Punching Process Optimization in a Metal Manufacturing Industry

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Abstract

Nowadays the metalworking sector is one of the most requested areas due to the exponential growth of industries dedicated to key manufacturing components related to metal products, such as mining, commerce, construction, furniture, office, and petrochemical, among others. Faced with a stricter demand and a highly competitive market, strategies are required to generate more agile and efficient processes in order to offer products with the required quality, but, as far as possible, at the lowest cost. This article presents the study and optimization of the punching process within a metalworking industry through the reduction of the times involved in the model changes of the: speaking bracket of Aristocrat – MARS Portrait Enclosure product. The above with the application of techniques such as Value Stream Mapping (VSM), Single-Minute Exchange of Die (SMED), and Poka-Yoke; in a framework of administration and project management. The development of the previous methodological framework allows represent and analyze the flows of materials and information involved in the punching process through the SMED. On the other hand, Computer-Aided Design (CAD) is used to design a plate that allows implement the SMED philosophy with the operators involved in the area. Subsequently, the plate is manufactured and defined as Poka-yoke for the forming dedicated tool to minimize errors in the operation of the process. Finally, this paper serves as an improvement project for the flex Company currently located in Mexico.

Keywords
Optimization, Punching, Manufacturing, Metal-mechanics, Project-management.

1. Introduction
In recent years, the metalworking industry in Mexico has experienced exponential growth due to the rapid expansion of the metal transformation industry market by the most important trading partner, the United States of America. In addition, it increases with the need to have reliable and quality suppliers in the industrial field that manage to reach the necessary standards to meet the needs of a new demand in the manufacturing sector, which leads to the search for a hand of specialized and technically prepared that is currently in full development.

For the country, the metalworking industry constitutes 17.6% of the Gross Domestic Product (GDP), according to figures from the National Institute of Statistics and Geography (INEGI). According to figures from the Internet Tariff Information System (SIAVI), based on registered imports, Mexico annually receives just over 7,000 pieces of metal-mechanic production equipment, to which higher levels of technology, innovation, and sophistication. Additionally, according to data from the National Chamber of the Iron and Steel Industry (Canacero), Mexico is the 14th steel producer in the world, it employs more than 700,000 people directly and indirectly and in 2018 alone, production was 20.2 million tons of liquid steel. (American Magazine -industrial, 2021).

It should be noted that in the recent past, the manufacturing processes in the field of metalworking were delegated to small production workshops where the technique and administration systems were scarce or barely covered the basic needs of their customers, the foregoing due to the fact that the products they were simpler and manufacturers had their own supply chains. Today, with increasingly sophisticated multi-service products such as high-end electronics, entertainment, and multifunctional household and industrial appliances, as well as the rapid transformation of advanced manufacturing sectors, the need for more efficient processes has become apparent. robust and more reliable quality systems.

For this reason, manufacturers of advanced manufacturing products are moving their metal supply chains to companies that guarantee proper compliance with the norms and quality standards necessary for a new industry in full development. With this growing demand from new customers, companies like Flex are increasing their manufacturing capacity through strategies to generate more agile and efficient processes in order to offer products with the required quality at the lowest possible cost.

This article presents a case study of the flex company currently located in Mexico for the sake of administration and project management where the study and optimization of the die-cutting process are addressed through the reduction of the times involved in model changes of a previously defined product. All above with the application of techniques such as Value Stream Mapping (VSM), Single-Minute Exchange of Die (SMED), and Poka-Yoke.

1.1 Objectives

The present study goals seek to develop a project management framework that allows the implementation of engineering tools that optimize resources, in the operational processes in a company with a turn in the metalworking sector, specifically in the time reduction of tools change set up in thin turrets, immersed in a punching process, for parts used in the assembly of metal cabinets that are the coating and structural support of casino machines distributed and marketed by furniture companies for American electronic games, such as the case of the Aristocrat company.

