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Lean manufacturing paradigm in the foundry industry

O paradigma da manufatura enxuta na indústria de fundição

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Abstract

The lean manufacturing paradigm has been used in an extensive manner at some industrial sectors, like automobile industry, which its assembly lines of components, presents better adaptability to the lean concepts. This paper starts with the proposition of applying lean manufacturing concepts in productive processes, and contributes a lot to turn corporations more competitive. The foundry industry, small to medium sized plant, has the difficulty of implementing improvements in its internal logistics systems, and, it has to deal with the problem of temperature processes dependency, such as the casting and the cooling processes. Focus on line balancing and lay out improvement, this work researched the lean manufacturing paradigm application, in a foundry industry in Brazil, with special attention to line balancing.

Key words: lean manufacturing, line balancing, lay out, foundry industry.

Resumo

O paradigma da manufatura enxuta tem sido amplamente utilizado em alguns setores industriais, como o automobilístico que, com suas linhas de montagem de componentes, apresenta maior facilidade para implementar esta estrutura de produção. Este trabalho parte da proposição de que a aplicação dos conceitos de manufatura enxuta nos processos produtivos vem em muito contribuir para tornar as empresas mais competitivas. A indústria de fundição de pequeno e médio porte, além da dificuldade em implementar melhorias em seus sistemas logísticos internos, tem ainda que lidar com fatores como processos dependentes da temperatura, tanto na fusão como no resfriamento das peças. Com o foco na melhoria do balanceamento de linhas de produção e melhoria do *lay out* industrial, este trabalho pesquisou junto a uma indústria de fundição do Brasil, a aplicabilidade do conceito de manufatura enxuta, em especial o balanceamento de linhas de produção.

Palavras-chave: manufatura enxuta, balanceamento de linhas de produção, *lay out* industrial.

1. Introduction

In a search of competitiveness to attend the customer's desire, it has emerged the necessity of better organizing the production processes and logistic, turning more agile or efficient the chain of productive process. This paper has the objective to understand how the small to medium enterprise of foundry sector have worked to improve their production processes, in way to obtain the competitiveness necessary nowadays to survive in the market.

This paper addresses to study the production in a way to improve the industrial lay out and line balancing of these small to medium industries, making the valuation of lean paradigm application, contributing to the knowledge about this kind of process.

The research of a well structured production process, with low level of intermediate inventories, more productivity and shortest times of supply, has been the main challenge imposed to the small to medium enterprise of industrial and services sectors.

Normally with unbalanced lines in their processes, the small to medium foundry industry is characterized by a higher level of inventory of raw material near its production area and a great volume of semi-elaborated products inside the production area, which turns arduous the internal movement of materials and the creation of a lay out to make flow the production. Moreover, the foundry industry has the complexity of its processes dependent of temperature, as ferrous or aluminum melting process as the product cooling processes.

The application of lean manufacturing concepts, in balancing of production lines, contributes a lot to develop more economic processes, guaranteeing a better attending to the clients.

The main practices are mentioned at the literature review following, as standard work, *Kanban*, and others. This paper has focus on the line balancing.

2. Research Methodology

The purpose of this research is to study the application of lean manufacturing paradigm at the small to medium sized foundry industry in Brazil. A simulation model was developed to compare the actual strategy with the lean strategy. Using a quantitative model based, we referenced Bertrand and Fransoo (2002) to show the main steps of this work:

- Identification of process or problem assumptions;
- Identification of types of operational process and decision problems considered;
- Developing operational definitions of the operational process and the decision system;
- Derivation of hypothesis regarding process behavior;
- Development of measurement system;
- Results of measurements and observations;
- Interpretation of data and observations in relation to the hypotheses;
- Confirmation and/or rejection of the theoretical model assumptions.

To conduct this research, the authors had the support of a small to medium sized foundry industry in Brazil.

