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Implementation of an advanced planning and scheduling system (APS) in Market-driven Foundries

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Abstract

The industrial sector of market-driven foundries is composed of small and mid-sized companies with little or no automation. They work with diversified production, involving several different metal alloy specifications in small tailor-made product lots. The characteristics and restrictions involved in a typical production environment at these industries challenge the formulation of efficient production schedules. This results in low use of resources, high level of in-process inventories and tardiness. This paper has the objective of analyzing the implementation of an advanced planning and scheduling system (APS) through the implementation and operation of an APS system in a foundry industry. Results indicate the use of APS systems as a viable tool to increase the efficiency of production scheduling in these industries.

Key-words: Production Scheduling; Advanced Planning and Scheduling Systems (APS); Market-driven Foundries.

1. Introduction

The dynamic environment in which industries are now found, primarily determined by market changes, increase and diversification of demand and increased competition, promoted the development of management tools and support to decision making. In this context, the departments of planning and production control have been given greater prominence and importance in the companies, and the consequences of their actions in production management have a clear and significant effect on the operations results.

Thereby, the technological tools used by industries in order to manage their production experienced a substantial upgrading in recent decades, both in the use and capabilities, and the performance given to industries based on the use of the different and modern systems available today. The advance of technology has promoted the improvement of the processing capacity of these tools, providing the popularization of production management systems, including the systems to generate short-term scheduling, based on real capacity of resources, incorporating different logistics and production management elements, being treated as systems of finite capacity (ZATTA, 2004).

The systems of finite capacity have continuously evolved, adding new features and increasing its scope of application until when, in the early 90's, these systems began to be known as Advanced Planning and Scheduling systems or APS systems, and the term "Advanced" refers to the use, by these systems, of sophisticated methods of logistics and / or math, as well as the fact that they address both production planning and scheduling, considering most of the characteristics and constraints of a production environment such as manpower and machines, materials and transportation (COX & BLACKSTONE, 2002) (ERHART and FAÉ, 2005).

A sector that begins to experience the benefits from the use of production management systems is the heavy industry (metallurgy and steel). This segment was usually seen as little user of management technology resources, but nowadays it has been quite interested to news

and sophistication of management tools, since they act in a market where deadlines are tighter and customer requirements are more specific and exclusive. However, foundry industries that work with a large number of customized products, known as market-driven foundries, despite the increasing need for the use of developed methods for production scheduling, remain outside the applicable solutions in the area (ARAÚJO, ARENALES and Clarck, 2006).

Recent researches and developments have tried to reduce this gap in implementation. TEIXEIRA JR. (2005) proposed a system for production scheduling designed for market-driven foundries and, later, a specific APS system for this industrial sector, providing the basis for the application of this study. Thus, this study aims to perform the implementation analysis of an advanced planning and scheduling system for market-driven foundries, through the implementation and operation of an APS system in a foundry industry located upstate Sao Paulo.

2. Market-driven foundries industrial sector

The industrial sector of market-driven foundries is comprised of small and medium-sized foundries which serve a large number of customers usually with customized make-to-order products. They employ intensive use of labor force, low level of automation and use of technology. The development of production scheduling in these industries involves a complex synchronization between the production of molds, usually made of sand mixed with resin, in the molding stage by means of press molding or manual molding, and the filling of these molds with metal alloys molten in furnaces, in the pouring stage. Finally, in the finishing stage, several types of cutting and sanding the trims and appendants of the foundry are conducted. This synchronization is to ensure that the cargo (runs) scheduled for furnaces, for each type of metal alloy, finds ready molds, of each corresponding metal-alloy, sufficient to

use all the molten metal alloy (TEIXEIRA JR., 2005) (ARAUJO, ARENALES and CLARCK, 2006).

Due to restrictions and variability of the typical productive environment of market-driven foundries, the synchronization of the stages of molding and pouring will be ineffective without relying on a support tool. In a typical market-driven foundry, this synchronization is achieved by maintaining high inventory levels between the stages of molding and pouring; nevertheless, satisfactory efficiency is not achieved in the use of furnaces. Despite this, there are few studies addressing the problem of production scheduling in market-driven foundries. The most part of available studies applies only to captive foundries or large iron foundries. The captive foundries tend to be part of larger industries working with a low variety of products and metal alloys, producing in large lots, often using automated molding machines and serving a relatively stable demand (SANTOS-MEZA, SANTOS and ARENALES, 2002).