Specifically, the development of the previous methodological framework will allow representing and analyzing the flows of materials and information that intervene in the punching process through the SMED. The use of Computer-Aided Design (CAD) will contribute to designing a test tray to implement the SMED philosophy with the involved area operators. With the use of specialized machinery, the previously designed tray will be manufactured and defined as a Poka-yoke that will be used as a tool intended to minimize errors in the operation of the process.

2. Literature Review

This literature review is divided into four main sections. The first describes some works that demonstrate the project management applicability in the manufacturing industry; the following sections show related items to the application of the VSM; SMED systems, and finally, the development of Poka-Yoke systems.

Project management is a fundamental process in the manufacturing industry due to the fact that project work is becoming a common methodology and of regular use in a wide sectors and organizations range, in addition, the speed of change and adaptation is increasing and many initiatives of these changes, are organized as projects, however, at the same time, it can be seen that the success rate of projects remains low and project management (PM) skills are reported to be growing in importance. (Asgard, 2022). These trends indicate the need to learn more about the methodology of project work and project management in particular, in the literature there are examples such as that of (Xu et al., 2012) who approached the problem of a heavy equipment manufacturing project which has a small amount of production at very high costs of design and preparation, and approaching it as a management issue instead of the fulfillment of deliveries issue or manufacturing details, to this implemented the validation of a systematic approach of a management system using tools such as interviews, documentary analysis and literature review, the original questionnaires were designed, delivered and returned for a better understanding of the subject after a brief field survey.

The graphic schemes that are generated through the VSM allow for representing, analyzing, and improving the materials flows and information involved in a production process. In the literature, there are some studies focused on the application of these tools within the industry, such as the case of (Rahima Shabeen & Aravind Krishnan, 2022), who applied a mapping of the value stream in the prefabrication of structural and assembly concrete elements to reduce processing time and increase production. Another case is that of (Kundgol et al., 2021) who identify those activities that do not add value or waste in the current production process in the aerospace industry. To date, several authors have proposed variants of the VSM for a more comprehensive and holistic analysis, such as the case of (Brown et al., 2014), who propose an extension of the conventional VSM that incorporates metrics for sustainability, calling it Sus-VSM, or else, (Ferreira et al., 2022) who explore the integration of Lean practice value stream mapping with hybrid simulation combining discrete event and agent-based simulation.

SMED systems have been of great support in the manufacturing industry throughout recent history, such techniques seek to maximize production processes, eliminating waste and activities that do not generate value to production, the literature reflects these benefits in various works, such is the case of (Monteiro, 2019) whose work focuses on the production times optimization in a machining industry through the mapping of activities in the value chain, managing to determine the processes with the longest operation time such as horizontal and vertical milling. Another case is that of (Afonso et al., 2022), who implement an innovative and systematic intervention model for the application of an ergonomic SMED model in an industrial unit of automotive steel springs. In addition, (Vieira et al., 2019) presents a project for the implementation of the SMED methodology to optimize the cold profiling process, in a population of five different profiling machines; or (Silva et al., 2020) who implement SMED in a cork company dedicated to the floating platform's production to reduce by 15% the time it takes to make series changes on a cutting line.

The development of Poka-Yoke systems deals with techniques used by the industry to reduce errors caused by human interaction in production processes. In the literature there are multiple works that address the development of these mechanisms as measures to reduce errors in the processes, such is the case of (Mohan Prasad et al., 2020) who use these lean manufacturing techniques in the textile industry in southern India, in order to make their production processes more efficient, given that particularly the textile industry has high and low volume in a wide variety of models. Another example is that of (Wiech et al., 2017) who based o Poka-Yoke principles develop an optical detection of objects solution for defect prevention on a milling machine in a learning factory; or (Solke & Sur, 2021), who design and implement a Poka-Yoke configuration to protect the vision of workers working on an axle manufacturing final assembly line.

