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THE INFLUENCE OF CHRONOANALYSIS ON THE DELIVERY OF LABORATORY RESULTS IN A SUGAR-ALCOHOLIC PROCESS

A INFLUÊNCIA DA CRONOANÁLISE NA ENTREGA DE RESULTADOS LABORATORIAIS EM UM PROCESSO SUCROALCOOLEIRO

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ABSTRACT

Objective: The objective of this study is to describe the use of the chronoanalysis technique in laboratory processes of a medium-sized industry in the sugar and alcohol segment and its impacts on process improvement, particularly on the response time of analytical results.
Theoretical Framework: Chronoanalysis is a technique based on the study of times and movements to identify and eliminate activities that do not add value to the process, aiming to optimize time and improve efficiency.
Methodology/Approach: Applied research, with a descriptive objective, based on a case study of a sugar and alcohol plant, addressing qualitative aspects of the quality control sector where it presents the mapping of activities.
Results: The application of chronoanalysis concepts allowed the identification and elimination of aspects that did not add value to the process, resulting in a significant reduction in analysis time by 33.65%. This improved the conditions for delivering results and facilitated the identification of flaws in the product manufacturing process.
Contributions, practical and social implications: The study demonstrated that the application of chronoanalysis can have a positive impact on the efficiency of laboratory processes, reducing the turnaround time for results and contributing to improving quality and efficiency in the sugar and alcohol industry.
Originality/Value: The findings could be highly relevant to other industries wanting to improve their laboratory processes and reduce the risk of non-conformities.
Keywords: Chronoanalysis; Study of time and movements; Standard time; Process mapping; Analyses.

RESUMO

Objetivo: O objetivo deste estudo é descrever o uso da técnica de cronoanálise em processos laboratoriais de uma indústria de médio porte do segmento sucroalcooleiro e seus impactos na melhoria dos processos, em particular no tempo de resposta dos resultados analíticos.
Teórico Referencial: A cronoanálise é uma técnica que se baseia no estudo de tempos e movimentos para identificar e eliminar atividades que não agregam valor ao processo, promovendo a otimização do tempo e a melhoria da eficiência.
Metodologia/Abordagem: Pesquisa de natureza aplicada, com objetivo descritivo, baseada em um estudo de caso de uma usina sucroalcooleira, abordando aspectos qualitativos do setor de controle de qualidade em que apresenta o mapeamento de atividades.
Resultados: A aplicação dos conceitos de cronoanálise permitiu identificar e eliminar aspectos que não agregavam valor ao processo, resultando em uma redução significativa do tempo de análise em 33,65%. A aplicação da técnica melhorou a qualidade do serviço prestado (análises químicas laboratoriais) e agilizou a identificação de falhas no processo de fabricação do produto.
Contribuições, implicações práticas e sociais: O estudo demonstrou que a aplicação acompanhada da cronoanálise pode impactar positivamente a eficiência dos processos laboratoriais, reduzindo o tempo de resposta e com isso elevando a qualidade, a eficiência e a confiabilidade dos processos produtivos.
Originalidade/Valor: Suas descobertas podem ser altamente relevantes para outras indústrias que desejam seus processos laboratoriais e melhorar o risco de não conformidades.
Palavras-chave: Cronoanálise; Estudo de tempos e movimentos; Tempo padrão; Mapeamento de processos; Análises.

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1. INTRODUCTION

The study of time and motion, as highlighted by Morlock et al. (2017), is essential for standardizing activities, reducing waste and improving process performance, with positive impacts on productivity, operational costs and also process ergonomics. Chronoanalysis, a technique associated with the study of times and movements, helps to eliminate unnecessary movements, reduce efforts and fatigue, in addition to optimizing processes and increasing profits, benefiting working conditions and worker motivation (NEGAARD et al., 2020).

Lack of time control, unnecessary movement and lack of information, among other factors, can harm process productivity (GUZEL; ASIABI, 2022). Chronoanalysis, as mentioned by Almeida and Ferreira (2009), plays an important role in measuring processing times and the quality of step data, contributing to improving the performance of production activities.

The organization of the workplace is essential for optimizing time and sequencing of activities, and combined with an adequate physical arrangement, it can increase productivity, which can be done based on chronoanalysis among other Lean techniques (GOROBETS et al., 2021; GUZEL; ASIABI, 2022). Despite the advantages provided by the procedure of analyzing times and movements in production processes, the care that must be taken with data capture and analysis are essential for a satisfactory result, in addition to obviously the correct execution of the procedures that involve the application of the chronoanalysis technique (BARNES, 1977; BREZNIK; BUCHMEISTER; VUJICA HERZOG, 2023).

The question posed in this study is: what are the impacts and limitations of applying the chronoanalysis technique in the quality control processes of laboratory analyses at a medium-sized sugar and alcohol plant?

The objective of this research is to apply the chronoanalysis technique in the operational procedures of a laboratory environment for chemical analysis of a medium-sized sugar and alcohol plant in the interior of São Paulo, producing sugar, ethanol and bioenergy, and to identify its impacts on the sector. The research, of an applied nature and descriptive objective, is based on the case study of the application of the chronoanalysis technique in the chemical analysis sector of the finished product (sugar) of a sugar and alcohol plant.

2. LITERATURE REVIEW

2.1 Methods engineering

Structuring an activity considering its chronological duration is paramount for determining the standard time of a task, which is the time spent on a given activity. This time is estimated based on a method and executed by an operator with knowledge of the operation, and the ability to perform it routinely, in conditions that allow its consistent and continued execution, in order to preserve its health condition (TAYLOR, 2018).

Studies of the times and movements performed by operators allowed the establishment of productive performance indicators and gave rise to Methods Engineering, which, based on the observation of how a task is performed (worker movements, sequence of activities and time required), began to identify problems in the processes and seek more efficient ways of executing activities (BARNES, 1977).

However, Barnes (1977, p. 277) adds that "The procedure to be followed in executing the time study may vary with some freedom, depending on the type of operation under study and the application to be given to the data obtained", and establishes 8 steps that he considers necessary for executing the chronoanalysis procedure: 1. Record information about the operation and operator; 2. Divide the operation into elements and record the complete operation of the method; 3. Observe and record the time spent by the operator; 4. Determine the number of cycles to be timed; 5. Evaluate the operator's pace; 6. Check if a sufficient number of cycles have been timed; 7. Determine the tolerances; and 8. Determine the standard time.

