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Statistical Analysis of Stoppages of A Metal Stamping Line: A Case Study

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Abstract:

Purpose: This article seeks to establish a statistical analysis to estimate the time of stoppages in a stamping line, which have a high variability that generates an unreliable scenario for the production program. Likewise, this document shows the methodological sequence to carry out a statistical analysis in a case study at an industrial level, considering variables of a real scenario.

Design/methodology/approach: The methodological sequence is divided into five stages. Initially, the information of the stamping process was collected, later the types of stoppage were categorized according to the characteristics of the process. A collection of historical data information on stoppage times was carried out. With the information collected, the percentage frequency of occurrence of stops due to tool changes and incidents in the process was determined, and they were characterized by a Weibull distribution. Finally, to verify the effectiveness of the downtime behavior, a model was developed to simulate the availability of the stamping line in the Vensim PLE® program.

Findings: The model showed that the frequency analysis and the Weibull distribution obtained a similar behavior to reality. The study verified that it is necessary to establish a categorization of the characteristics of the downtimes, according to the characteristics of the pieces produced to evaluate the information, in this way, the times of change by tooling were established through a frequency of use and the stoppages by additional incidences to the process were better.

Research limitations/implications: The basis for this study is the reliability of the information, especially in the data record. It has the disadvantage that the bias of the analyst is present when the information is recorded and analyzed.

Practical implications: The methodology presented in this article is a reference for industrial applications in which it is required to establish improvement scenarios based on the reduction of stoppages present in the production lines.

Originality/value: The importance of this study is that it was possible to establish a suitable workload allocation in the presses to optimize production.

Keywords: statistical analysis, stoppages, production, simulation

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1. Introduction

Work stoppages and downtime in production processes are very common, however its impact on the performance of the process is almost always unknown. The complexity is that a detailed record of stoppages times is not enough, but it is necessary to analyze them thoroughly. The analysis of their behavior allows setting scenarios to establish planning and decision-making options in the situations that arise in the production process.

Currently there are different studies focused on the analysis of stop times by statistical methods for later evaluation in the production process. Some studies take into consideration the development of maintenance plans and others a direct evaluation through simulation techniques.

Research by Barabadi, Barabady and Markeset (2014), demonstrated the application of reliability models with variables in the field of spare part predictions through a case study. Tsarouhas and Arvanitoyannis (2010), applied the normal distribution to determine the failure times and the logistic distribution for the repair times, with the aim of identifying the best fit of failure data in a reliability study for the packaging of beer production. Tsarouhas and Besseris (2017), tested and selected an optimal statistical model after considering several distributions, allowing them to make estimates of availability for different periods of time. Later, Tsarouhas (2018) conducted an investigation to determine which probability distribution provides the best fit to characterize the failure pattern at the levels of machinery and production line. Song, Li, Wang, Zhi and Wang (2019), used system based on BP (Back Propagation) neural network and two parameter-Weibull distribution to predict the dynamic failure rate of chemical process. This method can achieve a continuous dynamic prediction for future failure time points.

Gasca, Camargo and Medina (2017) analyzed and modeled the equipment reliability using Weibull, Logistics and Normal distributions, to determine the mean time between failures. This procedure provides indicators to make decisions that prevent unplanned downtime of equipment. More complex applications are presented in the study carried out by Assid, Gharbi and Dhouib (2015), who proposed a general control policy for a production system, in order to obtain optimal control parameters that minimize the total cost incurred for a specific level of customer service.

For this it is assumed that failures, repairs and urgent delivery times can be represented by any probability distribution. On the other hand, Huang, Chang, Zou, Arinez and Xiao (2018), establish a maintenance control law to schedule profitable maintenance, where production times are considered under normal conditions and generate a function for cost control.

In the field of simulation, the work developed by Sakurahara, Schumock, Reihani, Kee and Mohaghegh (2019) stands out, who developed a probabilistic methodology to improve the Common Cause Failure Analysis in the evaluation of probabilistic risk, where they generate data based on the simulation for the estimation of probability. Ståhl, Gabrielson, Andersson and Jönsson (2012) incorporated the statistical analysis of idle times, making use of both empirical and theoretical distribution functions, which apply to operating times and idle times. In the end, dynamic behavior is analyzed, involving cost terms, with the simulation. Alizadeh, Eskandari and Sajadifar (2017), assume an inventory system for continuous decaying items with stochastic lead time and Poisson demand, with the objective to minimize the expected long-run total cost of the inventory system, finally the simulation model is validated by statistical hypothesis test for the deterministic lead time case.

The stoppage times that occur during the production process of a stamping line are highly preferred, since they directly depend on the production requirements and combination of components.

The objective of this work is to determine the behavior of the stops caused by tool changes through statistical analysis in order to propose a reliable scenario for the development of a production program, which directly impacts the real availability to meet the customer's requirements. For this, a frequency percentage of occurrences of the stops was obtained according to the characteristics of the die used and the production combination, as well as a characterization with Weibull distribution for the incidences of the process. To verify the results obtained, a simulation of the production process was carried out in the Vensim® program, in which the impact of stoppages in future scenarios and the feasibility of production programs were evaluated considering the behavior of stoppages.

2. Materials and Method

To carry out the statistical analysis and evaluation of its behavior in a stamping line, five stages were required, which are explained below. Firstly, it was necessary to evaluate the types of stoppages that occur during the production process, classify them and analyze the main cause of their occurrence. Secondly, it was necessary to categorize the types of stoppages, this refers to associating them according to the type of part produced considering the characteristics of the process, since there are tools of different tonnage and modes of operation. As a third stage, we came up with the collection of information in order to obtain historical data and to be able to evaluate the behavior of downtime. Once the information was processed, the statistical analysis was carried out, in this fourth stage the type of distribution that would allow analyzing the behavior of stoppage times according to the previous categorization will be finished. Finally, in the fifth stage, the behavior of the stoppage times in the stamping line was evaluated using a model developed in the Vensim PLE® program.

2.1. Classification of Stoppages

The process of planning and controlling the production of the stamping line determines the amount of finished product that must be placed in the customer's plant on specific days and allows calculating the production requirements by operation to manufacture the finished product.

