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Improvement of the production scheduling for the casting line in a manufacturing company

Mejora de la programación de la producción de la línea de fundición en una empresa manufacturera

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Abstract

The present study was developed in a manufacturing company located in a Southern region of the state of Sonora, Mexico, and it is focused on setting forth a proposal for scheduling production in their casting line. The subject of study is a level of usage below desired, directly affecting the completion of production orders and, as a result, incurring in failure to deliver on time. The organization requires a tool to know the number of items it can produce and the required time to achieve production of the same. Thus, a technological solution for scheduling production was proposed to schedule production based on the equivalent unit's method. The results indicate that the company, when effectively using resources for the planning horizon, may execute orders by means of a tool that allows having formal and available information for decision-making.

Production schedule, Technological solution and, Equivalent units' method

Resumen

El presente estudio se desarrolló en una empresa manufacturera ubicada en una región del sur del estado de Sonora, México, y está enfocado a plantear una propuesta de programación de la producción en su línea de fundición. El objeto de estudio es un nivel de utilización por debajo de lo deseado, afectando directamente el cumplimiento de las órdenes de producción y, como consecuencia, incurriendo en fallas de entrega a tiempo. La organización requiere de una herramienta que le permita conocer el número de piezas que puede producir y el tiempo necesario para alcanzar la producción de las mismas. Así, se propuso una solución tecnológica para programar la producción basada en el método de la unidad equivalente. Los resultados indican que la empresa, al utilizar efectivamente los recursos para el horizonte de planeación, puede ejecutar órdenes mediante una herramienta que permite contar con información formal y disponible para la toma de decisiones

Programación de la producción, Solución tecnológica, Método de unidades equivalentes

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Introduction

One of the elements that companies must consider in planning a productive system is that of its production capacity. Chase and Jacobs (2014) define capacity as "the amount of production that a system is capable of generating during a specific period", that is, it has to do with the number of items that are produced in a shift, day, week, etc. According to Krajewski and Ritzman (2000), capacity is classified into different categories: maximum capacity, nominal capacity, and actual capacity. The actual capacity of a production process is what determines if the resource is enough to fulfill the demand; it is the most widely used when production is scheduled. In the computation of actual capacity, normal conditions such as downtimes, environmental conditions, unforeseen situations, or the absence of staff are taken into consideration, just to mention a few.

The two main concerns regarding production scheduling are the "priorities" and the "capability" (Wight, 1984). An incorrect scheduling leads to important effects on the operations side, such as the lack of efficiency, productivity, and harnessing of raw materials, which impacts on production costs (Romero et al., 2004). Thus, companies need to start a path of continuous improvement by implementing a correct production scheduling system (Alvarez et al., 2004). "Unfortunately, many producers have inefficient production scheduling programs" (Herrmann et al., 2007). In most cases, production scheduling is done empirically based on the experience of a workgroup (Berruto et al., 2006). In addition, in most food processing industries, and many related technology centers, there is a lack of technical and managerial labor that is familiar with simulation and optimization methods (Banga et al., 2003).

On the other side, schedules produced by information systems may help manufacturers improve deliveries, timely respond to customer orders, and create realistic schedules (LaForge and Craighead, 1998). Even so, "the greatest difficulty does not reside in the scheduling itself, but in its implementation" (Alvarez et al., 2004).

In the company under study, production scheduling is carried out informally and requires the development of computational tools to have better control in organizing customer orders in the casting production line. It is not a priority to diminishing costs nor expanding the line capacity, but to be able to produce customer orders on time. The current situation does not allow that production managers know what is being produced at a given time, and the date when delivery to the customer is feasible. There are several elements involved in the complex decision making, such as materials, equipment, labor, facilities, processes, and it becomes more complex as the demand, the number of products, and the number of customers, increase. How products are manufactured in the casting line may be an aspect that influences this complexity, as it has several workstations where product dimensions make manufacturing times vary. Given the above situation, how many different-sized products may be manufactured with the available resources? and how much time is required to comply with the delivery time agreed with the customer? The answers to these questions require considering different variables, and this problem is addressed in the present work proposing a computational tool to solve it. The objective of this research is to show a technological solution for production scheduling in the casting line of a company, based on the equivalent unit method, to in-crease both the production rate and the fulfillment of customer orders.