Understanding the original process is essential to be able to map it in detail, identifying its sequence, times and movements. According to Bezzato et al. (2021), mapping the process and analyzing the average execution times of its activities is essential to understand the context and improve its execution, resulting in reduced times and process improvement. Sotsek , Vivan & Oliveira (2022) point to the study of times and movements as an important tool for improving processes in the context of virtual environments and Industry 4.0 technology.

2. 2 Related studies

This subsection deals with the literature review on Methods Engineering in the SIMPEP (Production Engineering Symposium) and ENEGEP (National Meeting of Production Engineering) databases, and used the following keywords: methods engineering, process mapping, chronoanalysis, standardization, time and motion study and process optimization. Scientific databases such as *ScienceDirect* and *SciELO* were also used for searching, with the keywords: "process *mapping"* and *"time and motion". motion study"*. The summary of the identified works can be seen below (Frame 1) highlighting the objectives, gains and main characteristics of the works.

Frame 1
Studies related to the study of time and motion and process mapping.

Year	Authors	Study objective/area	Methods used and research gains	Main features
2017	Morlock et al.	Methods engineering: present an approach to the study of time and motion in a practical didactic learning environment.	The use of simulated time and movement analysis procedures to save designers time showed gains of around 15% in productivity and a reduction in efforts and accidents in the processes.	The work highlighted the importance of considering different aspects in the analysis of times and movements, such as technological, environmental and ergonomic variables.
2019	Serra & Vidal	Methods engineering: a study of movements in the development process of the ignition system of the special project Carcará Rocket design.	Use of the SIMO chart and time study. Time reduction, which went from 2 min and 59 secs. to 1 min and 44 secs., thus making the operator available for other activities and increasing production.	Observation of activities and storage of materials, mapping of the process and improvements, such as leaving inputs ready for product assembly, improving the storage location of materials for daily use.
2020	Santos, et al.	Application of method engineering techniques: case study in a supermarket located in the municipality of Penedo/AL.	Time and motion studies were applied. Improvements were made to the organization of the warehouse, the layout was changed, and workers were trained.	Analyze waiting time and physical exhaustion of workers, use of flowcharts and flowchart maps.
2020	Pastana, et al.	Methods Engineering: Case study in a Truffle factory in Belém/PA.	Use of chronoanalysis. Standardization of activities in which a difference of 6% convergence was obtained between real time and synthetic time, thus enabling standardization.	In addition to the study of times and movements, the control chart was used to check for divergent data. The floor plan process flow chart was created to determine synthetic times.
2020	Ceroni , et al.	Analysis of the activity time of a confectionery shop in Pelotas-RS using chronoanalysis.	Use of chronoanalysis and man-machine graph. Their combined use allowed the identification of idle time during the process. Increased productivity.	Interview with owners and employees to identify possible bottlenecks. Combination of chronoanalysis and human-machine graph tools for better identification and solution.
2020	Johansson & Nafisi	*Process mapping in industry – the self- centered phenomenon and how it effects continuous improvements*	Use of unguided process mapping and value-oriented process mapping. Both suggested proposals for improving time, but only the guided one proposed a way of achieving improved	This research article demonstrates comparisons in processes in which workers perform process mapping by themselves, and on the other hand shows individuals instructed and trained with process mapping, thus

Year	Authors	Study objective/area	Methods used and research gains	Main features
			quality of value objectives.	presenting gains in guidance for elaboration.
2021	Diniz & Pereira	Application of process mapping and 5S in the budgeting sector of a French construction company: a case study.	It presents the application of process mapping, Lean and 5S in an office, thus optimizing time and quality as well as reducing costs.	Production engineering tools have made it possible to standardize tasks, facilitating the transmission of knowledge to future workers. The use of 5S has helped in locating information.
2021	Bezzato , et al.	An Analysis of Different Load Loading Methods for a Food Company Based on a Time and Motion Study.	Tools such as process flow diagrams and chronoanalysis were used, resulting in a 47% reduction in process time.	The standardization of the operation facilitated the identification of problems, and the defined standard time allowed the evaluation of advantages and disadvantages of the modalities.
2021	Gorobets et al.	Application of time and motion studies in real and virtual environments under comparative conditions	The study of time and movements was applied in two environments (real and virtual) and it was noted that the productivity results were worse in the virtual environment.	The observational process of times and movements is fundamental to the accuracy of the analysis process and requires care in its collection.
2022	Sotsek , Vivan and De Oliveira	Identify the main methods and tools applied to the study of times and movements in the industry between 2010 and 2022.	The article uses a systematic literature review. 31 articles were selected between 2010 and 2022,	It was noted that, despite its importance, there are few academic productions in the area. It highlights the importance of chronoanalysis to increase productivity and ergonomics in industries, in addition to helping to reduce costs and improve working conditions.

Source: The authors.

The studies presented in Table 1 focus on the study of time and motion as well as the chronoanalysis technique and were applied in different contexts, of a basic and applied nature. They used several tools such as flowcharts, graphs and process flow diagrams, in addition to several techniques widely used in work in the Lean Manufacturing context such as process mapping, 5S, kaizen and Gemba walking. These tools are used to identify bottlenecks, improve efficiency and standardize processes. However, it is reasonable to state that all of them have the principle of giving visibility to the context under study to make it clearer and thus highlight its restrictive aspects.

Most studies highlighted increased productivity as the main gain, whether through reduced time or improved process organization, although improved quality and process standardization were also highlighted as relevant results.

The literature review also revealed a defined operational system for the application of chronoanalysis and other techniques in process improvement procedures: the recognition of the actual sequencing of procedural activities is the step identified in the research as being the start of the process, followed by the systematic collection of time and movement data associated with operational practice, to later be submitted for careful analysis by the professionals involved in the improvement. These steps identify the restrictive aspects of the process and thus allow for interventions that lead to operational improvements, whether in time or layout. It is also possible to note mentions of the lack of studies that highlight the application of these techniques in real processes, in order to reveal their sequential operationalization.

3. METHODOLOGY

This applied and qualitative research was based on the quality control sector of a sugar and alcohol plant in the interior of São Paulo - Brazil, specifically the chemical analysis laboratory, composed of several benches separated by similarity in the product manufacturing process. The area management defined the bench for chemical analysis related to sugar manufacturing, with results issued at 8:00 a.m., as the one chosen for the study, due to the high number of complaints about delays in analytical results from the industrial process team. The analyses considered in the investigation of sugar manufacturing refer to the quality of the final product with the respective analyses of VHP sugar: ash, color, Pol and moisture of the finished product.