Finally, addressing a specific overview of the case study of this paper, we have the case of (Costa et al., 2013) who uses the SMED methodology and Poka-Yoke systems in an elevator manufacturing company for the production process in a thin punching turret, indicating that the object of study was carried out specifically to manufacture the cabin panel due to the number of tools used (18 by total) being the most complex product to manufacture, the problems identified were: long set-up times (15.1 minutes), long movement distances of material by the operator (136.7 m) lack of standardized processes, high amount of WIP (work in process for its acronym in English) lack of dies and punches identification, and defects in the maintenance of the tools.

The previous review glimpses a contribution to knowledge in the development of a methodological framework constituted by lean-type engineering tools for the manufacturing processes optimization, highlighting the case study of a company dedicated to the metal enclosures production whose purpose is to serve as a coating and support for electronic casino machines mainly marketed in Las Vegas Nevada USA.

3. Methods

This study focuses on providing a solution to make the model change process for thin punching turret machines in the flex company more efficient, for which lean manufacturing techniques were used, consisting mainly of three phases:

Phase 1. Mapping of the value stream. This phase includes an analysis of the operations involved in the punching process through the use of the VSM technique, characterized by analyzing and improving the product's flow and information within any production process. In this phase, it is expected to detect those activities that do not add value to the product, or waste such as delays, downtime, prolonged idle times, and inventory problems, among others; coupled with it the cause or origin of these.

Phase 2. Single Minute Exchange of Die. The next phase implements a study based on SMED with the purpose of simplifying and optimizing the operations involved in the setup of the model change process for thin punching turret machines. In this phase, it is expected to detect and classify internal, external, and unnecessary tasks in order to propose solutions that allow optimizing model changes through the implementation of Poka-Yoke systems.

Phase 3. Poka-Yoke. The last phase includes the implementation of a technique aligned to continuous improvement, the Poka-Yoke development design according to the opportunities for improvement in the previous phase. This system will allow the reduction of time in the identification and search of the tools used by the operators in a more agile, simple and direct way, in addition to checking the dimensional parameters of the forming tools. With this phase it is expected to avoid unnoticed errors in the production processes of the case study and, on the other hand, to correct inefficiencies in the event that they are presented.

Figure 1 shows the methodological framework implemented as part of a project development framework for the optimization of the punching process of the flex company.

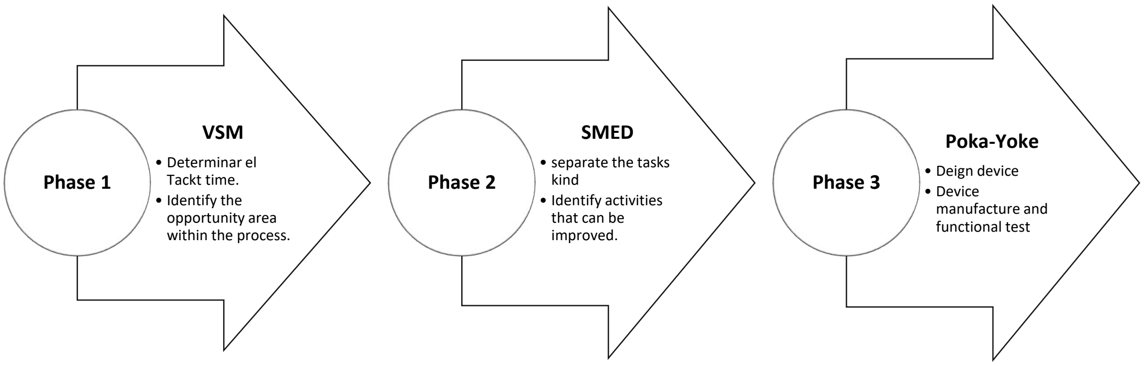

Figure 1. Solution framework.

4. Application of the methodology

The following section presents the solution development framework proposed in the previous section. The development of the VSM implementation, the SMED analysis and the Poka-Yoke system design are mainly described.

