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Integration of Quick Response Manufacturing and Lean Manufacturing to increase on-time deliveries in a metal-mechanical company

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Abstract*– Nowadays, companies sustain their permanence in the market with the satisfaction of their customers, and manufacturing companies, specifically those in the metal-mechanic sector, are no strangers to this. This is due to the fact that they have a method of working to order and a high variability of products with low volume, which leads to failure to meet delivery deadlines. Thus, in the field of industrial engineering, there is a percentage indicator that measures this problem. This is the "On Time Delivery" indicator which, with the efforts reviewed in the literature and success cases, is the most accurate for the analysis. The importance of solving this problem lies in the shortcomings of the models applied without a combined structure such as Quick Response Manufacturing and Lean Manufacturing. In this case study, a current value of 50.10% in orders with on-time delivery of the machining line was determined. This integrated model, post-validation, managed to increase the percentage of on-time deliveries to a final value of 91.07% (includes: final machine availability of 90.17%; Set-up time of 213.35 minutes and Cpk of 1.1651).

***Keywords--* Make to Order, Manufacturing Systems, Quick Response Manufacturing, Single Minute Exchange of Die, Total Productive Maintenance.**

I. Introduction

The metal-mechanic sector represents, within the national GDP, a 20% share. The relevance of this sector arises to a greater extent in the companies that work under order (manufacturing system). In this sense, 40.4% of the production of metal products is directly related to the metal-mechanic machine tool industry. At a contextual level, the main indicator measured On-Time Delivery (OTD) is related to its level of permanence in the market. In other words, the fulfillment in the delivery of orders in companies that have a varied production of products, but with low volume (High Mix Low Volume). There is an opportunity for improvement where there is a 10% drop in growth [1].

Within the problematic and conceptual framework presented, the non-fulfillment of orders based on the agreed dates is presented as a critical state. This is due to the fact that it is generated by the state of failure of each machine tool, excessive time in the machine configuration and assembly of the parts and, finally, in the post-machining reprocesses caused by the manufacturing system.

This case study has as its final objective the integration of a model that includes the Quick Response Manufacturing and Lean Manufacturing methodologies. The main differentiation of both methodologies is in the level of production and the variety of products. The general approach of the research work is focused on the principle of Dynamic Systems (Manufacturing Cells) of QRM and TPM and SMED of Lean Manufacturing.

It is important to mention what led to the search for the integrated model. For this, 6.59% is evidenced as the economic impact that represents the total turnover (January 2022 - March 2024) in the case study company due to the root-causes that will be detailed in the problem tree. Consequently, the opportunity for improvement was determined with the arduous choice of technical engineering improvements by evaluating the current situation of the company.

Finally, the results expected and obtained after the application of this model were validated by including the manufacturing systems. That is, the work cells of the dynamic systems, a key pillar of QRM.

II. Methodology

A. Problem analysis

The case study is developed in a metal mechanical MSE involving four production lines. The improvement opportunity focuses on the most important main line, the machining line. This line represents the most profitable in terms of revenue volume and is therefore key to the company's balance sheet. Below is a representation of the percentage of revenue with respect to all lines.

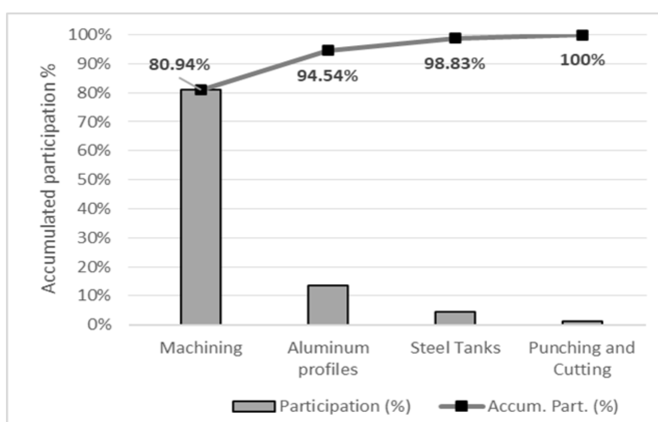

Fig. 1. Production lines according to % of revenue volume.

