Decision-making process for gluing on footwear parts using analytic hierarchy process (AHP) and statistics*

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ABSTRACT. In manufacturing processes, there are conditions that continually impact decision-making among when choosing among alternatives; the selection is usually influenced by critical aspects such as quality, productivity, costs and customer feedback, among others. This article analyzes different adhesives for the process of gluing parts for sports shoes in a company located in the city of Purísima del Rincón in Guanajuato, México. The analysis employs statistical engineering tools and an Analytic Hierarchy Process (AHP) methodology. The case studied deals with an issue with gluing parts. The glue currently employed is of good quality but has drawbacks such as its high cost and thickness, which leads to a time-consuming manual application, affecting productivity. We propose and apply an AHP model with input information obtained by means of industrial experimentation in order to select the best alternative. Objective and subjective judgments relate to the quality score, production capacity, ease of application, and utility per pair. The chosen alternative represented the best option after factoring in all aspects of interest for the overall goal.

KEYWORDS: analytic hierarchy process / manufacturing processes / decision making / shoe industry / footwear / adhesives / productivity

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PROCESO DE TOMA DE DECISIONES PARA EL PEGADO EN PIEZAS DE CALZADO POR MEDIO DE LA METODOLOGÍA ANALYTIC HIERARCHY PROCESS (AHP) Y ESTADÍSTICA

RESUMEN. En los procesos de manufactura continuamente existen condiciones para la toma de decisiones entre un conjunto de alternativas, comúnmente, la selección estará influenciada por aspectos críticos como calidad, productividad, costos, voz del cliente, entre otros. Este artículo presenta un análisis de los pegamentos utilizados en el pegado de piezas para calzado deportivo en una empresa ubicada en la ciudad de Purísima del Rincón en Guanajuato, México. El análisis se realiza con herramientas de ingeniería estadística y metodología del proceso analítico jerárquico (AHP por sus siglas en inglés). El caso de análisis trata de un problema que se presenta en el proceso de pegado de piezas, ya que, si bien el pegamento que se utiliza actualmente es de buena calidad, tiene algunos inconvenientes en cuanto a su alto costo y dificultad de aplicación, ya que debido a que es espeso y la aplicación manual requiere mucho tiempo, lo que afecta la productividad. Proponemos y aplicamos un modelo AHP con información de entrada obtenida por experimentación industrial para seleccionar la mejor alternativa. Los juicios objetivos y subjetivos están relacionados con el puntaje de calidad, la capacidad de producción, la facilidad de aplicación y la utilidad por par. La alternativa seleccionada representó la mejor opción considerando todos los aspectos de interés en el objetivo general.

PALABRAS CLAVE: proceso analítico jerárquico / procesos de fabricación / toma de decisiones / industria del calzado / calzado / adhesivos / productividad

1. INTRODUCTION

In manufacturing processes, decision-making requirements involve analyzing many qualitative and quantitative variables. The process requires effective selection strategies, which include obtaining data and essential information in order to adequately gauge its importance. Hence, making the best decision yields the best results for the objective pursued.

Many manufacturing companies at present continue to operate without the need to incorporate state-of-the-art technology, mainly because they cannot afford to increase costs or because supply and demand do not justify it. Based on the above, we present the following research hypothesis: the application of a methodology based on statistical engineering techniques, in conjunction with the Analytic Hierarchy Process (AHP) methodology (Saaty, 1980), can lead to efficient choices in a traditional manufacturing process without the need to implement costly technologies, allowing for a selection that adequately addresses quality, productivity and cost requirements, incorporating objective quantitative and subjective qualitative factors into the development of the selection.

There are scant cases of quality improvement analysis in footwear manufacturing processes in the literature. This investigation reports on an original case of application in shoe manufacturing. The area of opportunity lies in choosing the best adhesive for gluing parts. The objective of the present work is to evaluate three adhesive alternatives for gluing parts. The areas of knowledge in which this proposal contributes and impacts are: industrial engineering, footwear manufacturing, continuous improvement, statistical methodologies and decision-making tools

Based on the above, we designed a two-stage strategy based on statistical engineering techniques: the first stage employed a combination of sampling, descriptive statistics, and inference to evaluate bonding quality. For the second stage a timing of process durations, analysis of variance and statistical control were employed in order to evaluate the average process time. The combined results of the previous phases produce the inputs for the hierarchical analysis process in order to select the alternative that best addresses the objective-subjective aspects that are important to the gluing quality. The results for each alternative show differences in the degree of difficulty of application and in the qualitative and quantitative aspects of the gluing.

Footwear manufacturing is a significant economic activity that represents 28,7 % of production in the fashion sector, where it is tied to other branches such as leather tanning and finishing, fur and shoe manufacturing as well as the production of materials such as leather, fur, and substitutes (INEGI, 2018). The production chain involves various suppliers of national inputs and imports, including the manufacture of paints, coatings, adhesives, or sealants. Generally, the National Consumer Price Index (INPC) increases at a higher rate than footwear prices, but an upward trend in the product's manufacture has been observed in recent years (INEGI, 2013). The interaction between these factors, in addition to inflation, market competition and supply and demand highlight how important cost factors are in footwear manufacturing in order to remain competitive yet profitable.