4.1 Value Stream Mapping

To know the current situation of the problem, a VSM of the complete punching process was produced, from the beginning of the production order to the delivery of the cut parts to the next process. The product chosen for this case study was the set corresponding to the MARS PORTRAIT cabinet, whose income is the project that most income reports according to a Pareto diagram prepared by the planning department. With the production and demand attributes analysis of the chosen product during the month of February 2022, it was possible to determine that: the monthly demand for that cited month was 1,268 sets. According to equation 1, it is obtained that the available working time turns out to be 1140 minutes per day, considering that there are 19 working days, discounting non-working days and holidays. On the other hand, according to Equation 2, the non-productive time contemplates three shifts with 30 minutes for meals and 20 spare minutes (exercises and physiological needs), having a total of 150 minutes.

$$WM = WD * DM \quad \dots \text{ Equation 1}$$

Where:
WM = Work minutes
WD = Weekday
DM = Day minutes

$$NPT = ((\mathrm{MT} + \mathrm{FT}) * \mathrm{WS}) \quad \dots \text{ Equation 2}$$

Where:
NPT = Non-productive time
MT = Meal time
FT = Free time
WS = Work shift

The machine availability is contemplated at 85% of its total capacity and the waste is calculated at 3%. Likewise, it is contemplated that the total demand to be produced during the month of February considering waste is 1306.04 ≈ 1,306 sets according to Equation 3. The daily demand to supply this amount is 68.73 ≈ 69 pieces per day according to Equation 4.

$$TPD = \ MD * W \quad \dots \text{ Equation 3}$$

Where:
TDP = Total Demand Production
MD = Monthly demand
W = Waste

$$PDD = \frac{TPD}{WD} \quad \dots \text{ Equation 4}$$

Where:
PDD =Production daily demand
TPD =Total production demand

WD =Weekday

Equation 5 shows the available net time calculation, which is 841.5 minutes, and finally, Equation 6 shows the Tack Time, which concludes that to manufacture one set, about 12.24 minutes are required to meet the stipulated demand.

$$NAT = (WM - NPT) * 85\% \quad \ldots \text{ Equation 5}$$

Where:
NAT =Net available time
WM =Work minutes
NPT =Non-productive time
85% =Machine efficiency

$$TAKT = \frac{NAT}{PDD} \quad \ldots \text{ Equation 6}$$

Where:
TAKT = Takt time
NAT = Net available time
PDD = Production daily demand

Table 1 summarizes the described analysis above.

Table 1. Takt Time Definition

Atributte	Quantity	Units
Customer demand	1,268	Sets/monthly
Laborable days	19	Days
Work time per day	1,140	Min/days
Non-productive time	150	Min
Machine capacity	85	%
Scrap	3	%
Total production demand	1,306.04	Sets/monthly
Daily customer demand	68.73	Pieces (set)/day
Net available time	841.50	Min
Takt Time	**12.24**	**Min**

According to the above and with the analysis of the process and process history, Figure 2 shows the VSM of the punching process, which mainly consists of six activities: the order detonation, metal blanks change, tools selection, loading of tools on the machine, loading of the program and cutting process.

- Activity 1.- Detonation of the order: the production order is detonated through an email from the glider to the supplier, which in this case is the punching technician.

- Activity 2.- blank change: For the change of blanks, it is observed that two operators are necessary to move the blanks, there is a cycle time of 35 minutes and a model change (blank) in 1 minute. Operators must travel a total of 15 meters from the machine to the raw material warehouse.

- Activity 3.- tools selection: consists of preparing the tools for the next run; it is carried out by a single person (the technician on duty) with a cycle time of 50 minutes and a model change of 8 minutes on average, the search and tools identification is carried out by the technician and must travel 15 meters from the machine to the Tool Crib. It should be noted that this stage is where the opportunity for improvement was located.

- Activity 4.- Loading the program: it involves placing the program on the machine by selecting the CNC code, making the relevant adjustments to the parameters, and cutting speeds, with a cycle time of 25 minutes and no set up time.

- Activity 5.- Cutting process: it is the machine operation itself. Its operating cycle time for one set is 57.72 minutes without any setup time.

- Activity 6.- Punched parts delivery: the parts are delivered to the customer (in this case it is the next operation in the manufacturing chain: Press Brake) for subsequent processing.