3. Literature Review

The lean manufacturing paradigm, discussed in an extensive manner in the literature, is considered applicable to the majority of the industrial and service processes, bringing benefits like productivity improvement, more aggregate value in the products, waste reduction and higher level of customer's satisfaction. The term "lean" was introduced by Womack *et al.* (1992) to describe a "better way of organizing and managing our relationships with clients, supply chain, product development and production operations", based on the Toyota Production System (TPS). The lean principles can be briefly stated as *value* – enhancing value to the customer, *value stream* – identifying where the value is created and removing the waste where it is not present, *stream* – making the product to flow in line, without interruptions, *pull* – producing only what the customer or next process solicits, and *perfection* – to pursue the perfection, removing more waste continuously (Womack and Jones*,* 2004).

Kasul and Motwani (1997) studied the Toyota Production System (TPS) implementation strategy at a medium-size automotive manufacturing corporation, located in the Midwest region of the USA. Motwani (2003) revisited this case studied, discussing the strategic implementation of lean manufacturing paradigm and the significant benefits in manufacturing operations. In his article, we can find the lean manufacturing concepts, requirements and success factors of implementation. He constructed his research based on the analysis of strategic initiatives, learning capacity, cultural readiness, information technology leverage ability and knowledge-sharing capability, network relationships, change management practice and process management. They presented on their papers some elements of TPS, with definitions that we have from the Lean Enterprise Institute (2003):

- *One piece flow:* making and moving only one piece when necessary.
- *Standardized work:* precise work procedures for each worker in a production process.
- *Set-up reduction:* reduction of the necessary time to change de product in line by other.
- *Kanban:* visual device that authorizes or gives instructions to product or remove items in a pull system.
- *Jidoka:* system of ensuring defects will not pass from one operation to the next.
- *Heijunka:* distribution of the production volume and type over the available production time, avoiding intermediate inventories.
- *Takt time:* the time available to production divided by the customer's demand.
- *Cell production:* production sequencing of similar products, in a flow next approximately continuous.
- *Value Stream Mapping:* mapping the processes involved in the creation of a product, since the customer's request to the customer's receipt of the product.

Some authors have researched not only the lean paradigm benefits, but the main difficulties of implementation, with a critical view over the effects on work organization and workforce. Forza (1996) studied the differentiation of lean production and traditional plants, with more critical view on work organization practices in relation to lean production. He proposed a framework which would be useful to research linkages between work organization and lean production practices, emphasizing the importance of human resources.

Lee and Oakes (1996) discussed some templates for change in smaller component suppliers, as world-class manufacturing (WCM), lean production (LP), total quality management (TQM) and business process re-engineering/redesign (BPR). They stated "the smaller firms at first and second-tier levels in the manufacturing sector supplier chain appear to be becoming more aware that in order to remain competitive they must implement new methods in one form or another".

Baker (1996) presents an account of some implementation problems in value chain development. In his case study, he focuses on material conversion value chain and the problems regarded organizational environment.

To show us the impacts in the social aspects of manufacturing process, Harrison and Storey (1996) constructed a critical analysis about new manufacturing strategies implementation, like Just-in-Time (JIT), Total Quality Management (TQM), Lean Production (LP) and Word Class Manufacturing (WCM). The authors explored the subject through their concept of New Wave Manufacturing (NWM), with an approach of the unsuccessful implementation factors of these manufacturing paradigms, as well as the implications in the social field of production.

Conti *et al.* (2006) presented a study about the lean implementation and the possible stress on workers with this new form of work. In attention to buffers and work pace control, they stated that are not so related to more stress but the cycle time reduction can increase the workers stress level.

But many authors dedicated their studies to compare the various manufacturing strategies and proving the improvement in productivity and work environment with better work organization. Chakravorty and Atwater (1995) compared through simulation, the performances of lines designed using the line balancing based on traditional western approach and based on the Just-in-Time (JIT) approach. In traditional western lines, the total time needed to produce a determined number of pieces is divided by the desired cycle time, defining the number of work stations. The just-in-time lines are based on the philosophy of continuous improvement through the elimination of waste and a pull system of production. They developed a simulation model for both forms of line designs. The results indicated that when inventory in the system is low, the balanced line performs better than JIT line, and when the inventory in the system is high, the JIT line performs better than the balanced line. Chakravorty and Atwater (1996) extend their study to a third philosophical approach and compared a traditional balanced lines with a pull-based line designed and operated using the JIT philosophy, and a line designed and operated using the theory of constraints (TOC). This work presents as result after simulation that JIT lines perform better when variability in the system is low and appear to be able to achieve the highest output level given sufficient inventory. When the variability is higher, it is better to use the TOC approach that is less affected by variability within the system.

