Principles and Practices of Lean Production applied in a Metal Structures Production System

R. Carvalho, A. Alves, and I. Lopes

***Abstract*—This paper presents a work undertaken in a metal structures production system in a company producing several assorted products for the civil construction. The work aim was to improve the production process, solving several productive problems encountered in the production system, such as: deliveries delays, long lead times, too many material handling, high stocks, errors and defects in metal structures assembly and production, and unnecessary motions. The identified problems were analyzed and improvement actions were scheduled and subsequently implemented. These improvement actions were based on Lean production organizational model and some Lean tools. The 5S methodology was implemented in the workplace as well as mistake proofing mechanism, standardized procedures, production activity control system and layout reconfiguration. These actions led to a reduction of the lead time, work in progress, transports, delivery delays, defects and errors in assembly and production.**

***Index Terms*— Lean production, Kaizen, 5S, VSM.**

I. Introduction

LEAN production is a well established organizational model implemented in companies through all the world. Since the publication of the "Machine that changed the world" [1], "Lean" is the word that had been used to refer Toyota Production System (TPS) [2]. This word was used by a MIT researcher [3] because TPS was "doing more with less": less human effort, less space, less inventories, less investment in new tools. This was achieved through tools and principles: Just-In-Time (JIT), *autonomation*, flexible work force and creative thinking [2]. Later, these were renewed in Lean Thinking principles: i) create value for the customer; ii) map the value stream; iii) create flow; iv) pull the production and v) pursuit perfection [4]. This last principle has to do with waste (*muda*, in Japanese) continuous search and continuous improvement (*kaizen*, in Japanese) [5]. TPS considered seven "deadly" kind of wastes: overproduction, unnecessary motion, unnecessary transport and handling, defects, inventories, waiting, over-processing [6]. Eliminating such wastes and putting in action the principles referred require diverse tools like Value Stream Mapping (VSM) [7]; 5S [2]; pull system [2]; standardized operating procedures (SOP) [8], [9], mistake proofing or poka-yoke mechanisms [2], to mention only a few.

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The work objective was to improve production processes in a metal structures production system, through identifying wastes and, applying Lean principles, tools and techniques, to reduce/eliminate these. Basic tools like ABC analysis, cause and effect diagrams, process flow diagrams, sequence diagrams and other, and more recent tools like Value Stream Mapping (VSM), were used to diagnose the production system. Kaizen, mistake proofing mechanism, 5S, Constant work in process (CONWIP) production activity control system [10], standardized operating procedures were implemented to solve the encountered problems and eliminate waste. Some performance measures were improved.

The work described in this paper was developed in a context of an Industrial Management and Engineering (IME) master thesis final project. The methodology used by the researcher was the Action Research [11] where he participated actively in the company action, collaborating with all intervenient in action. This methodology involves a five phase's cyclical process: 1) diagnosing; 2) action planning; 3) taking action; 4) evaluating and, 5) specifying learning. Other projects with these purposes had been developing using the same methodology [12], [13], [14].

This paper is organized in six sections. This first section introduces the objectives, reviews the main concepts about Lean production and presents the research methodology and paper organization. The second section describes the production system current situation and diagnoses this focusing one product: the metal frames. The actions planned for the improvement and its implementation were discussed in the third and fourth section. The fifth section evaluates and presents the results, and, finally the sixth and last section presents some conclusions.

II. Diagnostic Phase

A. *Product identification*

The production system target by this study produces on demand several types of product for the civil construction, such as: footbridges, spatial trusses, stairs, gutters, gates, grids and frames. The production system is organized into five sections: cutting, welding, drilling, bending and deburring. The materials or semi-finished products flow between sections depends on the product that is manufactured.

Therefore, a product has been selected using the ABC analysis, based on invoicing for each product of the production system (see fig.1).

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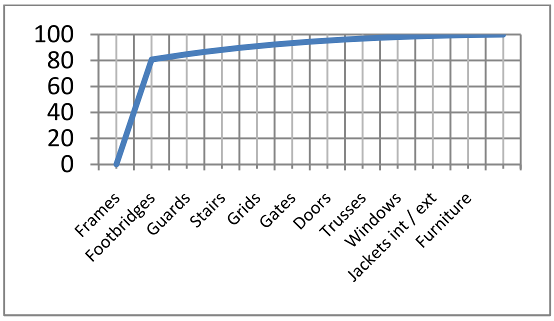


Fig. 1. ABC analysis for the selection of the product to be analyzed.