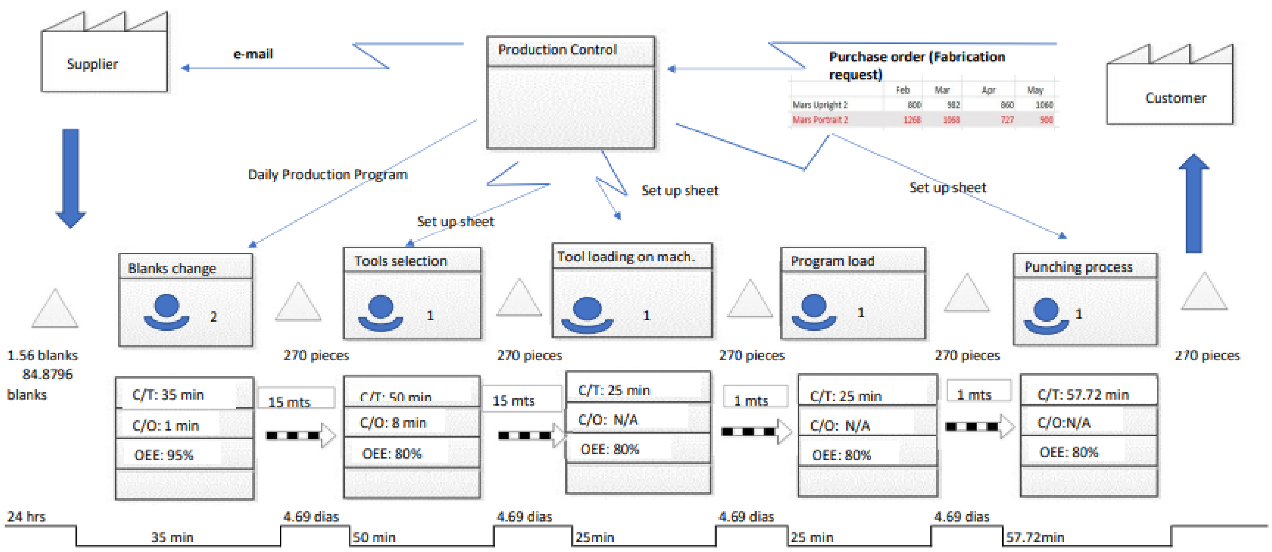

Figure 2.VSM of the punching process in Aguascalientes flex

4.2 Single Minute Exchange of Die

For the SMED elaboration, a Pareto diagram was first made in order to identify the process with the most opportunity for improvement based on the operation times and complexity. Figure 3 shows the aforementioned diagram.

The two activities that provide a greater operation time (80%-20%) within the complete punching process are the cutting process and the tools selection, in this way the operation to which the SMED was applied was determined, for the punching process case, it was not possible to improve because this time depends 90% on the efficiency of the machine, with the operator having very little participation in this work. Therefore, the activity of the SMED approach was: the selection of tools.

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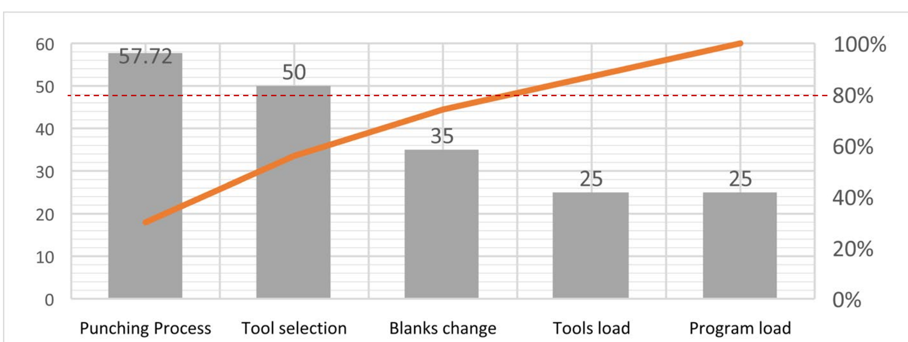