As the machining line has the highest participation, it is also where the low level of order fulfillment (on-time deliveries) occurs. This could be demonstrated with a qualitative and quantitative diagnosis. The manufacturing systems for each part, calibration methods and machine configuration were evaluated.

Once the critical production line was identified, we proceeded with the economic impact analysis. This was done to detail the monetary losses generated by the low compliance with on-time delivery of orders.

TABLE I
ECONOMIC IMPACT

SERIAL N°	MOTIVES	PERCENTAGE	AMOUNT ($)
1	MACHINERY-EQUIPMENT SHUTDOWN	51.36%	$ 17,672.45
2	BREAKS FOR ELEMENT PREPARATION	33.01%	$ 11,358.41
3	REPROCESSES IN PRODUCTION	15.63%	$ 5,378.12
TOTAL			**$ 34,408.98**

Subsequently, after recognizing each detail of the economic impact, we proceeded to evaluate and link these reasons with the root causes that originate the main problem. For this, the analysis involved diagnosing with engineering tools such as Failure Mode and Effects Analysis (FMEA). Likewise, the taking of times for each activity according to the preparation of the machine before and during the production of the metal parts. Finally, the analysis of the process was carried out to establish its capacity by means of the Cpk index. According to the result will determine how the current method of the manufacturing system works.

Consequently, the previous sections are translated into a problem tree for a visualization of the context in which the company finds itself in relation to the main problem and the root-causes that generate it in a quantified way.

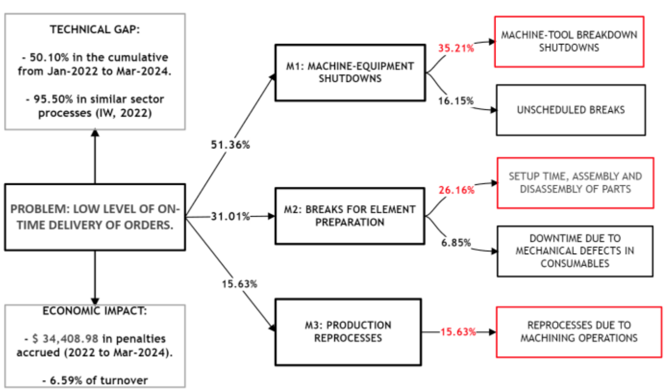

Fig. 2. Problem Tree.

According to the problem tree, it can be concluded that the analysis and the proposed solution model are aimed at mitigating the root causes enclosed in the red box. Likewise, the respective percentage of each one is shown, where 35.21% corresponds to "Machine-Tool Breakdown Shutdowns", 26.16% to "Setup Time, assembly and disassembly of parts" and 15.63% to "Reprocesses due to machining operations".

With the situational context of the company, the detail of the level of fulfillment of orders with on-time deliveries can be added. This is done by quantifying the actual delivery data by month and year diagnosed.

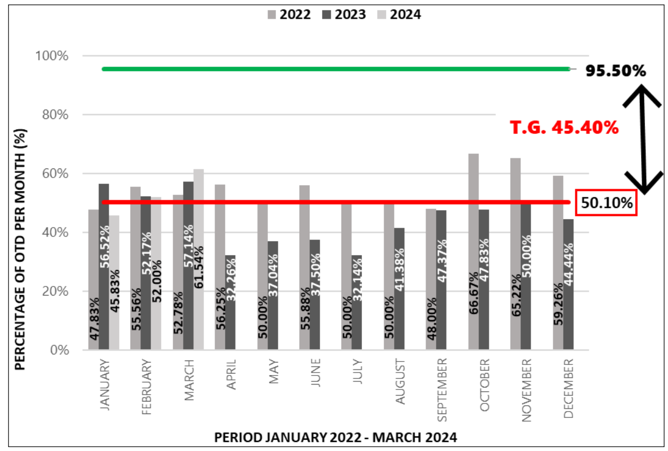

Fig. 3. Analysis of the company's OTD against the sector's target.