Implementing a production scheduling proposal using computer software enables correct manufacturing of production orders, generated by customer orders, allowing for greater efficiency. By allocating a correct distribution of time to manufacture the production orders, the equipment in the casting line will decrease its sub-utilization. A more efficient production scheduling leads to higher levels of service, improving customer satisfaction, and efficient use of resources. Information regarding production times of incoming orders in the casting production line will be readily available for the production manager, who may therefore watch delivery times. Besides, the manager will be able to adapt to production variations by knowing the productive horizon in the casting line based on future production orders.

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Background

Technological advances and the demand for highly customized products have forced manufacturing companies to adapt and develop new solutions to become more dynamic and flexible to cope with changing markets. Companies must adopt modern methods, techniques, and tools based on the planning and integration of production processes, value analysis, and follow-up and control methods for manufacturing orders, to reduce their production costs (Filip, 2018). In this highly competitive scenario, production scheduling plays a fundamental role in ensuring that all operations and processes are executed on time in the company (Alemao et al., 2021, Frazzon et al., 2018).

Production scheduling determines the launching of manufacturing orders and the sequence of operations (Gonzalez, 2005), while in the master production schedule the number of final items that will be produced during specific periods is detailed (Krajewski and Ritzman, 2000). Production scheduling specifies the future times to execute production events (Maynard, 2005). In addition, it can be said that production scheduling is an activity that consists in determining production plans and schedules, according to the operation priority, and therefore determining start and completion times to achieve the maximum level of efficiency (Pajuelo Flores, 2001). The objective of production scheduling is to determine when production orders will start being processed. The process consists of determining the times to conduct production activities, and then adapt the schedule to the production plan, and at the end support the decisions and actions to accomplish the desired production objectives (Maynard, 2005). It is advisable that, in a flexible system, the periods within a production schedule be short-term, by weeks or days. The company under study is a company in the industrial manufacturing sector transforming raw materials into end products using machinery, labor, and tools. There are two main characteristics of the make-to-order system for this company: the demand is variable and the production system is highly organized, to fulfill orders and comply with customer requirements in the right time and manner.

Some companies still regard production as a residual activity, eminently technical, and lacking strategic perspective, with concrete objectives to be accomplished, and whose entire responsibility relies only on the plant managers (Becerra et al., 2008). Today, there are multiple and, in some cases, complex production scheduling techniques. Among the techniques based on operations research, some aim to the optimization of the company resources, seeking the maximum or minimum value of an objective function, subject to certain constraints with a defined number of variables (Herrera, 2011). Berruto et al. (2006) propose a production scheduling optimization method based on a two-step optimization procedure using mixed-integer linear programming. Berruto et al. (2006) show the challenge of planning in a bottling plant, highlighting that in this industry a considerable amount of time is required in production planning and that planning is highly influenced by demand seasonality and numerous types of containers required for distribution.

The proposal of Romero et al. (2004) presents a case study for a company in the construction sec-tor, in which it was determined that through a design for production scheduling it is possible to optimize the allocation of raw materials to process a customer order. Alvarez et al. (2004) proposed operation scheduling in wood furniture manufacturing through Theory of Constraints, pointing out the importance of leveraging production by a comprehensive usage of the installed capacity. Chergui et al. (2018) analyze the planning, nesting, and scheduling problem in additive manufacturing. The mathematical formulation of the problem is presented, and a heuristic approach in Python is proposed to solve it. The objective of their proposal is to satisfy the requests received from different customers, distributed by expiration dates. Frazzon et al. (2018) show a hybrid approach to integrate scheduling of production and transportation processes combining mixed-integer linear programming, discrete event simulation, and a genetic algorithm. In the proposal of Filip (2018), tools focused on production scheduling and efficient management of the manufacturing cycle in the company are presented, as well as the decision tree method as a technique to improve decision-making activity for the launch of a new product.