Figure 3. Pareto diagram of the punching process operations

The first stage in the elaboration of the SMED was to separate the internal and external tasks, later in a second stage, an evaluation of the time capacities of the personnel involved was carried out and two specific internal activities were located, which could be transformed into external activities: the tools revision and the preparation of these. Finally, in a third stage, it will be explained that it was possible to perfect the identified tasks through the design and manufacture of a Poka-Yoke for the most complex pieces, understanding these as those that require the greatest preparation due to the number of forming tools to be used, and In this way, eliminate search times and make the process of reviewing dimensional parameters more efficient. Table 2 shows the breakdown of the SMED analysis for the tool selection operation.

Table 2. SMED Analysis.

	Operation	Tool selection activity	Internal activities	External activities	Improvement proposal
SMED IMPROVEMENT PROCESS	*Stage 3*	Refine identified tasks		Make tooling preparation and measurement.	- Poka-Yoke elaboration for identification
				Locating the tools in the Tool Crib.	
	Stage 2	Convert internal tasks to external	- Make a review of good condition tooling.	Technician moving from the machine to the Tool Crib to look for a tool.	
			- Place the punches in turret.	Locating the tools in the Tool Crib.	
				Walk back to the machine.	
				Locating the necessary tool in the program's installation sheet. Make tooling preparation and measurement.	
	Stage 1	Separate internal and external tasks	Locating the necessary tool in the program's installation sheet.	Technician moving from the machine to the Tool Crib to look for a tool.	
			Make a review of good condition tooling.	Walk back to the machine.	
			Make tooling preparation and measurement.		
			Locating the tools in the Tool Crib.		
			.		

4.3 Poka-Yoke

The Poka-Yoke approach was based on being a visual tool for the technician whose use is: to quickly identify the forming tools to use in the next run, in addition to facilitating their storage in the tool crib and verifying the forming parameters on site. As mentioned above, the product chosen according to its manufacturing importance was the MARS PORTRAIT cabinet, which has within its components the RIS-179105 SPEAKER PANEL part, this being the most complex with a total of 10 tools: 4 for forming and 6 for cutting. Figure 4 shows the CAD design of the said part in an isometric view.

Once the analysis piece is defined, the following Poka-Yoke was designed and manufactured: by using CAD tools (SolidWorks), a tray was developed that contains the 4 forming tools, which represent 80% of the setup time. These tools can be seen in Figure 5, which were purchased from the Wilson Tool company.

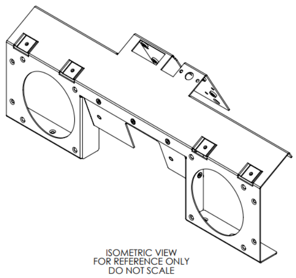


Figure 2. RIS-179105 SPEAKER PANEL

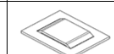
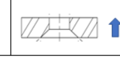
Name	ID	Station	Image Reference
TNE0098.087U	SO: 1776783-70	B	
TNB866.063.591A120U	SO: 1690733-20	B	
TN70248.134A120D	SO: 1905255-80	B	
TN70248.134A120U	SO: 1905255-90	B	

Figure 3. Forming tools 179105

For the Poka-Yoke design, a space was assigned for the matrix and punch of each forming tools, and identification plates were placed, in addition, brackets were placed with the physical sample of the form figure to corroborate dimensional parameters within the same tray. Figure 6 and Figure 7 show the Poka-Yoke design with the criteria and specifications described above.

Subsequently, manufacturing was carried out using internal materials from the flex company, the Poka-Yoke is made up of a total of 10 pieces in different calibers, emphasizing making only the core (tray base) in a solid gage and the other components in light materials (table 3 appendants) since the technician has the option of transporting it to the preparation site.