Figure 3 shows the ratio of order fulfillment by month and year. Also, enclosed in a red box is the current value of the company's main indicator, the OTD of 50.10%. However, there is a technical gap of 45.40% with respect to the first level sector, where it is 95.50%. This indicates a critical problem in the company whose monetary values were described in the economic impact. Among the initial steps is the identification of indicators for the evaluation of the case study and where the solution model will be supported. The table of indicators is shown below.

TABLE II
INDICATORS

N°	Indicator	Formula	As Is
1	% On-Time Delivery	$\frac{\text{Orders delivered on time}}{\text{Total orders delivered}}$	50.10%
2	% Availability	$\frac{MTBF}{(MTBF+MTTR)}$	69.74%
3	Setup Time (min)	$\sum_{i=1}^{n}(TiempoActividad_i)$	439.23 min
4	Cpk (Reprocesses)	$\frac{\mu - LI}{3\sigma}$	0.0134

The indicators shown in Table 2 are key to measuring the success of the solution model that will be presented in the following sections. The main indicator shows a current value of 50.10% with respect to the OTD. This value comes from a set of incidences and deficiencies in the current manufacturing system. That is, it does not contemplate an optimal method where it is affected by machine tool failures, high setup times and reprocessing rate that results in a non-capable process. Therefore, the indicators of availability, setup time and Cpk that evaluate each aspect mentioned respectively are shown.

B. Literature Review

In this subsection, we seek to understand the link between root causes and the engineering tools that will solve them. In which, the success cases applied to the situational context with similar engineering tools are highlighted. To achieve this, it is subdivided into five typologies where the most important and relevant aspects are covered.

B.1. TPM and SMED to increase OTD in metalworking companies

In this typology, tools can be diversified to achieve the objective, such as TPM and SMED. With this approach, an increase of 46.80% in OTD was achieved [2] and 86% in the metal-mechanical company [3]. On the other hand, in comparison with a successful case, it was possible to increase the OTD by 44.33% with respect to the current situation based on a diagnosis with VSM [4]. The literature review indicates that companies with MTO (Make-To-Order) production achieve successful results with 85% in the final OTD.

B.2. TPM to increase overall equipment efficiency on machine-tools

This typology seeks to establish the fundamental parameters in which companies contemplate the application of TPM. That is, they manage to control the average efficiency of the equipment and machine tools involved in their process [5]. Two success cases are described where the analysis focuses on availability as a key factor. In the first instance, for three machines (Machining Centers - CM) it is possible to reduce downtime and availability increases to 42 hours for CM1, 30 hours for CM2 and 55 hours for CM3 [6]. The final comparison indicates improvements in turning center availability to 96.2%, which leads to an OEE of 62.6% [5].

B.3. SMED to reduce machine Setup Time

The reduction in machine set-up and adjustment times are key to achieve the proposed objective. The application of SMED is the most suitable for this purpose and the success cases are varied for the support of this technique. For the change of dies in a die cutting machine, an average reduction of 66.29% in setup time was achieved [7]. Likewise, it was determined the improvement in SETUP time to 265 seconds with a cycle time reduced to 28 minutes [8] and under the same problematic approach was reduced from 29 to 20 minutes (30%) [9].

B.4. QRM and SMED methodology to increase productivity in manufacturing companies

In similarity of context for manufacturing companies, the Industry 4.0 step is known to be at the forefront in the market. The main results of these success stories are detailed below as: increase in productivity to 96%, reduction of downtime from 18% to 4% (16 hours per month) and 2 breakdowns per month [10]. Increase from 6 to 10 units produced per day (80.51% final productivity) [11]. In addition, improvements in the welding area with 13 pieces per hour (28.3% increase in productivity) [12]. However, productivity as an improvement went from 40% to 98% on complex orders by operating between 70-80% of resource capacity whose main result was an increase in on-time final OTD order delivery performance of 80.61% [13].