Once the stamping line personnel (supervisors) receive the plan, they translate it into orders and proceed to prepare the production orders. Once the supervisor reviews the production requirements of the requested components (material, press and die to be used), the workload for each of the presses is prepared. The operator receives verbal notification from the supervisor of the component to be produced. At that time, the tooling and/or sheet change is carried out, as the case may be.

Finally, the normal production of the assigned batch is carried out, once the production of the assigned batch is completed, the supervisor assigns a new workload, and at the end of the shift, it notifies and records the production of the line with the production control and planning department. The stamping line consists of 15 presses; 8 of them work manually and 7 work progressively, in Figure 1 the available types of presses are presented.

(a) (b)

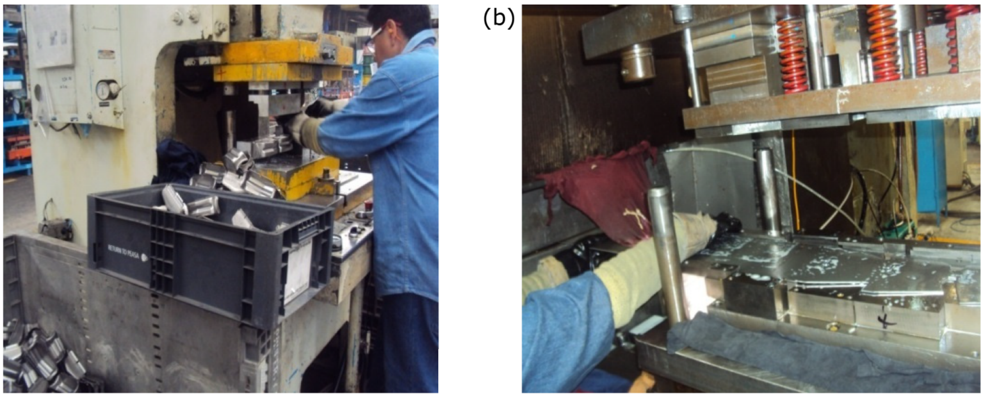


Figure 1. Types of presses used in the stamping line (a) manual press and (b) progressive press

Around 2000 pieces are manufactured in the stamping line, between finished and semi-processed products in blanking, deep drawing or sheet-metal-forming operations. Because each piece and material have specific characteristics in its operating conditions, there is a high variability in the times of stoppages for the change of tooling, as well as delays attributed to incidents of the process. This situation has a direct impact on the delivery time, causing delays in the deadlines for the delivery of finished product.

It was found that each piece has specific characteristics in relation to its production time, tool preparation time, material and delay times. This last feature is caused by activities related to the process; these effects are explained below. Tooling change times affect the initial input workflow since it is assembly, adjustment of operating conditions and initial inspection of the process. The selection of tooling (press and die) is predetermined by the design and manufacturing characteristics of the finished product, that is, that a particular product is assigned to use the press and the die needed for its operation.

The delay times caused by incidents in the process correspond to times that affect the continuous workflow of the production process of a workpiece. Activities that generate these delay times are the setting of the piece in the workplace, setting of the piece in the container and/or box, parts lubrication, cleaning of the tray, setting of boxes of finished product and testing of inspection. This causes small stoppages to occur continuously within the workflow, and additional times are generated to produce the final piece.

In both situations it was found that the stoppages were not considered within the standard production and were not categorized according to the type of piece to be produced considering the characteristics of its process. When this is considered, an adequate workload allocation can be established in the presses, not only seeing the delivery priority criteria, but also the processing times and delaying times as part of the production schedule planning.

2.2. Categorization of Stoppages Time

It was determined that the 2000 pieces are made in the stamping line, share certain characteristics in relation to the requirement of material, tooling to be used, operating conditions and family of products. This allowed us to establish two proposals for grouping, which helped to gather and analyze information, for further evaluation according to statistical methods.

2.2.1. Group Proposal 1. Process Characteristics and Material Requirements.

It was identified that tooling change times depend on the characteristics of the dies, the press in which they will be used and the material change requirement. For this grouping proposal, firstly, the size of the die and the amount of clamping nuts used for its placement in the press were taken into account. Being obtained when the dimension of the die is higher, also it requires more time for preparation of the tool.

Second, the material change requirement was analyzed. If a sheet change is necessary, then the option with power (AC) is considered, which only occurs in presses that work progressively. The proposal for grouping these characteristics is established in Table 1.

Characteristics	Presses	Grouping code
Die height < 300 mm. Two clamping nuts. The operation performed on this die does not include material feed.	Presses of 45, 60, 80, 110, 160 and 200 Tons	Die MWOF (Medium die without feed)
Die height > 300 mm. Eight T clamping nuts. The operation performed on this die does not include material feed.	Straight side presses of 300 Tons	Die LWOF (Large die without feed)
Die height > 300 mm. Eight T clamping nuts. The operation performed on this die include material feed.	Straight side presses of 300 Tons	Die LWF (Large die with feed)

Table 1. Group proposal 1, considering process characteristics and material requirements

2.2.2. Group Proposal 2. Operation Mode

The delay times attributed to additional activities to the process, depend directly on the number of components produced and the mode of feeding of the material to be used in the process, which can be manual or automatic.

If the sheet is automatically supplied to the process, it is not necessary to stop the press to perform activities such as setting the parts or lubricating. On the other hand, if the material is fed manually, a series of continuous stoppages occur to setting the boxes of finished product, inspect the process, lubricate during the process and place the parts. The suggested proposal is summarized in Table 2.

Grouping code	Characteristics
Parts WOF (Parts without feed)	Manual feeding. Activities of setting pieces in workplace, in box or container, lubrication of parts, cleaning the burr tray, arrangement of boxes of finished product and inspection tests, are carried out.
Parts WF (Parts with feed)	Automatic feeding. Activities of cleaning the burr tray, disposal of finished product boxes and inspection tests are presented.