Most of the studies available on production scheduling apply for large iron foundries; however, this sector does not show the same nature of industrial environment as market-driven foundries, since it does not use the stages of molding and finishing, producing ingots or bars of different types and sizes through continuous furnaces and rolling machines, configured according to the specifications of the product they want to obtain (TANG et al., 2001) (COWLING, 2003) (PACCIARELLI and PRANZO, 2004), (ZANONI and ZAVANELLA, 2005), (BELLABDAOUI and TEGHEM, 2006), (PAN and YANG, 2009).

The production scheduling in market-driven foundries was approached by VOORHIS and PETERS (2001) who proposed a model of integer nonlinear scheduling for the problem. However, the model does not present a viable solution to real problems (NP-Hard). NONAS and OLSEN (2005) presented a formulation that meets only market-driven foundries that work with only one type of metal alloy, disregarding the problem of sizing and sequencing of the loads of the furnaces in the stage of pouring, focusing mainly on the problem of allocating

the requests to the available molding boxes, according to the size of the piece and of the boxes, in the molding stage. ARAUJO, ARENALES and CLARCK (2006) proposed a model of mixed-integer scheduling to the problem; however, the model is applicable only for small foundries that have a single furnace, in which the molding stage can be considered as infinite capacity.

A model of binary integer scheduling to the problem, considering the main characteristics and constraints of the production environment of market-driven foundries, can be found at TEIXEIRA JR. (2005). The author also proposed heuristics methods for the solution of the developed model which show results near the upper limit of solution in viable computing time of practical implementation, as well as he proposes the technological basis to implement the methods of solution in a computer system for production scheduling in foundries. The deployment of the heuristic methods and the interfaces with the users proposed by TEIXEIRA JR. (2005) meeting the requirements of features needed in an APS system (COX & BLACKSTONE, 2002), was developed and made available in PLANNION (2009).

3. Implementation of an APS system in a market-driven foundry industry

This study was based on a medium-sized foundry located upstate São Paulo. The company has around 70 employees and two furnaces, working with a large number of different customers and products in a little automated production environment, having the main characteristics that define a market-driven foundry, according to TEIXEIRA JR. (2005). The system employed in the study is an APS system built specifically for market-driven foundries, developed as a continuation of the study presented by TEIXEIRA JR. (2005) and available in PLANNION (2009), being able to run on personal computers with the operating system Microsoft Windows XP ® or Windows Vista ®.

The current scheduling process used by the company is based on the experience of the production manager, without any computer support. Notably, the scheduling developed by the industry is not very effective, creating some problems such as low levels of use of furnaces, frequent delays in product delivery, low flexibility to adapt to changes in the productive environment and high levels of in-process inventories.

The performed analysis, considering the production environment of the company, as well as the APS system taken for study, demonstrated that the existing characteristics and constraints on the production environment could be effectively considered in the system. The implementation of the system was performed by a pilot project in which the company provided a specific computer for this purpose. It was raised all the necessary information to implement the software, such as: the capacities of productive operations in the steps of molding and finishing, the capacity of the furnaces and the maximum number of daily runs possible for each furnace, in the step of pouring, as well as the work time and schedule of the company. The company also made available a database containing information of the products to be produced, such as weight, type of alloy and minimum lot production, as well as data on customer requests for a specific period, so that pilot study could be carried out as close as possible to its reality. In *Figure 1* you can see some screenshots of entries, like the screen of work schedules entries, assets entries and products and materials entries.