Within the areas of knowledge related to the improvement of footwear, gluing and adhesives processes, Amaya and Moreno (2018) presented an investigation based on the reduction of glue mixing time in a tank, analyzing aspects related to high energy consuming factors and the behavior of adhesive components. Orgilés-Calpena et al. (2019) conducted a critical review of the glues used in the footwear industry, classifying the different adhesives used in each stage of product manufacturing. Markkanen (2009) published a book about operator risks and injuries due to adhesive use in the footwear industry, which is an essential factor in decision-making.

Elsewhere, an article published by Paiva et al. (2015) about adhesives used in the automotive industry offers a detailed analysis of the most commonly used materials in footwear manufacture along with their properties, surface treatments, mechanical properties as well as types of adhesives, machinery, and other related aspects. Pizzi and Mittal (2018) have authored a book on adhesives for the footwear industry. It details the adhesives' physical, chemical and mechanical properties by analyzing their components and gluing performance. Calderón-Andrade et al. (2020) applied discreet reengineering and simulation of events to improve productivity in a shoe manufacturing company.

Rodriguez Benitez (2016) has published an implementation of Lean techniques (Value Stream Mapping, 5S and Poka Yoke) to improve quality and production flow in a shoe company. Marcelo et al. (2016) published an application of automation, layout, and movement study strategies to improve the productivity of a shoe manufacturing process. Mendez et al. (2021) presented their concept design of a footwear manufacturing plant based on expert systems and discrete-event simulation. In applications of improved adhesive distribution methods, Pagano et al. (2020) proposed the use of a guided robotic vision system; Xie and Li (2016) presented a path-planning adhesive spray application by a robot, and Zeng and Li (2015) proposed a similar proposal on the optimal distribution of the adhesive with the registration of a point cloud.

The case analyzed here deals with a problem in the footwear gluing stage, before the stitching process: the glue currently employed is of good quality; however, it poses some issues at the time of application since its viscous consistency requires particular care and attention when it is applied manually, hence increasing process times and hindering productivity. Our approach is to look for competitive alternatives to the current glue based on cost, productivity, ease of application and utility criteria. The AHP methodology is a suitable option as it allows for the evaluation of objective quantitative and subjective qualitative criteria. For this reason, it is proposed as the basis for a methodology based on employing statistical experimentation and a qualitative evaluation of the alternatives in order to determine the best option for the process.

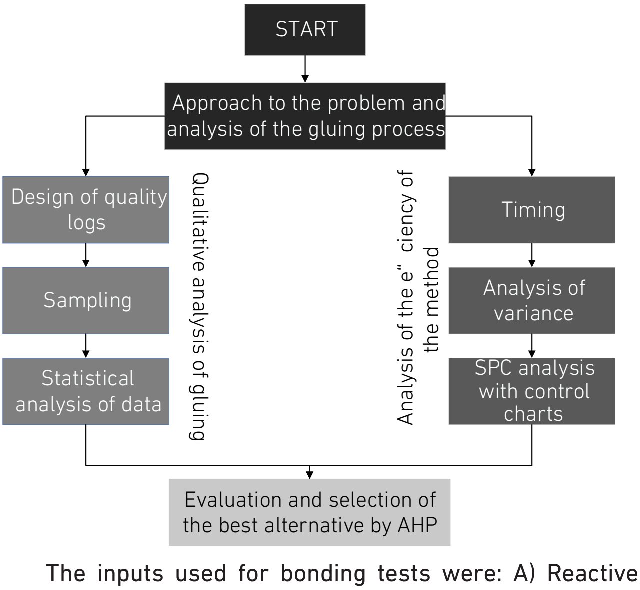
The objective of the methodology proposed in this article is to select the best option among a set of alternatives, in which it is necessary to carry out experimentation within the process and to conduct interviews with experts in order to obtain the data necessary to propose a hierarchical analysis. Statistical support provides reliability in the information obtained to adequately discriminate between options that are close in quality ratings. The application within a footwear process represents an additional contribution to the literature on improving manufacturing processes.

2. METHODOLOGY

The proposal employs statistical methods to evaluate qualitative and efficiency aspects through an experimental research design. The proposed methodology for the analysis is shown in Figure 1. It begins with selecting the gluing method that shows the best results in the descriptive research. The decision-making process is then completed with the AHP technique to integrate objective and subjective aspects in the selection process. For the selection, there are three options are currently available, each of which requires the use of specific inputs, while their efficiency is evaluated by timing the process duration.

Figure 1

Research Methodology



The inputs used for bonding tests were: A) Reactive adhesive (MXN 930.00 per

15-liter bucket); B) an economy adhesive (MXN 52.00 per liter) and thinner (MXN 20,00 per liter)

Bonding tests were performed with three different methods:

Reduced adhesive application (economic)

Reactive adhesive application (highest quality)

Adhesive Reactor + technique (stripe remover)

To qualitatively evaluate the gluing quality on the parts, we designed log formats to grade the quality according to the following criteria:

Number 3: Excellent quality.

