USING LEAN PRINCIPLES & SIMULATION FOR PRODUCTIVITY IMPROVEMENT: THE CASE OF A CERAMIC INDUSTRY

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ABSTRACT
In this work is illustrated an application of lean principles & simulation in order to increase shop-floor productivity at Vista Alegre Atlantis, SA, a well-known Portuguese ceramic industry. The case study reported in this paper is the outcome of the business internship program sponsored by the Department of Economics, Management and Industrial Engineering of University of Aveiro for the students in the Industrial Management and Engineering master program. A simulation model of the current operation of the finishing section was developed, along with the creation of a value stream mapping and the identification of waste, in order to ascertain its limitations and problems. The relevant operational performance measures such as throughput, work-in-process, and queue statistics, were analyzed to allow the proposal of a set of changes to the existing manufacturing operations. The outcome of the simulation study was taken into account by the decision-makers and the recommendations are being implemented.

Keywords: lean manufacturing, productivity, simulation, ceramic industry

1. INTRODUCTION
Nowadays industry is facing a change in market conditions and customers' requirements. Many organizations are competing in a "red ocean" (Kim and Mauborgne 2005) struggling to reduce production costs and maintain a certain margin of profit.

Lean manufacturing concepts and tools are proving to be a good practice for those organizations who want to become more competitive through waste reduction and value-added creation, despite some criticism regarding aspects such as the human factor and the capacity to deal with variability (Hines et al. 2004) or the critical differences between the application of lean principles in a discrete manufacturing environment and in a continuous process manufacturing environment (Howell 2010). Typically, as frequently referred in the literature, the major benefits of adopting lean manufacturing principles and tools include inventory and lead time reduction, improved product quality and essentially waste (*muda*) elimination, i.e., everything that our customer is not willing to pay for (Melton 2005).

Uncertainty in demand has become the new challenge in ceramic industry (Grahl 2003). In order to fulfil costumer requirements, ceramic industries must be able to adapt their level of productivity and their time of response to market as well as improving their level of quality, being "focused on continuous improvement" (Howell 2011).

The study reported in this paper was carried out at Vista Alegre Atlantis, SA, (Figure 1) a distinguished Portuguese ceramic industry that is facing the problems mentioned above and that needs to increase shop-floor productivity while maintaining high levels of quality and flexibility.

Figure 1: Ceramic art from Vista Alegre (source: http://www.myvistaalegre.com/pt/)

The study focus the elimination of waste and the creation of value to the customer. Using lean manufacturing principles and tools and simulation techniques was possible to analyze different scenarios seeking for the one who meet the new market challenges.

2. SYSTEM IN ANALYSIS: THE FINISHING SECTION
Through the observation of *gemba* it was possible to analyze the current layout of the finishing section, the main processes and the current flow of materials and information. This section finishes the pieces produced in the two high-pressure machines Netschz and Sama. As can be observed in Figure 2, the finishing section

has three workstations (P1, P2 and P3) being P1 and P2 responsible for making the finishing operations and P3 for storing the pieces in the transporter (to be transported for the downstream process) and recording the pieces produced. When needed, P3 makes some finishing operations. If the pieces that are being conformed in the high-pressure machines have a long finishing time, then some are processed completely in workstation P1 and others are sent unfinished to P3.

Between P1 and P3 there is a round turntable which is used as a WIP buffer and between P2 and P3 there is a conveyor which also serves as a WIP buffer.

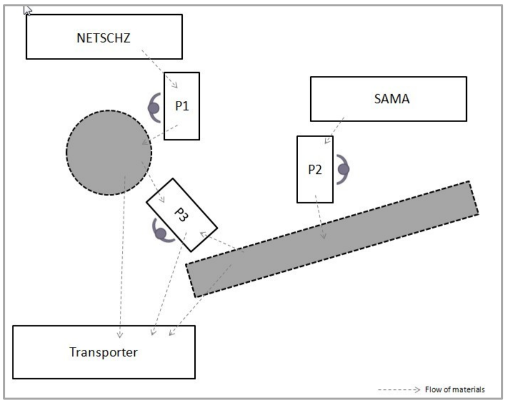

Figure 2: Layout of the finishing section

In this first analysis, it was possible to observe that exists a considerable amount of stock in buffers during the process. With this first information obtained in the field it was made a Value Stream Mapping (VSM) and a process chart (Figure 3) in order to map the activity, providing a better understanding of the process in analysis and in order to find opportunities for improvement.