Table 2. Group proposal 2. Operation mode

2.2.3. Group Proposal 3. Proposal for Group 1 and 2

Considering that the second classification depends on the material feeding mode, it can be directly related to the group proposal 1, considering the type of die to be used. The proposed classification based on the operation mode of each component and its relation to the type of die, is summarized in Table 3.

From both proposals it can be concluded that the processes with manual feeding will be presented as many scheduled stoppages, but when the feeding of the material is automatic, the stoppage time due to change of tooling will be the longest. The frequency in both cases depends directly on the different quantities of pieces to produce.

Grouping code 1	Grouping code 2
Die MWOF (Medium die without feed) Die LWOF (Large die without feed)	Parts WOF (Parts without feed)
Die LWF (Large die with feed)	Parts WF (Parts with feed)

Table 3. Group proposal for group 1 and 2

2.3. Information Log

Once the characteristics of the pieces were categorized, the information was registered. For this, the production of a significant month for the company was analyzed, registering both the quantity and the combination of production, where the registration of 138 by-products was obtained. 80% of this production corresponds to 110 pieces, whose production frequency is significant for the stamping line.

For the study, a format was designed to record the times of the different activities during the production process both manually and automatically. Registered activities consist of change of tooling and material, operating conditions, work cycle and external elements.

This study was carried out during the three work shifts contemplated by the company and the average qualified operator was evaluated. Subsequently, the time recording method was followed with a stopwatch, by the continuous method. This method considers not to zero the stopwatch when a time is recorded, but is accumulating, this allowed us to record the full time of the entire cycle without omissions.

2.4. Statistical Analysis

Once the information was consolidated, the statistical analysis of the downtimes was carried out. For this, the best fit of the distribution curve was evaluated, taking as reference the behavior of the data obtained in the frequency histogram. In the case of stoppages for the change of tooling it was determined that it was necessary to establish a percentage of frequency taking into account the characteristics of the parts. It was also considered to use the Weibull distribution to have a value of reliability with which predictions of such behavior can be made.

In the case of stoppages attributed to delays due to incidents, once the distribution curves have been obtained, a normal distribution is observed skewed to the left and with a large variation of classes to the right. What is sought with the use of probabilistic models is knowing with certainty what is the work performance time of the equipment for which it was created and considering certain specific operating conditions (Gutiérrez & De la Vara, 2014). It is important to mention that equipment failures (stoppages machines) registered (measurable) over time are non-negative values that often have an asymmetric behavior with positive bias (Gutierrez & De la Vara, 2014).

This makes them have a different distribution than the normal distribution that usually has a symmetrical behavior, so in this case it is advisable to use the Weibull distribution. Another important factor to consider is the distribution of risk, in the normal curve the risk is usually always increasing and depends directly on standard deviation, whereas for Weibull may be increasing, constant and decreasing. The effectiveness of the Normal and Weibull curves was verified by the goodness of fit test by the Kolmogorov-Smirnov (K-S) method, and the probability distribution of the error of the functions obtained was evaluated. This method is a non-parametric test used to verify the normality of a distribution where it is more sensitive to values near to the median than to the limits of the distribution.

2.5. Development of the Simulation Model

Based on the System Dynamics (SD) methodology, we developed a model to apply the probability functions and the frequency of occurrence of stoppages times, using the Vensim PLE® simulation software. This software offers certain advantages because it is easy to understand and allows a quick design of the model, structured by the variables and incorporation of equations.

In our model we evaluate the behavior of the availability percentage for the stamping line during the month in which the study was carried out. The model consists of flow variables and auxiliary variables for determining the behavior of stoppages as a function of time and evaluate the accumulations of the variables of interest.

3. Results and Discussion

Figure 2 shows the consolidation of the frequency and times of scheduled and unscheduled stoppages.