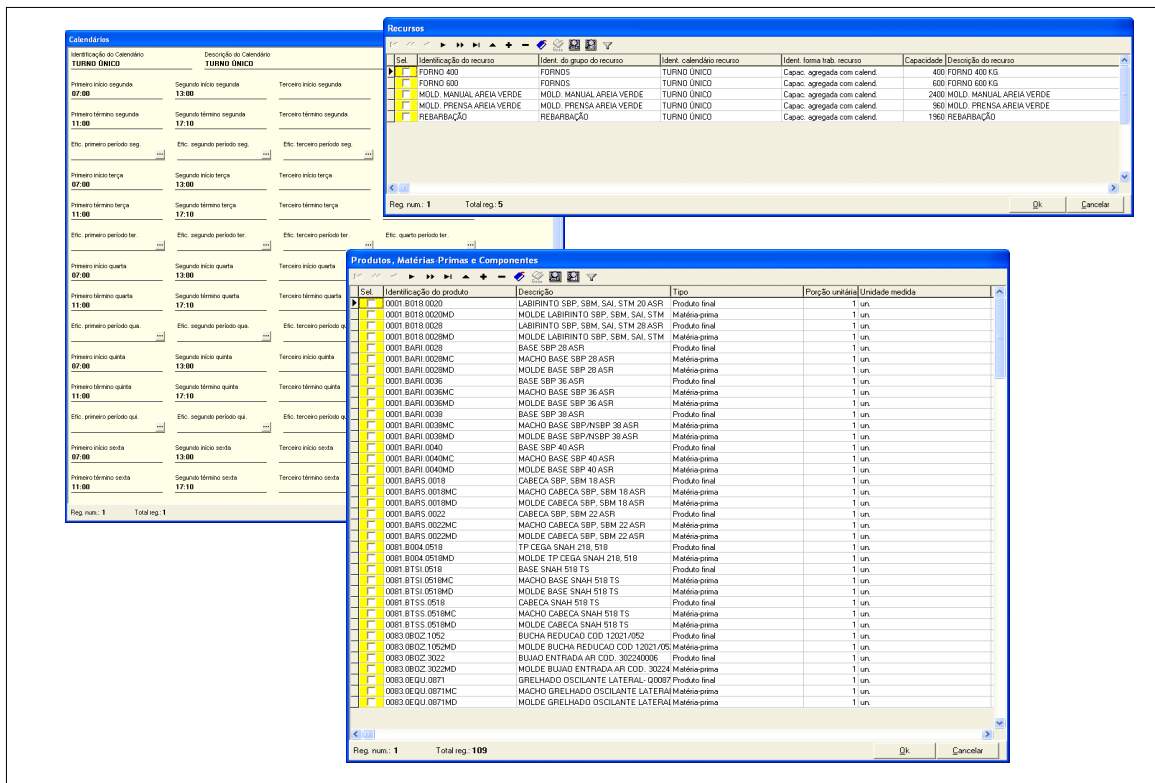


Figure 1. Main entries screens of the implemented system

These entries could be imported directly from the database provided by the company, allowing a considerable saving of time in deploying the system. This done, the structure of materials of the products manufactured by the industry was set up, using the desktop "Product Structure", as can be seen in *Figure 2*.

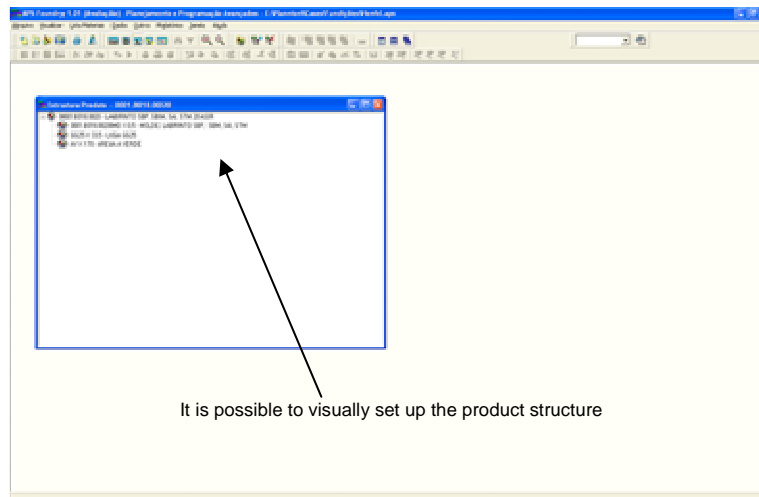


Figure 2. Desktop “Product Structure”

The specifications of the production process, involving the productive operations, time and resources are registered on the desktop "Production Route". *Figure 3* shows this desktop.

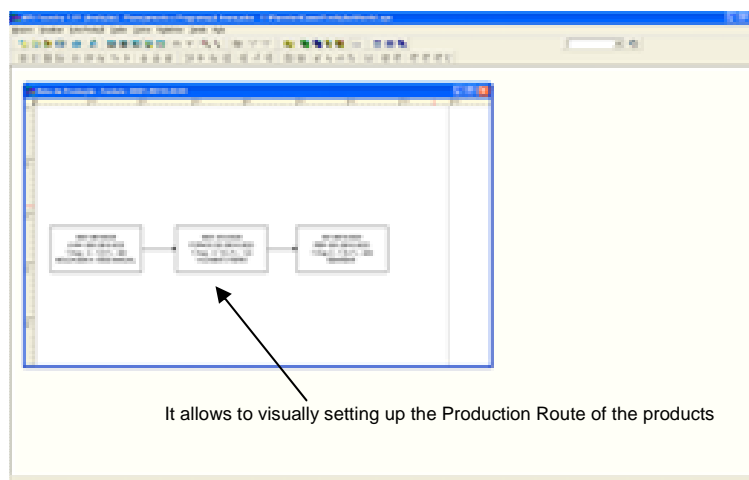


Figure 3. Desktop “Production Route”

