia.

Abstract

Measurement is a key aspect to evaluate the result of any process. Assembly lines should be measured considering the reliability of both the product and the production process. The purpose of this study was to develop a methodology that would allow knowing the status of an assembly line and that would integrate a measurement model to obtain a reliability index for a line of this type in the automotive industry. The two products resulting from this study were the methodology with its structure in stages and the mathematical model. The methodology is composed of five stages and the model of four elements. Reliability could be calculated for an automotive assembly line using the mean of the best fit distribution. This made it possible to detect the index that most affected general reliability. The index that most affected the general reliability value was availability with 75.55 %, followed by the efficiency index with 87.25 %, continuing with the quality index with 90.15 % and, finally, with the least effect, is the index of delivery capacity with 97.75 %.

Keywords: quality, deliverability, reliability, availability, efficiency.

Resumo

A medição é um aspecto fundamental para avaliar o resultado de qualquer processo. As linhas de montagem devem ser medidas considerando a confiabilidade do produto e do processo de produção. O objetivo deste estudo foi desenvolver uma metodologia que permitisse conhecer o estado de uma linha de montagem e que integrasse um modelo de medição para obter um índice de confiabilidade para uma linha deste tipo na indústria automotiva. Os dois produtos resultantes deste estudo foram a metodologia com sua estrutura em etapas e o modelo matemático. A metodologia é composta por cinco etapas e o modelo por quatro elementos. A confiabilidade pode ser calculada para uma linha de montagem automotiva usando a média da distribuição de melhor ajuste. Isso possibilitou detectar o índice que mais afetou a confiabilidade geral. O índice que mais afetou o valor de confiabilidade geral foi a disponibilidade com 75,55%, seguido do índice de eficiência com 87,25%, continuando com o índice de qualidade com 90,15% e, por fim, com o menor efeito, é o índice de capacidade de entrega com 97,75% .

Palavras-chave: qualidade, capacidade de entrega, confiabilidade, disponibilidade, eficiência.

Fecha Recepción: Noviembre 2021 **Fecha Aceptación:** Junio 2022

Introduction

Currently, manufacturing companies seek to improve the reliability of their assembly lines (Golmohammadi, Tajbakhsh, Dia and Takouda, 2019; Ping-Chen, Yi-Kuei and Yu-Min, 2019). This in order to be competitive with respect to delivery time, production rates and quality standards that customers demand (Choomlucksana, Ongsaranakorn and Suksabai, 2015; Rodríguez, Sánchez, Martínez and Arvizu, 2015). To meet these requirements, companies often resort to various methods, among which one of the most popular is the world class, which is associated with production practices based on flexibility, continuous improvement and reliability, among many others. others (Petrillo, De Felice and Zomparelli, 2019).

To know the performance of the world-class philosophy, measurement is important. Even more, it is one of the key aspects that affect the growth and improvement of companies. If companies want to move forward and be competitive in the long term, they need to implement a proper performance measurement system to be able to systematically and continuously measure and evaluate each area of their business activities (Papulová, Gažová, Šlenker, & Papula, 2021).

One way to measure performance is through reliability. According to Ebeling (2019), reliability is the probability that a component or system will perform a required function during a given period of time when used under the established operating conditions, that is, it is the probability that a failure will not occur. over time.

One of the methods the automotive industry has used to assess the efficiency of its production processes is overall equipment effectiveness (OEE). Okpala and Anozie (2018) comment that OEE is an applied technique for the measurement of the main production characteristics, including performance efficiency, quality rate and availability. Its objective is to increase speed and reduce defective products, machine stops (downtime) and poor quality products by machines, as well as machines and equipment that work below their production capacity.

On paced assembly lines, all stations can start operations at the same time and also pass workpieces with the same frequency. In this type of lines, a fixed time value (cycle time) restricts the work content of the stations (Adeppa, 2015).

In paced assembly lines with conveyors, either belt or rail, the product moves through a number of workstations arranged in the required sequence. Each station or work zone is assigned to a certain number of assembly operations. In each area, one or more operators can work simultaneously, and the average production load of each of the operators in all areas must be the same. The equality of workload in the operators is what provides a constant rate of output of the product (Mauergauz, 2016).

The assembly lines of the automotive industry can be influenced by factors that affect the actions of human beings, such as the environment and the methods used in the development of the work itself. It should also be considered that they may vary due to raw materials, machinery and other factors. This variation can influence the reliability of the assembly line in the automotive industry. An unreliable system can cause many direct and indirect unexpected losses, for example: accidents, penalties for not meeting stipulated delivery dates, defective products, downtime, machine breakdowns, among others. (EI-Lawendy, 2013).