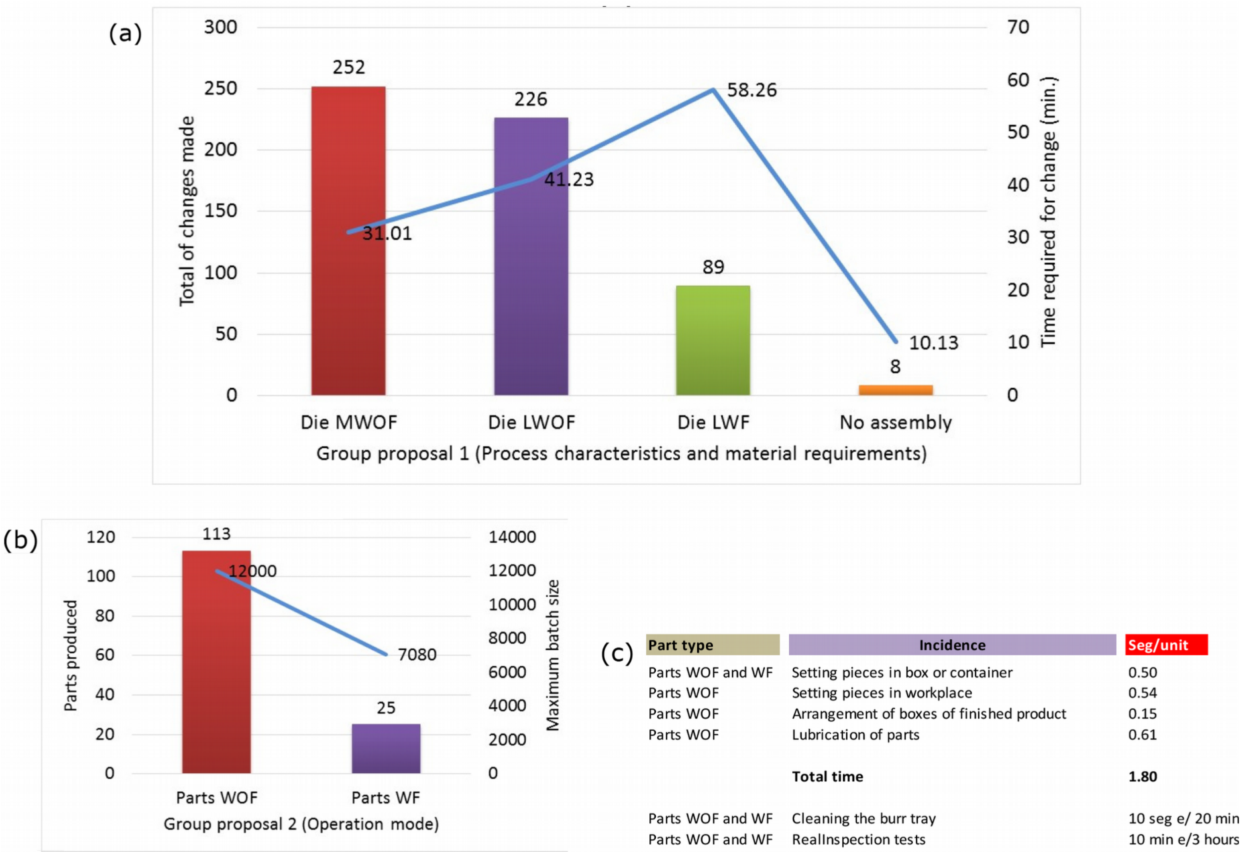


Figure 2. Consolidated data for stoppages times: (a) change of tooling; (b) delays due to incidents of the process and, (c) explanation of time incidents.

The average times of the change of tooling and material, according to the proposal of grouping 1, can be observed in Figure 2(a). During the period under which the study was carried out, 567 changes of tooling were recorded, of which 252 correspond to the dies of a dimension smaller than 300 mm and whose feeding of the material was manual. Also 226 changes were made in dies with manual feed and with the same dimensions as the previous die. Finally, 89 changes were made in dies with dimensions greater than 300 mm, and with automatic material feeding. Finally, 8 changes were made in the only hydraulic press. We decided to include this category, because although this press does not perform assembly, inspection and adjustment of initial conditions are performed.

From the result of the average time analysis it can be established that for each part that uses a die larger than 300 mm and with automatic feeding, 58 minutes are required to change of tooling. In this case, where a die of the same size is required, but without considering the automatic feeding of the material, 41 minutes are required. Lastly, for dies with dimensions smaller than 300 mm and with manual material feeding, 31 minutes are required.

The result of the observations and record of times made for stoppages caused by incidents of the process, is shown in Figure 2(b). During the month of study, there was a production of 113 pieces where the material feed system was manual, also the highest recorded batch was 12,000 units. In the same month, 25 pieces were registered with automatic material feeding conditions, where the largest batch size registered was 7080 units.

It is important to mention batch sizes because to record incidents, such as the case of setting in a box, container and workplace, it was necessary to consider the amount of components handled by the operator, in order to estimate the average time of setting per unit. In the case of the activities of removing tray and inspection tests, it was necessary to record the frequency with which these activities were performed to determine their total time during the production process.

In Figure 2(c), it is observed that, for each piece produced, where the feeding system is manual, 1.80 seconds correspond to delay times attributed to additional process activities. On the other hand, when the material feeding system is automatic, only 0.5 seconds are recorded for each piece produced. For both parts (with and without automatic feed), it should be considered that for every 20 minutes of production a 10-second stop is recorded to remove the tray burr, and every 2 hours a 10-minute stop is presented to inspect the production. With this information we proceeded to perform statistical analysis. General data and frequency histogram for stoppages times are shown in Figure 3.

In the case of Figure 3(a), which corresponds to the stoppages due to tooling change, a behavior according to the frequency of occurrence of change of tooling and material was obtained. That is, the varying behavior of these times is controlled by the combination of production. In the case of the behavior of the stoppage times due to incidents, Figure 3(b) shows that the data are skewed to the left, that is, the longest unscheduled stoppage time occurs in the ranges of 30 minutes to 2 hours.

The frequency histogram and the trendline curve obtained above can represent the way in which the stop times are distributed. However, to analyze the variability in the behavior of the data is necessary to determine the frequency of occurrence of time caused by changes of tooling. Because these are directly dependent on the combination of production and the probability function of stoppages caused by incidents.

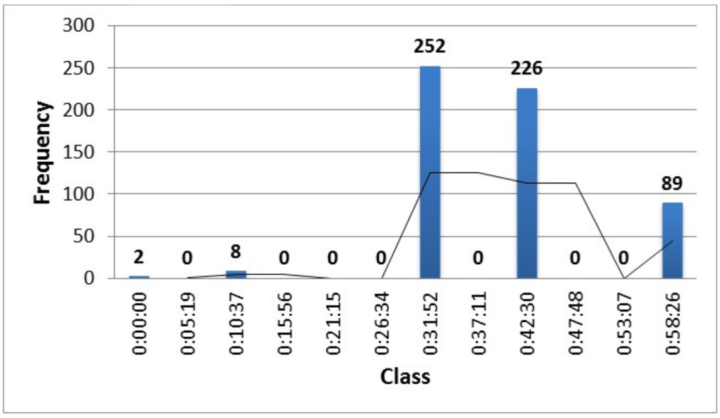
3.1. Stoppages Time Caused by Change of Tooling

The amount and stoppages times for tooling change are closely related to the frequency of production of different types of pieces. Since each tooling change time depends directly on the type of piece to be produced, considering that the feeding of the material can be manual or automatic.

Besides this it was determined that there is a factor of 4.16 ratio between the parts to produce and the amount of change per piece. This means that for each type of part to be considered for the production process, on average will be made 4 changes of tooling for each of them. For the analysis presented, if the total of 138 types of by-products is multiplied by this factor, a total of 575 changes is obtained.