The graph presented in fig. 1 reveals that the product with the higher invoicing is frames. Frames (fig.2a) are metal profiles used as pillars or beams in constructions such as metallic support structures of signs, footbridges of shopping malls or factories (fig.2b), among others.

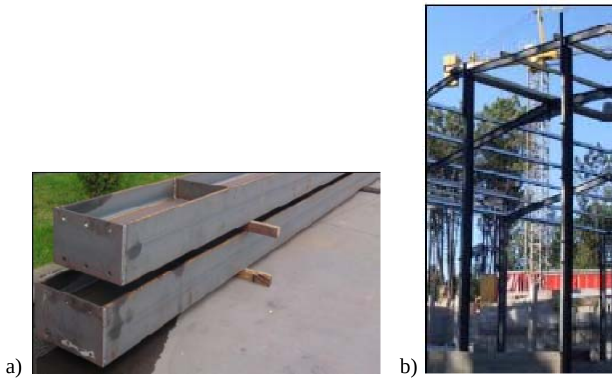


Fig. 2. a) Frames and a b) mounting structure for a factory

B. Frames production process

All the manufacturing products in the company are produced based on technical drawings that are attached to the work order. Frames requirements (dimension, area and weight) and quantity are indicated in the bill of materials that also follows with the work order.

A process analysis graph was developed (fig.3) for the production of frames. The cycle times of operations involved in the manufacturing of this product were not known. Then, a time study was made, performing several observations during one week for a type of frame designated by UNP180. Frames are composed by two parts, a profile and sheets on the ends that are joined in operation 14.

The time analysis indicated a total time for all the operations of about 26 minutes, without including time spent with motions, transports, and quality control. In fact, the total time involved in the manufacturing of the analyzed type of frame was 40 minutes, spending about 15 minutes in non-value added activities.

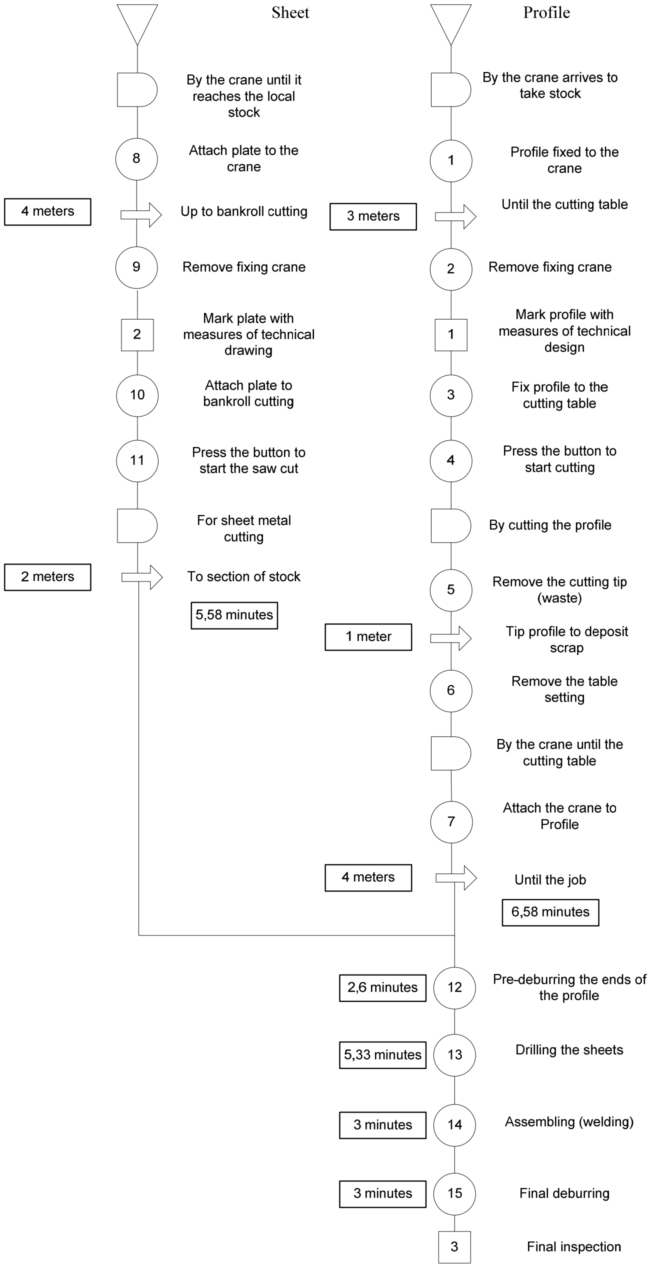
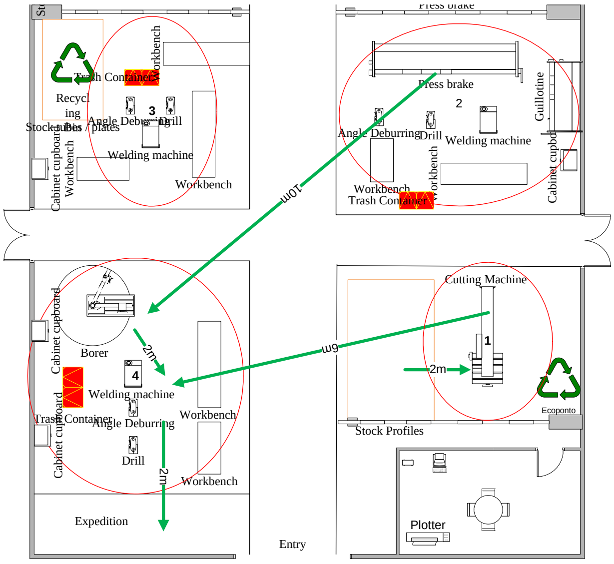