The research took as reference the laboratory activity carried out by 01 experienced professional (technician), responsible for the chemical analyses and reports of VHP sugar. The procedures adopted in the investigation took as a reference basis the works of Barnes (1977), Barnes (1991) and Thakre , Jolhe & Gawande (2009) which define in general terms the main stages of the improvement of a process based on the study of times and movements as being the recognition of the current state of the process, including here its sub-operations , its appropriate sequencing, its characterization in terms of times and movements with the capture of the corresponding data, the analysis and election of the improvement points, development of the improvements and their incorporation into the operational routine including here the aspects that involve the training of the team involved. For the case under study, the operational sequence adopted for the application of the chronoanalysis technique was: the collection and analysis of initial data of the procedure (original state), proposal of improvements for the process, implementation of the improvements, training for the adaptation of the professional (technician) to the new process, and collection of data after the implementation of the actions, which required a period of 25 days.

The first stage of the investigation was observational and sought to evaluate the entire routine of the selected chemical technician. The period observed was 5 consecutive days, corresponding to the professional's work schedule (5 to 1). It was noted that in addition to the sugar analysis performed at 8 am, another one at 12 pm was also performed, but without complaints. This fact can be explained by the time professionals have to travel to collect samples in the industrial sector: 16 samples are collected at 8 am, while only 4 are collected at 12 pm. The 8 am collection consists of more samples due to the need to analyze more byproducts of the sugar manufacturing process. The 8 am analysis, chosen for analysis, is critical due to its extra demands, but it is the most appropriate for evaluation, allowing a single timer per day to observe the sequence and priorities of the tasks. Once the observation stage was completed, a report was structured with information about the method in its current state.

The subsequent investigation step was to divide the operations into micro-operations to identify and measure handling times and machine times. These data were collected by means of continuous timekeeping, since repetitive readings (individual with the stopwatch resetting after each micro-operation) could influence the observer to neglect waiting records or false movements, as warned by Barnes (1977). After the timekeeping process, all observations and time records were used to structure the document called the observation sheet, which contains all the time spent by the chemical technician on laboratory analyses, and which will be presented in the results section (Table 2).

To obtain the number of cycles required, i.e. the number of times the observer needs to perform timings, formula (1) presented by Martins & Laugeni (2005) was used.

$$n = \left(\frac{z \cdot R}{E\mathrm{r} \cdot \; d_2 \cdot \bar{x}}\right)^2 \quad (1)$$

Where:

- n = number of cycles
- z = coefficient of the standard normal distribution for a given probability
- R = sample amplitude
- And $_r$ = relative error
- d ^{2} = coefficient based on the number of timings performed preliminarily
- $\bar{x}$= sample mean (formula 2)

However, to apply formula (1), five to seven previous timings are required (for this study, the number of six initial timings was adopted). Of the individual timings, the average time is a variable used throughout the research, and for this, formula (2) is applied. The amplitude (R) is the subtraction of the highest value of the timed time from the lowest value. Where d_2 = 2.534, in which a relative error of 5% was admitted, resulting in z = 1.96, data provided through table (4.2) Coefficient for calculating a number of timings and Normal distribution, by Martins & Laugeni (2005). Before proceeding with the next steps, it is necessary to ensure the number of timed cycles, which is essential for the study, as long as there are readings with coherent and conclusive data.

$$TM = \frac{C1 + C2 + C3 + C4 + C5 + C6}{6} \quad (2)$$

Where:

TM = Average Time

C = time of individual timings

Once the number of cycles required has been determined, the technician's rhythm is assessed, one of the most important and difficult phases to assess, according to Barnes (1977), as it involves the personal judgment of the observer who compares the worker's rhythm with his or her own concept of normal rhythm. However, the author emphasizes that there are some systems that can be applied to assist in this judgment, such as the Westinghouse System for evaluating rhythm, which was used in this research.

The Westinghouse System for evaluating rhythm is a system that allows the evaluation of the worker's efficiency in relation to a given activity, and is composed of four factors that have assigned values (Table 1) such as ability, effort, conditions and consistency. Among these values, the observer will make a comparison with the table, and with his personal evaluation, will identify the level in each of these factors, and then perform a sum with an assigned value of each factor ($\sum y$). Through the observer's evaluation and the assigned values, the formula (3) is applied.

$$V = 1 + \sum y \quad (3)$$

Where:

- V = Speed or pace factor
- y = Rhythm assessment (Table 1)

Table 01
Supporting data for y in estimating worker performance.

ABILITY		Y	EFFORT		Y
Super-skilled	A1	+ 0.15	Super-skilled	A1	+ 0.13
	A2	+ 0.13		A2	+ 0.12
Excellent	B1	+ 0.12	Excellent	B1	+ 0.10
	B2	+ 0.08		B2	+ 0.08
Good	C1	+ 0.06	Good	C1	+ 0.05
	C2	+ 0.03		C2	+ 0.02
Average	D	0.00	Average	D	0.00
Regular	E1	- 0.05	Regular	E1	- 0.04
	E2	- 0.10		E2	- 0.08
Weak	F1	- 0.16	Weak	F1	- 0.12
	F2	- 0.22		F2	- 0.17
CONDITIONS		**Y**	**CONSISTENCY**		**Y**
Ideal	THE	+ 0.06	Perfect	THE	+ 0.04
Excellent	B	+ 0.04	Excellent	B	+ 0.03
Good	W	+ 0.02	Good	W	+ 0.01
Average	D	0.00	Average	D	0.00
Regular	AND	- 0.03	Regular	AND	- 0.02
Weak	F	- 0.07	Weak	F	- 0.04

Source: adapted from Barnes (1977).

It is natural that interruptions occur during an activity, whether due to personal needs (activity that demands physical effort) or operational needs (waiting for the completion of the operation of a certain piece of equipment). Identifying these interruptions is of great importance for the chronoanalysis process because they are related to the determination of tolerances, which according to Barnes (1977), is essential to obtain satisfactory data. The methodology used to calculate the tolerance factor uses the rest time for physiological needs that the company grants to the worker during the workday, presented in formula 4 (Martins & Laugeni, 2005).

$$FT = \frac{1}{1-p} \quad (4)$$

Where:

FT = Tolerance factor

p = is the break time (given by the company), divided by the working time

To obtain the standard time, it is essential to have the normal time of the activities. The normal time (TN) is calculated from the average of the timings (formula 2) multiplied by the worker's pace (V) as described by formula 5. The standard time is defined as specified in formula 6 (Martins & Laugeni , 2005).

$$TN = TM \cdot V \quad (5)$$

$$TP = TN \cdot FT \quad (6)$$

The success of a good layout improvement proposal depends on the care taken in studying the times and movements involved in the activity, and one of the precautions that the observer must take in this stage of the chronoanalysis process is to pay attention to the information on the current layout and the identification of the flow of activities/materials. In this sense, when performing the timings, the movements in relation to the activity, positioning, idle times and layout of the equipment must be analyzed, as these are the details that allow the identification of activities that do not add value to the process, and that reveal the points that can be optimized with the possibility of reducing/reducing the standard time of the activity.