(a)

Mean	0:38:55
Typical error	0:00:26
Median	0:41:23
Mode	0:31:01
Standard deviation	0:10:15
Sample Variance	0:00:04
Kurtosis	18:33:01
Asymmetry coefficient	0.37851767
Range	0:58:26
Minimum	0:00:00
Maximum	0:58:26
Sum	374:11:29
Count	577
Class number	10.1671037
	11
Amplitude	0:05:19



(b)

Mean	0:57:27
Typical error	0:01:42
Median	0:46:20
Mode	1:09:00
Standard deviation	0:40:42
Sample Variance	0:01:09
Kurtosis	206:12:53
Asymmetry coefficient	2.21
Range	5:32:13
Minimum	0:00:00
Maximum	5:32:13
Sum	552:25:08
Count	577
Class number	10.167
	11
Amplitud	0:30:12

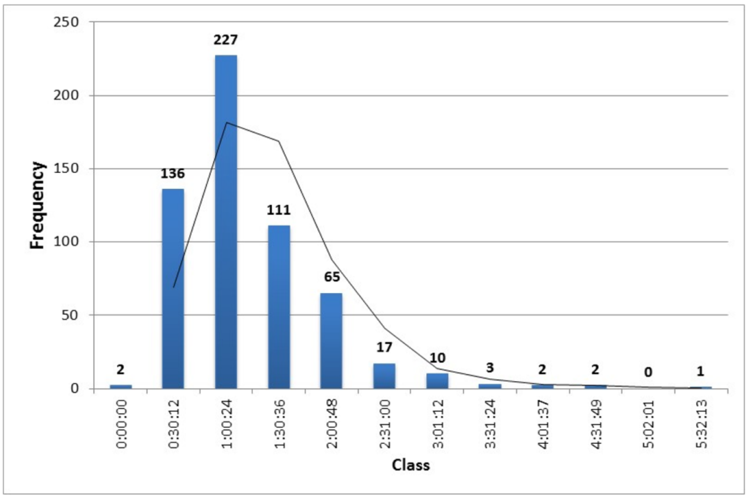


Figure 3. General statistical data and histogram: (a) tooling change time and, (b) delay time attributed to process incidents.

From Figure 2(a), the percentage of participation of the 138 by-products and percentage of participation of the dies were analyzed, as follows:

a) 63 by-products needed a large die (larger than 300 mm) without automatic feeding. That is to say, 46% of the total volume of production had an average of 41 minutes of scheduled stoppages and the percentage of utilization of this die was 39%.

b) While 49 by-products were made in a medium die (less than 300 mm) without automatic feeding. This corresponds to that 36% of the production volume showed 31-minute stoppages and the die used had a 44% share.

c) With a percentage of less than 18%, 25 by-products were made in a large die (greater than 300 mm) with automatic feeding, representing 28 minutes of stoppages and a percentage of utilization of this die of 15%.

d) Finally, only a by-product was made that represents 1% in the hydraulic press, in which the assembly is not carried out, but if inspection activities are performed.

From this, it follows that the frequency of use of the die depends on the frequency with which each of the types of parts are produced and it is possible to establish a direct relationship between the two. To verify that the frequency percentage is duly established, three months of production were evaluated. For each month it was considered to determine the times of stoppages due to change of tooling according to the percentages explained here, later they were compared with the real results once the production plan was executed. The results of this verification are shown in Figure 4.

Month 1
Items to produce 125 125
Ratio 4.17 Total of changes 521

Type of die used (grouping 1)	Item				Die				Stoppage time (min)			
	% Participation	Theoretical	Actual	% Difference	Frecuencia de uso	Theoretical	Actual	% Difference	Average tiem	Theoretical	Actual	% Difference
Die MWOF	46%	58	59	1.7%	39%	203	204	0.5%	41	8331	8581	2.9%
Die LWOF	36%	45	44	-2.3%	44%	229	227	-0.9%	31	7106	6929	-2.6%
Die LWF	18%	23	22	-4.7%	15%	80	81	1.2%	58	4654	4723	1.5%
Hydraulic press	1%	1	1.3	0.0%	1%	7	7	0.0%	10	73	72	-1.8%

Month 2
Items to produce 118
Ratio 4.17 Total of changes 492

Type of die used (grouping 1)	Item				Die				Stoppage time (min)			
	% Participation	Theoretical	Actual	% Difference	Frecuencia de uso	Theoretical	Actual	% Difference	Average tiem	Theoretical	Actual	% Difference
Die MWOF	46%	54	53	-1.9%	39%	192	198	3.2%	41	7862	8176	3.8%
Die LWOF	36%	42	40	-4.9%	44%	216	213	-1.6%	31	6706	6472	-3.6%
Die LWF	18%	21	23	8.6%	15%	76	74	-2.3%	58	4392	4501	2.4%
Hydraulic press	1%	1	1	1.7%	1%	7	7	4.4%	10	69	67	-2.9%

Month 3
Items to produce 130
Ratio 4.17 Total of changes 542

Type of die used (grouping 1)	Item				Die				Stoppage time (min)			
	% Participation	Theoretical	Actual	% Difference	Frecuencia de uso	Theoretical	Actual	% Difference	Average tiem	Theoretical	Actual	% Difference
Die MWOF	46%	60	58	-3.1%	39%	211	210	-0.6%	41	8661	9094	4.8%
Die LWOF	36%	47	47	0.4%	44%	238	239	0.3%	31	7388	7573	2.4%
Die LWF	18%	23	24	2.5%	15%	83	85	1.9%	58	4838	4911	1.5%
Hydraulic press	1%	1.3	1	0.0%	1%	8	8	0.0%	10	76	73	-4.0%

Figure 4. Scenario evaluation for three months, considering the frequency of participation of the article and frequency of use of the die.

The results of the evaluation showed that there is a variation of less than 5%, in the percentage of use of die, in the participation of the type of piece and in the times of accumulated stoppages, so it is considered that the ratio is appropriate and can be used to establish future scenario analysis.

3.2. Stop Times Caused by Process Incidents

To analyze the stoppages caused by incidents, the different curves of continuous probability distributions that best fit the behavior of the frequency histogram were evaluated. In this way, it was determined that the distributions of continuous variable probability to be considered to perform the analysis would be Normal and Weibull distribution. For this their characteristics and applications were considered (Badii & Castillo, 2009).

Once the parameters $\mu = 57.27$ $\sigma = 40.41$ have been determined, it is possible to establish the probability distribution function considering a normal distribution, which is established by (1).

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad f(x) = \frac{1}{102.0098} e^{-\left(\frac{1}{2}\right)*\left(\frac{x-57.27}{40.42}\right)^2} \tag{1}$$

The behavior of the graph in Figure 5(b) indicates that the mean value of the data is greater than the median, so that most of the data is above the value of the arithmetic mean. Therefore, it can be concluded that there is a greater probability that the delay times will last more than 57 minutes in the production program cycle contemplated.