With the entries of the information of the production environment and the set up of the products structures and production routes, the deployment of the system was completed. With this, it is possible to start using the system, i.e., it is possible to operate the system in the assessed company. The system operation performs daily production scheduling in order to

meet the needs of delivery orders and maximize the use of production resources. The main desktop used to operate the use of the system is the desktop of orders to schedule, as can be seen in *Figure 4*.

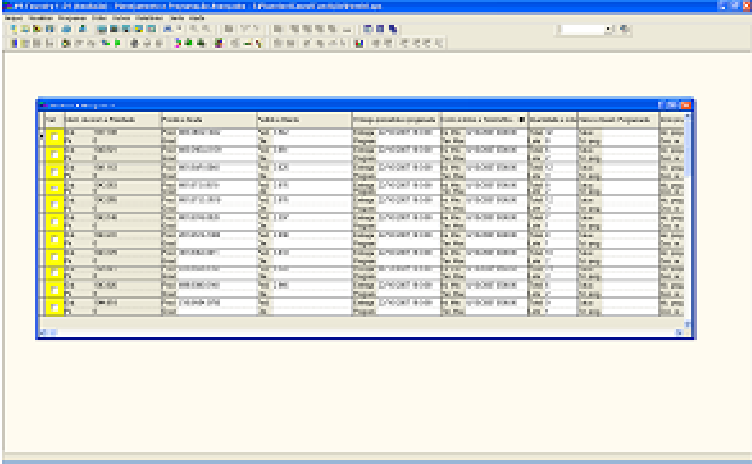


Figure 4. Desktop “Orders to Schedule”

For each day, you select the orders to schedule for the day, as well as the orders of the previous days that haven’t been scheduled. The desktop “Orders to Schedule” allows the programmer to visualize the production orders sorted by several attributes, such as date of arrival of the request, date of the order delivery, customer, among others. The programmer then selects the orders to be scheduled according to his needs, as can be seen in *figure 5*.

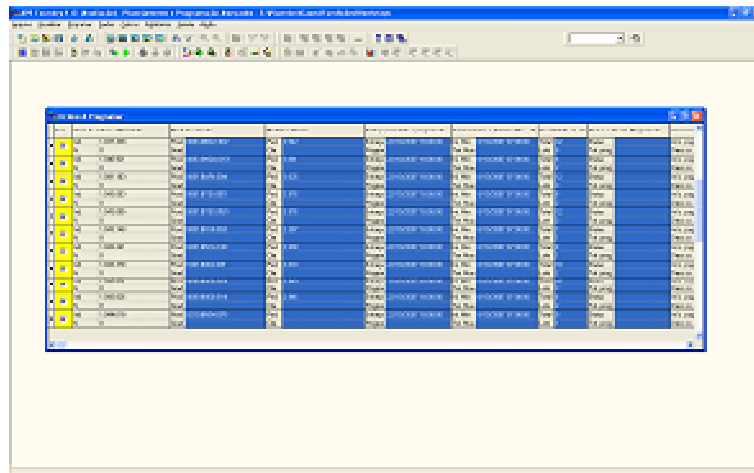


Figure 5. Selection of the production orders to be scheduled

The system builds on the production orders selected to calculate the synchronization between the steps of molding and pouring. This calculation is performed through the choice of the production lots of each order that will compose each furnace run. Since this selection process involves a difficult combinatorial problem (*NP-Hard*) (TEIXEIRA JR., 2005), the system applies a heuristic optimization method known as "Beam-Search", to optimize the use of production resources, at the same time that it prioritizes the orders with more urgent delivery dates. More details on the heuristics employed can be found at TEIXEIRA JR. (2005).

The optimization method applied in the system can be configured to meet the needs of the company that is applying it, and it is possible to set the minimum percentage for loading the furnaces, the number of runs that a furnace can accomplish in the scheduling time and the calculation time. In *Figure 6* the configuration screen of the optimization method parameters can be seen.