Of course, there are some methodologies to measure reliability, such as those carried out by El-Lawendy (2013) and Kostina, Karaulova, Sahno and Maleki (2012), among others. Regarding the work of El-Lawendy (2013), it is a model that proposes to calculate the reliability of a manufacturing system made up of people and machines. This model is based on three main aspects that come from the definition of reliability: function, time, and operational and environmental conditions. These three factors were brought together into a key performance indicator for the machine and the person in order to use it to rate performance. The trustworthiness of the people was measured with the work done, the rate of successful work through the HEART method and the idle time; Machine reliability was measured using production rate, mean time between failures, mean time to repair, and number of defective units. The integration of the reliabilities of people and machines was carried out with the reliability block diagram, either in series or in parallel.

Also, El-Lawendy (2013) proposed a series of steps to evaluate the reliability of a production system made up of people and machines. The series starts with defining the system components, then defining the design conditions and system goals, collecting the data, calculating component reliability, integrating human reliability and machine reliability to assess system reliability. production system and finally obtain the reliability of the system.

The reliability model presented by El-Lawendy (2013) was designed to be developed in organizations where the machines work under the supervision of the personnel, who perform small tasks such as feeding the machine with the material and operate without greatly influencing the reliability of the machine. manufacture, assembly and handling of products.

Tsarouhas and Arvanitoyannis (2014), For their part, they conducted a study where the reliability of an automated yogurt production line was analyzed. The series correlation and trend tests validated the assumption of independence and the equivalent distribution was applied to the failure data. And according to the failure data itself, the parameters of the best fit theoretical distribution were determined. In addition, they developed reliability and failure rate models for the entire production line. The models resulted in a useful tool for both assessing current conditions and predicting reliability to update yogurt line operations management policies.

In the study in question by Tsarouhas and Arvanitoyannis (2014) it was determined that the Weibull distribution provided the best fit for the yogurt production line to describe the time between failures; the failure rate of the production line increased, which implied that the currently applied maintenance strategy is not adequate and must be updated in the near future; and to avoid quality and productivity related losses, reliability needs to be improved initially in the pasteurization boiler and secondly in the filling machine.

Although this background is already available, there is still a need to apply studies to measure and analyze reliability, specifically to generate a methodology to measure the reliability of assembly lines in the automotive industry, taking into account machines, tools , its operators and other components, assuming that the methods are part of the production operators and that there is a controlled environment.

The objective of this research was to develop a methodology that would allow knowing the state of the system of an assembly line in the automotive industry and that would integrate a measurement model that would result in a reliability index. In addition, include the needs of customers in the reliability measurement model, referred to through the fulfillment of deliveries on time, production standards, quality and availability. As a complementary objective, the best fit distribution was selected for the delivery capacity, efficiency, quality and availability data (downtime and time between outages) to determine the parameter of the mean of said distribution and calculate the index of total reliability of an assembly line in the automotive industry, in addition to calculating the percentage of relative error that is avoided if instead of selecting a theoretical distribution assumed without verification, the best fit distribution is selected.

Theoretical framework

Probability distribution function

A probability distribution is a characterization of the possible values that a random variable can assume along with the probability of assuming them. A probability distribution can be discrete or continuous, depending on the nature of the random variable it models (Evans and Lindsay, 2015).

To generate the probability distribution for a continuous random variable, suppose you have a set of measurements on a continuous random variable and create a relative frequency histogram to describe the distribution of these; for a small number of measurements, a small number of classes can be used; then as more and more measurements are collected, more classes can be used and the class width reduced. The profile of the histogram will change slightly, most of the time becoming increasingly jagged. When the number of measurements gets very large and the class widths get very narrow, the relative frequency histogram appears more and more like a smooth curve, this smooth curve describes the probability distribution of the continuous random variable (Mendenhall, Beaver and Beaver, 2015).

For detailed reliability evaluations, it is important to choose a data distribution as the basis of estimation. The most widely used statistical distributions in reliability are the Weibull and the exponential (O'Connor and Kleyner, 2012). In addition, other distributions used in this study were normal, lognormal, logistic, and loglogistic.

Anderson–Darling statistic

The Anderson-Darling statistic measures how well the data follows a specific distribution, since, for a particular data set and distribution, the better the distribution fits the data, the lower this statistic will be. You can also use the Anderson-Darling statistic to compare the fit of various distributions to determine which is the best. However, to conclude that one distribution is the best, the Anderson-Darling statistic must be substantially smaller than the others. When the statistics are close to each other, additional criteria, such as probability plots, must be used to choose between them (Flores and Flores, 2021). The reliability for the selection of the parameters for the mathematical model is based on the Anderson-Darling statistic.

Materials and method

Materials

The materials needed for this research were a desktop computer, a laptop, an external data storage memory, a digital stopwatch, word processing software (Microsoft Word), software to create the database (Microsoft Excel), software of statistics (Minitab), articles of scientific and technological popularization that deal with the subject, data collection sheet (see annex 1) and an assembly line of the automotive industry with its production operators, machines or tools.

Method

The method applied in this study was determined in accordance with what Hernández, Fernández and Baptista (2014) mention. It started with an exploratory study because the topic in the automotive industry has been little studied. In this stage, it was sought to generate a methodology that would allow knowing the state of the system to be evaluated and that would integrate a reliability measurement model for assembly production systems based on the methodology and model presented by El-Lawendy (2013). and the integration of the OEE concept.