The parameters of the Weibull distribution were obtained by the method of maximum likelihood. It was decided to choose this method since there is no significant variation in the method to use (Serrano, 2013) and by using MATLAB® software to obtain the parameters, modifying part of the source code (Fernandez, 2011). The probability distribution considering the parameters obtained $\alpha = 1.5651$ and $\beta = 64.6239$ is established by (2).

$$f(x;\alpha,\beta) = \left\{\left(\frac{\alpha}{\beta}\right)\left(\frac{x}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x}{\beta}\right)^{\alpha}}\right\} \qquad f(x;\alpha,\beta) = \left\{\left(\frac{1.5621}{64.6239}\right)\left(\frac{x}{64.6239}\right)^{1.5621-1} e^{-\left(\frac{x}{64.6239}\right)^{1.5621}}\right\} \tag{2}$$

Since the Beta value (β = 64. 6239) is greater than 1, the risk function is increasing, that is, the failure rate increases with increasing time. Similarly, as the Beta value decreases, the distribution form resembles a Normal probability density function. The similarity between both graphs is notorious and according to the values obtained from the Beta value in the two functions, both behaviors can be represented as a Normal distribution.

(a)

Class	*Frequency*	*Min**	*Normal distribution*	*% Distribution*	*Weibull distribution*	*% Distribution*
0:00:00	2	0	0.004	8%	0.000	0%
0:30:12	136	30	0.008	25%	0.012	26%
1:00:24	227	60	0.010	53%	0.009	59%
1:30:36	111	91	0.007	79%	0.005	82%
2:00:48	65	121	0.003	94%	0.002	93%
2:31:00	17	151	0.001	99%	0.001	98%
3:01:12	10	181	0.000	100%	0.000	99%
3:31:24	3	211	0.000	100%	0.000	100%
4:01:37	2	242	0.000	100%	0.000	100%
4:31:49	2	272	0.000	100%	0.000	100%
5:02:01	0	302	0.000	100%	0.000	100%
5:32:13	1	332	0.000	100%	0.000	100%
	576		0.004	8%		

Mean	0:57:27	alpha	1.5621
Standard deviation	0:40:42	beta	64.6239
Median	0:46:20		
*Minutes			

(b)

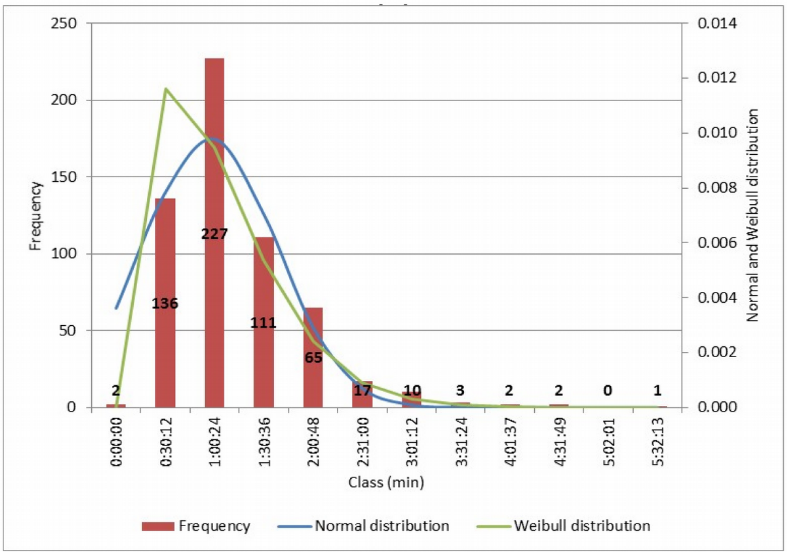


Figure 5. (a) Distribution percentage Normal and Weibull, and (b) normal and Weibull distribution function

3.3. Effectiveness of Adjusting the Distribution Curves

It is important to analyze whether the distribution curves obtained (Normal and Weibull) are appropriately adjusted to the data set of time delays. In the Kolmogorov-Smirnov (K-S) goodness of fit test, a comparison between some cumulative and theoretical distribution function is carried out. For the case study, it corresponds to the comparison of the Normal and Weibull distribution functions in relation to the actual data.

x_i - is the "ith" value observed in the sample (whose values have been previously sorted from lowest to highest);

$F_n(x_i)$ - is an estimator of the probability of observing values less than or equal to x_i;

$F_o(x_i)$ - is the probability of observing values less than or equal to x_i when H_0 is true.

Thus, D is the largest absolute difference observed between the observed cumulative frequency $F_n(x_i)$ and the theoretical cumulative frequency $F_o(x_i)$ obtained from the probability distribution specified as a null hypothesis.

The statistical test for goodness of fit K-S, is shown in 3.

$$D = Sup_{1\le i\le n}|F_n(x_i) - F_o(x_i)| \quad (3)$$

3.3.1. Criteria for Decision Making

If $D \le D\alpha \rightarrow$ *Accept* H_O otherwise the hypothesis is rejected.

The value of $D\alpha$ is obtained from the Table of Critical Values for this type of goodness of fit test, where this value depends on the size of the selected sample and not on the type of function being analyzed.

For the practical calculation of the D statistic, the following values must be obtained by (4), (5) and (6)

$$D^+ = MAX_{1\le i\le n}\left\{\frac{i}{n} - F_o(x_i)\right\} \quad (4)$$

$$D^- = MAX_{1\le i\le n}\left\{F_o(x_i) - \frac{i-1}{n}\right\} \quad (5)$$

$$D = max\{D^+, D^-\} \quad (6)$$

3.3.2. Goodness of Fit Test

If $H_O = X \sim N(56.23, 37.63)$ and $W(1.5621, 64.6239)$ the analyzed data follow a normal and/or Weibull distribution

If $H_1 = no\ H_O$. The analyzed data do not follow a normal and / or Weibull distribution.