Salamanca Leguizamón et al. (2009) conducted research in which a heuristic method was proposed for solving the problem of sequencing flow shop systems with unlimited buffers to minimize the make span. Using the proposed method, there were better responses compared to the FIFO (First In, First Out) rule, LPT (Longest Production Time) rule, SPT (Shortest Production Time) rule, and the Palmer heuristic method, for the make span, flow time, average flow time, percentage of machinery utilization, percentage of machine idleness, total waiting time, and average waiting time indicators. Petrovic et al. (2016) uses the method based on the particle swarm optimization algorithm and chaos theory to propose solutions to problems related to planning and programming processes. The optimal scheduling plans presented by Petrovic et al. (2016) are obtained through multi-objective optimization of production time and cost. The optimal scheduling plans are generated with three objective functions: interval, balanced level of machine utilization, and mean flow time. Hubbs et al. (2020) examine the application of deep reinforcement learning to a chemical production scheduling process considering uncertainty. Hubbs et al. (2020) model achieves dynamic programming by comparing the results with a mixed-integer linear programming model (MILP) that schedules each time interval on a receding horizon. Cheng et al. (2015) consider an integrated production and distribution scheduling problem for manufacturers. The objective function presented by these authors is to minimize the total cost of production and distribution for the manufacturer. An ant colony optimization method is proposed to solve the production stage and a heuristic method for the distribution stage.

In the project by Pajuelo Flores (2001), it was concluded that estimated times and the constant follow-up of new or special products to estimate the creation at process and bottling levels are key to obtain the desired results. The application via software used was the Excel database, but it was determined that there are other alternatives to scheduling, such as Access and Microsoft Qry.

The author mentions that the use of equivalent system units, as implemented in his project, may also apply to manufacturing companies, and although each situation is different, there should be no reason for the basic report criterion to vary; it would only modify how information is required for production line being analyzed.

There are some reports on the application of scheduling tools to real situations. For example, Ferro et al. (2021) apply discrete event simulation software to optimize the production planning of a company in the textile sector in Brazil. Also, Micieta et al. (2021) developed a dynamic production scheduling system and they tested it on fictitious data but al-so in data coming from a company that produces railway wagons and bogies. Although García-Menéndez et al. (2021) apply their methods to randomly generated instances, the production environment described by them corresponds to a real steelmaking process flow.

The present article presents a technological solution for scheduling the production of decorative items in the casting line of a manufacturing company.

Methods

The case study is a company in the Mexican manufacturing sector that works using a make-to-order (pull) production system. The products are frames for mirrors and paintings, and decoration items, all produced by reaction-injection molding of polyurethane resin. Once the production starts, the reactions are heated and mixed to be injected into molds. After cooling, the units are separated from the molds, sent to finishing processes, and assembled with mirrors or paintings. The final assembled product is packed for shipping to the customer.

The methodology is based on the Index Method (Garcia-Menendez et al., 2021), adapted to the project, because it provides backward scheduling, which means that it calculates the number of pieces that must be produced from the last day of the stipulated time until day zero of the production, to complete the production on time, using the real capacity of the production line.

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For the development of the project, the following materials were used:

- Company sales catalogs of the different models. It was used to classify the items by size.
- A 10-meter flexometer. It was used to obtain the sizes of the items which were not in the catalogs, to classify them by sizes accordingly.
- Registry tables. Results obtained for the standard times were registered here.
- Chronometers. These were used to measure the total standard times, per item size, in each station.
- Minitab version 17. It was used for data analysis, normalizing casting line process times, and obtaining statistical information from the process.
- Student t-distribution Table, to obtain the corresponding sampling formula value.
- Company sales registries to calculate the actual line capacity.
- Casting line production registries to calculate the actual line capacity.

Determination of the standard average times per size

The classification of the items was done with help of the catalogs that are managed by the Sales area, for the years 2012 to 2018, identifying visually the items and their dimensions. Some of the items in the catalog were no longer produced, so at first, an audit in the molds area revealed which ones were no longer produced, doing a register of this. After that, a comparison of the molds catalogs was made to have a reference of the limits of the size by item. For the classification, those items with more demand were selected to determine which were small, medium, and large. The classification in sizes was based on the press used for the production.