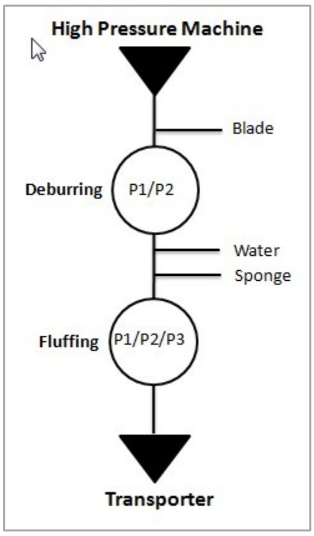

Figure 3: Process chart for the finishing process

This section works in continuous labor with four shifts, each one works eight hours a day. The machines don't have high setup times or other significant constrains.

While looking at the process in *gemba* it was possible to identify several types of *muda* such as waiting, transportation and movement.

It is believed that this section is operating below its capacity due to flow inefficiencies. The time that pieces are waiting to be processed causes high costs associated with non-quality. The actual level of productivity is estimated in 80% and every shift finishes an average of 2000 pieces.

3. DEVELOPING THE SIMULATION STUDY

Simulation is becoming a key strategy in order to describe and analyze different scenarios in industrial plants, because it supplies fundamental data of the new system without implementing it, becoming a cheaper solution (Bruzzone et al. 2013). Simulation can be utilized to explore and document potential opportunities for improvement and it is especially useful in the presentation of results to the direction board (Adams et al. 1991).

Longo (2011) states that modelling and simulation is the best methodology for solving problems in real world complex systems.

Bruzzone et al. (2013) suggest that a simulation model must follow a set of steps in order to achieve the maximum potential of the methodology. In recent years, a lot of research in how to develop a simulation study has been made and it is possible to conclude that the required steps to achieve the best path include problem formulation, conceptual modelling and data collection, operational modelling, verification and validation (V&V), experimentation, and output analysis (Kelton et al. 2010).

The use of simulation is particularly advantageous when the complexity or operational variability of the systems under study renders the application of purely analytical models impossible.

3.1. Formulating the problem

A simulation model of the current operation of the finishing section was developed. The main objective of this simulation study was to document the current state of the section in analysis, identify waste (*muda*) in the process, and improving productivity in 15 % by using lean tools and concepts in the model.

The relevant operational performance measures such as throughput, work-in-process, and queue statistics, were analyzed to allow the proposal of a set of changes to the existing manufacturing operations.

The model was developed using Arena® software from Rockwell Software. This benchmark software is the adopted environment for the simulation courses at University of Aveiro, providing the required features to develop, analyze and animate valid and credible simulation models.

3.2. Conceptual modelling and input data collection

In developing the simulation model particular care was taken to model the finishing process as close to reality as possible. In this stage it was necessary to determine which data would be necessary to use in the model and if this information was available. Talking to a ceramic engineer of the plant it was possible to find that most of the information required was stored in the enterprise information system SAP, but data was not trustable (in some cases).

For example, the data provided by SAP for the processing times of the components were not valuable since were outdated. The solution was to measuring the times in the field. In this stage, a constrain appeared. In this section, thousands of references are processed, and the processing times vary substantially for different references. Thus, an ABC analysis was made in order to identify the most relevant references and simplify this input parameter. It was possible to conclude that four references represent 22% of the total production. These four references were used to determine the processing times used as input in the simulation model.

The time between arrivals for the pieces who would be processed in the model, coming from the two distinct high-pressure machines, has been determined using SAP and was considered as a deterministic input parameter.

The availability of data for the processing times of the tasks involved in the finishing process allowed the fitting of proper distributions to these data. The distributions and its parameters were selected using the Arena's software module Input Analyzer (Figure 4). The distributions obtained were analyzed trough visual inspecting, square error value and p-value, in order to guarantee a "good" fit.

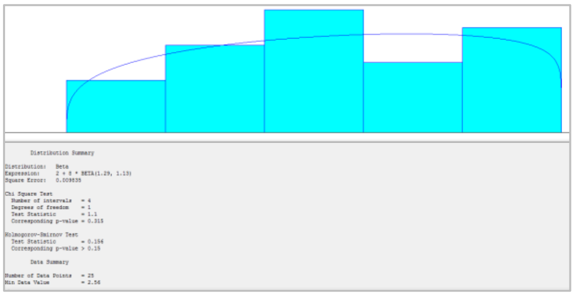

Figure 4: Fitting values to a standard distribution using input analyzer

Regarding material handling operations, a round turntable and a conveyor transport the pieces, and both have buffer functions as well. They were modeled as conveyors and the data necessary was gathered on the field, such as length or velocity. As neither maintenance procedures nor equipment failures influence significantly the regular operation of the system, these were ignored.

One of the *muda* found was movement, that is, human resources have to leave their working stations to get the pieces they need to work and then pass those pieces to the next process. This *muda* was modeled considering the operator in the workstation as the transporter resource. The priority of the process was considered "high" and the priority of the transportation was considered "low". This way the operator finishes the component before getting another one. Since the transportation time varies, input data were gather on the field and then fitted to a standard distribution using input analyzer.