Toni and Tonchia (1996) explored the lean production paradigm leading to the adoption of management by process and emphasized the necessity of creating some performance measurement indicators, treating each stage or process as a sub-factory, each with its own management criteria and responsibilities.

Others philosophies are researched, like Muffatto (1999) that studied the similarities, influences between and evolution of the lean production model and the Volvo production system, from the point of view of assembly design, work organization and automation. He concluded that the lean concepts applied in Japanese industries have changed to refine and perfect the various techniques (or mechanism) of this philosophy and are been adopted by many European and American firms.

Neumann *et al.* (2006) presented a study comparing parallel and serial flow strategies in design of production system. They explored the advantages and disadvantages in changing of parallel cell based assembly to serial line assembly in Swedish company, focused on productivity and ergonomics.

Owing the variability of the market, some authors have studied the importance of manufacturing flexibility. Garg *et al.* (2002) examined the need of multi-skilling of workers in an assembly line under probabilistic demand conditions to solve the line balancing problem at different production rates, and illustrated the model created by simulation in a real life case of assembly operations of an engine plant. They explored the greater benefits offers by multi-skilling of workers, such as reduction in overtime costs, greater employee versatility, leading to job enlargement, increased worker awareness and participation in the manufacturing process and flexibility in operations.

Gerwin (2005) presented his study of 1987, about the flexibility needed to support the uncertainty generated owing the variability of demand for the kinds of products, different product life cycles, machine downtime, meeting raw material standards and others uncertainties. This author suggests some measures for each type of flexibility as mix, changeover, modification, rerouting, volume, material and sequencing flexibilities. With these measures, it is possible to compare the nature of flexibility in Japanese, American or other region factories manufacturing the same products. Schmenner and Tatikonda (2005) revisited the Gerwin's work to update based on the changes occurred like as machines capabilities, computer based controls improvements, machine and process flexibility.

The lean manufacturing paradigm literature has been concentrated in the area of automobile industry, but some authors have researched the application in different sectors. Lee and Alwood (2003) proposed a lean response to the problems encountered in temperature dependent processes during interruptions, such as metal forming, food manufacture and chemical processing. In their study, they attempted to verify the lean manufacturing concept of stopping the production line to find the "root cause" of the problem, when an interruption occurs. They created a script, implemented in a simulation, which provides a means of establishing standardized practices adapted for temperature dependent process, where the operators participate directly in a decision-making process.

Lapierre and Ruiz (2004) customized the commercial software MsAccess97, to solve the problem of balancing and management of complex assembly lines. Starting with a simple heuristic approach, the researches offered a good solution on a real industrial case. Applied in an assembly line of appliances, with two sides and two different heights, achieved determine the number of workstations and workload distribution, and compare the heuristic to the handmade solutions.

Simons and Zokaei (2005) discussed the application of lean paradigm in a new sector – the United Kingdom red meat industry and explain how some lean techniques applied in industries can improve productivity and quality, specifically in the red meat cutting plants. They focused on some lean techniques such as "takt time" and "work standardization".

Rajakumar *et al.* (2005) proposed a model to solve the assembly parallel planning problem of a textile machine in a shop floor, with precedence relationship. The objective was to determine strategies of sequencing (random, shortest processing time and longest processing time) to allocate assembling operations to workers, in a way of obtaining better balancing in their workloads, using a computer simulation program.

This paper addressed to study the application of lean paradigm at the small to medium sized foundry industry in Brazil, in a way to improve the industrial lay out and line balancing, using a simulation model developed to test the concepts.

4. Brief Background of the Company

This research was conducted by the authors at a medium-sized custom made castings industry, located in Southeast of Brazil. This industry, Fundigusa Comércio e Indústria Ltda., was founded in 1984, and is active in the home and international markets of special, custom made castings, in ductile, grey, white iron castings, alloy and steel. His manufacturing process is continuously upgraded to improve the quality of the products and services. To keep in touch with customers demands, it builds long standing relations by mean of transparent attitudes and actions in constant close cooperation with its employees, suppliers and clients where it emphasizes quality, commitment and, above all, social responsibility. It works actively with the preoccupation of respecting the interaction between industry and environment. It invests in the habilitation of its workforce and stimulates value creativity, competence, productivity and results through internal and external training courses. Thus, it has a good environment to application of lean manufacturing paradigm.

