Application of Lean Manufacturing Concepts and Value Stream Mapping to a Company that Manufactures Engineering To Order Road Transportation Products

Fernanda A. Breitenbach and Joao C.E. Ferreira*

Universidade Federal de Santa Catarina
Departamento de Engenharia Mecânica, GRIMA/GRUCON
Caixa Postal 476, Florianópolis, SC, 88040-900, Brazil

ABSTRACT

In the current economic scenario, it is an increasing trend companies seeking to adapt their production systems to meet the new market demands, and at the same time to increase efficiency in their processes. Among the various methodologies available, lean manufacturing stands out as a valuable approach to have an efficient supply chain. Lean manufacturing seeks to eliminate waste, and to optimize the company resources. This paper describes the implementation of lean manufacturing concepts in a company that manufactures custom (ETO - Engineering to Order) products for road transportation (e.g. tow truck). Value Stream Mapping (VSM) was applied to one of the products of the company, which has a high variety of parts, materials, and assembly processes. VSM corresponds to a visual representation of the flow of materials and information for a product family, helping: (a) analyze the value stream in the current state, (b) identify the main sources of waste, (c) propose improvements to the current state, (d) add value to the customer. The results obtained were as follows: 75% reduction in storage time of raw materials, 49% reduction in the manufacturing lead time, 80% reduction in transport time of materials and products, 94% reduction in setup time of the assembly area, 75% reduction in waiting time, 50% reduction in positioning time of parts and subassemblies, and 20% reduction in processing time. This shows the potential application of lean concepts in ETO manufacturing environments, and the procedure proposed in this paper can be used as a reference by other similar companies.

1. INTRODUCTION

Competition has been increasing between supply chains, not just between companies [1]. This requires companies to increase the efficiency and effectiveness of their processes, seeking to improve its productivity, with fewer resources and at the lowest possible cost. Companies should seek to continually improve its products and processes, reducing lead times of products, updating its facilities and machinery, offering products to customers with high quality, quickly and with reduced costs.

The concepts of Lean Manufacturing are characterized by trying to eliminate all forms of waste in the production system, spreading the idea that all activities and efforts spent in a production environment should have a single goal: to add value to the product, creating customer value.

Due to customer needs and market niches, many companies meet customer demand predominantly through Engineering to Order (ETO) products, in which customer orders are issued from the sales department to the design department which, after development and detailed design, send the drawings to production. Then the process of product manufacture begins, preferably without inventory of parts, subassemblies and finished products. According to Pires [2], ETO is an extension of Make to Order (MTO) production, and the product design is almost entirely based on customer specifications. The ETO production system is characterized by a low volume production of goods, often tending to a single product [3].

However, in Engineering to Order (ETO) production environments, a great difficulty is encountered when changing the conventional practices into procedures seeking to eliminate waste through Value Stream Mapping (VSM) [4, 5]. Unlike the high volume production companies, in which standardization of production processes and the stability of demand are evident, ETO companies find many obstacles which require that some lean manufacturing concepts are adapted exclusively for this production environment. In addition, many companies that produce a wide range of parts present difficulties in the implementation of lean manufacturing concepts, and such difficulties are caused mainly by reduced visibility of the parts to be mapped [6]. This difficulty in applying lean concepts in assembly lines with high variability of parts forces companies to develop specific implementation methods, taking into account peculiarities of each company.

Thus, this work seeks to implement the concepts of lean manufacturing, specifically VSM in a company that manufactures customized products for road use, where many of its processes are craft-like, and the products

* Corresponding author: Tel.: +(55) 48 37214021; Fax: +(55) 48 37217615; E-mail: j.c.ferreira@ufsc.br

have a high variability. It is intended to reduce lead time, to eliminate waste, and keep the assembly line flexible in order to meet the demand for custom products.

2. Lean Manufacturing

Lean Manufacturing can be defined as an approach that seeks a better way to organize and manage the relationships of a company with its customers, supply chain, product development and production operations, through which it is enabled to do more with fewer resources and less time [7]. Lean manufacturing is an approach used with the aim of providing an adequate flow of value and reduce waste.

Waste can be defined as any activity that does not add value to the product or service [7]. Ohno [8], Shingo [9] and Slack et al. [10] identified seven major wastes: overproduction, waiting, excessive transport, losses in processing, unnecessary inventory, unnecessary movement of operators, and defective products. The application of VSM in the production system allows to identify losses and develop ideas and actions to eliminate waste.