B.5. Reduction of reprocesses through TPM pillars, autonomous and preventive maintenance

As a last classification of the literature reviewed with the scientific articles, the reduction of the rework rate is determined by partially considering the TPM pillars such as autonomous and preventive maintenance. Relationally with this case, a reduction in the rework rate from 13.5% to 9.5% was obtained corresponding to the main CNC machining line [14]. However, the line availability increased by 11.1% and the efficiency increased to 62%. Likewise, with the implementation of the TPM pillars, the number of defective products that were rejected (rework) was reduced by 30% and productivity increased by 35% [15].

C. Innovative Proposal

C.1. Justification Model

The basis of the model lies in the integrated application of Quick Response Manufacturing and Lean Manufacturing methodologies. This is due to the fact that the case study company presents a type of work-to-order production (Make-To-Order). In that sense, it leads to a high variety of products and low volume of these. However, the choice of which tools and pillars of each type of philosophy to support the solution model was made after a thorough root cause diagnosis analysis.

C.2. Proposed Model

The purpose of this is to increase the main indicator of the case study, OTD (On-Time Delivery) and the current manufacturing system. To this end, it is also essential to improve the other three indicators described above. This is how the solution model proposed for this case study is presented below. It has four components described with a primary focus.

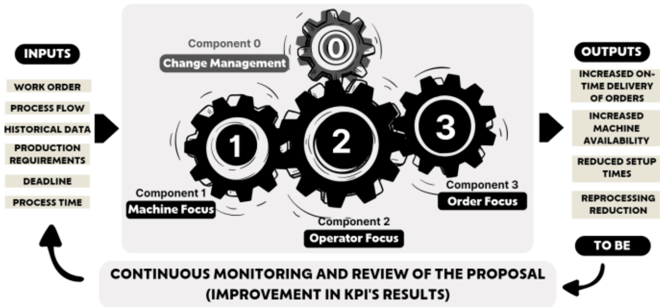

Fig. 4. Proposed Model

The model shown involves a previous or zero component, prior to the application of the following main components. It also details the inputs and outputs that lead to the success of the model and the review focused on continuous improvement.

C.3. Model Detail

In the following sections, the development of each component to solve this problem will be described in a very precise manner and, subsequently, the improvement in the results will be evidenced. The proposed solution model focuses on improving on-time delivery (OTD) of orders by identifying three key root causes: low machine availability, high setup times, and a high rework rate (Cpk). These issues are addressed through the three main components of the model: change management, machine focus, operator focus, and order focus.

C.3.A. Component 0: Change Management

This component has the importance of setting the pace for the implementation of the complex tools of the following components. That is, raising awareness and fostering an organizational culture based on 5S and continuous improvement focused on the medium and long term. In other words, to introduce in a basic and technical way the fundamentals of Lean and QRM tools. This is divided into learning modules that will become company policy, since the application must be carried out until an organizational culture is achieved.

C.3.B. Component 1: Machine Focus

This component has the final objective of increasing the availability of the machines with the implementation of the TPM pillars as the main tool: Autonomous and Preventive Maintenance. Low machine availability, measured as the percentage of active time, is a critical cause of delays. The **machine focus** component centers on optimizing machine utilization through the implementation of preventive maintenance practices and Total Productive Maintenance (TPM). By improving machine availability, OTD increases because machines are operational for a greater percentage of the scheduled time, reducing downtime and allowing more orders to be processed efficiently.

Autonomous maintenance: In this pillar, the operating personnel are involved as the executor of the corrective measures on their own machine. That is to say, with the established formats and parameters, the operator is trained for the activities of lubrication, spare parts change, material enablement in the machine. These steps are defined in each format as well as the details of the red cards and the machine inspection sheets.

Preventive maintenance: The objective of this pillar of productive maintenance is relevant in the model because it focuses on the action of periodic plan review tasks. To identify in advance each component to avoid anomalies and this is achieved with the historical data of failures in the machines. The use of the IPERC tool also contributes to this preventive diagnosis.