Subsequently, descriptive research was carried out, this is related to the field study where the methodology was tested along with its measurement model to determine the reliability of an assembly production system. Finally, an explanatory study was carried out to indicate the behavior to find the causes of low reliability and indicate where and how improvements should be made to the system.

Structure of the mathematical model

The mathematical model developed in this document is a variant of that proposed by El-Lawendy (2013). It should be noted that this model also considers the OEE concept and the just-in-time premises with the aim of satisfying customer demand in terms of time, quality and quantity and at the same time generating a minimum waste of time and resources in production. In this context, reliability is achieved through availability, avoiding line stoppages, with the ability to deliver to customers, with the efficiency of the line, and with the quality of the products that are manufactured.

Therefore, a single general reliability equation is structured that coincides with the key performance indicators such as efficiency, quantity fulfillment to customers, quality and availability. The mathematical model for calculating the reliability of an assembly line is in equations 1 and 2.

General reliability equation:

$$Confiabilidad = Índice\ de\ Capacidad\ de\ Entrega \times Índice\ de\ Eficiencia \times Índice\ de\ la\ Calidad \times Índice\ de\ Disponibilidad \tag{1}$$

Breakdown of the general reliability equation:

$$Confiabilidad = \left(\frac{Piezas\ Entregadas}{Piezas\ Acordadas\ con\ los\ Clientes}\right) \times \left(\frac{Piezas\ Fabricadas \times Tiempo\ Estándar}{Tiempo\ de\ Fabricación}\right) \times \left(\frac{Piezas\ No\ Defectuosas}{Piezas\ Producidas}\right) \times \left(\frac{TMEP}{(TMEP + TMDP)}\right) \tag{2}$$

With regard to the above, Freivalds and Niebel (2014) mention that the mean downtime (MTDP) is the one that represents the interruption of an operation due to machine or tool breakdowns, lack of material, etc. The concept of failures is expressed here as synonymous with the concept of production stoppages. In addition, the mean time between stops (MTEP) is considered to be the time available.

In the same sense, the objective of the mathematical model is to find a performance index of an assembly line in the automotive industry that also reflects the actual operation and that in turn facilitates the calculation of the probability that a system performs its intended function. for a specified period of time under a specified set of conditions.

Structure of the proposed methodology and its application

In addition to how to calculate reliability, a five-stage methodology is presented, structured as an extension of the methodology presented by El-Lawendy (2013), although with several changes. Following is the five-stage methodology:

Stage 1. Identify the study area

This consists of selecting, knowing and defining the components of the assembly line. Identification of the study area is the start of almost any project. The study was applied in an automotive assembly plant located in Hermosillo, Sonora, Mexico, specifically in the final assembly area, where the dashboard of automobiles of an internationally recognized brand is assembled. This is an automated line that is composed of several workstations in series, although configured as a single system because this dashboard travels from one station to another, attached to a mechanical device or conveyor rail, from which the dashboard It is disassembled until the end of the line and whose operation is carried out by means of a common control system at a constant rate for the entire line.

The assembly line is made up of 34 work stations; each of them can generate a production stoppage. At each station, operators perform manual operations, assembling parts to the board and in some cases performing various jobs where hand tools such as drills and barcode readers are used. The board assembly line typically operates three eight-hour shifts Monday through Friday and two eight-hour shifts on Saturdays.

Stage 2. Obtain information from the study area

This stage consisted of establishing the data collection plan. The data was collected using the format of annex 1 and these were complemented with those collected by the different areas involved, so that in the next stage it would be possible to empty the information in the database. Assembly line data was collected on 61 occasions and each time lasted one hour. Thus, a sample of 1,366 production stoppages was obtained, where 3,735 final products were manufactured and then reviewed by quality personnel.

For the delivery capacity, information was collected on the parts delivered and the parts planned to be delivered to customers. To obtain the efficiency index, information on manufactured parts, standard time per work station and total manufacturing time was collected. Regarding the quality index, the information collected was both the parts made and the defective parts. In relation to the availability index, information was collected on downtime caused by certain failures and operating times. This information was supplemented with information obtained from the manufacturing area, the production area, the quality area and the maintenance area. Other information collected included parts delivered per hour to customers, parts planned or agreed to be delivered per hour to customers, standard time per work station, and defective parts per hour.

The analyst, before starting the data collection, was located at a safe distance and as close as possible to the station under analysis in order not to affect or stop the activities of the assembly line.

Stage 3. Apply the mathematical model

Applying the mathematical model consists mainly of calculating the reliability of the system or process using equations 1 and 2. Once the data was collected, they were transferred to an Excel database for management and analysis. The data in Excel was arranged in different worksheets according to the station number to later generate summaries of this data.

The delivery capacity index was obtained for 61 samples using the part of equations 1 and 2 that corresponds to this index, from whose resulting data the best fit distribution and its parameters were found with the Minitab software. Then, from the 61 delivery capacity data of the assembly line, the best fit distribution (see table 1) and its parameters were determined using the Minitab software.