2.1 Value Stream Mapping

Value Stream Mapping (VSM) is a technique that was developed by Rother and Shook [4], which is used to describe how production works and how it should operate in order to create an optimized value stream. With this technique it is possible to represent all the steps involved in the flow of materials and information, helping to see the value increase from the customer to the supplier [4, 11]. The steps for applying VSM are:

- Selection of a product family: Initially products are grouped into families, taking into account the similar processes applied to each product and the common equipment in the processes.
- Mapping the current state: after selecting the family of products to be analyzed, mapping is begun, which is performed by using a set of symbols that represent processes and flows. Door-to-door mapping is carried out from customer to supplier, drawing the current state map with its flows of materials and information.
- Mapping the future state : from the current state map, a map of the future state is drawn, seeking to eliminating waste previously identified, and proposing potential improvements.
- Improvement plan: in this step an implementation plan of the improvements is proposed, consisting of tasks, responsibilities and targets to be met to achieve the future state.

The information at the company considered in this study was obtained through interviews with people involved in manufacturing, and members of senior management. Customer demand data were obtained from reports and production planning software. With regard to map data, which include lead times, inventory, and other information for preparing the current map were obtained by monitoring the manufacturing of products.

3. Description of the Company Considered in this Research and its Production Process

The company considered in this study is located in the state of Santa Catarina, Brazil. It has a main manufacturing plant and a branch plant, both located in the same city. In its two manufacturing plants the company performs the processes of cutting, bending, punching, stamping, machining, and also woodworking, welding, sandblasting, painting, and assembly, with approximately 270 employees. In these plants seven models of road equipment are produced: semi-trailer, bi-train, chassis, container, trailer, and canvas.

Since it is an ETO product, with custom and unique features, many specifications are not fully defined by the client, generating many uncertainties and changes that delay project completion. Many of these delays are generated by the client, who does not completely define the dimensions and characteristics of the product, nor purchases the tractor vehicle, nor delay the decision on project approval. Inventories of components and finished products are not generated, since every order is a new product, being unfeasible early production of parts and sub-assemblies, much less the final product.

The company's industrial structure is composed of several sheds built according to need and market demand. Since its layout is not carefully planned, there are many space constraints and waste throughout the operations.

The assembly line is organized according to the assembly sequence of the product, and the product moves between sectors depending on the processes applied to the product, characterized by a functional (job shop) layout. However, due to the large size of the product and materials moving towards it, and also the presence of subassemblies before each operation, a portion of the line can be considered as fixed position layout. It should be noted that each product does not have a dedicated assembly line. Since each area has a structure, suitable jigs and equipment adapted to each product, completely different products can be assembled on the same line.

The current production model for the semi-trailer is the push system, where the products are manufactured on a scheduled basis. The production flow of parts is not continuous, because the production schedule for each machine is isolated. Operators receive manufacturing orders with the description of what should be produced. Items are pushed to the next area or operation without considering whether the item will be consumed or not.

4. APPLYING THE VALUE STREAM MAPPING

4.1 SELECTING A FAMILY OF PRODUCTS

The product chosen for this research was the semi-trailer (Figure 1), due to its strategic importance to the company as it has the highest profit margin compared with the other manufactured products. However, due to its larger size, it has one of the largest lead times in the production line, demanding a high amount of materials and resources compared with the other products manufactured. There is a great need for physical space for its movement, and there is a high incidence of stops on the assembly line. Thus, much of the improvement opportunities for the product and the production process of the semi-trailer directly benefits the other products manufactured on the assembly line, since these products go through the same areas and operations, differing only by the technical characteristics and the materials used. An analysis was carried out for the current value stream of the assembly process, following up its assembly operations from receipt of the parts to completion.

(a)

(b)

Figure 1. Product considered in this research: (a) Chassis of the semi-trailer, (b) Semi-trailer.

4.2 MAPPING THE CURRENT STATE

After selecting the product and its boundary limits, information recording was begun for the value stream on the door-to-door level of the semi-trailer assembly, from the chassis assembly to the final assembly. The information collected on the assembly line was recorded on the mapping sheets, which contain information about the product, times of each operation, the number of employees involved, and the distances to transport the parts, fixtures and equipment. These data are needed for the preparation of the current state map.

At this stage it was difficult to determine the actual time of the operations, since the number of assembly operations is large, being directly proportional to the variety of materials and parts used in assembly. These factors hinder the process of mapping the value stream.

In order to represent the value stream for the semi-trailer in a current state map, it was necessary to follow the path of the product, timing the operations, the employees involved, and the distances traveled. Timing was taken along the process chain for the same product, showing the lead time and the waiting between operations.

In a basic ETO system design can be developed from the initial contact with the client, but the stages of detailing and production start only after the receipt of the formal order. This interaction with the customer is usually intensive and the product is subject to some modifications, even during the production phase. Therefore, delivery times tend to lie between medium (between 3 and 4 months) and long (over 5 months), and lists of materials are usually unique to each product [2].