3.3. Operational modelling

As already mentioned, the simulation model of the actual ceramic finishing system was developed using the Arena simulation software. This model was used to: (i) allow for a better understanding of the actual system, (ii) identify critical aspects and opportunities for improvement, (iii) gain the confidence of the decision makers and (iv) try lean solutions in order to improve the productivity of the system-in-analysis.

The run parameters of the model were defined as following:

- Replication length: 1 day of operation;
- Number of replications: 10.

The number of replications was determined through a trial-and-error approach until confidence intervals were reasonable.

The operational model was developed using several modules from Arena templates and it was developed a 2D animation model (Figure 5) illustrating the dynamic behavior of resources, transporters, conveyors, and buffers.

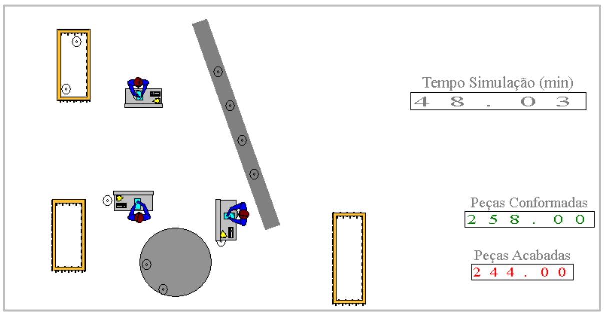

Figure 5: Animation model of the finishing section actual layout

After the operational modelling phase of the study it was conducted the V&V phase and the results were analyzed.

3.4. Verification and Validation (V&V)

The model was verified and validated using different techniques such as animation, internal validity, predictive validation, structured walkthrough, and examination of model traces. The team member who accompanied the project on site was crucial in this process, as he combined the knowledge of the simulation tool being used with the perception gained on the finishing process details.

The animation and the comparison of predicted performance measures with the known behavior of the current system (predictive validation), were the dominant techniques employed, as they allowed the involvement of the decision makers in the validation process.

When the model was experimented, for the first time, the throughput value was 33% lower than the expected value. This occurred due to a fail in the input data. It was considered that the capacity of the human resources was one, when in fact, when transporting components they carry one, two or more depending on the size and weight of the pieces. This parameter was refined and the output values become validated.

The verification and validation process was crucial for gaining the decision-makers' confidence in the outcome of the simulation study.

3.5. Output Analysis

After V&V the model was run and the output data analyzed. A bottleneck analysis was made in order to determine possible causes for the existing low level of productivity.

Analyzing the output given by the simulation model it was possible to extract the following results (statistical estimates of the performance measures based on 95% confidence intervals):

- The total number of pieces created by the high-pressure machines was 2532.
- The average throughput of the finishing section was 2027 pieces.
- Work in progress for "pieces for finishing" was, in average, 26,7 ± 1,15 and "pieces for transporter" was of 145,48 ± 2,42.
- Workstation 2 is the one which retains the pieces more time, this value is in average 55.9 ± 0.6 seconds and workstation 3 is the one which retains the pieces less time (25.8 ± 1.2 seconds).
- The waiting time since the components are created in Netschz until they start to being processed is in average 20,2 ± 1.05 minutes, and in Sama it is 31,3 ± 0,55 minutes, which causes a high number of components waiting to be processed after the high-pressure machines.
- The operator 2 is being in utilization an average of 98,6% ± 0.01. Operator 3 is the one who is less occupied being in utilization an average of 55,6% ± 0.01.

Observing this information, it was possible to conclude that the number of finished components represents approximately 80% of productivity, which is very similar to the data observed on the shop-floor. Operator 2 is the bottleneck , being in use most of the time, while operators 1 and 3 have some idle time.

A large number of pieces is being produced by the high-pressure machines but the actual organization of the finishing section does not have capacity to finish all the production. This bottleneck creates a considerable number of intermediate stock and work in progress. These factors have a negative effect on the quality level of the final product.

3.6. New scenario for the finishing section

Given the attained simulation results, the objective was then to redesign the finishing section in order to achieve a growth of 15% in productivity.

Some changes were made in the layout of the section to provide a better flow of materials and to concentrate the waste in one operator, the "logistics operator". The function of this operator is to do all the operations (e.g., transportation) that do not create value to the final consumer but are necessary in the process. If he has some idle time, he will help the other operators to finish some pieces.

Figure 6 depicts the proposed solution for the new layout of the finishing section. The idea is to have a cellular layout with operators that are concentrated exclusively in creating value.