Tabla 1. Prueba de bondad de ajuste para el índice de capacidad de entrega, parámetros de distribución y porcentaje medio por distribución.

Distribución de los datos	Estadísticos de prueba y parámetros por distribución					
	AD (ajust.)	Valor-p	Ubicación	Forma	Escala	Media
Normal	9.922	< 0.005	0.96117	N/A	0.07511	0.961166
Lognormal	10.198	< 0.005	-0.04307	N/A	0.08703	0.961419
Exponencial	24.726	< 0.003	N/A	N/A	0.96117	0.961166
Weibull	10.631	< 0.010	N/A	25.41911	0.98717	0.966208
Logística	8.796	< 0.005	0.97747	N/A	0.03307	0.977473
Loglogística	8.872	< 0.005	-0.02417	N/A	0.03668	0.978288

Fuente: Elaboración propia

Table 1 shows that no distribution passes the test with the p-value, however, the distribution with the best fit is the one where the value of the Anderson-Darling statistic (adjusted AD) is smaller, this being the logistic distribution. From the parameters of the logistic distribution (see table 1), the average delivery capacity was determined, which represents the delivery capacity index for the entire assembly line, which is 0.977473, that is, 97.75%.

The efficiency index for the entire assembly line was calculated by means of the efficiency found for 61 samples using the part of equations 1 and 2 that corresponds to this index, only instead of using the standard time, the standard time was used. the latest station, since it is this station that sets the pace of the entire assembly line, whose resulting data was found the distribution of best fit and its parameters with the Minitab software. In this way, the efficiency index for the entire assembly line was determined according to the location parameter of the resulting best fit distribution.

Then, from the 61 assembly line efficiency data, the best fit distribution (see table 2) and its parameters were determined. Table 2 shows that some distributions passed the test with the p-value, however, the distribution with the best fit is the one where the value of the Anderson-Darling statistic (adjusted AD) is smaller, this being the Weibull distribution.

Revista Iberoamericana para la Investigación y el Desarrollo Educativo
ISSN 2007 - 7467

Tabla 2. Prueba de bondad de ajuste para el índice de eficiencia, parámetros de distribución y porcentaje medio por distribución

Distribución de los datos	Estadísticos de prueba y parámetros por distribución					
	AD (ajust.)	Valor-p	Ubicación	Forma	Escala	Media
Normal	0.879	0.062	0.87192	N/A	0.06830	0.871921
Lognormal	1.097	0.016	-0.14021	N/A	0.08112	0.871989
Exponencial	23.692	< 0.003	N/A	N/A	0.87192	0.871921
Weibull	0.663	> 0.250	N/A	16.07147	0.90166	0.872545
Logística	0.728	0.063	0.87625	N/A	0.03861	0.876255
Loglogística	0.796	0.033	-0.13359	N/A	0.04491	0.877858

Fuente: Elaboración propia

From the parameters of the Weibull distribution (see table 2), the average efficiency was determined, which represents the efficiency index for the entire assembly line, which is 0.872545, that is, 87.25%.

The quality index was determined directly using the part of equations 1 and 2 that corresponds to this index (see table 3).

Tabla 3. Índice de calidad para toda la línea de ensamble

	Piezas defectuosas durante el estudio	Piezas no defectuosas durante el estudio	Piezas realizadas durante el estudio	Índice de calidad por motivo de paro
Línea de ensamble	368	3367	3735	90.15 %

Fuente: Elaboración propia

The availability index was obtained by means of the stoppage times and the times between stoppages, in both cases the best fit distribution and its parameters were found with the Minitab software. The TMDP and the TMEP were determined in order to calculate the availability using the part of equations 1 and 2 that corresponds to this index.

To calculate the availability index, information was collected on downtimes and times between downtimes (availability) in seconds. In the case of the assembly line, 1,366 downtimes were analyzed. Then, from the 1366 assembly line downtimes, the best fit distribution (see table 4) and its parameters were determined.

Tabla 4. Prueba de bondad de ajuste para los tiempos de paro de la línea de ensamble, parámetros de distribución y tiempo medio por distribución

Distribución de los datos	Estadísticos de prueba y parámetros por distribución					
	AD (ajust.)	Valor-p	Ubicación	Forma	Escala	Media
Normal	161.169	< 0.005	25.37701	N/A	33.92373	25.3770
Lognormal	3.831	< 0.005	2.80268	N/A	0.89130	24.5227
Exponencial	37.514	< 0.003	N/A	N/A	25.37701	25.3770
Weibull	34.527	< 0.010	N/A	1.04516	25.93300	25.4790
Logística	73.114	< 0.005	19.61378	N/A	11.91564	19.6138
Loglogística	1.521	< 0.005	2.78672	N/A	0.49222	25.1012

Fuente: Elaboración propia

As previously mentioned, the distribution with the best fit is the one where the value of the Anderson-Darling statistic (adjusted AD) is smaller and in this case it is the loglogistic distribution, however, in the analysis carried out with the Minitab software it turned out that there is another distribution with a better fit, namely the three-parameter loglogistic distribution with Anderson-Darling statistic (adjusted AD) = 1.289, location parameter = 2.75735, scale = 0.5098, threshold value = 0.40174, and mean time = 25.6516.