Number 2: Regular quality.

Number 1: Poor quality (does not pass)

In the sampling logs, a qualitative evaluation is applied to 4 quality criteria: firm gluing, clean cut, ease of peeling and material smoothness. It is important to define the amount of evidence, as material waste produces parts that do not meet the expected quality. In order to define sample size, we performed a preliminary sampling of 10 pairs, resulting in a sample standard deviation of. The sample size was calculated according to equation 1.

$$n \geq \left(\frac{Z_{\frac{\alpha}{2}} \cdot \hat{S}}{E} \right) \approx 48\ samples \quad (1)$$

Where: n = sample size, $Z_{a/2}$ = 1,96 is the 0,95 quantile of the standard normal distribution given a confidence level of 95 %, E = permissible error = 0.05. The data obtained from the samples is shown in Tables 1-3. The total score represents the sum of the four qualitative factors of the gluing process.

Table 1

Quality log for reduced adhesive (economy) testing.

QUALITY LOG					24/01/2022
Lot 1: Reduced adhesive (economy)					
Start Time = 01:40 p. m.			End Time = 02:15 p. m.		
Pair sample number (n)	Firm gluing	Clean cut	Ease of peeling	Material smoothness	Total score
1	1	3	3	2	9
2	2	3	3	1	9
3	1	3	3	2	9
4	2	3	3	2	10
5	2	3	3	2	10
6	1	3	3	1	8
7	2	3	3	1	9
8	2	3	3	2	10
9	2	3	3	2	10
10	1	3	3	2	9
11	2	3	3	1	9
12	1	3	3	3	10
13	1	3	3	3	10
14	1	3	3	3	10
15	2	3	3	2	10
16	2	3	3	1	9
17	2	3	3	2	10
18	2	3	3	3	11
19	2	2	3	1	8
20	1	2	3	1	7
21	1	2	3	3	9
22	1	2	3	2	8
23	1	2	3	1	7
24	1	2	3	2	8
Total	36	66	72	45	219

QUALITY LOG					29/01/2022
Lot 1: Reduced adhesive (economy)					
Start time = 12:00 p. m.			End Time = 12:35 p. m.		
Pair Sample number (n)	Firm gluing	Clean cut	Ease of peeling	Material smoothness	Total score
1	2	3	3	2	10
2	2	3	3	2	10
3	2	3	3	2	10
4	2	3	3	1	9
5	1	3	3	1	8
6	2	3	3	1	9
7	1	2	3	1	7
8	2	2	3	2	9
9	1	2	3	2	8
10	1	3	3	2	9
11	1	3	3	2	9
12	1	3	3	2	9
13	1	3	3	2	9
14	1	3	3	3	10
15	2	3	3	3	11
16	1	3	3	3	10
17	2	3	3	3	11
18	2	3	3	2	10
19	2	2	3	1	8
20	2	2	3	2	9
21	1	2	3	1	7
22	2	2	3	2	9
23	1	2	3	1	7
24	2	2	3	2	9
Total	**37**	**63**	**72**	**45**	**217**

Table 2

Quality log for Reactive Adhesive testing (Highest Quality).

QUALITY LOG					29/01/2022
Lot 3: Reactive adhesive testing (highest quality)					
Start time = 02:05 p. m.			End time = 02:55 p. m.		
Pair sample number (n)	Firm gluing	Clean cut	Ease of peeling	Material smoothness	Total score
1	3	3	2	2	10
2	3	3	2	2	10
3	3	1	2	2	8
4	3	3	2	2	10
5	3	1	2	2	8
6	3	3	2	2	10
7	3	3	2	2	10
8	3	1	2	2	8
9	3	3	2	2	10
10	3	3	2	2	10
11	3	3	2	1	9
12	3	3	2	1	9
13	3	1	2	1	7
14	3	2	2	2	9
15	3	1	2	2	8
16	3	2	2	2	9
17	3	1	1	1	6
18	3	1	1	1	6
19	3	2	1	1	7
20	3	2	1	1	7
21	3	1	2	1	7
22	3	1	1	2	7
23	3	1	1	1	6
24	3	1	2	2	8
Total	72	46	42	39	199

QUALITY LOG					29/01/2022
Lot 4: Reactive adhesive testing (highest quality)					
Start time = 03:25 p. m.			End time = 04:16 p. m.		
Pair sample number (n)	Firm gluing	Clean cut	Ease of peeling	Material smoothness	Total score
1	3	3	2	2	10
2	3	2	1	2	8
3	3	1	1	3	8
4	3	2	1	2	8
5	3	1	2	2	8
6	3	2	2	2	9
7	3	2	2	3	10
8	3	1	2	2	8
9	3	2	2	3	10
10	3	1	2	2	8
11	3	2	2	1	8
12	3	1	1	1	6
13	3	1	1	1	6
14	3	2	2	2	9
15	3	1	1	3	8
16	3	2	2	2	9
17	3	1	1	3	8
18	3	1	2	1	7
19	3	2	1	1	7
20	3	2	1	3	9
21	3	1	2	1	7
22	3	1	1	2	7
23	3	1	1	1	6
24	3	2	2	3	10
Total	**72**	**37**	**37**	**48**	**194**