4. RESULTS AND DISCUSSION

4.1 Contextualization of data

Data collection for the time and motion study was performed in the industrial laboratory sector, on the VHP sugar chemical analysis bench of a medium-sized plant with a single technician over a period of 25 days. The chemical technician is responsible for collecting, analyzing and entering the results into the company's system, and his bench is equipped with scales, a shaking table, a thermostatic bath, a conductivity meter, a saccharimeter, a moisture analyzer, among other equipment, as well as laboratory glassware such as graduated pipettes and volumetric flasks and several other utensils for the analytical preparation of samples. The initial observations on the first day were crucial to better understand the analytical process and the worker's routine. It is worth mentioning that the professional responsible for the analyses has proven ability for the role, having been trained for it, and has 16 years of experience in activities of this nature.

The worker begins his/her work at around 6:00 a.m. every day. When he/she arrives at his/her workstation, his/her routine begins with a 15-minute safety briefing, followed by the collection of samples, which takes approximately 45 minutes (it is worth noting that the collection includes samples from the entire process and not just the sugar). Upon arrival at the laboratory, the samples are taken to the bench to begin analysis. By management's order, the sugar analysis results should be issued at 8:00 a.m., however, the technician is only able to finalize the release of the results at 8:15 a.m. (a 15-minute delay), which generates dissatisfaction among the beneficiaries of these analyses, which is seen in the increase in the number of calls and complaints.

4.2 Data analysis

The initial observational stage showed that the technician responsible for the analyses did not perform a single analysis at a time, but rather all four (color, ash, Pol, and moisture) simultaneously, which was only possible to confirm due to the researcher's full command of analytical procedural techniques. Having full command of the process proved to be an important prerequisite for research of this type, as it allows the researcher to identify the procedures that are in fact part of the selected operation, a fact also evidenced in the work of Cerone (2020), who emphasized the importance of the participation of professionals involved in the activity based on their procedural knowledge. Technical experience with the activity is a decisive factor in the correct structuring of procedures, and reveals details that are often imperceptible in everyday life, but which burden the operation, as revealed, for example, in the work of Guzel and Asiabi (2022).

The difficulty that arose after the analytical procedures began was identifying and reading the stopwatch at the end of each stage, due to the simultaneous analyses. It was necessary to carefully evaluate the manner and order in which the activities were performed, so as not to lose information during the timing process. The solution found to adequately measure the start and end points of the stages was to prepare a detailed list with all the activities and their micro-operations (a total of 11, as can be seen in Table 2).

The development of the list of operations, their sequence and respective times involved took seven days, the first of which was intended to observe and identify the stages of the technician's activity. The time collection was done once a day, always at the beginning of the professional's shift, when he arrived at the laboratory with the samples.

Table 02

Data from the six initial timings of laboratory analyses of VHP sugar.

Micro-operations	Activities	Timings (min: sec., hundredth sec.)					
		1st	2nd	3rd	4th	5th	6th
1	Sample organization	08:13,8	07:59,3	08:35,4	08:08,3	08:19,2	07:43,9
2	Equipment calibration	10:06,0	10:12.3	09:22,0	10:38.4	10:20,2	09:52,7
3	Weighing Pol analysis and dilution	07:11,8	06:45,9	07:13,7	06:58,6	07:36,0	07:03,0
4	Weighing, Color Analysis and Dilution	04:44,9	04:39,8	04:28,1	04:09,2	04:12,2	04:42,2
5	Weighing, ash analysis and dilution	01:02.5	01:05,5	01:08,9	00:59,6	01:02.5	01:03,7
6	Ash analysis preparation	04:16,7	04:02.8	04:22,9	03:52,8	04:01,7	04:08,9
7	Color analysis preparation	13:09,9	13:24,8	13:39,4	12:45,8	12:36,2	12:15,9
8	Pol analysis preparation	10:36.7	10:19,1	10:44.7	09:43,0	10:09,2	09:54,2
9	Pol Filtration	04:21.5	04:03,6	04:17.6	04:02,1	04:42,3	04:31,0
10	Moisture analysis	02:27.3	02:17,2	02:19,3	02:32.7	02:12,2	02:22,3

11	Typing the results into the system	07:51,7	08:11,4	08:09,2	07:44,8	07:32,5	08:22,5
	Total activity time (h: min: sec)	01:14:03	01:13:02	01:14:21	01:11:35	01:12:44	01:12:00

Source: author's own.

A large amount of movement by the worker was observed to access the equipment, especially in micro-operations 3, 4 and 5, related to weighing the samples for the dilution process. Organizing and cleaning the bench during the analyses was another evidence of the numerous interruptions that the activity suffered. Based on the six initial timings, calculations of the average and the necessary cycles (formulas 1 and 2) were started, to validate whether the timings performed would be sufficient or not, as shown in (Table 3).

Table 03
Number of cycles required for timing .

Micro-operations	Average (min: sec., hundredth sec.)	Amplitude	Mean ($\bar{x}$) (seconds)	Amplitude (R) (seconds)	$n = \left(\frac{z \cdot R}{Er \cdot d_2 \cdot \bar{x}}\right)^2$
1	08:10,0	00:51.5	490	52	3
2	10:05,3	01:16.4	605	76	4
3	07:08,2	00:50,1	428	50	3
4	04:29,4	00:35,7	269	36	4
5	01:03,8	00:09,3	64	9	5
6	04:07.6	00:30,1	248	30	4
7	12:58,7	01:23.5	779	83	3
8	10:14.5	01:01,7	614	62	2
9	04:19.7	00:40,2	260	40	6
10	02:21,8	00:20.5	142	20	5
11	07:58,7	00:50,0	479	50	3

Source: author's own.

Table (3) presents the value of n (according to formula 1), which was the minimum number of cycles measured in the chronoanalysis process, confirming the adequacy of the actual procedure adopted that collected 6 measurements. The next step was the evaluation of the rhythm, which was an estimate of the professional's performance (table 1), considering his/her ability, effort, conditions and consistency of the task.