Fig.3. Process analysis diagram for frame UNP180

The layout presented in fig. 4 shows the materials flow of frames in the plant. The cutting of profiles is made in section 1 according to the measures indicated in technical drawings. At the same time, the cutting of sheets is made in section 2. Profiles and sheets are transported to section 4 where the profiles are chamfered and sheets are drilled before being welded together. Then, the unions of the profiles with sheets are deburred. After this operation, the frames are transferred the stock of finished products waiting for shipment.



Legend:
1: Cutting section
2: Sheet cutting and bending section
3: Cutting section and assembly
→ Flow of frames parts/materials
4: Assembly and drilling section
5: Expedition

Fig.4. Layout and materials flow

As shown by fig. 4, with the described manufacturing process and layout, materials have to travel long distances.

C. *Value Stream Mapping of present state*

The VSM of present state for the frames was created and is in Fig. 5. The lead-time for the frames was around 12 days (90 hours) but these frames could be produced in 2,5 hours. This indicates about 3% of value-added activities, meaning that a high percentage of activities do not add any value to the frames. High WIP, high transports and material handling, bottlenecks were also showed in the VSM.

The takt time was calculated, considering a demand of 276 orders in each shift. The takt time being 38,3 minutes, it was clear that the welding operation was the system bottleneck and there was an significantly unbalancing between the operations (fig. 6).

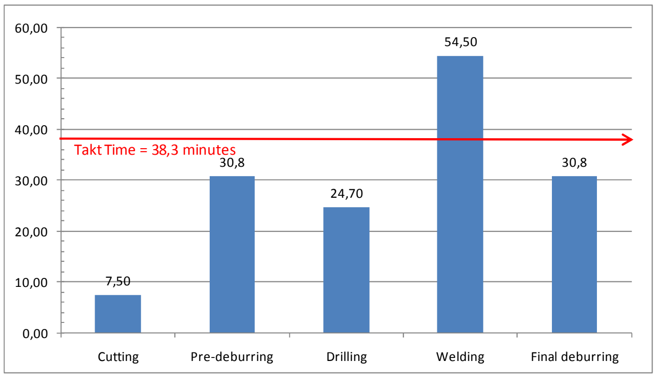


Fig.6. Operations balancing graph

A more detailed study, based on a sampling time study, was necessary to reveal the percentage in value-added and non-value activities. The results are in the Table I and II.