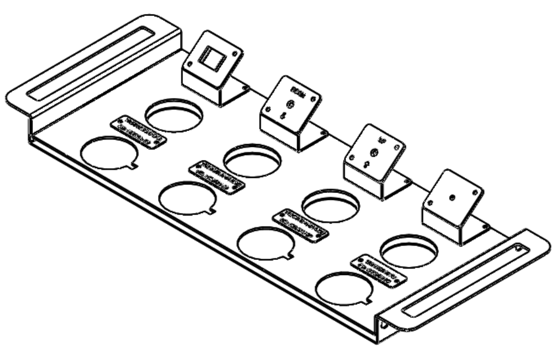


Figure 4. Isometric model view

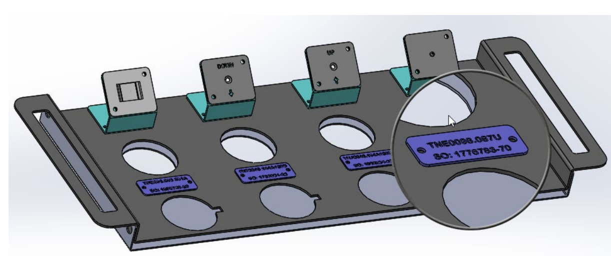


Figure 5. Poka-Yoke final design

As can be seen in Figure 8, the cutting of the materials was programmed using the Radan software and processed on a Bystronics Byspeed3015 laser machine.

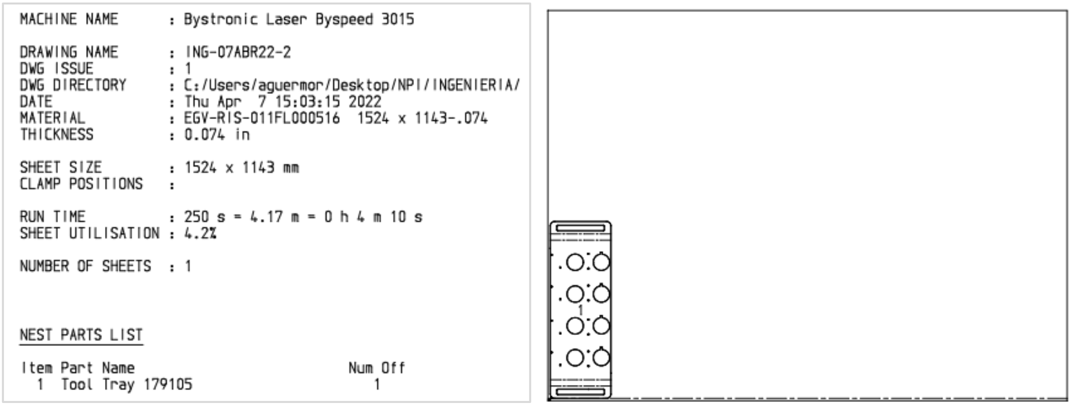


Figure 6. Poka-Yoke Main base programming in Radan Software

Subsequently, the piece was assembled by riveting and put on a test improvement review. Figure 9 shows the process of said assembly. Finally, in order to test the previously made system, some tools were mounted on the Poka-Yoke to put in work, as shown in Figure 10 and additionally, Figure 11 shows an example of the measurement of physical parameters with the Bridge tool TNB866. 063.591A120U.

Figure 7. Poka-Yoke final Assembly

Figure 8. Putting the Poka-Yoke into work

Figure 9. Bridge Punching tool TNB866.063.591A120U

5. Results and Discussion

This article had several results focused on the optimization of manufacturing processes, among which the following stand out:

- The part RIS-179105 SPEAKER PANEL model change was made more efficient. It was reduced the search and transferring time of the tools for the set from 50 to 37 minutes, which represents a 26% improvement.

- The search for tools on the shelf has been eliminated, offering greater time flexibility to the technician to place the tools on the turret.

- It was possible to eliminate 26 seconds of verification with vernier tools through the sample figures, reducing 1.73 minutes (26 * 4) of the total 8 min of set up, leaving 6.27 minutes, which corresponds to 21.6% improvement.