Table 3

Quality log for Reactive Adhesive + technique (stripe remover)

QUALITY LOG					02/02/2022
Lot 5: Reactive adhesive + technique (stripe remover)					
Start time = 03:36 p. m.			End time = 04:06 p. m.		
Pair sample number (n)	Firm gluing	Clean cut	Ease of peeling	Material smoothness	Total score
1	3	3	2	2	10
2	3	3	2	2	10
3	3	3	2	2	10
4	3	3	2	2	10
5	3	3	2	2	10
6	3	3	2	2	10
7	3	3	2	2	10
8	3	3	2	2	10
9	3	3	2	2	10
10	3	3	2	2	10
11	3	3	2	3	11
12	3	3	2	3	11
13	3	2	2	3	10
14	3	2	2	3	10
15	3	2	2	3	10
16	3	2	2	3	10
17	3	2	2	3	10
18	3	2	2	3	10
19	3	2	2	3	10
20	3	2	2	3	10
21	3	2	2	3	10
22	3	2	2	3	10
23	3	2	2	2	9
24	3	2	2	2	9
Total	**72**	**60**	**48**	**60**	**240**

QUALITY LOG					05/02/2022
Lot 6: Reactive adhesive + technique (stripe remover)					
Start time = 11:35 p. m.			End time = 12:08 p. m.		
Pair sample number (n)	Firm gluing	Clean cut	Ease of peeling	Material smoothness	Total score
1	3	3	2	2	10
2	3	2	2	3	10
3	3	3	2	3	11
4	3	2	2	3	10
5	3	2	2	3	10
6	3	3	2	2	10
7	3	3	2	2	10
8	3	3	2	2	10
9	3	3	2	2	10
10	3	3	2	2	10
11	3	3	2	3	11
12	3	3	2	3	11
13	3	3	2	3	11
14	3	2	2	3	10
15	3	2	2	2	9
16	3	2	2	2	9
17	3	3	2	3	11
18	3	2	2	2	9
19	3	2	2	3	10
20	3	2	2	2	9
21	3	2	2	3	10
22	3	2	2	2	9
23	3	3	2	2	10
24	3	3	2	3	11
Total	72	61	48	60	241

Once the evaluations were completed, the most representative descriptive statistics were calculated in terms of position and variation from the information collected from the sampling: averages, standard error of the mean, sample standard deviation and variance. The descriptive statistics analysis made it possible to identify significant differences between levels for each of the alternatives and estimate variations in the ratings given by the analyst.

In the following phase of the study we analyze significant level differences between the alternatives. We applied hypothesis tests for difference of means with unknown and different standard deviations. These inference tests used an inferential procedure based on the Student t distribution, applying a test statistic as shown in equation 2. A type 1 error of $\alpha = 0{,}05$, with an alternative hypothesis testing $H_1\colon \mu_A \neq \mu_B$.

Where $\overline{x}_A - \overline{x}_B$ is a comparison between the sample averages for each pair of alternatives, n_A and n_B are the sample sizes and $\hat{s}_A$ and $\hat{s}_B$ are the standard deviations from samples. The criterion of rejection for H_0 is applied if p-value <, meaning that there is a significant difference in the total score between gluing methods; this analysis completes the qualitative evaluation phase of the gluing.

Work times were measured parallel to the gluing tests to measure each method's efficiency. As stated in the problem of this study, each adhesive alternative requires varying degrees of effort and precision to glue the parts.

The importance of the time study lies in its relationship to productivity: the treatment with the lowest average time is the most efficient, as it increases productivity and has a positive effect on costs. The gluing process is timed for each pair using a digital chronometer, after which the data is entered in the designed format (Table 4). Once the samples for the qualitative gluing analysis and efficiency were completed, the analysis then employed statistical tools.

Comparing the time for each alternative is, in a way, an analysis of variance that focuses on the researcher's interest in comparing each treatment in terms of its population means, not to mention that comparing their variances also proves essential (Montgomery & Runger 2011), as shown in equation 3:

$$\begin{gathered} H_0\colon \tau_1 = \tau_2 = \cdots = \tau_k = 0 \\ H_1\colon \tau_i \neq 0 para alg\acute{u}n i \end{gathered} \quad (3)$$