TABLE I
VALUE-ADDED TASKS AND THEIR PERCENTAGES

Value-added	**Percentage**
Cutting	7%
Welding	19%
Pre-deburring and final deburring	21%
Drilling	7%
Other tasks	5%
TOTAL	**59%**

TABLE II
NON VALUE-ADDED TASKS AND THEIR PERCENTAGES

Wastes	**Percentage**
Transports	15%
Waits and motions	7%
Inspection	12%
Others	7%
TOTAL	**41%**

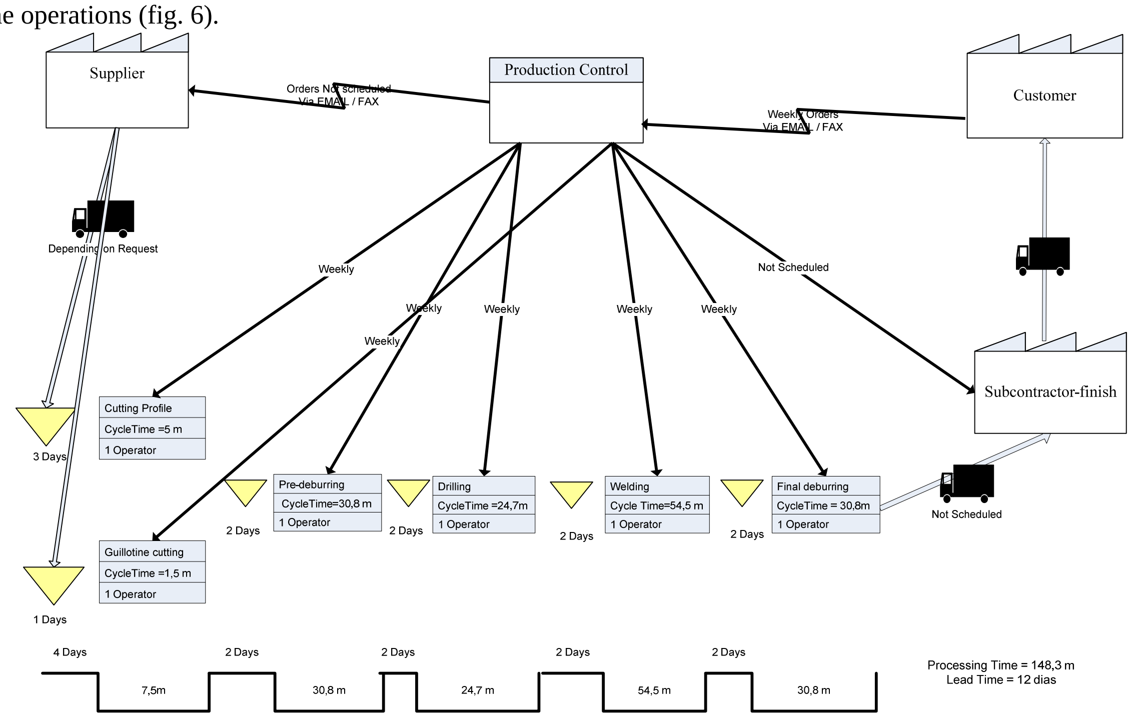


Fig.5. Value Stream Mapping of frames manufacturing

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D. *Analysis of quality problems*

Beside the losses incurred by the motions, transports and high work in process which can be associated with the layout and production organization and scheduling, some problems and errors occurs which affect the production time and then the delivery of products on schedule.

These problems were:

- Lack of raw material to carry out the work order;
- Technical drawing does not comply with customer requirements;
- Incomplete work order;
- Defective parts and products.

These problems, when occur, were registered in the non-conformity sheet. However, their analysis was not performed.

A further analysis allowed identifying the causes of defective parts or products, as shown in cause and effect diagram (fig.7).