Figure 6 shows the estimated parameters (D^+, D^-) for the first and last data of each of the probability distribution curves, considering a sample of 577 data.

		N	
i	*xi*	*Fo(xi)*	
1	0	0.0666	
2	0	0.0666	
3	10.0524	0.1085	
⋮	⋮	⋮	

Figure 6. Calculation of the D^+ and D^- values for the Normal and Weibull distribution

The following is a summary of the calculation for the D + and D- values for the delay time data for each of the distribution functions. From these data the test statistic calculation is performed, and the validity of the null hypothesis is analyzed:

$$D_{Weibull}(0.05511) \le D_\alpha(0.056617) \rightarrow Accept\ H_O$$

The data fit a Weibull distribution

$$D_{normal}(0.1099) \ge D_\alpha(0.056617) \rightarrow Rejected\ H_O$$

The data do not fit a Normal distribution. Therefore, when performing the goodness of fit test by the Kolmogorov-Smirnov (K-S) method, the values of the delay times are adjusted to a Weibull distribution curve, but do not conform to a Normal distribution curve.

3.4. Error Distribution

Once the probabilistic distribution curve that best fits the behavior of the real data has been determined, it is necessary to analyze the probabilistic distribution of the error generated by the behavior of the probabilistic curves with the actual data, see Figure 7.

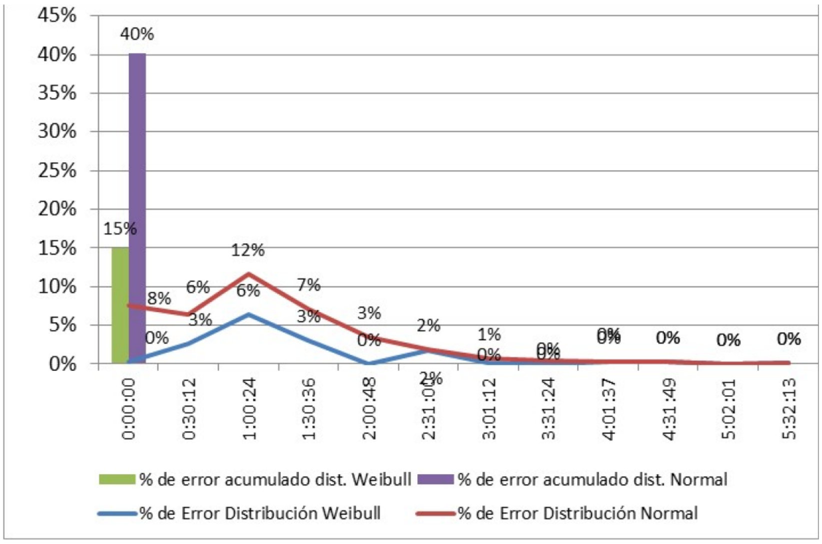


Figure 7. Percentage of relative error of the normal distribution and Weibull distribution

To analyze whether the error of these curves can be represented by a particular distribution curve, the absolute error they generate is analyzed. In Figure 7 it can be seen that the Weibull distribution curve shows a smaller variation in the error behavior in relation to the Normal distribution curve. This indicates that the data are better adjusted to the Weibull distribution curve. It is determined that the probabilistic distribution curve that generates the lowest percentage of error when representing the behavior of delay time data is the Weibull distribution. This distribution accumulates a total of 15% accumulated error. On the other hand, the normal distribution accumulates a total of 40% error when representing the behavior of the actual data.

3.5. Simulation Model

The model developed in the Vensim PLE® software (Figure 8), allows us to evaluate the percentage of availability for each type of press and the stamping line according to the material feeding characteristics (manual or automatic). Which is determined from the relationship between the operating time of each group considered and the total available time, which in this case corresponds to 22 hours per day considering 30 days per month.

The model is made up of flow variables and auxiliary variables. The former represents variations in operating times and available over time. The second ones represent the parameters where the initial data or conditions are entered, such as tooling change times, percentage of participation, relationship factor and types of by-products.

The equations that determine the behavior of the scheduled stoppages for each type of die, have in common the variables of by-product type and ratio factor. The equations that determine the behavior of the programmed shutdowns for each type of die, have in common the variables of by-product type and ratio factor.

Both variables are multiplied, and their result is multiplied by the percentage of participation of the type of die and its corresponding tooling change time. Finally, the daily time value is averaged, considering the number of days to evaluate. In (7), the mathematical expression for the Die MWOF is shown.

$$D\ MWOF = \left(\left((\text{by} - \text{product type} \times \text{ratio factor}\right) \times \%\ participation\ D\ MWOF\right) \times \text{Tool change time}\ D\ MWOF\Big)\ Final\ Time \tag{7}$$

The equation that determines the behavior of stoppages times caused by process incidents is determined by the Weibull distribution function, and its mathematical expression is shown in (8). Min - the minimum value returned by the function. Max - the maximum value returned by the function. S - its value starts at 0 and has an average of 1 before stretching, shifting and truncating. Shif - is the offset parameter (alpha) that indicates how much the distribution will shift to the right after it has been extended. Stretch - is the stretch parameter (Beta) that indicates how much the distribution will stretch before it shifts and truncates. Seed - is a dimensional argument that depends on the behavior of the graph, its value is usually zero.

$$Random\ Weibull\ (min, max, S, shif, stretch, seed) \tag{8}$$

Incorporating the values of the Weibull function to (8), the mathematical expression representing the time of stoppages due to incidents in the process, becomes (9).

$$Random\ Weibull\ (0, 332, 1, 1.5621, 64.6229, 0) \tag{9}$$

Both functions (7 and 8) determine the behavior of the operating time flow which is represented by (10), as in the previous case, it is exemplified for a Die MWOF

$$\text{operating time}\ D\ \text{MWOF} = Available\ time - D\ \text{MWOF incident stoppage} - \text{Stoppage by tooling change D MWOF and D LWOF} \tag{10}$$

In the developed model it is also possible to calculate the availability percentage of the entire assembly line. For this, it is necessary to consider the amount of presses that use a particular die according to the design, material feed and operating mode characteristics.