5. Mapping the Process

The main activities of this foundry industry are the production of metal casting products of different classes to different applications, as technical (high degree of exigency) as general utilization pieces. It produces products that will be used in areas like cement industry, elevators, mining, railway or subway, metallurgy and others. The operations of the industrial process can be resumed as:

- Molding process, including sand preparation, modeling and cores production;
- Melting process in induction furnace, including scrap and alloys elements preparation;
- Metal treatment before pouring;

- Pouring;
- Shake-out (unmolding) and sand recycling;
- Cleaning, cut burr, drilling and finishing;
- Inventorying, packaging and shipping.

Figure 1 presents the diagram of central industrial process.

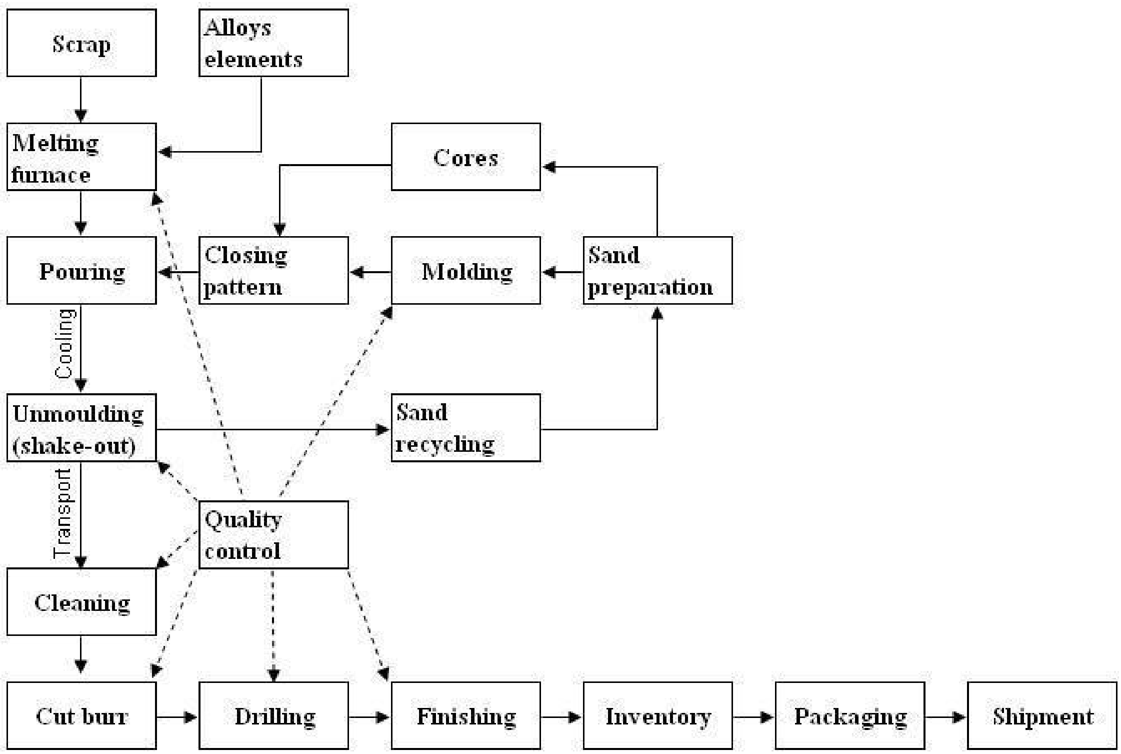

Figure 1: Diagram of central industrial process.

The foundry process consists of pouring molten metal in to a cavity called as mold which is the negative of the object, prepared with compacted sand and followed by solidification in the preconceived shape inside the mold, forming the casting. The foundry process stages, object of this research, are described below.