C.3.C. Component 2: Operator Focus

This component implements the SMED (Single Minute Exchange of Die) tool and establishes the direct relationship of analysis with the operator's activities on the machine. That is, to be able to quantify and recognize the activities performed for the manufacture of metal products. In order to reduce setup times and downtime. The steps to follow are: *Establish the machine to be evaluated*; *identification of total activities*; *classification of internal and external activities*; *conversion of internal to external activities* and, finally, *optimization of the most recurring activities*.

High setup and preparation times are addressed through the **operator focus** component, which emphasizes training and empowering operators. By applying the principles of Quick Response Manufacturing (QRM) and techniques such as SMED (Single-Minute Exchange of Dies), the aim is to significantly reduce changeover times. Additionally, work cells allow operators to work more autonomously and flexibly, quickly adapting to changes in demand and increasing overall efficiency.

C.3.D. Component 3: Order Focus

In this section, the order-focused component is developed. This arises from the fact that the current manufacturing system in the company is based on the type of machine. However, the QRM methodology establishes a focus on the order. This generates a fluidity in the process and more versatile for this company that works to order (MTO). In this sense, with the implementation of QRM considering the fundamental pillar of Dynamic Systems (Work Cells or Manufacturing) the process is renewed and becomes a capable process. In other words, the manufacturing system focuses on complex orders that require a high degree of customization present in this company with characteristic high product mix and low volume (HMLV).

The high rework rate (Cpk) indicates failures in product quality, leading to delivery delays. The **order focus** component centers on ensuring that orders are fulfilled right the first time, without defects. This is achieved by implementing in-line quality controls and using Statistical Process Control (SPC) tools to monitor and improve process performance. By reducing rework, not only is OTD improved, but costs associated with defects are minimized, maximizing efficiency in order delivery.

D. Model Adaptability

The integration of Quick Response Manufacturing (QRM) and Lean Manufacturing can be successfully applied across various sectors beyond metalworking.

In the food and beverage industry, for instance, the combined application of these methodologies allows for reduced production times and improved efficiency in highly perishable processes, ensuring product freshness and quality. In the textile sector, the integrated implementation can shorten delivery times and enhance the ability to respond to changes in market demand, which is crucial in a highly variable environment. Moreover, in the pharmaceutical industry, QRM and Lean can optimize drug manufacturing by reducing bottlenecks in production and ensuring the quick delivery of critical products, which has a direct impact on public health. In each of these sectors, the combination of QRM and Lean not only improves efficiency but can also reduce operational costs by 15-25% and increase customer satisfaction by reducing response times by 20-40%.

III. RESULTS

The results generated after the implementation of the model were validated in three scenarios. Table 5 shows the scenario with the most successful results. These values exceed the current and expected values. It should be noted that the To Be values are quantified based on success cases in similar contexts.

Technical Criteria for Model Validation

Number of Operators: Include in the model the actual number of operators available on each shift and their distribution across different workstations.

Number of Critical Machines: Consider the quantity and type of critical machines for the production process, as well as their availability and downtime.

Dynamic Systems of Manufacturing Cells (QRM): Implement the structure of manufacturing cells in the model, ensuring that the interactions and flows between operators and machines are representative of the dynamic systems in the work environment.

Order Stratification upon Entry into the System: Include a stratification system to prioritize orders upon entry, considering urgency, value, and fulfillment capacity based on resource availability.

Setup and Changeover Times: Integrate setup and changeover times into the model to reflect the impact of these on productivity and overall efficiency.

Rework Rates and Quality: Include parameters related to product quality and rework rates (Cpk) in the model to evaluate how these affect OTD.

Material Flows: Adequately represent the flows of materials and products throughout the production line, including control points and intermediate storage.

Performance Metrics: Define and measure key performance indicators (KPIs), such as OTD, production efficiency, machine utilization, and rejection rates, to evaluate the model's performance.

The authors indicate that the simulation validation method is the most suitable when the aim is to check how the variables act with the model and based on the model tools [16], [17]. In other words, the Arena simulation software will be used to validate the machine availability, the setup time and thus the rework rate. Among the variables to be considered as critical to control in the system are number of machines, number of operators, arrival of a complex order, number of reprocesses, mean time between failures (MTBF) and repairs (MTTR), initial setup times (SETUP) and with these data we seek to obtain the improvements with the new flows of dynamic systems. To finally improve the overall process in the machining line, with the Cpk greater than 1.00.