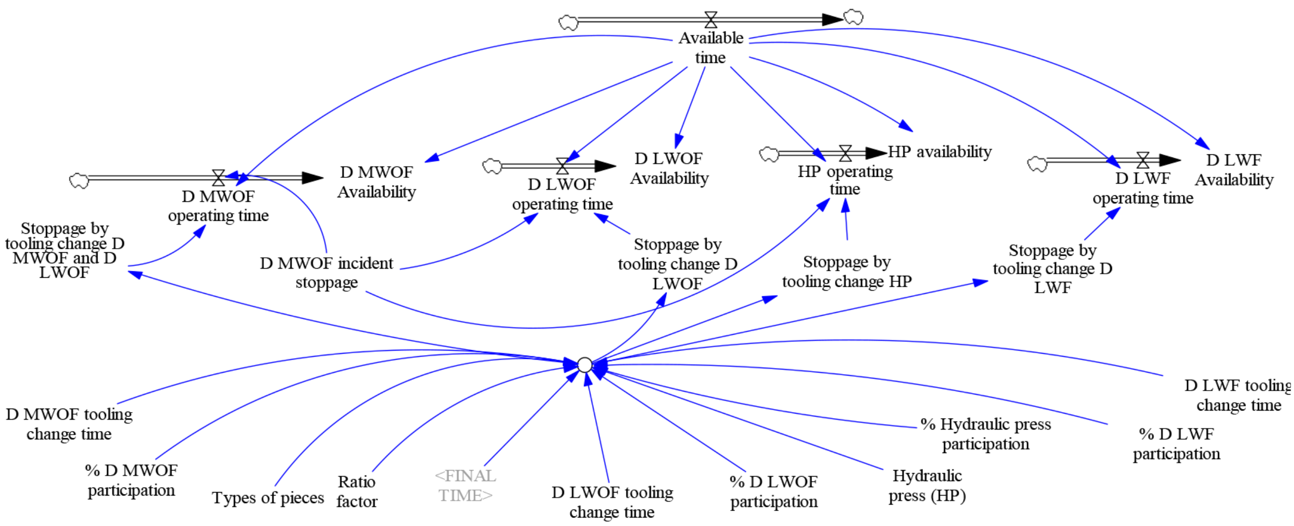


Figure 8. Model developed for the evaluation of the availability percentage

In our case it was identified that 7 presses use the D MWOF, 7 presses use the D LWOF, 6 presses the D LWF and there is a single hydraulic press that has its own die. These quantities were incorporated into the model, multiplying the flow variables by each of the presses to be used mentioned above. For example, the D MWOF operating time flow was multiplied by 7, since it is the total presses used in that category. The availability percentage for a press using the D MWOF and the total availability of the stamping line are shown in Figure 9.

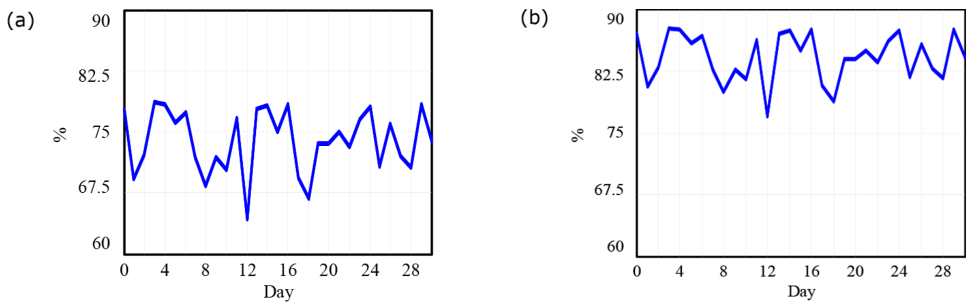


Figure 9. Percentage of availability; (a) presses using a D MWOF and (b) total availability for the stamping line

In Figure 9(a), it is observed that the availability for presses using the D MWOF ranges between 61% and 80%. In this case, these presses are affected by scheduled stoppages of 277 minutes per day, and unscheduled ones ranging from 0 to 311 minutes according to the Weibull distribution. Therefore, these values affect the available time corresponding to 1320 minutes per day. The total available time of the line is shown in Figure 9(b), where it is determined that the percentage varies around 80%. This is because, in this value the total operating time and available time of the entire line for automatic and manual presses are being considered.

4. Conclusions

The study of times made allows to determine that the average times of the change of tooling range between 31 and 58 minutes, which depends on whether the material feeding system is manual or automatic, respectively. While the stoppages caused by delays attributed to additional activities to the process, range between 1.80 and 0.5 seconds for each piece produced, also considering the manual or automatic feeding system.

Throughout the study it was evident to find that stop times have a high variability. Groups proposals were made considering the combination of production, characteristics of the parts, features tooling and especially the type of feed material. With this, it was possible to establish a categorization of the characteristics of stoppages, and reliable scenarios were obtained to determine their behavior.

In the case of stoppages times for change of tooling, the data was not adapted to a particular distribution curve, however it was possible to establish a use frequency of the dies with each of the types of pieces produced and establish a direct relationship with the tooling change time to be used.

For example, the medium die (less than 300 mm) without feeding had the highest percentage of utilization (44%) and its average stoppage time is 31 minutes. That means that for every 100 changes of tooling are made, 44 changes correspond to this type of die, accumulating a stoppage time of 1364 minutes, additionally, this is representative in 36% of the production volume.

On the other hand, for stoppages times caused by additional incidents to the process, two distribution curves were evaluated that best fit the behavior of the data histogram. Therefore, it was established that the Weibull distribution guarantees a better time performance. Which it was obtained by evaluating the effectiveness of adjustment of the distribution curves and the distribution of the error, where this distribution showed data of 15% of the accumulated error.

Finally, the simulation model developed in the Vensim PLE® simulation software, allowed to establish scenarios of the availability percentage of a particular die or of the complete stamping line. What has a great relevance and could be widely used in the metalworking industry, since the development of scenarios allows to evaluate the best combination of production that guarantees the desired percentage of availability. Thus, different programming options are obtained considering the characteristics of the parts and the customer's requirement, in order to optimize the process resources.

Declaration of Conflicting Interests

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