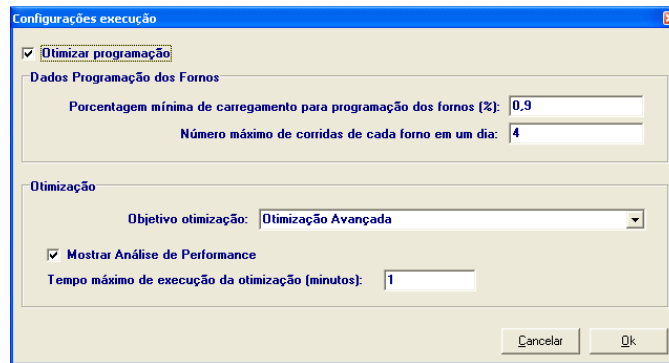


Figure 6. Configuration screen of the optimization method parameters

Once defined the optimization parameters, you choose them in the menu "Program / Run Program. The system will try to schedule as much as possible of the lots of each production order; however, due to the complying with the constraints of synchronization between the steps of molding and pouring, not all lots can be scheduled, since the furnaces cannot be programmed with partial capacity, forcing some lots not to be scheduled for production. Unscheduled lots continue in the desktop "Orders to Schedule" and will be available to be scheduled along with new production orders that will be received in future periods. The system then carries the information of each order not completely scheduled, as can be seen in *Figure 7*.

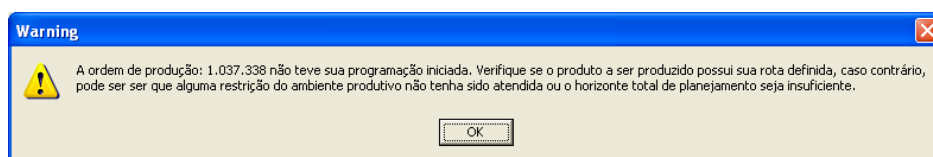


Figure 7. Information of an unscheduled production order

On the desktop "Orders to Schedule" it is possible to check which orders have been scheduled and the scheduled date of delivery by checking the field "Program", as can be see in *figure 8*.

It is important to note that in some orders, it occurs the scheduling of only some lots and not the order in full.

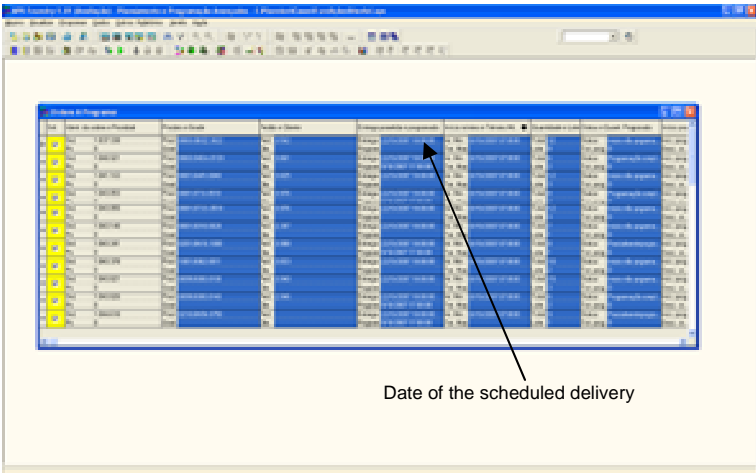


Figure 8. View of the date of the scheduled delivery of the production orders

A detailed schedule of all manufacturing operations of the scheduled production orders can be viewed on the desktop "Scheduling". This desktop consists of a "Gantt Chart" with the schedule of the established production and allows the production manager to interact with the scheduling; changing it according to the specific needs of the production environment. The desktop "Scheduling" is shown in *figure 9*.

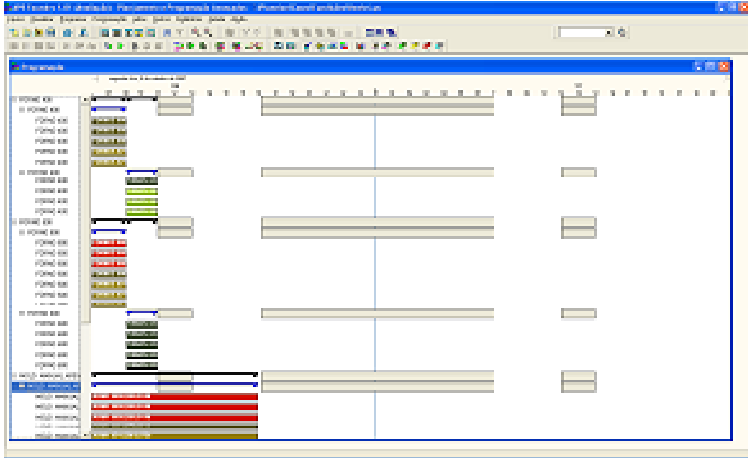


Figure 9. View the "Gantt Chart" on the desktop "Scheduling".