Molding: consists of preparing a bi-part molding box containing foundry sand prepared to receive the pattern (bi-part), made normally of wood, and with the same shape of the piece to be produced. The mold production consists of preparing, collocation and packed in through a vibratory process, the foundry sand around the mid-pattern installed over a plane surface of wood, with a frame of box (casting flask). After the sand compact, this box is reversed in 180º, removing the mid-pattern and preparing the paths for entrance of molten metal (pouring sprue), airway (vent) and putting the males (negative forms to produce cavities within the casting). The two parts (cope and drag) are assembled, forming the mold, which will be positioned around the area of pouring the molten metal and cooling.

Furnace: according the metal of the piece to be produced, molten metal is prepared in furnaces with different capacities, heated by fuel oil, coke or by electric induction, melting the scrap of steel or castings and alloys elements. The molten metal is adjusted in his composition, according customer's specification and so, it is handcraft transported to the specific area and pouring the molten metal into the mold.

Cooling: after the pouring process, a time is needed to cooling and solidification of the piece produced.

Shake-out (unmolding): after the cooling process, castings are removed from the molds. The pieces produced are removed by operators, separating the two molding box and removing the major part of sand that involves the pieces. The pieces are transported to the cleaning area and the sand will be recovered and reutilized.

Cleaning: consists of removing the foundry sand from saliencies and re-entrances of the casting. Shot blast is a common form of work in cleaning that remove sand and expose the surface for inspection and further work.

Cut burr: pouring sprue, vents and risers are removed from the castings.

Quality control: inspection to detect defects such as cracks, flashing, inclusions, etc., including the quality report.

The prior processes have different productivity levels. Because of this, intermediate inventories of semi-elaborated products are created between operations, and congest the industrial area. The production scheduling will follow the priority of deliverables negotiated with customers, and not specifically the ideal production scheduling.

6. Simulation

Among specific software to develop models of simulation existing in the market, it was chosen the Arena, of Rockwell Softwares, that presents a graphic interface directed to development of models, activity and statistical analyzes of in and out data. The Arena software adopts an approach by process to execute a simulation. According to Filho (2001), this methodology is intuitive, the model represents the flow of entities of the system and is directed to modeling of process that will executed by entity classes of the system, that compete by resources to execute some activities or co-operate to execution of others.

"The simulation of an established reality can be seen as an operation of the model which represents. After the model development, different scenarios associated to it can be analyzed. The steps of construction of a model pass by problem definition, variables identification, conceptual model development (logic model), data collection, computational implementation, model validation and scenarios analyzes. The last step, scenarios analyses can be seen as a response of the model to a determined configuration, with some questions like this: "What would happen if the system operates in this situation?". These responses are helpful to decision maker, because he can test a series of alternatives and choose one that he think more adequate to that situation. This analysis of scenarios imply in the observation of various characteristics of the system as resource utilization rate, existence of bottlenecks, queuing times, etc." (Pinto and Pinto, 2005, p. 2231).

Before creating the computational model, the conceptual model is defined (described as follows), with the consideration of the main aspects of real process. The molten metal arrives in two pouring pans, each one with 50 kilograms. This paper focuses on the beginning of pouring the metal process and it considers arriving in a constant rate, and the pouring process is dependent only over the resources availability (operators and melting pans). The melting pans are pouring separately. To process the pouring metal, two operators are needed, but the model considers only one that represents a double resource (two operators) – this consideration is done for all activities executed with 2 operators. Each pouring pan pours metal into 4 molds, that is, it has the capacity to fill 4 molds. Each mold has 2 castings, and each melting pan has the capacity of 4 molds (each double castings; one mold weight 12.5 kilograms – thus 4 molds weight 50 kilograms, that is the capacity of each melting pan).

After cooling, start the process of shake-out (unmolding process). Each mold has 2 castings and each arrival of melting ferrous (or pouring metal start process), produces 16 metal castings. The pieces are grouping to perform a lot of 200 pieces, when they are transported to the finishing area, by three workers. The first process in the finishing area is the cleaning process, executed by one operator of the cleaning machine. The lot size of cleaning process is 75 pieces. Each casting goes, the next step, to the cutting burr process, with 4 workers available. The next step is drilling and finishing, that is not scope of this study. It was considered one shift of work (6AM to 3PM), 5 days per week. The model considers that activities are no-preemptive, when the shift finishes or lunch time, the workers finish the work before stop. But the model does not consider overtime work, for finish the work for example. Stop to go to bathroom, phone calls, and other considerations are not done.