Now, in the same sense, to calculate the availability of the entire assembly line, 1347 times between stops (availability) in seconds were also analyzed. Then, from the 1347 times between stoppages of the assembly line, the distribution of best fit was determined (see table 5) and its parameters.

Revista Iberoamericana para la Investigación y el Desarrollo Educativo
ISSN 2007 - 7467

Tabla 5. Prueba de bondad de ajuste para los tiempos entre paro de la línea de ensamble, parámetros de distribución y tiempo medio por distribución

Distribución de los datos	Estadísticos de prueba y parámetros por distribución					
	AD (ajust.)	Valor-p	Ubicación	Forma	Escala	Media
Normal	204.862	< 0.005	94.02376	N/A	135.92492	94.0238
Lognormal	68.883	< 0.005	4.13216	N/A	0.78257	84.6174
Exponencial	102.276	< 0.003	N/A	N/A	94.02376	94.0238
Weibull	101.813	< 0.010	N/A	1.03293	95.64631	94.3968
Logística	133.751	< 0.005	69.14656	N/A	45.64676	69.1466
Loglogística	60.641	< 0.005	4.02370	N/A	0.42423	76.6734

Fuente: Elaboración propia

Again, it is commented that the best fit distribution is the one where the value of the Anderson-Darling statistic (adjusted AD) is smaller and in this case it is the loglogistic distribution, however, in the analysis carried out with the Minitab software it turned out that there is another distribution with a better fit, the three-parameter loglogistic distribution with the Anderson-Darling statistic (AD adjusted) = 53.915, location parameter = 3.87275, scale = 0.47816, threshold value = 6.87773 and with a mean time = 79.2648.

To calculate the availability index of the entire assembly line, the part of equations 1 and 2 corresponding to this index was used, where the TMDP = 25.6516 and the TMEP = 79.2648. Therefore, the availability index for the entire assembly line is 0.7555 and in percentage is 75.55%.

Once all the indices of the general reliability equation were calculated (see equations 1 and 2), it was possible to calculate the reliability index of the entire assembly line. Table 6 is a summary where the value of the reliability index of the assembly line is found considering the distributions of best fit for each index and the value per index that makes up the general reliability.

Tabla 6. Índice de confiabilidad de toda la línea de ensamble y distribución de mejor ajuste por componente de la confiabilidad.

	Índice de capacidad de entrega	Índice de eficiencia	Índice de calidad	Índice de disponibilidad	Índice de confiabilidad	Confiabilidad (%)
Índices con distribuciones de mejor ajuste	0.9775	0.8725	0.9015	0.7555	0.5809	58.09 %
Distribución de mejor ajuste	Logística	Weibull	N/A	TMDP = 25.6516 con loglogística 3p		
				TMEP = 79.2648 con loglogística 3p		

Fuente: Elaboración propia

Stage 4. Carry out the analysis of results

Table 7 shows the number of stoppages and the stoppage time per stoppage generating station. In this table it is observed that the station that generates the greatest number of stoppages is station 10 with 197 stoppages accumulated during the study, while the stations that do not generate stoppages are stations 1, 27, 28, 30 and 32, which results in a total of 1,366 stoppages accumulated during the study for all the stations on the line.

In the same table 7 there is also the stoppage time in seconds per stoppage generating station. In this regard, it is observed that the station that generates the longest downtime is station 10 with 5081 lost seconds accumulated during the study, while the stations that do not generate downtime are stations 1, 27, 28, 30 and 32, which results in a total of 34,665 seconds lost, which is equivalent to 9,629 hours unemployed accumulated during the study.

Tabla 7. Cantidad de paros y tiempo de paro en segundos por estación generadora del paro.

Cantidad de paros y tiempo de paro en segundos por estación generadora del paro								
Estación	Frecuencia de paros	Tiempo de paro en segundos	Estación	Frecuencia de paros	Tiempo de paro en segundos	Estación	Frecuencia de paros	Tiempo de paro en segundos
1	0	0	13	48	826	25	18	395
2	64	3465	14	86	1352	26	12	297
3	27	544	15	30	845	27	0	0
4	30	685	16	31	705	28	0	0
5	117	3005	17	88	1917	29	1	7
6	31	809	18	33	848	30	0	0
7	57	1268	19	1	269	31	2	26
8	30	885	20	43	1115	32	0	0
9	22	774	21	42	1315	33	39	588
10	197	5081	22	36	1027	34	56	1321
11	69	1404	23	80	1775	Total	1366	34665
12	38	844	24	38	1273			

Fuente: Elaboración propia

With respect to the delivery capacity index for the entire assembly line, it presents a trend towards the objective value that every organization pursues, that is, at 1 or 100%, and follows a logistic distribution with a mean of 0.977473. Regarding the efficiency index, it was determined that, based on the data sample, this index follows a Weibull distribution with a mean of 0.872545. The quality index for the entire assembly line was 90.15%, without considering a distribution of best fit because a single number was obtained (see table 3).