Once all the necessary changes in production scheduling were accomplished, this schedule is established, so that it can be operated in the production environment. The process of establishing a schedule transfers the scheduled orders to the desktop "Established Orders", separating them from the orders that have not yet been scheduled. Figure 10 shows this process and the transference of the scheduled orders from the desktop "Orders to Schedule" to the desktop "Established Orders".

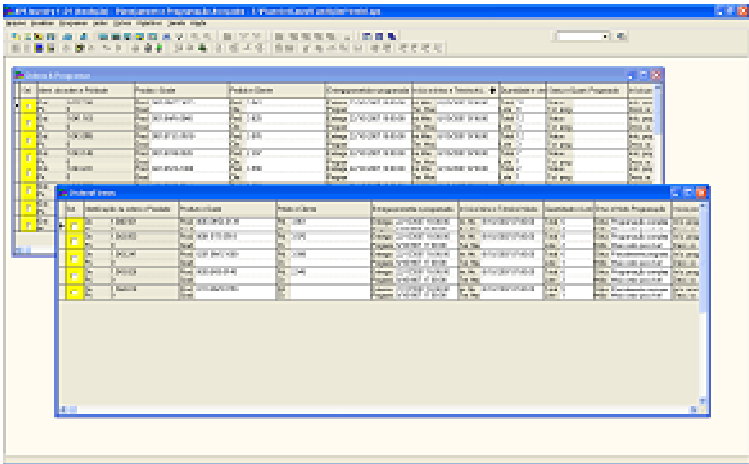


Figure 10. Desktop "Established Orders"

Since the assessed APS system allows quick viewing of all production orders, both the ones already established and those still to be scheduled, it enables managers to deal proactively with the scheduling of the production, making the necessary changes in order to meet the demands of the productive environment and customers.

In the assessed industry, it is usually necessary to perform some, if not many, changes to an established production scheduling, in order to adapt it to the changes and demands imposed by the production environment, and also by customers; that is always done manually. The studied system is also able to meet this need in the industry, allowing the change in the

established schedules, helping managers to make these changes in order to maintain a high level of resource use.

The system provides the established scheduling through various types of printed reports, assisting in the scheduling operation in a production environment. To the managers, these reports are available digitally, as well as in printing version, in order to view the full schedule, with all established orders, allowing the actual monitoring of their accomplishment. For the operators, the reports are generated with the operations under the responsibility of each one, as well as with the materials needed at each step; it allows the operator the proper planning for the tasks. In all reports, the information is followed by a bar code, which allows the record of the accomplishment of operations by optical readers.

4. Analysis of the results obtained with operating the APS system in the assessed company

The analysis of the operation of the APS system was based on a simulation of the system use through the pilot implementation conducted at the company, involving five days of production scheduling in the company studied. This simulation was based on the actual data of order arrivals during the considered five days, as well as on the actual information in the production environment, such as the ability of resources and time involved with manufacturing operations in the steps of molding and finishing, the capacity of the furnaces in weight (kg) and the maximum number of possible loads (runs) per day. However, at the request of the company, changes were made in the original data provided, in order to avoid the disclosure of classified information from the production environment, but without jeopardizing the environment studied.

Considering the changes made in the original data provided, as well as the current mode in which the company is preparing its production scheduling, using stocks between the steps of

molding and pouring in order to achieve synchronization between them, it is not possible to compare the performance presented by the schedules generated by the system with the actual schedules manually performed in the company. It is also important to consider that the orders used for the first day of the scheduling simulation, were those ones which arrived the day before the date considered as the start date in the simulation, which can affect the efficiency of resource use in the first days of the scheduling simulation, due to the possibility of low diversity of orders.