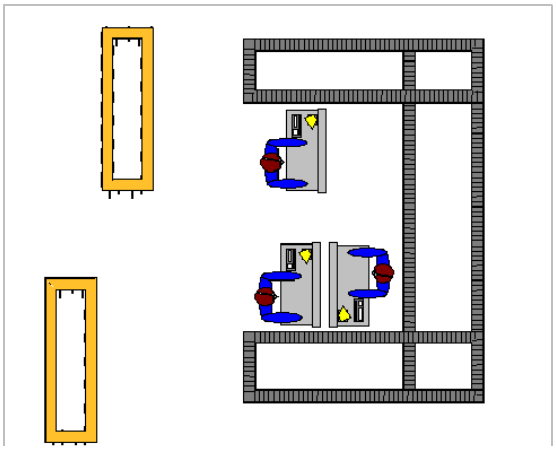

Figure 6: New layout for the finishing section

For this simulation it were considered the same conditions of the previous model for the creation of pieces. This time is deterministic so, maintaining the same replication parameters it is expected to obtain an equal number of created pieces. In the processing time of the pieces by operators 1 and 2 it were excluded movement and transportation times, because these operators are now focused only in creating value.

The results for this new simulation scenario were the following:

- The total number of pieces created by the high-pressure machines was 2532.
- The average throughput of the finishing section was 2403 pieces.
- The work in progress for Netschz pieces was in average 40,9 ± 1,15 pieces and for Sama was 40.9 ± 1,14 pieces;
- Value added time for Netschz pieces was in average 0.64 minutes and for Sama 0.63 ± 0.01 minutes.
- The waiting time since the components are created in Netschz until they start to being

processed is in average 13,9 ± 0.42 minutes, and in Sama it is 13,8 ± 0,41 minutes.

- All resources are being used approximately in average 97% of the time.

4. DISCUSSION

Analyzing the values obtained in the different simulations we can conclude that with the introduction of relatively small lean-based modifications the system-in-analysis was able to finish more 16% components that those which are finished today (the objective was 15% of improvement).

The proposed cellular layout provided a continuous flow, which reduced substantially the work in progress, and the time components were waiting to be processed. All the operators are occupied almost 100% (Figure 7 and Figure 8) of the time, and operators 1 and 2 are dedicated to operations that create value, while operator 3 has concentrated all the *muda* operations that are required but do not create value (supply, per example).

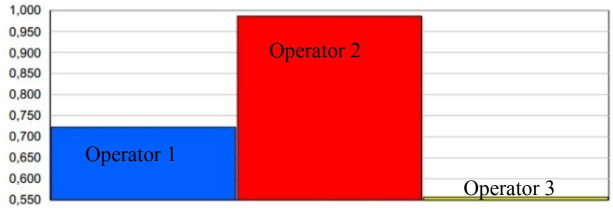

Figure 7: Operators' utilization before modifications

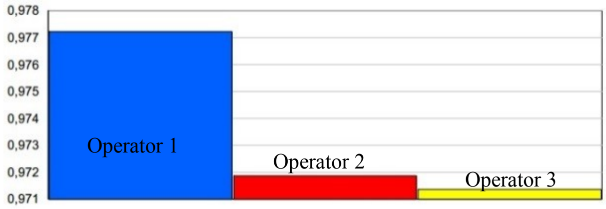

Figure 8: Operators' utilization after modifications

As one can see, the operation of the finishing section for the new scenario is smoother, that is, the workload is now more evenly distributed, the WIP is considerably lower, and the productivity is increased by 16%, as desired.

Other scenarios are being studied by the company such as the option of including one more operator in the section and the opportunity to increase the output rate of the high-pressure machines.

5. CONCLUSION

The development of successful projects involving both the universities and the industry is, generally, difficult to undertake. In the project presented in this paper this difficulty in communication was overcome, due to the fact that one of the university team members worked fulltime within the company throughout the duration of the project. He not only established a privileged communication channel between the university and the company, but also directed management and staff attention to the project.

During the development of the simulation study, formulating the problem and gathering data were the critical steps (the most complex and most time expensive).

Simulation studies can become a powerful tool for analyzing the actual state of a factory or section, and for analyzing possible modifications to the actual state, using DoE and comparing the outputs. This is especially efficient if all intervenient are focused on the goal.

By testing new scenarios in a simulation environment it is possible to save money spend in disrupting systems or implementing "poor" operational solutions. Using simulation techniques involves considerable costs of software and training but, the benefits of using this tool to dynamic evaluate complex systems are unique and can faster outweigh the initial investment.

The company's goals were fully attained and the suggested modifications to its manufacturing operations are being implemented, as a result of the outcome of the simulation study.

This successful case study of university/industry interaction in the simulation field can be used as a showcase to the benefits that SME's can get from the use of simulation.

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