Table 4

Recorded gluing test times for each batch

Day	24/01/22	Day	29/01/22	Day	29/01/22
Lot 1: ReducedaAdhesive (economy)		Lot 2: Reduced adhesive (economy)		Lot 3: Reactive adhesive testing (highest quality)	
Start time = 01:40 p. m.		Start time = 12:00 p. m.		Start time = 02:05 p. m.	
End time = 02:15 p. m.		End time = 12:35 p. m.		End time = 02:55 p. m.	
n	Time (min)	n	Time (min)	n	Time (min)
1	1,47	1	1,43	1	2,11
2	1,44	2	1,46	2	2,12
3	1,46	3	1,44	3	2,13
4	1,45	4	1,47	4	2,12
5	1,47	5	1,45	5	2,11
6	1,46	6	1,46	6	2,12
7	1,45	7	1,47	7	2,11
8	1,44	8	1,45	8	2,1
9	1,46	9	1,43	9	2,13
10	1,45	10	1,46	10	2,12
11	1,47	11	1,45	11	2,14
12	1,44	12	1,44	12	2,12
13	1,46	13	1,45	13	2,12
14	1,45	14	1,46	14	2,13
15	1,44	15	1,44	15	2,12
16	1,48	16	1,47	16	2,11
17	1,47	17	1,46	17	2,13
18	1,48	18	1,48	18	2,15
19	1,46	19	1,45	19	2,14
20	1,45	20	1,5	20	2,11
21	1,47	21	1,48	21	2,14
22	1,46	22	1,48	22	2,15
23	1,45	23	1,45	23	2,13
24	1,47	24	1,47	24	2,14
Total time	35	Total time	35	Total time	51

(*continúa*)

(*continuación*)

Day	29/01/22	Day	02/02/22	Day	05/02/22
Lot 4: Reactive adhesive testing (highest quality)		Lot 5: Reactive adhesive + technique (stripe remover)		Lot 6: Reactive adhesive + technique (stripe remover)	
Start time = 03:25 p. m.		Start time = 03:36 p. m.		Start time = 11:35 p. m.	
End time = 04:16 p. m.		End time = 04:06 p. m.		End time = 12:08 p. m.	
n	Time (min)	n	Time (min)	n	Time (min)
1	2,12	1	1,25	1	1,25
2	2,12	2	1,25	2	1,27
3	2,12	3	1,24	3	1,26
4	2,12	4	1,24	4	1,24
5	2,12	5	1,25	5	1,24
6	2,12	6	1,26	6	1,23
7	2,12	7	1,25	7	1,26
8	2,12	8	1,26	8	1,25
9	2,12	9	1,24	9	1,23
10	2,12	10	1,25	10	1,25
11	2,12	11	1,25	11	1,26
12	2,12	12	1,25	12	1,25
13	2,12	13	1,26	13	1,25
14	2,12	14	1,26	14	1,26
15	2,12	15	1,26	15	1,24
16	2,12	16	1,25	16	1,25
17	2,12	17	1,25	17	1,26
18	2,12	18	1,24	18	1,23
19	2,12	19	1,27	19	1,24
20	2,12	20	1,24	20	1,25
21	2,12	21	1,25	21	1,24
22	2,12	22	1,25	22	1,26
23	2,12	23	1,24	23	1,26
24	2,12	24	1,24	24	1,27
Total time	50,88	Total time	30	Total time	30

The linear model is defined by:

$$Y_{ij} = \mu + \tau_i + \epsilon_{ij} \begin{cases} i = 1,2,\dots,a \\ j = 1,2,\dots,n \end{cases} \quad (4)$$

Where is the global mean of experimental data, the alternatives' treatments and. We also analyzed residual assumptions for normality, independence and constant variance. The criterion for verifying the difference between the alternatives is whether $f_0 > f_{\alpha,a-1,a(n-1)}$ then H_0 is rejected, which can also be verified with the p-value criterion.

The next phase of analysis involved applying control charts to individual units, which are used with sample sizes of 1 in slow processes for continuous type variables in order to verify the existence of special causes for variation within the process and determine which treatment has the best efficiency, that is, the shortest average time and the least variation. The formulas used for calculating the control limits in the individual charts are shown below:

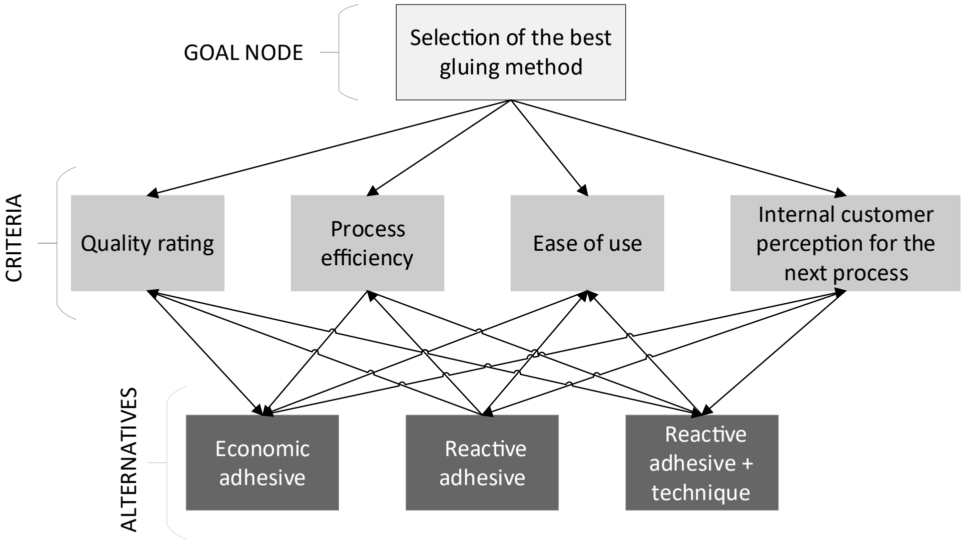
$$LCS = \overline{x} + 3\frac{\overline{R}}{d_2}$$
$$LC = \overline{x} \qquad (5)$$
$$LIC = \overline{x} - 3\frac{\overline{R}}{d_2}$$

Where $\overline{x}$ is the central line estimated by the average of time observations in treatment *i*, $\overline{R}$ is the average moving range of measurements and constant d_2 takes its value from the sample size: 1,128. Control charts were analyzed according to Nelson's rules to verify the existence of special causes of variation. All statistical studies were conducted on the MINITAB 18 software.