This simulation aimed to further build confidence in using the system by production managers and supervisors. The analysis of the scheduling performance generated by the APS system shows that the system was efficient in the use of furnaces, rationalizing their use according to the production of molds in the molding step and working near their maximum capacities, reducing the consumption of energy per kg of molten metal. The simulation was based on two blast furnaces with a capacity of 400 kg and 600 kg of metals, respectively. Each of these furnaces can hold up to 4 loads per day and should be loaded only when there are ready molds enough to consume all the molten metal-alloy in the loads. It can be observed that the level of resource use in the steps of molding and finishing has also remained high, although the scheduling generated by the APS system does not employ in-process inventories to synchronize these steps.

Regarding the resource use in the molding step, in *figure 11* it is possible to view a percentage of use for each scheduling day for the resources of press molding. It is possible to observe that the rate of using these resources increases from the third day of scheduling, reaching almost all the capacity available on the fifth day of scheduling. Regarding the first two days, the low use may be explained by the low need for use of these resources by the production orders available for scheduling. It is important to note that the schedule of what has been molded is

sent to the step of pouring on the same day or, maximum, the next day because the schedule of the steps of molding and pouring are synchronized.

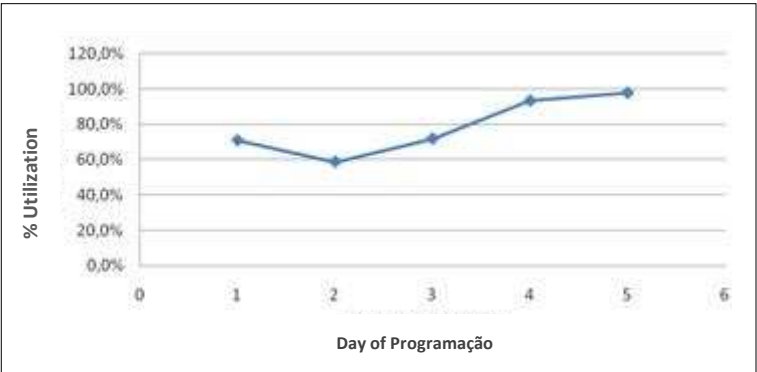


Figure 11. Percentage of resource use in the press molding

Still for the molding step, the percentage of utilization of the manual molding resources can be viewed in *Figure 12*. Note that, similarly, the utilization rate increases when the program goes on the considered days as a higher volume of production orders require the use of those resources.

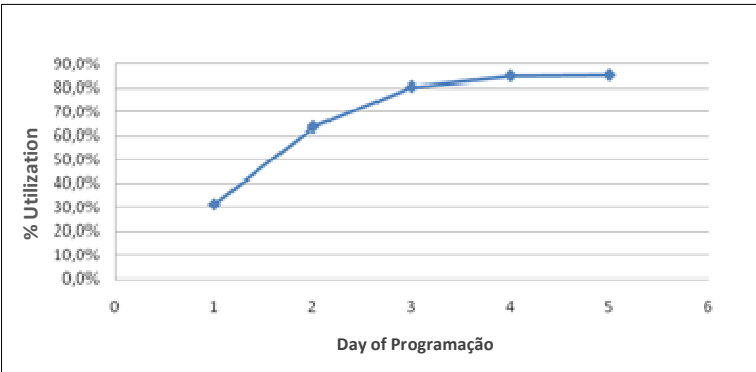


Figure 12. Percentage of utilization of manual molding

For the pouring step, it is generated the scheduling of the furnaces. In *figure 13* it is possible to assess the percentage of use for each load (running) of the 400-Kg furnace. Note that for

the five-day simulation of the 400-kg furnace could hold up to 20 runs, however, for the total of orders available for scheduling, 9 runs with loads close to its loading capacity were sufficient to meet the needs of smelt. Two of these runs were scheduled for the first day, 2 for the third day, 4 for the fourth day and one for the fifth day.