Likewise, it presents restrictions at a quantitative level, since not all orders are considered, but only those that are analyzed due to the failure to deliver on time.

Consistent with the description of the validation scenario, all these variables and considerations involved in the overall system are established. To validate the model, the Arena 16.20.03 software was used. It should be noted that the implementation and validation require effective awareness with the introduction of component 0 (change management); for components 1, 2 and 3 will be validated with the simulation and the steps to follow to ensure the expected results are:

a) Take the initial times
b) Establish the types of distributions with the Input Analyzer and verify the "p" value.
c) Data entry in Arena Software
d) Definition of the optimal "N" (output Analyzer repetitions)
e) Verification of new results

Where: "N*" indicates the optimal number of runs to validate with a reliability close to 100% and to be able to contemplate greater security in the results obtained. Whose restrictions are given when the N* is greater than the Observed N, it is then when the next evaluation proceeds until an Observed N > N* is obtained. As can be seen in the values highlighted in red in the following tables.

TABLE III
CALCULATION 1 N* OUTPUT ANALYZER

IDENTIFIER	N OBSERVED	H*	N*
TAVG (system time)	30	2.11	1.00
NC (Quantity Finished Parts)	30	14.40	1.00
NC (Abandonment of defective parts)	30	0.36	107.00
NC (Reprocessing Rectified Parts)	30	2.17	14.00
NC (Reprocessing Turned Parts)	30	2.17	18.00

TABLE IV
CALCULATION 2 N* OUTPUT ANALYZER

IDENTIFIER	N OBSERVED	H*	N*
TAVG (system time)	107.00	2.11	2.00
NC (Quantity Finished Parts)	107.00	14.30	1.00
NC (Abandonment of defective parts)	107.00	0.38	86.00
NC (Reprocessing Rectified Parts)	107.00	2.23	14.00
NC (Reprocessing Turned Parts)	107.00	2.28	17.00

Consequently, the diagnosis of the current situation is described to make the quantitative comparison of the results and the present values.

TABLE V
RESULTS

INDICATORS	AS IS	TO BE	RESULTS
On-Time Delivery	50%	> 75%	91.07%
Availability	70%	> 90%	90.17%
Setup Time	439.23 min	>= 40%	213.35 min
Cpk (Reprocesses)	0.0134	> 1.00	1.1651

In addition, the success of the solution model is based on the motivation of this research and that it can be replicated in metalworking companies where deficient manufacturing systems are involved.

IV. DISCUSSION

As a fundamental part of the case study, the success of the model is ensured due to the fact that there are additional validations to the results shown. In other words, the pessimistic, conservative, and optimistic scenarios were evaluated. The most successful results are in the latter scenario. These results offer a broader panorama for future research, for example, to apply to the other three production lines of this same company.

In addition, the shortcomings found during the research emerged during data collection and analysis. This is how the use of software with the capacity to apply Finite Element Analysis (FEA) to diagnose 100% the failures and functional defects of mechanical parts in machines and production is proposed. On the other hand, in the critical analysis, the stratification of the types of orders and products must be foreseen so as not to incur incorrect values during the data analysis.

V. CONCLUSION

It was determined that the main OTD indicator increased from 50.18% to 91.07%. Consequently, with the improvements implemented and after validation, it was determined that the availability increased from 69.74% to 90.17% of the machines in the machining line. Likewise, a final setup time of 213.35 minutes was obtained, which represents a reduction of 51.43%. Finally, the reprocessing index yielded a value of Cpk = 1.1651, which indicates a capable and more controlled process.

In this sense, with the defined validation, improvements in these indicators were achieved according to references (To Be). In the first instance, with the improvement of availability exceeding 90%, reducing setup time by more than 40% and with a Cpk greater than 1, the technical gap corresponding to the main OTD indicator was reduced. In other words, exceeding 75% and close to 95.5% ensures the success of the application of the TPM, SMED and QRM tools

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