Regarding the availability index for the assembly line, when treating the data in seconds of the downtime, it was found that they follow a loglogistic distribution of three parameters, with a location parameter = 2.75735, scale = 0.5098, threshold value = 0.40174 and with a mean time = 25.6516. Next, when treating the data in seconds of the time between stoppages related to the availability index for the entire assembly line, it was found that they follow a three-parameter loglogistic distribution with location parameter = 3.87275, scale = 0.47816, threshold value = 6.87773 and with a mean time = 79.2648.

The index that most affected the general reliability value was availability with 75.55%, followed by the efficiency index with 87.25%, continuing with the quality index with 90.15% and, finally, being the index that least affected the value of general reliability was that of delivery capacity with 97.75%.

Stage 5. Make the proposal for improvement or recommendations

The reliability index obtained for this case study, applied to a car dashboard assembly line, was 58.09% and the index that most affected this value was availability with 75.55%. Therefore, it is advisable to increase the availability index, attending first to what affects the most. The elements that affect availability are the TMDP and the TMEP. In the case of the former, it is convenient to have a very low or zero TMDP, and in the case of the latter, it is beneficial to have a very high TMEP; in this way a high availability rate can be ensured.

Attention to problems on the assembly line requires a team of conscientious individuals, where the assembly line operators are the ones who have the ability to discover, correct anomalies and learn from those mistakes so as not to continue with them. In addition, it is necessary to ensure that operators have optimal conditions in order to increase the effectiveness of the line's operation.

It is important to consider that downtimes are the main problems that are present in this study, however, currently in this organization there is no sufficiently documented system to be able to measure the process under study in a balanced way.

The current computer system generates some data to quantify the number of minutes that are presented by each station and for the total assembly line, but not for the causes or reason for stoppage. In addition, the analysis mechanisms that can provide information and focus efforts to reduce both the number of stoppages and stoppage times are not established.

This organization has many support elements, manufacturing engineering, maintenance, quality, systems department and others, however, it will be necessary to consider the development of adequate communication together with a structuring of procedures that allow information to be taken from analyzes to make the respective improvements.

In the same sense, it is advisable to establish more efficient communication systems so that the personnel that provides the raw materials have more precise information and thus meet the demands for materials in advance.

With regard to the systems department, it is advisable to establish direct communication with the production department of the board assembly area and establish a problem solving team so that when a problem occurs it is possible to initiate and establish containment actions and then establish prevention actions using some problem-solving methodology.

That is, for improvement, problem-solving teams can be formed using the seven basic quality tools or methodologies such as the eight disciplines, among others.

Results

The results show that, using the methodology in conjunction with the measurement model, the reliability index can be obtained. The foregoing is consistent with the objective of this research, which was to develop a methodology that allows knowing the state of the system to be evaluated and that integrates a measurement model that yields a reliability index for an assembly line in the automotive industry.

The methodology in this study resulted in five stages: 1) identify the study area, 2) obtain information from the study area, 3) apply the mathematical model, 4) perform the analysis of results and 5) make the proposal for improvement or recommendations.

Regarding the measurement model of this study, it was possible to obtain a reliability index for an assembly line in the automotive industry. For this, the delivery capacity for the assembly line was first calculated according to the best fit distribution of the collected data; then the efficiency index for the assembly line was calculated according to the best fit distribution of the collected data; then the quality index for the assembly line was calculated, and finally, the availability index for the assembly line was calculated.

Discussion

To determine the elements of the methodology, the study by El-Lawendy (2013) was taken into account, who, to evaluate the reliability of a production system made up of people and machines, proposed six steps: 1) define the components of the system, 2) define the design conditions and system objectives, 3) collect the data, 4) calculate the reliability of the components, 5) integrate the reliability of people and the reliability of the machine to evaluate the reliability of the production system and 6) rate the reliability of the system.

In the methodology presented in this study, most of the steps of the methodology developed by El-Lawendy (2013) are included, although without considering the last step, annexing the implementation of the improvement proposal or recommendation and without considering contribution weights. in the indices that make up the general reliability equation.

Conclusions

The objective was fulfilled by presenting the methodology that allowed knowing the status of the system to be evaluated and the mathematical model that resulted in a reliability index for an assembly line in the automotive industry.

To avoid any percentage of relative error, the best fit distribution of the data must be considered. Alternatively, there is the option of choosing the index distributions with the smallest relative error. The important thing is to find the means by distribution and select the mean with the best-fit distribution to input into the reliability formula.

The best fit distributions are the best in all indices; even so, it is possible to observe different alternative scenarios, among them the most optimistic would be to select the distributions with the least relative error and the most pessimistic would be to select the distributions with the greatest relative error.