The worker, with 16 years of experience, demonstrated good skill (+0.03) and mastery of the activity. Laboratory analyses use delicate utensils that require little physical effort to handle, hence the classification of low effort in this item. However, the collections that the technician performs at the beginning of his routine require physical effort, due to access to distant locations and on uneven floors and stairs, which led to this effort being classified as regular (-0.08). The working conditions were classified as good (+0.02) because the laboratory environment is air-conditioned at 20°C and the equipment is considered appropriate in ergonomic terms. The consistency of the activity was classified as regular (-0.02) due to delays in delivering laboratory results, despite the professional's extensive experience with analytical methods. Based on the classifications and the researcher's judgment, the technician's operational speed (formula 3) resulted in 0.95, which together with the average of the initial timings of each micro operation , allowed the calculation of the normal time (formula 5) for each micro operation.

To calculate the standard time, it is necessary to calculate the tolerance factor (formula 5), which is related to the time the worker has available to produce. In this case, the worker works a day of 8h20min, with 1h for lunch and a period of 20min for his/her physiological needs, defined by the company. Disregarding 1h for lunch, we have 7h20min (440min), which when divided by the rest period (20min), results in the variable p (0.05), used to calculate the tolerance factor (formula 4), which resulted in 1.05. Using data from the normal time and the tolerance factor, the standard time of the activity was calculated (formula 6), which can be seen in Table 4.

Table 4 shows that the VHP sugar analyses have a total standard time of 4815.25 seconds, of which the worker's movement during the analysis preparation proved to be the most important item related to time loss. This occurs in micro-operations 3, 4 and 5, when the technician prepares the sample for weighing the sugar (moves to another bench to compose the sample, and then accesses the equipment, the shaking table, responsible for diluting the sugar). While a sample is being diluted, the worker moves to weigh the next analysis.

Table 04

Normal time and standard time data in seconds.

Micro-operations	Mean ($\bar{x}$)	Speed (V)	Normal Time (NT)	Tolerance Factor (FT)	Standard Time (ST)
1	490	1.05	514.50	1.05	538.94
2	605	1.05	635.25	1.05	665.42
3	428	1.05	449.40	1.05	470.75
4	269	1.05	282.45	1.05	295.87
5	64	1.05	67.20	1.05	70.39
6	248	1.05	260.40	1.05	272.77
7	779	1.05	817.95	1.05	856.80
8	614	1.05	644.70	1.05	675.32
9	260	1.05	273.00	1.05	285.97
10	142	1.05	149.10	1.05	156.18
11	479	1.05	502.95	1.05	526.84
Total Time			4596.90		4815.25

Source: author's own (2022).

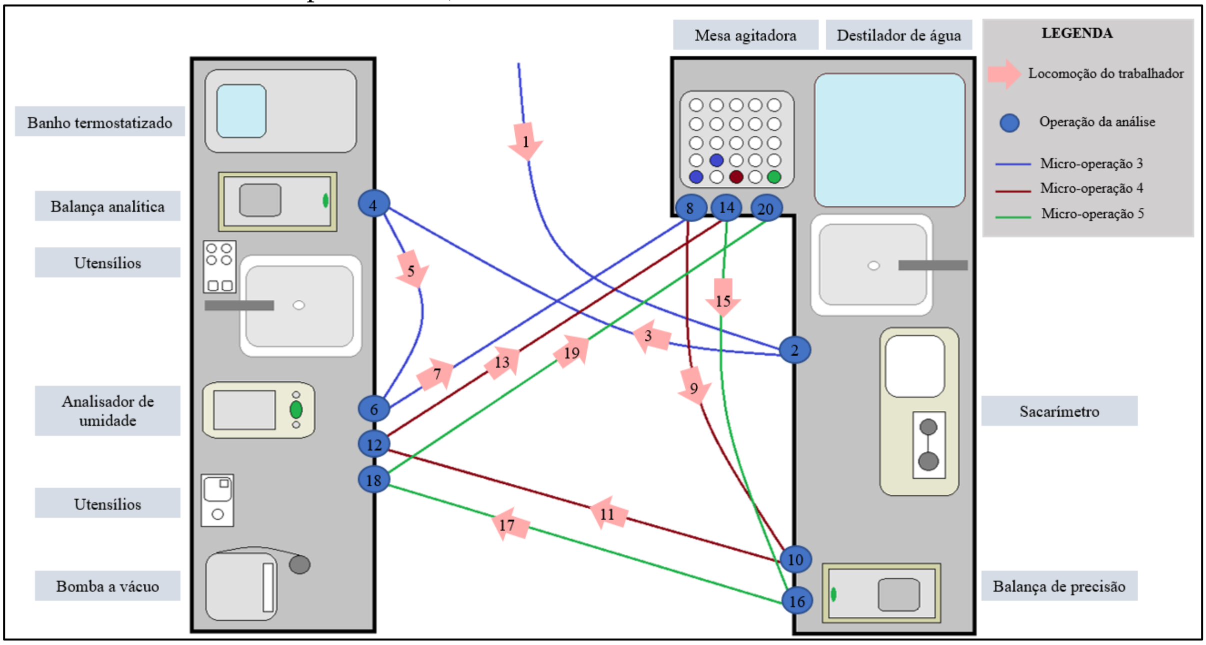
When preparing the ash analysis, at the time of weighing (micro-operation 6), it was also noted that the technician, when placing the sample to be diluted on the shaking table, was moving to organize the work bench. The professional claimed that when weighing the sugar for analysis, he could only continue the analytical procedure when the sugar was completely dissolved in the solution, and since there were no diluted samples, he was moving to organize the work bench, thus interrupting the analytical process.

Another aspect evaluated was the amount of sugar weighed for the analysis, a quantity directly proportional to the dissolution time. For the color and Pol analysis, which were the first samples prepared, 20 and 26 grams of sugar were used respectively in approximately 40 mL of distilled water, and for the ash analysis, only 5 grams of sugar for the same amount of distilled water. The consequence of this sequence of activities was the absence of diluted samples at the end of the weighing, which caused the interruption of the analytical procedure.

The process flow (Figure 1) better illustrates the technician's movements, from preparing the sugar and weighing it for Pol analysis, weighing it for color analysis, to weighing it for ash analysis, which corresponds to 20 actions.