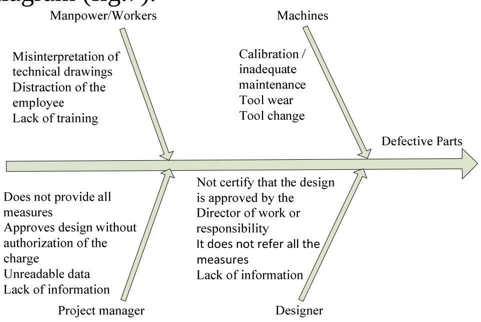

Fig.7. Cause and effect diagram for defective products

Defective parts were originated mainly by incorrect processing which involved welding or drilling of a component on the wrong side and incorrect dimensions. Incorrect processing was due to:

- Misinterpretation of technical drawings by workers;
- Lack of dimensions in the technical drawings;
- Lack of scale or dimensions with different scales in technical drawings;
- Lack of attention of workers.

III. Proposed improvement action plans

Following the diagnostic phase, an action plan was delineated involving managers and supervisors. The actions plan (table III) uses the 5W1H tools to define: the action to be implemented (what), the objective of implementation of the selected methodology (why), the department responsible to assure the success of implementation (who), the area covered by the changes (where), the deadline for each action (when) and how the action will be implemented (how).

TABLE III
Improvement Actions Plan

What?	Why?	Who?	How?	Where?	When?
Implement 5S	Frequent motions originated by tidiness	Planning depart.	Workshops about 5S and creation of an implementation plan	Production plant	Until 31-7-10
Decrease lead time	Delays in frames deliveries	Planning depart.	One piece flow	Assembly section	Until 31-7-10
Limit WIP in cutting section	High level of stocks	Planning and production depart.	Definition of a upper limit and buffers identification	Raw materials stocks	Until 31-8-10
Propose an alternative *layout*	High transport of material between section	Planning and production depart.	Analyzing handlings between sections	Production plant	Until 31-8-10
Kaizen principles	Errors and recurring defects	Production Depart.	Going to the work place and talking with workers	Production plant	Until 31-8-10

The takt time determination makes possible to estimate the operators number necessary to the frames production. Four workers is sufficient for the frames production and future state VSM was designed (Fig. 8). The balancing graph was also projected based on the wanted situation (Fig. 9) putting three workers working in the drilling, welding and deburring operations and two workers cutting and pre-deburring.