With regard to the above, for the delivery capacity index, the data of the mean of the logistic distribution fits very well and as an alternative scenario it can be the mean of the loglogistic distribution, not recommending the mean of the normal distribution or the mean of the exponential distribution. For the efficiency index, the mean of the Weibull distribution fits very well and as an alternative scenario the mean of the lognormal distribution can be chosen, not recommending the mean of the loglogistic distribution. For the quality index, it is obtained by formula without considering any distribution.

The availability index, like the quality index, is obtained by formula, with the difference that it is considered the mean of the distribution of best fit for downtime and the mean of the distribution of best fit for downtime. between stops. For the TMDP it is appropriate to consider the mean of the loglogistic distribution of three parameters and as an alternative scenario it can be the mean of the Weibull distribution, not recommending the mean of the logistic distribution. For the TMEP it is appropriate to consider the mean of the loglogistic distribution of three parameters and as an alternative scenario it can be the mean of the loglogistic distribution, not recommending the mean of the Weibull distribution.

In addition, where there is greater relative error is in the average of the stoppage times and the times between stoppages. It should be remembered that both are used to calculate the availability index. Which means that the general reliability index mainly depends on the result obtained in the means of the best fit distributions for both the stoppage times and the times between stoppages.

The main resulting products in this study were on the one hand the methodology with its structure in phases and on the other hand the mathematical model. On the part of the methodology, it is composed of five stages. On the part of the mathematical model, it is composed of four elements.

When applying both the methodology and the mathematical model in an assembly line, the index that most affected the general reliability value was availability with 75.55%, followed by the efficiency index with 87.25%, continuing with the quality index with 90.15 % and, finally, the index that least affected the general reliability value was the delivery capacity with 97.75%.

Regarding availability, it turned out to be the lowest index and, therefore, the one that most affects. The elements involved in its calculation are the TMDP and the TMEP. In the case of the former, it is convenient to have a very low or zero TMDP, and in the case of the latter, it is beneficial to have a very high TMEP; in this way a high availability rate can be ensured.

Regarding the operators, we recommend maximizing their skills and knowledge about the operations to be carried out at the work stations, about the characteristics and conditions of the raw materials to be assembled and about the tools to be used, with adequate training for the specific needs of the operator. each workstation and each individual.

Furthermore, addressing assembly line problems demands a team of conscientious individuals; Assembly line operators must have the ability to discover, correct anomalies, and learn from those mistakes so as not to continue with them. In addition, it should be sought that the operators have the optimal conditions in order to increase the effectiveness of the line's operation.

Undoubtedly, the information and data for its treatment are important, therefore, it is advisable to obtain more information for a longer time to find those missing ones. In addition, it is advisable to monitor month by month the behavior of the reliability index and of all the indices that must be calculated to obtain the reliability index. Finally, it is advisable to implement the proposed methodology in more production lines.

Future lines of research

It is important to extend this investigation towards the detection of the causes that generate an increase or decrease in each of the indices declared in this document in order to obtain and improve the reliability of the system. The concepts of industry 4.0 and visual factory, which in essence seek to achieve efficient monitoring and communication, can be extended to help find the causes and thus generate focused projects to obtain an increase in system reliability. It is possible to establish online measurement or instant monitoring systems with the help of sensors and electronic devices that provide indexes from the monitoring of the causes and that these are presented to both management and customers so that they feel as part of the company. organization. At the end of the day, that is the trust or reliability that customers demand from their suppliers.

References

Adeppa, A. (2015). A Study on Basics of Assembly Line Balancing. *International Journal on Emerging Technologies*, *6*(2), 294-297.

Choomlucksana, J., Ongsaranakorn, M. and Suksabai, P. (2015). Improving the Productivity of Sheet Metal Stamping Subassembly Area Using the Application of Lean Manufacturing Principles. *Procedia Manufacturing*, *2*, 102-107. Retrieved from https://doi.org/10.1016/j.promfg.2015.07.090.

EI-Lawendy, D. (2013). *An Approach to Evaluate Integrated Human - Machine System Reliability*. Saarbrücken, Germany: Verlag/Publisher.

Evans, R. J. y Lindsay, M. W. (2015). *Administración y control de la calidad* (9.ª ed.). Ciudad de México, México: Cengage Learning.

Flores, C. E. y Flores, K. L. (2021). Pruebas para comprobar la normalidad de datos en procesos productivos: Anderson-Darling, Ryan-Joiner, Shapiro-Wilk y Kolmogorov-Smirnov. *Societas*, *23*(2), 83-106.

Freivalds, A. y Niebel, B. W. (2014). *Ingeniería industrial. Métodos, estándares y diseño del trabajo* (13.ª ed.). México: McGraw-Hill.

Golmohammadi, A., Tajbakhsh, A., Dia, M. and Takouda, P. M. (2019). Effect of timing on reliability improvement and ordering decisions in a decentralized assembly system. *Annals of Operations Research*, *312*, 159-192. Retrieved from https://doi.org/10.1007/s10479-019-03399-5.