Figure 01 shows that there are two scales on site, one precision (two decimal places) and the other analytical (four decimal places). According to the technician, the Pol analysis has a weighing tolerance of ±0.0010 grams, while the tolerance for preparing the color and ash analyses is ±0.04 and ±0.10 grams, respectively. Due to the requirements, it was suggested that a single piece of equipment be used for weighing, the one with the highest precision, which, in addition to meeting the technical needs of the various analyses, avoids unnecessary displacements.

Figure 1
Process flow of micro-operations 3, 4 and 5



Source: The authors.

Unnecessary worker movement is one of the most common aspects in improvement work involving time and movement, such as the one in question, and is rarely optimized, being one of the richest sources for improving productivity and comfort for the operator, as also pointed out in the works of Bezzato et al. (2021) and Diniz and Pereira (2021) that involved very different economic segments, exemplifying the scope of this characteristic in the processes.

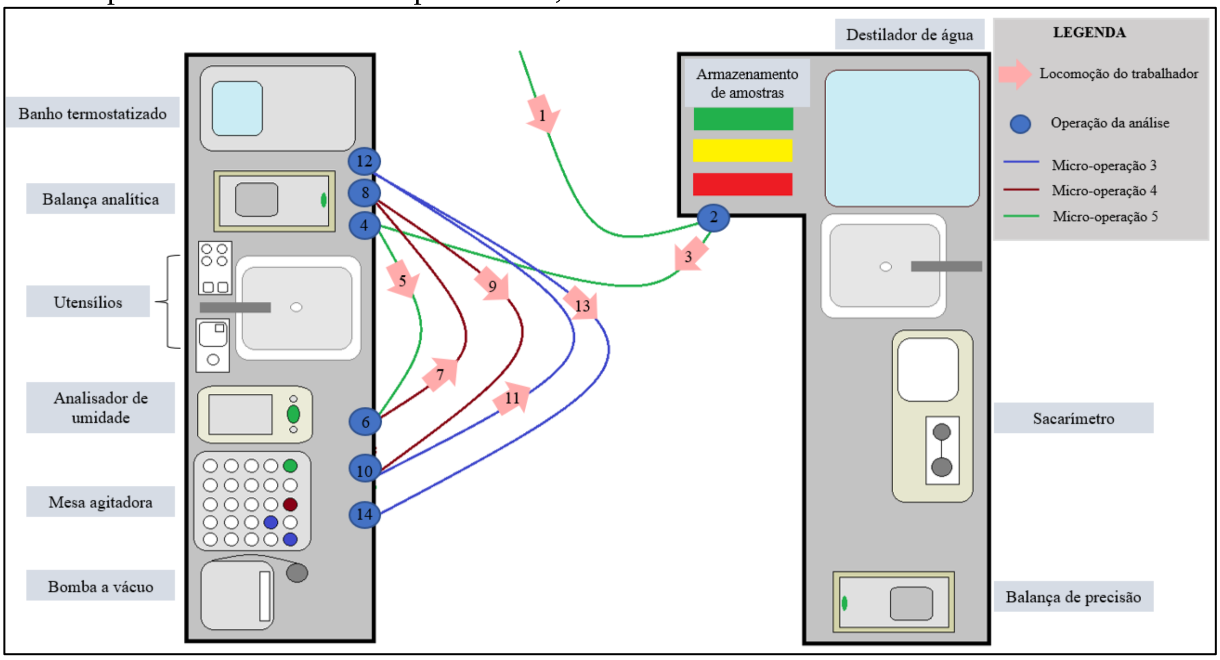
Another critical aspect of the process is related to sample storage. The samples collected by the technician in the industrial sectors are randomly arranged on the laboratory workbench, which subsequently requires time to reorganize the samples (micro-operation 1 – called sample organization), an activity that obviously does not add value to the process. The suggested solution for this problem was to demarcate a fixed space on the bench with colors, according to the level of priority of the samples. The color red would indicate samples with priority analyses, yellow, intermediate priorities, and green, non-priority analyses.

To reduce the technician's movement in micro-operations 3, 4 and 5 to access the equipment (shaking table) and increase the efficiency of the process, changes were suggested in the positioning of the equipment and the order of the analyses, starting with the fastest ones (first the ash analysis, then the color analysis and finally the Pol analysis). This order would allow the diluted ash analysis sample to be made available at the end of the Pol analysis weighing, avoiding interruptions in the analysis process to organize the workbench, which would only be done once at the end of the entire activity. In this way, the micro-operation of organizing and cleaning the workbench was created, after the micro-operation of typing the analyses into the system (issuing the results to the beneficiaries). All suggestions were discussed and approved by the management and the technician, and can be seen in Figure 2 (new layout and analysis flow).

The stage of implementing improvements, such as changing the layout and the new chronological order of the analyses, required that the technician be trained and adapted to the new environment, before a new collection was carried out, to check the effectiveness of the actions. This stage of incorporating the changes into the workers' operational routine is not a trivial activity, much less easy to implement, as it involves changes in habits and the manager's ability to deal with this aspect of management without generating conflicts. Therefore, the involvement of workers in the process is vital for its success, as also evidenced in the reports of Johansson & Nafisi (2020).

It can be seen (Figure 2) that the change in the location of the equipment (shaking table) opened up space on the work bench, which was used for new storage of samples (priority by color), improving their identification and handling. The use of only one scale in the analytical process, and the new chronological order of the analyses, also contributed to reducing the professional's travel time and increasing the efficiency of the activity.

Figure 2
Current process flow of micro-operations 3, 4 and 5



Source: The authors.

The comparison between the old and new arrangements reveals that in the old layout the professional performed 20 actions, of which 10 involved moving to access equipment and utensils, while in the new layout, the number of actions was reduced to 14, with 7 involving moving, as can be seen in Frame 2, which highlights (on the left side) the actions that were eliminated.

Frame 2

Relationship between old and current activities

OLD		CURRENT	
Action	Activity description	Action	Activity description
1	Direct to sample withdrawal	1	Direct to sample withdrawal
2	Get sample	2	Get sample
3	Take sample for weighing	3	Take sample for weighing
4	Weighing sugar for Pol analysis	4	Weighing sugar for ash analysis
5	Take the heavy sample to the preparation bench	5	Take the heavy sample to the preparation bench
6	Prepare Pol sample	6	Prepare sample and leave on shaking table to dilute
7	Take sample to shaking table		
8	Leave the Pol sample to dilute		
9	Direct to weighing color analysis	7	Direct to weighing color analysis
10	Weighing sugar for color analysis	8	Weighing sugar for color analysis
11	Take the heavy sample to the preparation bench	9	Take the heavy sample to the preparation bench
12	Prepare color sample	10	Prepare sample and leave on shaking table to dilute
13	Take sample to shaking table		
14	Leave color sample diluting		
15	Direct to weighing of ash analysis	11	Direct to weighing Pol analysis
16	Weighing sugar for ash analysis	12	Weighing sugar for Pol analysis
17	Take the heavy sample to the preparation bench	13	Take the heavy sample to the preparation bench
18	Prepare ash sample	14	Prepare sample and leave on shaking table to dilute
19	Take sample to shaking table		
20	Leave ash sample to dilute		

Source: The authors.