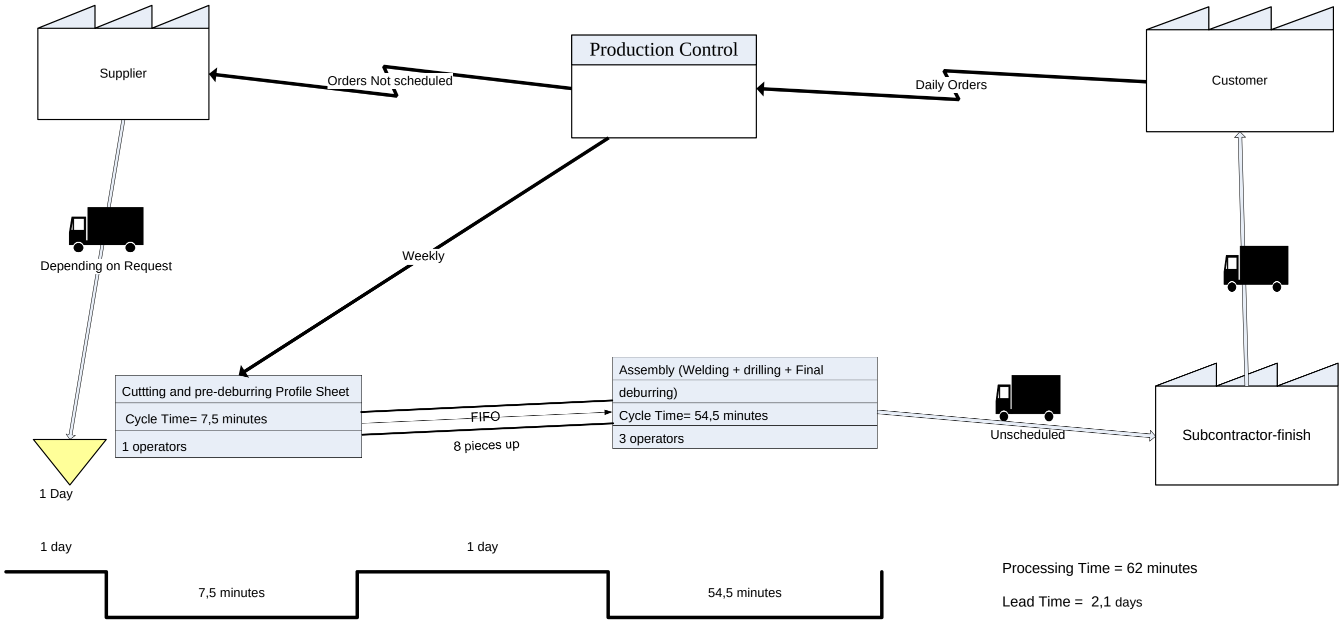

Fig.8. Future state VSM

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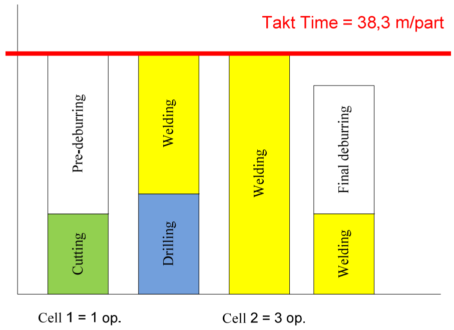

Fig.9. Proposed operations balancing graph

IV. Implementation of Improvement Actions

A. 5S implementation

The first action to be initiated was the implementation of 5S. With the implementation of 5S, it is intended to keep:

- an organized space for raw materials reducing the time spent in the motions of raw materials (mostly of high dimensions),
- an organized workstations to avoid the time spent by worker in search for tools;
- a safe workplace avoiding accidents by removing unnecessary materials and waste from the workplace.

A 5S team was formed, composed of the production director, supervisor, the researcher and the Health and Safety responsible in company. The team organized a training session about 5S that was performed by an external entity.

The team prepared an implementation plan, including activities to be performed and its scheduling. The implementation plan was communicated to all employees by the production director focusing what was expected of them.

A general cleaning was made throughout the plant by the workers. The workers were also involved in the organization of the tools and workstation, once the organization must be done according to the works methods. This also allows a better acceptance of the changes. Fig.10 shows two spaces to store tools.

The raw materials were organized by dimensions. This change allowed space saving which implies a greater mobility to proceed with the cutting of raw materials (usualy large).

After the achievement of the first 3S of the 5S methodology, the team encouraged the workers to performed daily tidiness and housekeeping, defining a check list to be followed by workers. The researcher was asked to check daily the workspace and workstation of every worker, identifying non-compliance of the established rules and potential improvements.

To initiate the implementation of 5S, the team used the lockers available for storage of tools, however the company intends to acquire workbenches that will replace the existing lockers. Until then, housekeeping habits will be deeply rooted in the workers.


Fig.10. Storages spaces for tools

The company also plans to mark the factory floor so as to outline work sections, circulation area for movement of people and transporting materials carts, as well as areas for workbenches setting.

B. CONWIP implementation

Pull system was implemented using CONWIP instead of kanban due to the demand unpredictable and dissimilar products. It was defined an upper limit WIP in the cutting section according the system capacity. Also, it was implemented the one-piece-flow (OPF) concept using the CONWIP and the FIFO rule. This led to the lead time reduction. The tasks in the drilling, welding and deburring sections were aggregated in one section and before this section a buffer was installed. Welding was the system bottleneck and the buffer implementation becomes possible putting these semi-finished products sooner in the surface finishing subcontract companies.

C. Implementation of mistake proofing mechanism

A mistake proofing mechanism was implemented in the manufacturing of frames. As mention before, the incorrect processing is frequent in the manufacturing of metallic structures. Concerning frames, assembling sheets and profile is critical since the sheets need to be welded to the profile in the right position.

The solution implemented to avoid processing errors as well as to make the task easier for the worker was a system comprising two pins, where the holes of the sheet will fit, as shown in fig. 11.


Fig.11. Mistake proofing mechanism for frames assembly

D. Layout reconfiguration

A new layout was proposed in order to reduce transport time of materials between sections. The time spent in transport is the highest waste identified in the manufacturing process of frames. The layout was reconfigured through the formation of three cutting cells (functional cells: C1; C2; C3) and three assembly cells (Fig. 12). The functional cells only cut the raw-material and the assembly cells execute the other operations: drilling, welding and deburring (CM1; CM2; CM3). This simplifies the flow and reduces the travelled distances in 25% related to the previous layout (Fig. 4).