Hernández Sampieri, R., Fernández Collado, C., & Baptista Lucio, M. (2014). *Metodología de la Investigación* (Sexta ed.). México: McGRAW-HILL.

Kostina, M., Karaulova, T., Sahno, J. and Maleki, M. (2012). Reliability estimation for manufacturing processes. *Journal of Achievements in Materials and Manufacturing Engineering*, *51*(1), 7-13. Retrieved from http://jamme.acmsse.h2.pl/papers_vol51_1/5111.pdf.

Mauergauz, Y. (2016). *Advanced Planning and Scheduling in Manufacturing and Supply Chains.* Moscow, Russia: Springer International Publishing Switzerland. Retrieved from https://link.springer.com/book/10.1007/978-3-319-27523-9.

Mendenhall, W., Beaver, R. J. y Beaver, B. M. (2015). *Introducción a la probabilidad y estadística* (14.ª ed.). Ciudad de México, México: Cengage Learning.

O'Connor, P. D. and Kleyner, A. (2012). *Practical Reliability Engineering* (5th ed.). New Delhi, India: John Wiley & Sons.

Okpala, C. and Anozie, S. (2018). Overall Equipment Effectiveness and the Six Big Losses in Total Productive Maintenance. *Journal of Scientific and Engineering Research*, *5*(4), 156-164.

Papulová, Z., Gažová, A., Šlenker, M. and Papula, J. (2021). Performance Measurement System: Implementation Process in SMEs. *Sustainability*, *13*(9), 1-19. Retrieved from https://doi.org/10.3390/su13094794.

Petrillo, A., De Felice, F. and Zomparelli, F. (2019). Performance measurement for world-class manufacturing: a model for the Italian automotive industry. *Total Quality Management & Business Excellence*, *30*(7-8), 908-935. Retrieved from https://doi.org/10.1080/14783363.2017.1408402.

Ping-Chen, C., Yi-Kuei, L. and Yu-Min, C. (2019). System reliability estimation and sensitivity analysis for multi-state manufacturing network with joint buffers-A simulation approach. *Reliability Engineering and System Safety*, *188*, 103-109. Retrieved from https://doi.org/10.1016/j.ress.2019.03.024.

Rodríguez, R., Sánchez, D., Martínez, J. L. and Arvizu, E. (2015). A case study: SMED & JIT methodologies to develop continuous flow of stamped parts into AC disconnect assembly line in Schneider Electric Tlaxcala Plant. *IFAC-PapersOnLine*, *48*(3), 1399-1404. Retrieved from https://doi.org/10.1016/j.ifacol.2015.06.282.

Tsarouhas, P. H. and Arvanitoyannis, I. S. (2014). Yogurt production line: reliability analysis. *Production & Manufacturing Research*, *2*(1), 11-23. Retrieved from https://doi.org/10.1080/21693277.2014.881268.

Anexo 1

Figura 1. Formato de recopilación de datos.

Fecha	# de estación	Nombre del operador						
Turno		Nombre de la persona que captura						
Hora de inicio del paro	Hora de fin del paro	Motivo del paro: oper, herr, mat, otro (especif)	Falla o problema.	Comentario (acción tomada)	Hora inicio rotaciones			
					Rot	391/533	Rot	391/533
Hora inicio ausencia o demora operador	Hora fin ausencia o demora operador	Cubierto por otro operador (si/no)	Motivo de ausencia o demora operador	Comentario				
Periodo del turno en que se presenta el defecto	Tipo de defecto	Cantidad de piezas con el defecto	Defecto debido a: oper, herr, maq, mat, otro (especif)	Comentario (acción tomada)				
					Hora fin rotaciones			

Fuente: Elaboración propia

Rol de Contribución	Autor (es)
Conceptualización	Gilberto Orrantia Daniel «principal» Jaime Sánchez Leal «que apoya» Jorge de la Riva Rodríguez «que apoya»
Metodología	Gilberto Orrantia Daniel «principal» Jaime Sánchez Leal «que apoya»
Software	Gilberto Orrantia Daniel
Validación	Gilberto Orrantia Daniel «principal» Jaime Sánchez Leal «que apoya»
Análisis Formal	Gilberto Orrantia Daniel «principal» Jaime Sánchez Leal «que apoya»
Investigación	Gilberto Orrantia Daniel
Recursos	Gilberto Orrantia Daniel
Curación de datos	Gilberto Orrantia Daniel
Escritura - Preparación del borrador original	Gilberto Orrantia Daniel
Escritura - Revisión y edición	Ericka Berenice Herrera Ríos
Visualización	Gilberto Orrantia Daniel
Supervisión	Jaime Sánchez Leal «igual» Jorge de la Riva Rodríguez «igual» Rosa María Reyes Martínez «igual»
Administración de Proyectos	Gilberto Orrantia Daniel
Adquisición de fondos	Gilberto Orrantia Daniel