A decision-making model must include and evaluate all tangible and tangible measurable qualitative and quantitative factors, all of which can be assessed with an Analytic Hierarchy Process (AHP). The goals, criteria and determining choices for the purpose of the decision are shown in Figure 2.

Figure 2

AHP Hierarchization of the studied problem



A criterion matrix was created for the target node using the following scale: 1- Equal, 3- Moderate, 5- Strong, 7- Very Strong, and 9- Extreme (Equation 6). This matrix compares the subjective importance of each criterion.

$$\begin{matrix} Criteria \\ QualityRating(A) \\ ProcessEfficiency(B) \\ Easeofuse(C) \\ Internalcustomerperceptionforthenextprocess(D) \end{matrix} \begin{bmatrix} (A) & (B) & (C) & (D) \\ 1/1 & 1/1 & 3/1 & 1/3 \\ 1/1 & 1/1 & 4/1 & 1/2 \\ 1/3 & 1/4 & 1/1 & 1/4 \\ 3/1 & 2/1 & 4/1 & 1/1 \end{bmatrix} \quad (6)$$

Four criteria were chosen for the judgment analysis: A) quality score, which is the average score obtained in the sample logs using the four qualitative factors of the study as a direction vector. B) production capacity, which is obtained by dividing the available process time by each alternative's average time and is directly integrated into the study as a vector. C) ease of application, the operator's qualitative and subjective assessment after applying the three methods, which is integrated as pairwise comparison matrix making the comparison similar to the matrix.

For criterion D, the economic benefit from the adhesive application cost per pair are as follows: we know that the company sells each pair at MXN 168,00 of which the company makes a 15 % profit after expenses. Consequently, the benefit vector is estimated based on adhesive cost per pair and is directly incorporated into the decision model. A summary of the vectors of goal criteria and the qualitative and subjective criteria matrix are shown in Table 5.

Table 5

Objective vectors and comparison matrix for decision problem criteria.

	Quality score vector		Production capacity vector	Pairwise Comparison Matrix – Ease of Application				Utility vector
	Quality rating	Average time	Production capacity per day	Economy Adhesive	Reactive adhesive	Reactive adhesive + technique	Adhesive cost per pair $	Utility per pair $
Economy Adhesive	9,083	1,4583	309	1/1	1/2	4	26,26	21,26
Reactive adhesive	8,188	2,1204	212	2	1/1	3	24,42	21,39
Reactive adhesive + Technique	10,021	1,25	360	1/4	1/3	1/1	30,09	20,69

It is essential to perform a comprehensive statistical analysis of data adequacy, data, aspects such as the presence of variation, the original data normality for the descriptive statistics, residuals in the variance analysis model and the interpretation of p-value in the hypothesis tests. The control charts allow for analyzing the existence of special causes of variation using the Nelson criteria, allowing additional actions to stabilize and improve it.

3. RESULTS

A statistical analysis of the total score for each alternative showed an approximately normal behavior in their distributions, as the histograms in Figure 3 illustrate. The descriptive statistics in Table 6 show that the adhesive treatment + stripe remover has highest average with 10,02. It also displays the least variation with a standard deviation of 0,565, suggesting that this gluing method presents the least variation in qualitative factor ratings, for which initial preference is given Reactive + Technical glue for having the least variation in score averages across samples.