The availability of resources at the activity site, such as the necessary utensils for preparing the analysis near the scale and the shaking table, and the elimination of redundancies, such as the use of two scales, was the basis for eliminating trips that did not add value to the process. In this scenario, the professional can prepare the sample, and place it in the equipment for dilution, and only then move on to weigh the next sample.

After the ten-day period for the technician to adapt, new time measurements were taken (Table 5) to certify and validate the changes, following the same methodological procedures as the original collection. The average sample time and the number of cycles required to check whether the timings performed were sufficient were calculated again (Formulas 1 and 2) and presented in Table 6.

The number of cycles required to validate the timings did not exceed 5 (Table 6), and since 6 timings were performed, according to the adopted procedure, the requirement of cycles necessary to continue the research is considered to have been met. Based on the data in Table 6, the normal time of the activity was calculated (Formula 5), which allowed us to reach the standard time (Formula 6), as shown in Table 7. As can be seen in Table 7, the standard time of the current activity became 3195.05 seconds, which allowed the publication of the results of the analytical process at 07:40, 35 minutes earlier than normally done (08:15).

Table 05

Final timing checklist.

Micro-operations	Activities	Timings (min: sec., hundredth sec.)					
		1st	2nd	3rd	4th	5th	6th
1	Sample organization	04:37,2	04:13,9	04:51,2	04:40,2	04:18,3	04:22,8
2	Equipment calibration	07:23,4	06:40,6	07:31,5	07:24,8	06:57,2	07:06,2
3	Weighing, ash analysis and dilution	02:26,4	02:37,4	02:40,2	02:23,6	02:39,1	02:19,2
4	Weighing, Color Analysis and Dilution	01:50.4	02:01,3	01:44,2	01:49.3	01:59.3	01:55,2
5	Weighing Pol analysis and dilution	06:23,1	05:57,0	06:31,1	06:40,2	06:03,5	06:12,3
6	Ash analysis preparation	01:54.7	02:02,9	02:07.3	02:00,9	01:50.2	01:59.3
7	Color analysis preparation	10:06,9	09:41,2	09:30,4	09:12,3	09:25,2	10:02,3
8	Pol analysis preparation	01:35,9	01:44.7	01:39,2	01:40.2	01:38,2	01:31,2
9	Pol Filtration	02:06,4	02:17.3	01:59.4	02:03,8	02:00,2	02:09,2
10	Moisture analysis	00:56,3	01:03,2	01:04,2	00:58,3	01:00,8	01:05,3
11	Typing results into the system	05:16,1	05:37,2	05:21,5	04:58,9	05:00,3	05:30,2
12	Organization bench	04:03,8	03:56,2	04:02,3	04:25,4	04:23,8	04:31,0
Total activity time (min: sec., cent. sec.)		48:40.6	47:52.9	49:02.5	48:17.9	47:16.1	48:44.2

Source: The authors.

Table 06

Number of cycles required current model

Micro-operations	Average	Amplitude	Mean ($\bar{x}$)	Amplitude (R)	$n = \left(\frac{z \cdot R}{Er \cdot d_2 \cdot \bar{x}}\right)^2$
	(min: sec., hundredth sec.)		(seconds)		
1	04:30,6	00:37,3	271	37	4
2	07:10.6	00:50,9	430	51	3
3	02:31,0	00:21,0	151	21	5
4	01:53.3	00:17,1	113	17	5
5	06:17,9	00:43,2	378	43	3
6	01:59,2	00:17,1	119	17	5
7	09:39,7	00:54,6	580	55	2
8	01:38,2	00:13.5	98	13	4
9	02:06,1	00:17,9	126	18	5
10	01:01,3	00:09,0	61	9	5
11	05:17.4	00:38,3	317	38	3
12	04:13,7	00:34,8	254	35	5

Source: The authors.

Table 07

Current data of normal time and standard time in seconds.

Micro-operations	Mean ($\bar{x}$)	Amplitude (R)	Speed (V)	Normal Time (NT)	Tolerance Factor (FT)	Standard Time (ST)
1	271	37	1.05	284.55	1.05	298.78
2	430	51	1.05	451.50	1.05	474.08
3	151	21	1.05	158.55	1.05	166.48
4	113	17	1.05	118.65	1.05	124.58
5	378	43	1.05	396.90	1.05	416.75
6	119	17	1.05	124.95	1.05	131.20
7	580	55	1.05	609.00	1.05	639.45
8	98	13	1.05	102.90	1.05	108.05
9	126	18	1.05	132.30	1.05	138.92
10	61	9	1.05	64.05	1.05	67.25
11	317	38	1.05	332.85	1.05	349.49
12	254	35	1.05	266.70	1.05	280.04
Total time of activities				3042.90		3195.05

Source: The authors.

5. CONCLUSION

The study reinforced the importance of the chronoanalysis technique as a powerful method engineering tool that assists in the detailed analysis of activities.

The research described in great detail the steps used in the application of the chronoanalysis technique in a real environment, revealing the difficulties faced in each of them, such as taking time when performing simultaneous activities, and how to use instruments to measure the time of operations and their capture, aspects that are not covered in the specialized literature, but that define the success or failure of the application of the technique. Aspects such as these are important to assist in the correct replication of the technique, applications that are covered in the literature with little or no level of operational detail, limiting their reproduction in real environments.

The development of this work contributed to the specialized literature mainly by offering technical-operational evidence of the application and applicability of chronoanalysis in a real environment distinct from traditional industrial processes such as the metal-mechanical segment, responding to the vacancy of work of this nature. The contribution was also made by presenting a detailed and defined procedural system for the application of the technique, together with the precautions that should be considered depending on the nature of the activities evaluated.

The procedural system adopted for the technique in this study led to an initial standard time for the evaluated activity of 4815.25 seconds, considering the aspects of the worker's pace and tolerance factors, aspects that in a traditional chronoanalysis procedure would not be accounted for.