The foregoing contributes to the goal fulfillment of the project because the demand established by the client is now easily achievable and additionally, extra capacity was added to cover the needs of other clients, it is also worth noting that this study aligned to the resolution of the problems based on an engineering project management framework that will allow the flex company to implement new improvement proposals based on techniques supported by an accurate and efficient methodological framework.

5.3 Future research

As future work, it is intended to strengthen the validation of Poka-Yoke systems through the implementation of a study of times and movements that allows increasing the cutting capacity in the other projects, elaborating devices such as the one proposed in this study, designed specifically for the manufacture of the most complex parts in the different cabinets. On the other hand, additional activities will be reviewed within the VSM that can also be integrated into this or another improvement analysis in the punching cutting process.

6. Conclusion

This paper demonstrates that analysis techniques in production processes are effective and that constant training in the area of research, and especially engineering project management, is a basic methodology in the industry, in addition to planning, The use of research techniques and training in assertive communication, these techniques today are an extremely indispensable tool, where the main objective is the delivery of reliable results that give certainty to the different challenges that companies currently face.

For the metalworking industry, project management techniques represent a starting point for the analysis of new opportunity areas, where production processes can be studied with a reliable methodological framework, giving greater chances of success when implementing better engineering techniques.

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Biographies

Erick Guillermo Moran Martinez. Mechanical engineer with a specialty in manufacturing, is graduated from the Technological Institute of the city of Aguascalientes. He obtained his degree in 2008 through the option of the EGEL exam (general exams for graduating with a degree) with a mention of outstanding performance. He has worked since 2009 in industries of the metalworking sector (Diseko Soluciones and Maindsteel) as a product and manufacturing engineer in areas such as design, product and development of industrial metal transformation processes, his specialty being laser and punching cutting. He is currently an NPI (New Product Introduction) engineer incorporating and developing new product processes for the industrial area at the flex company located in the state of Aguascalientes, Mexico.

Missael Alberto Román del Valle. Originally from the city of Orizaba in the state of Veracruz, he obtained the title of Industrial Engineer with a specialization in Manufacturing and Reliability in 2015, later graduating with honors from the Postgraduate Studies and Research Division of the Technological Institute of Orizaba, which awarded him the degree of Master in Industrial Engineering with a specialization in Decision Analysis Systems with a focus on the logistics sector through the defense of the research work "Optimal design of packaging and packaging under functional and environmental aspects for a lemon fruit and vegetable company Persian", which is based on the development of a mathematical model based on Artificial Intelligence techniques and solved through the application of multi-criteria Genetic Algorithms for the generation of optimal values for the definition of the design and structure of an export package international in the agricultural sector. During his academic training, he was a founding member of the Student Chapter in Engineering Sciences endorsed by the Mexican Association of Logistics (AML), he has also taught courses on System Dynamics in logistics and industrial processes, has participated in the preparation of articles and presentations for the International Logistics and Supply Chain Congress (CILOG), in addition to having the AML-ProGLOBAL certification. Today he is part of the State System of Researchers and works for one of CONACYT's Public Research Centers, the Advanced Technology Center, CIATEQ A.C.; in which he works as an Associate Researcher in the Logistics and Supply Chains area, responsible for the information systems laboratory.

Appendants

Table 3. Construction materials of the Poka-Yoke

	Component name	Material	Gage
1	Tool Tray	CRS (Cold Rolled Steel)	14
2	Tester bracket	CRS (Cold Rolled Steel)	16
3	B866.063.591A120U tower	CRS (Cold Rolled Steel)	18
4	TN70248.134A120D tower	CRS (Cold Rolled Steel)	18
5	Bottom Tool Tray	CRS (Cold Rolled Steel)	18
6	TNE0098.087U ID plate	CRS (Cold Rolled Steel)	18
7	TN70248.134A120U tower	CRS (Cold Rolled Steel)	18
8	TNB866.063.591A120U ID plate	CRS (Cold Rolled Steel)	18
9	TN70248.134A120D ID plate	CRS (Cold Rolled Steel)	18
10	TNE0098.087U POKAYOKE	CRS (Cold Rolled Steel)	18