Figure 3

Histograms of the total score for the three Alternatives

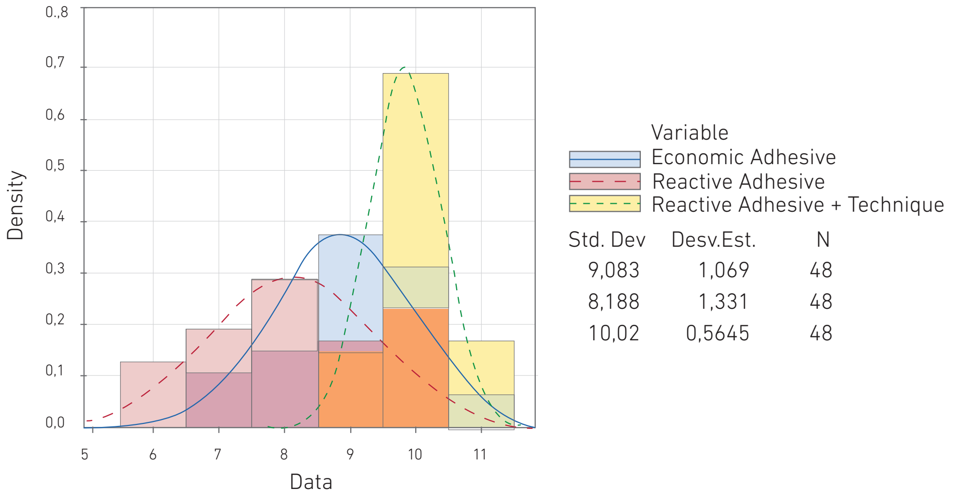


Table 6

Descriptive statistics for each alternative's total scores

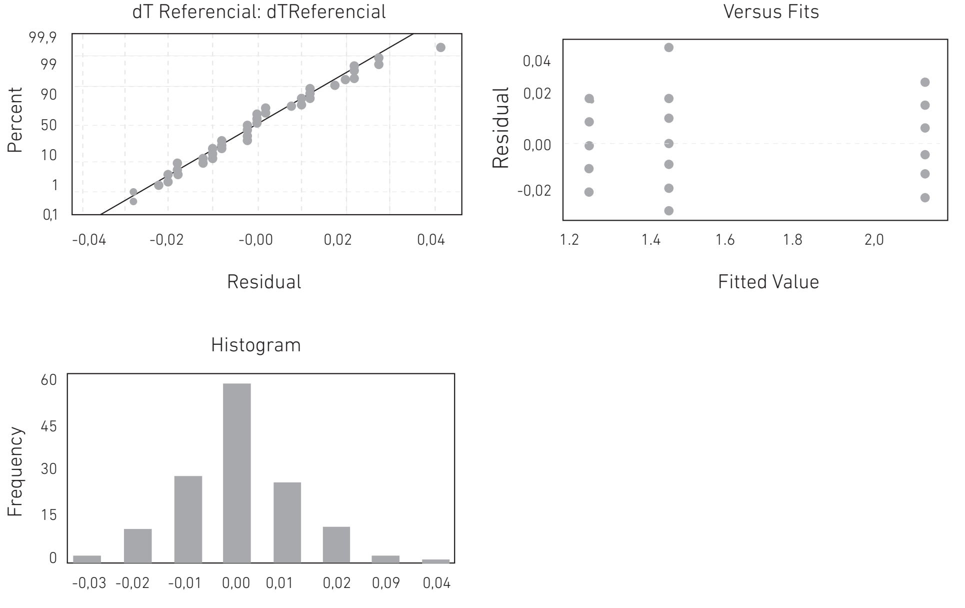
Quality	Total Count	Average	Standard error of the mean	Standard Deviation	Variance	Mode
Economic Adhesive	48	9,083	0,154	1,069	1,142	9,000
Reactive adhesive	48	8,188	0,192	1,331	1,773	8,000
Reactive adhesive + Technique	48	10,021	0,082	0,565	0,319	10,000

A hypothesis test for comparing means was applied in order to evaluate the average score of the Economy Adhesive against other alternatives. Comparing the means between the Economy Adhesive to the Reactive Adhesive yields a value for test statistic and for p-value < alpha 0.05, which indicates a significant difference between their means, with Economy Adhesive having an advantage. Comparing the economy adhesive to the Reactive Adhesive Treatment + Technique yields a value for test statistic and p-value < 0,05, which indicates a significant difference between their means, where the Reactive adhesive + technique has the advantage in addition to also being the treatment with the highest mean in the qualitative scores, where it also differs greatly from the other two alternatives.

Figure 4 shows the analysis of variance in the processing times and the graphs for the regression model residuals. The study shows a value and p-value < 0,000, which indicates a difference in treatment averages for at least one pair of alternatives compared in the analysis. The regression model shows a good fit of the linear model, with ; The model explains most of the variation with . The assumptions of independence, normality and constant variance for the residuals are properly met, which validates the results of the variance analysis.

Figure 4

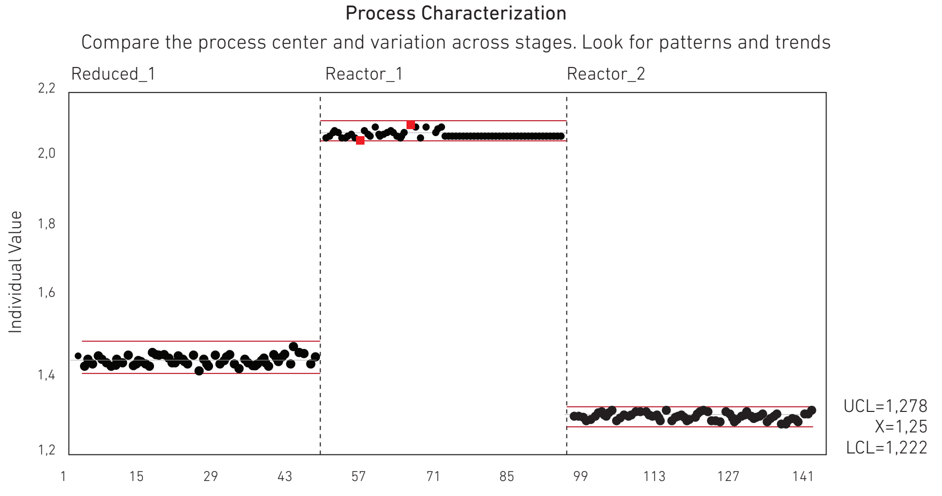
Analysis of variance in process times for each alternative