The time and motion study provided a broad and detailed view of the reality of the tasks, which allowed the manager greater visibility of the generation of value. The identification of opportunities for improvement, such as those related to wasted time, caused by disorganization of the site and the inappropriate sequencing of samples, equipment and utensils that were far apart, became more evident. The technique also allowed for the improvement of activities, from the moment it identified errors in the procedure normally used.

The investment in improvement actions to reduce wasted time made it possible to reduce the standard time of the activity by approximately 33.5%, from 4815.25 seconds to 3195.05 seconds, even with the creation of a new micro-operation, that of entering the analyses into the system. The chronoanalysis ultimately allowed the results to be issued in the system within the appropriate timeframe, meeting the original demand of the company's sectors, which complained about receiving analytical information from the laboratory late.

Another point that deserves to be highlighted is the ease of understanding and applying the technique, since neither the researcher nor the manager and the laboratory chemistry technician had this expertise at the beginning of the investigation, but were able to develop it taking as a reference the scientific and technical evidence found in the literature review, and apply it in non-traditional production processes, such as the laboratory analytical procedures of a medium-sized sugar and alcohol plant.

Although there are motivating aspects for implementing chronoanalysis, as previously mentioned, it is important to pay attention to the care that must be taken when implementing the technique, such as choosing the method of timing (continuous model or with interruptions (stops) in the stopwatch). Ignorance of these aspects may lead the observer to disregard idle times and false movements, resulting in inaccurate results for the study. In-depth knowledge of the activity is a vital prerequisite for applying the technique and for achieving its full potential, since it enables the evaluator to see details and values of each micro-operation and judge them in light of the reference values.

The experience provided by the application of chronoanalysis, that is, seeing processes in a more systematic and critical way regarding the values actually generated, is a skill that should be disseminated in other areas of the company, allowing the development of a culture for process improvement.

The application also fostered a better relationship between management and operations, since the mutual analysis of activities was a recurring procedure in this context. This procedure allowed greater integration between hierarchical levels and a greater understanding of the real reasons that challenge the achievement of organizational goals.

The application of the chronoanalysis technique was limited to a small environment with few workers, whose activities are specified with great precision and rigorously controlled, a fact that may limit its full generalization to other areas of the company, especially those that do not have similar structures and dynamics. It is important that other applications be carried out in other areas of the process, so that the impact of the nature of the activities on the results of the chronoanalysis technique can be assessed. One issue that draws attention is the nature of the activity (manufacturing or service) and its influence on the effectiveness of the technique.

Despite the limitations presented, chronoanalysis was essential for the development of the critical and systemic sense of the professional researcher, refining his way of evaluating time beyond the obvious evidence of timed time, allowing a vision with greater integrative capacity, inserting details of the activity into the context, which are the key to implementing improvements in a given workplace.

REFERENCES

Almeida, DD, & Ferreira, J. (2009). Analysis of the methods time measurement (MTM) methodology through its application in manufacturing companies. *Flexible Automation and Intelligent Manufacturing,* 1, 2009.

Barnes, R. M. (1977). *Motion and time study: design and measurement of work.* Blucher Publishing.

Barnes, R. M. (1991). *Motion and time study: Design and measurement of work.* John Wiley & Sons.

Bezzato , GA, Pontes, HLJ, Sousa, LFD, Uchôa, GSM, & Neto, JCB (2021). An analysis of different cargo loading methods for a food company based on the study of time and motion. *In Proceedings of the XLI National Meeting of Production Engineering,* Paraná, 2021.

Breznik , M., Buchmeister , B., & Vujica Herzog, N. (2023). Assembly line optimization using MTM time standard and simulation modeling —A case study. *Applied Sciences* , 13(10), 6265.

Ceroni , MAI, Bemvenuti , RH, Rodriguez, AM, & Pereira, AS (2020). Analysis of the activity time of a confectionery shop in Pelotas-RS using chronoanalysis. *In Proceedings of the 40th National Meeting of Production Engineering, Paraná, 2020.*

Diniz, MN, & Pereira, TF (2021). Application of process mapping and 5S in the budgeting sector of a French construction company: a case study. In *Proceedings of the XLI National Meeting of Production Engineering,* Paraná, 2021.

Guzel , D., & Asiabi , A.S. (2022). Increasing productivity of furniture factory with lean manufacturing techniques (Case study). *Tehnički glasnik* , 16(1), 82-92.

Gorobets , V., et al. (2021). A VR- based approach in conducting MTM for manual workplaces. *The International Journal of Advanced Manufacturing Technology,* 117, 2501-2510.

Johansson, A., & Nafisi, M. (2020). *Process mapping in industry – the self- centered phenomenon and how it affects continuous improvements.* In 53rd CIRP Conference on Manufacturing Systems, Sweden, 2020.

Martins, PG, & Laugeni, FP (2005). *Production management* 2nd ed. Editora Saraiva.

Morlock, F., et al. (2017). Teaching methods-time measurement (MTM) for workplace design in learning factories. *Procedia Manufacturing* , 9, 369-375.

Negaard, B.J., Lyons, K.P., Nichol, C.L., & Polgreen, L.A. (2020). What does a pharmacist do? A time and motion study. *Research in social and administrative pharmacy* , 16(9), 1314-1317.

Santos, FDS, Lima, GHF, Santos, VRV, Omena, WADS, & Santos, CCDS (2020). Application of Methods Engineering techniques: case study in a supermarket located in the municipality of Penedo/AL. In *Proceedings of the XL National Meeting of Production Engineering,* Paraná, 2020.

Serra, RDS, & Vidal, NDN (2019). Methods engineering: a study of movements in the development process of the ignition system of the special project Carcará Rocket design. In *Proceedings of the XXVI Symposium on Production Engineering,* Maranhão, 2019.

Pastana, AJC, Reis, PDNCD, Costa, DHN, & Santos, ACDO (2020). Methods Engineering: case study in a truffle factory in Belém/PA. In *Proceedings of the XXVII Symposium on Production Engineering,* Belém, 2020.

Sotsek , NC, Vivan, MF, & de Oliveira, AR (2022). Time and motion study in the industry 4.0 era: A systematic review of the literature. Journal of Production Management, Operations and Systems, 17(3), 01. https://doi.org/10.15675/gepros.v17i3.2879

Taylor, F. W. (2018). *Principles of scientific management* (5th ed.). Atlas.

Thakre, AR, Jolhe , DA, & Gawande , AC (2009). Minimization of engine assembly time by elimination of unproductive activities through 'MOST'. *In 2009 Second International Conference on Emerging Trends in Engineering & Technology* (pp. 785-789). IEEE.