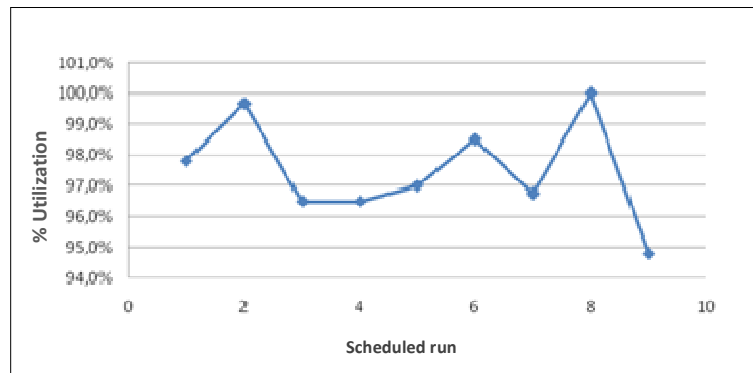


Figure 13. Percentage of use of the 400-kg furnace in each scheduled run

Meanwhile, the percentage of use of the 600-kg furnace is available in *Figure 14*. It is possible to analyze that, for the duration of the simulation, the 600-kg furnace was scheduled 18 times within the 20 possible times, where on the first day 2 runs were accomplished, while in other four days, all the four runs were scheduled for this furnace. It is important to note that the heuristic method for calculating the schedule makes the choice between the 400-kg and the 600-kg furnace, depending on the availability and necessity of the furnaces to meet the optimization goals established; further details, see TEIXEIRA JR. (2005).

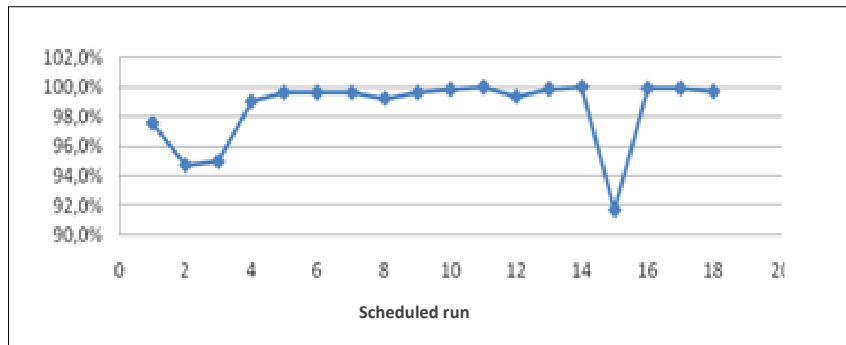


Figure 14. Percentage of the use of the 600-Kg furnace in each scheduled run

Finally, in *figure 15* it is shown the percentage of use of the available resources in the finishing step. The use of resources at this stage reflects the production of the molten products in the pouring step, according to the schedule generated for these products. It is possible to analyze that the use of resources has also remained high after the third day of scheduling.

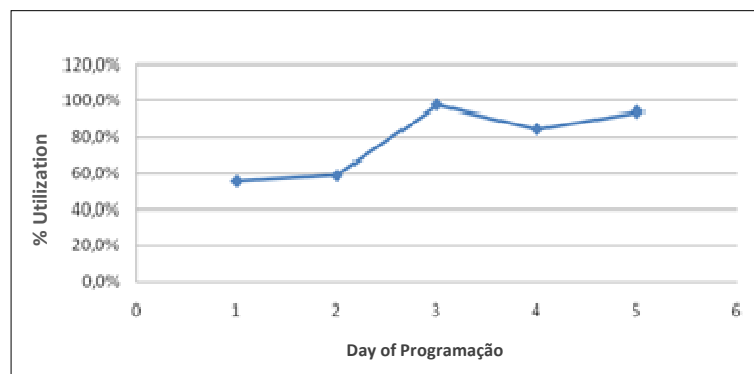


Figure 15. Percentage of use of finishing resources

The analysis of performances presented by the schedules generated by the system confirms the efficiency on the synchronization between the steps of molding, pouring and finishing, without the need of in-process inventories of ready molds, maintaining a high level of resource use in the three steps of the production process in the referred company. It is possible

to note that the first two days of the scheduling simulation showed worse performance in the use of resources. This could be explained by the lower range of production orders available for scheduling at the beginning of the simulation. Despite this, the efficient use of resources has increased gradually and stabilized at high levels as the inflow of new orders has stabilized after the third day of simulation.

5. Conclusions

The preparation of this study was based on an APS system applicable in market-driven foundries. With the implementation of the referred system in the industry, it was possible to evaluate that the system includes all the features and constraints in the company. The deployment was facilitated due to the possibility of importing the data from the production environment, including produced products and production orders, directly from the business management system of the company, reducing the time and effort required for deployment.

The analysis of the system operation in a pilot application demonstrated, from a few days operating the system, a stabilization of the utilization of the production resources at high levels, without the use of in-process inventories to synchronize the steps of production, reducing the production cycle time, suggesting the use of the APS system as an effective tool to schedule production in market-driven foundries.

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