The difference between the 3 treatments was also verified using the confidence intervals in the Tukey and Dunnet tests. This difference was additionally verified in the control charts study, shown in Figure 5. We observe no splices or overlaps in the control limits of the 6 standard deviations for each of the alternatives. The Reactive adhesive has a higher time average, while the Reactive adhesive + technique has a lower time average, again showing an advantage in this regard. Analysis of special causes for control charts showed non-compliance with Nelson rules 1, 2 and 6 in the alternatives. The process is consequently considered to be unstable and out of control.

Figure 5

Control charts for individual units in alternatives



Statistics	Reduced_1	Reactor_1	Reactor_2
N	48	48	48
Mean	1,4583	2,1225	1,25
StDev(overall)	0,014780	0,0097849	0,010106
StDev(within)	0,016599	0,0066018	0,0094311

Table 7 shows the priority vectors obtained from the AHP for the criteria and alternatives. We can see that the gluing quality is most essential criterion, followed by utility per pair. The alternative node shows the Reactive Adhesive + Technique advantage in quality score and production capacity, two quantitative objective factors. The Reactive adhesive shows higher priority in terms of ease of application (qualitative subjective) and utility per pair (quantitative objective). The economy adhesive alternative is presented as the second-best option in all criteria.

Table 7

Priority vectors for AHP analysis

CRITERIA	PRIORITY
Quality Score	0,44435
Production capacity	0,0693
Ease of application	0,20671
Utility per pair	0,27963

(*continúa*)

(*continuación*)

ALTERNATIVES	Quality Score	Production capacity	Ease of Application	Utility per pair
Economy Adhesive	0,33281	0,35073	0,35856	0,33565
Reactive Adhesive	0,30001	0,24064	0,51713	0,33770
Reactive Adhesive + Technique	0,36718	0,40863	0,12431	0,32665

Table 8 shows the general priorities for each alternative, the decision being on the Reactive Adhesive + Technical Adhesive, which overall presents the highest expected value with 0,357432; secondly, the economy adhesive with a value of 0,343354 and lastly, the Reactive Adhesive with a value of 0,299214.

Table 8

Priority vectors for AHP analysis

Alternative	Ideal Value Vector	Standard Value Vector	Raw Value Vector
Economy adhesive	0,960614	0,343354	0,171677
Reactive adhesive	0,83712	0,299214	0,149607
Reactive adhesive + Technique	1	0,357432	0,178716

4. DISCUSSION

The analysis of alternatives was subjected to different quality, productivity and appreciation criteria. The economy glue showed a good average performance in all analysis factors. The Reactive Adhesive + technique method performed well in the scoring studies and average times, presenting a significant difference from other two treatments in both factors. The introduction of the cost factor allowed the inclusion of this quantitative objective factor into the model, where the Reactive showed an advantage, which was also true when evaluating the subjective factors of the operators' ease of use.

The decision problem was determined by using the AHP methodology, in which all objective and subjective aspects can be incorporated in order to select the best option. Reactive adhesive + Technique was the best result among the 3 alternatives, as it has the best results in the following aspects:

- Vest quality in gluing.
- Lowest average processing time.
- Most negligible variation in the process.

- Most controlled and stable process.
- Acceptable ease of application.

The cost factor can also be paid, effectively offset insofar as the excellent quality of the shoe gluing will maintain the company's competitivity level and ensure a continuity in orders.

5. CONCLUSIONS

Many manufacturing companies today continue to employ artisanal processes, surviving in the current competition thanks to the quality of their processes. The decision-making process is made easy where cutting-edge technologies and modern strategies such as automation and industry 4,0 are available. However, if such technologies are unavailable, selecting and identifying objective and subjective factors that may have importance in the decision-making process in improving a process or kaizen becomes increasingly complex.

Statistical engineering makes it possible to objectively evaluate qualitative and quantitative aspects of the criteria presented in the decision-making process. Incorporating the statistical results enables the production of evaluation methods that have a reasonable degree of precision and discrimination when detecting significant differences among the treatments of interest and make it possible to select those that are directly related to root causes that can improve product quality or solve process issues.

The use of statistical methodologies and the AHP enables a selection of the best adhesive and bonding method by means of a model that factors in qualitative and quantitative aspects based on other characteristics desired by customers such as cost, shipment times, product quality, the operators' perception of the ease of application, suppliers and available materials on the market.

This research creates an area of opportunity for its application in other types of processes, as well as the incorporation of more automated methods and technologies, such as laboratory instruments for regulatory testing, better methods for glue distribution on cuts and more. Similarly, in introduces opportunities for more complex analyses of hierarchical analysis such as diffuse AHP models, artificial intelligence techniques and optimization models.

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