A pilot test was carried out for each class (small, medium, large) to measure the standard times. The method to register times was based on the technique of back-time-to-zero, because the chronometer started measuring when the material started processing in the station. There was a continuous cycle because the chronometer stopped until the material was unloaded and stored in the rack. All the times were registered in paper worksheets. With the data obtained, Minitab was used to calculate the appropriate sample size according to the formula (1):

$$\mathbf{n} = \left(\frac{t * S}{E * \bar{x}}\right)^2 \qquad (1)$$

Where:

t= value corresponding to the Student´s t-distribution (with 90% confidence level, t=2.064)

S= Standard deviation of standard times

E= percentage error (10%)

x=standard time average value

n = size of the sample

After applying the formula, the results indicated that it was necessary to collect additional standard times. For every size, 25 samples were obtained initially. According to the results of the formula, 25 data were required for large size items, 32 data were required for medium size items, and 39 data were required for small size items. The difference to 25 was the number of additional time data required. These samples were measured again in the casting line, and the results were added to the worksheet in Minitab 17.

Evaluation of the real production rate in the casting line

With data are drawn from sales and monthly production registries in the casting line, a comparison was conducted to know the actual production rate and how information is handled within the company. Production is registered monthly, and sales are registered daily. Some differences were found, indicating an inconsistency in the data between the records of the departments of Sales, Production planning, and the Production line.

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Scheduling proposal using the equivalent unit method

An Excel file was created with all the information on the standard times per item according to its size, percentage of units, equivalent units, and equivalent production, as shown in Table 1.

Production	Units produced	Cycle time (Hrs)	Equivalent units	Production equivalent units
Small	19	0.53	1.0392	12
Medium	24	0.51	1.0000	14.4
Large	30	0.68	1.3333	24
Total	73		3.3725	50

Table 1 Initial date
Source: own elaboration

Once that information was obtained, the sequencing method was developed based on equivalent units. After that, the planning horizon that will be taken into account to conduct the production scheduling was determined. Then, the sequencing method was applied by using the planning horizon and the actual capacity in the production line, which led to the overall sequencing logic together with the use of macros to design the main window and its respective buttons. Table 2 shows the production plan of one day, but it must be developed for each day of the planning horizon, linked to the data in Table 1 to follow up the method. In this way, the overall sequencing logic can be integrated using macros as will be shown in the homepage window and its respective buttons.

Total Day 1	Production	UE	Total UE	Factor	Prod UE	Prod Real	Gap
100	Small	1.0	104	0.244	16	16	84
55	Medium	1.0	55	0.129	9	9	46
200	Large	1.3	267	0.626	42	31	169

Table 2 Planning horizon
Source: own elaboration

Identification of improvements and corrections using a pilot test

Once the scheduling software was ready, a pilot test with a previous production order from the strongest customer was conducted, to simulate a more realistic situation of the casting line scheduling. Data from past orders were used in the Excel file to see the behavior of the proposed schedule. The operation of the Excel file was presented to the managers of the company to obtain their feedback, making some amendments to the software.

Results

Table 3 presents the dimension limits to classify items by size. As a result, a catalog was created in which the produced items can be found according to their size: small, medium, and large.

Height Dimensions	Width Dimensions	Classification
60 cm – 110 cm	95cm - 120cm	Small
94cm - 113cm	121cm – 159 cm	Medium
93cm - 114cm	160cm - 216cm	Large

Table 3 Dimension limits for size classification
Source: own elaboration

It was decided that the pilot time-keeping test run 25 times per item size, adding a total of 75. Times were entered in a Minitab 17 database to obtain the missing data for the sampling size formula, which is the average cycle time value and the standard deviation (see Table 4).

Size	Average Cycle time per item (min)	Standard Deviation
Small	31.73314667	9.637632124
Medium	29.8760336	8.149762866
Large	40.619704	9.78443599

Table 4 Cycle time averages and standard deviation per item size in pilot test
Source: own elaboration

Medium-sized items exhibit less time because they are the ones which are produced the most, and operators have better control of the molds and how they must be worked; longer times appear for the large items because the molds are heavier and it is more com-plicated to have control over the same. On the other hand, when small items are worked, they normally do not have a high priority, which results in operators not taking the molds out of the presses, thus extending the cycle time and obtaining the following times ac-cording to each size:

- Larger items take an average of 0.68 hours to complete the cycle.
- Medium-sized items take an average of 0.51 hours to complete the cycle.
- The small items take an average of 0.53 hours to complete the cycle.

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The times per station were used to determine the unproductive time for each of the three item sizes. An average time per station sum was carried out (see Table 5) which was considered as the productive time, and afterward, it was subtracted from the cycle time. The results are presented in Table 6, Unproductive time in minutes per item size. The presses are scheduled for ten minutes, regardless of the size of the mold; this is the time it takes the polyurethane to correctly react and reduce the possibility of defects in the end product.