The probability distribution curves for execution times of each activity were obtained as stated following. After thirty measurement of time, data were adjusted by Input Analyzer (tool of adjusted of distribution inside Arena). The table below shows each activity duration in minutes.

Table 1. Activities duration.

Activity	Duration
Pouring	4.15 + LOGN(2.53, 1.69)
Transport of melting pan	TRIA(4.5 , 5 , 5.5)
Mold cooling	TRIA(30 , 35 , 40)
Shake – out (unmolding)	0.15 + GAMM(0.0305, 2.44)
Casting transport to finishing area	2 + WEIB(4.21, 8.38)
Cleaning	NORM(21.3 , 4.2)
Cur burr	2 + WEIB(0.952, 1.83)

It is important to stand out that more data about each activity would conduct to a better performance of our model, bring near the reality.

One of the most important phases of simulation is to validate the model. In case of the results produced by the computational model present an error of great magnitude in relation to the real values of the current process, can have a logical error in the model, data error, or problems in the conceptual model.

The validity of our model was done comparing the quantity of castings (tons) produced on one month. Our model presents an error lower than 4% in relation to the mean production monthly of the process studied. Moreover, the high rate of cleaning workers occupation (and queuing in this activity) obtained in the model is justified by overtime work frequently performed by these operators, to achieve the production in this sector.

To obtain the results, 10 replications were realized, three months each, starting with zero production in the system, and considering the time of heating furnace of two days.

7. Discussion of Results

The simulation study considers five scenarios. The original scenario (C0) considers four operators in the cut burr process, and was evaluated in more four scenarios:

- C1: to hire more four employees to the cut burr area;
- C2: workload balancing, considering that operators of shake-out (unmolding), cleaning and cut burr process can execute any activity of these process;
- C1_2: scenario C1, with reduction of 0.5 minutes at the pouring process;
- C2_2: scenario C2, with reduction of 0.5 minutes at the pouring process.

The table bellow shows the results of simulating.

Table 2. Simulation results.

Scenario	Occupation rate of cut burr process operator	Mean queuing in the cut burr area	Monthly mean production (tons)
C0	71.7%	133	32.58
C1	35.8%	116	32.58
C2	41.7%	108	33.05
C1_2	36.8%	111	33.75
C2_2	42.8%	108	34.45

The initial idea was to simulate only scenarios C1 and C2, but the results, in spite of presenting a better operational condition, considering queuing and occupation rate in the cut burr area, do not contributed to increase the monthly production in case of hiring people or shows a little advantage in case of balancing the line. The analyses of this situation presents that the monthly production is limited by the pouring process. For that reason, we simulated some changes on the pouring time.

Observing the process, can be noted that there is a high utilization rate of the cut burr operators, the occupation rates of shake-out and cleaning process operators are very low on the original scenario, that suggest a great unbalancing of the workload in the studied process. The data of the table presents little difference between the results of hiring employee and balancing the line. As the hiring process involves costs, and not obtain more production, the operators' workload balancing is the best alternative, because will reduce the occupation rate of the cut burr workers, improving the performance and productivity of others employees, and some gain in the production quantity. If this balancing is coming with a little reduction on pouring times, can increase the monthly production; the pouring time 0.5 minute short, in the balancing model, can signify an increase of 6% in the production.

8. Conclusion

In this article we have studied the leveling production problem at a small to medium foundry industry in Brazil. It focused on the process of pouring metal inside the mold, cooling casting, shake-out, and transport to the finishing area, cleaning and cut burr processes. It presents a computer simulation model that has been used to balance the workflow of production operations. At the foundry industry where the research collected data, the scenarios simulated suggested to explore alternatives to reduce the time of pouring times through an improvement in industrial lay out and workload balancing including worker's multiskilling training. These procedures can lead to reduce the waste of time and reduce the queuing inside the processes, an agreement with lean manufacturing paradigm.

The lean concepts, besides the automobile industry, can be applied in the foundry industry, bringing benefits of better productivity and making the production flowing, as showed in this article.

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