E. Standardized operating procedures

Work standards were defined to improve the efficiency of the manufacturing process of metallic structures. The cause and effect diagram developed in the diagnostic phase reveals that the mainly source of problems in manufacturing was inefficient work order preparation. Therefore, some rules have been defined concerning the preparation of technical drawings and work orders to be checked by the project manager:

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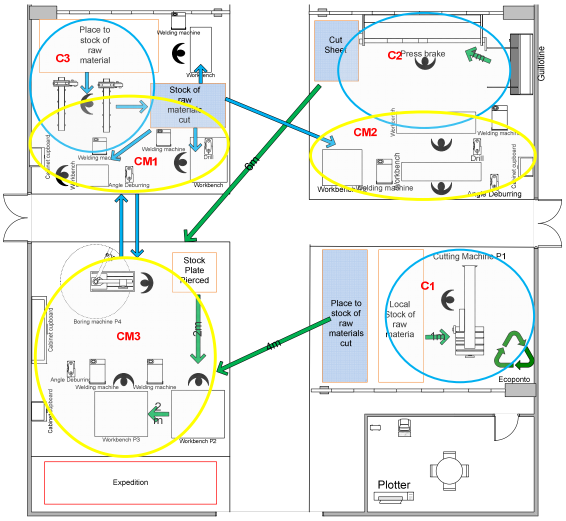

Fig.12. Proposed layout and materials flow

- All measures should be given in millimeters;
- All measures should be presented in the following order: height, width and depth;
- Changes to the initial design have to be communicated immediately to the production director;
- The assembly scheme must follow technical drawings;
- Material specification (dimensions, thickness, surface finishing) should be well defined;
- Measures should be validated only when documented, dated and signed;
- All measures should be given for work preparation.

The work order will be initiated only after the accomplishment of all these rules. Some rules for supervisor were also defined and implemented, mainly concerning the accomplishment of tidiness and cleaning rules by workers and the monitoring of work order status. For workers, beyond the rules derived from 5S, other rules were imposed in order to control consumed materials.

V. Results and Evaluation

The better organized system "putting things in the right places", the facilitation to find out the raw-materials and the tools, the cleanness and enjoyable environment promoted by the 5S implementation led to reduced motions and waits. The layout reconfiguration and one-piece-flow reduced the transport time and promoted the continuous flow. The distances travelled were reduced in 25%. One-piece-flow also permitted the semi-finished products delivery to the subcontracted surface finishing company. CONWIP implementation limited the system load, promoted the exact quantity to be produced and facilitated the stocks control and raw-material orders. The mistake proofing mechanism reduced significantly the errors and defects and avoided the frames transport and returns to the company due to erroneous point holes in the civil construction local. All these implementations reduced the wastes and the lead-time. This was reduced to 2 days, i.e., 80% related to the previous lead-time.

VI. Concluding Remarks

This work was undertaken in a production system of metal structures of a company supplying diverse products for civil construction. The work was developed by an Industrial Management and Engineering (IME) student in a master thesis final project. The proactive attitude assumed by of the student, adopting the role of an action researcher, engage a synergetic collaboration of employees, administrator, supervisor, Health and System responsible inside a team work. The administrator´s support was crucial to achieve the objectives proposed for this project.

This project results were very satisfactory for the company. This was expressed to the researcher that was invited to continue implementing this organizational model to other company sections. At the beginning of the project the tool already known by the company was the 5S, in an early state of implementation. Using this knowledge, the tool implementation was deep and facilitated the presentation and discussion of other tools. These tools implementation led to the lead-time reduction of about 9 days, mainly due to the transport time reduction and continuous flow permitted by the layout reconfiguration, CONWIP implementation and one-piece-flow. As a conclusion this project achieved production process improvement and reduces wastes in the production plant.

As a future work the researcher intends to analyze, propose and taking actions to implement these and other tools to the carpentry section of the company. The findings of the action research in the metal structures will be replicated in this section in order to implement a Lean culture in the company.

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