Size	Station 1	Station 2	Station 3	Station 4	Station 5
Small	2.012	2.790	2.399	10	2.964
Medium	4.057	3.285	2.651	10	2.639
Large	4.481	5.531	3.064	10	4.378

Table 5 Average time in minutes per station
Source: own elaboration

Size	Productive Time	Cycle Time	Unproductive Time
Small	20.966	31.805	10.884
Medium	22.633	30.753	8.119
Large	27.468	40.619	13.151

Table 6 Unproductive time in minutes per item size
Source: own elaboration

The main time factors involved in how long it takes the operators to work a mold are their weight, and production priority. Medium-sized items normally have a high pro-duction priority, but due to their weight, it takes longer to arrange the molds in the stations; the small items remain at a mid-point due to priority.

The next step was to have reliable data regarding the actual casting line production. To achieve this, the production logs that the production administrator had from previous months were used (See Table 7). These logs do not specify the size of the item that was produced; therefore, the casting line station operator's logs were taken into consideration to verify the information. The operator's log is created from the production orders provided by the administrator, and it is here where the item is annotated before it goes into the press. That is how the number of items per average size that are produced daily. (See Table 8).

Month	Days worked	Total items	Daily average
February	19	1345	71
March	19	1759	93
April	21	1260	60
May	22	1934	88
June	21	1277	61
July	22	1527	69
August	22	1502	68

Table 7 Production administrator's monthly casting line production log
Source: own elaboration

Item Size	Darly Production Percentage	Daily Production Average
Small	26%	19
Medium	33%	24
Large	41%	30

Table 8 Log of items by size produced daily in the casting line injection station
Source: own elaboration

The information provided by the production administrator's log made it possible to know that, on average, 73 items may be produced daily, and according to the injection station, 41% of production are large items, reflecting a greater production demand, and those of least de-mand are the small items, representing 26%.

To develop the production schedule proposal, it was necessary to start by finding a plat-form that, based on the company's computing equipment capabilities, could schedule the equivalent unit method. It was decided to use Microsoft Excel because, by using macros and Visual Basic, it was possible to develop a sequencing method with the fluency and professionalism of specialized software. The sequencing program is shown in the following screenshots (See Fig. 1), in which follow-up is given to production order scheduling.

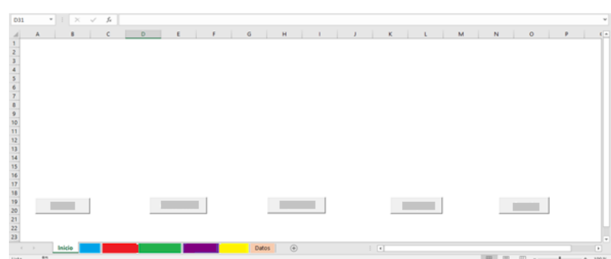

Figure 1 Homepage Screen
Source: own elaboration

Figure 1 shows the Homepage screen, and in the lower part of the same, some but-tons give access to the order capture window. The worksheet of each color will be used to capture and process the scheduling for each order.

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Figure 2 shows the order capture window which resulted from clicking on one of the buttons for the corresponding customer. This window contains sections to enter the number of units to be produced according to their size.

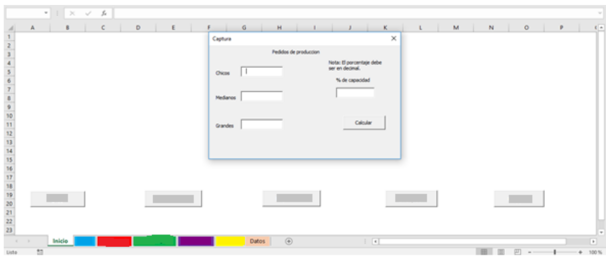
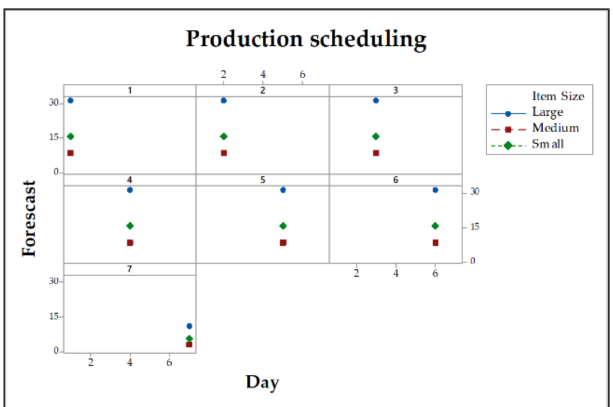


Figure 2 Order Capture
Source: own elaboration

In addition, there is a section in which the dedicated capacity percentage of the mentioned order can be set.

The objective is to have several production orders that are executed with different capacities, which will directly reflect the time it takes for orders to be completed. To conclude the order capture process, the calculate button should be clicked. (See Figure. 3).



Item Size	Total items	Items per day	Delivery policy	Capacity	Dedicated production
Small	100	16	6	80%	
Medium	55	9	6	80%	
Large	200	31	6	80%	

Figure 3 Order contents
Source: own elaboration

Figure. 3 shows the results of production scheduling by sequencing. In the upper part of the figure, there is a summary of the scheduling where essential information is shown for decision-making. The contents of the order may be appreciated, the items per day that have to be produced, and the delivery policy that was handled for such order; the policy will be based on the percentage of dedicated production.

On the scheduling table (See Figure. 4) a planning horizon of 20 days may be appreciated. In such a table the daily production of each model will be reflected, as well as the day in which production will be concluded.

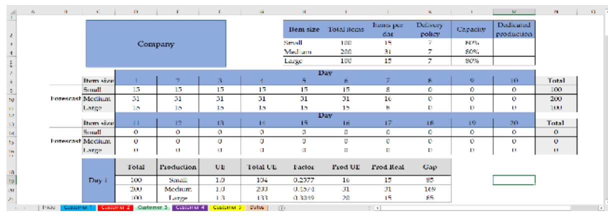


Figure 4 Daily Description
Source: own elaboration

In Figure. 4 there is a detailed description of daily scheduling. As the page is scrolled down, the necessary days to execute production can be observed; the description shows the sequencing procedure either by the indexes or the equivalent units method. Moreover, it has drop-down menus to incorporate special orders within the scheduling process.

Discussion

Among the improvements obtained with the solution concerning what was available before its implementation, the following could be mentioned: Production was increased when suggestions were given on the required time to manufacture each of the products. There was formerly an average of 72 daily items processed, and currently, there are 90 items manufactured, which leads to an improvement of 25% in the process efficiency. This was possible without investing in any equipment, hiring staff, or making changes in the production line. This efficiency will increase as long as there is a better usage of resources, resulting in being able to process more orders or cover less time in the processing the same, which leads to increased production capacity.

Another benefit obtained was the fact that, at any given time, knowledge of the time required for product manufacturing is available at any moment; the data allows determining production priority to fulfill customers' orders, and guarantee satisfaction.

The main contributions of the project for the company were the improvement of the production rate and the organization of their production scheduling activity. The first one helps to meet the delivery dates required by the customers, or at least allows promising more realistic due dates. The second one establishes a baseline to implement more complex algorithms to reduce makespan or setup times, or to reduce backlog in the future.

Conclusion

It was possible to achieve a proposal oriented towards meeting the needs in terms of production scheduling, which also helps create production mixes per item, and determine what capacity percentage will be dedicated to each incoming order.

The proposed production scheduling for the company under study will allow them to know delivery times and the number of items per size, resulting in compliance with delivery times and improved operations efficiency, as well as more efficient usage of the resources involved. By implementing this proposal, the company enters a continuous improvement process, as this favors correct scheduling using a technological solution, opposed to that conducted empirically or informally.

The improvement of 25% was achieved for this company according to its conditions. The company is a Small-Medium Enterprise, such that it can be expected that the scheduling approach is the same for many companies of this size. A similar improvement just because of the organization of the scheduling activity can be expected for companies of the same size.

It is important to mention the relevance of having good control of data, but it is also essential to be supported by software to carry out production schedule as this is conducive to not only having a clear and reliable vision of how production orders should be executed but also to have information that leads to decision-making to process customers' orders in the best way without generating additional costs in the production of the same.

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