Manufacturing orders are sent to the company by sales representatives or through direct customer contact. The sales sector issues the order and forwards it to the design sector for product development, and after the design is completed the details of the product structure (Bill of Materials - BOM) and drawings are sent to production. After issuing and distributing the manufacturing orders, the manufacturing of parts, sub-assemblies and assembly of the product begins.

The mapping of the semi-trailer was divided into two stages (chassis and semi-trailer), due to the amount of existing operations that hinder the visualization of information on a single map. The assembly stage of the chassis (Figure 2) consists of the following operations: assembly of the front of the chassis, assembly of beams, suspension assembly, chassis body assembly, and axles assembly. In the second map (Figure 3), the chassis is considered as a semi-finished product, which is incorporated into new parts for assembling the chassis structure, yielding the final product (i.e. semi-trailer). This second stage consists of the following operations: assembly of the structure of the chassis, grinding, abrasive shot blasting, painting, outer coating, inner coating, installation of doors, and final assembly.

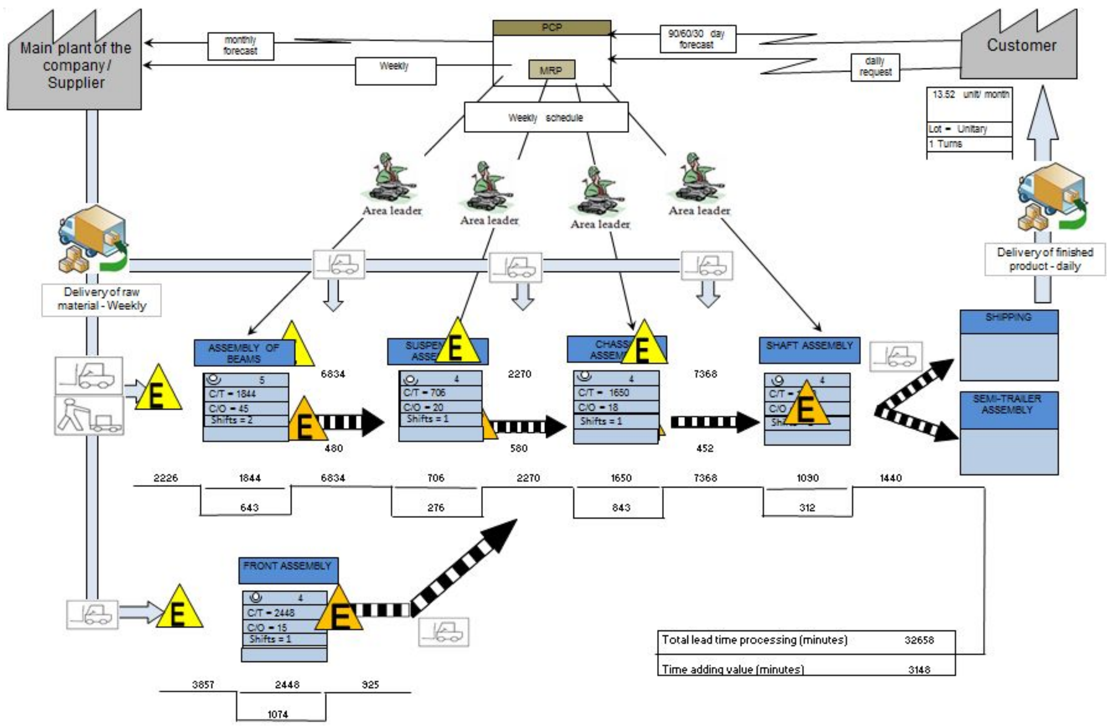

Figure 2. Current state map of the chassis.

With the completion of value stream mapping on the door-to-door level, and the survey on the product demand, the current state map was prepared, providing a broad overview of the flow of materials and information, from receipt of parts and subassemblies until the completion of the product.

Waiting times of semi-finished products and parts inventory waiting to be used in the assembly operations are represented by triangle icons between operation areas. These inventories wait at the same time, and so they are shown in parallel, with the higher inventory time transferred to the timeline of the map.

It is observed on the map the times that are part of the lead time for producing the product, and many of them do not add value. These times include: waiting, preparation of assembly area, preparation of jigs, positioning of parts, cleaning and inspection.

By analyzing the current map, the following sources of waste were identified in the production system:

- High levels of inventory of parts and semi-finished products, due to the instability of demand and lack of inventory control;
- Pushed production and lack of adequate control and scheduling, contributing to the increase in inventory;
- Delays in delivery of parts to the assembly line, causing delays, stops, and anticipation of production;
- Disorganized layout causing accumulation of materials, long distances to be traveled, loss of parts, and difficulty of moving people and materials between the assembly areas;
- Operations that are craft-like, causing assembly errors, rework, and lack of skilled labor due to the diversity of options available for each product;
- High setup times, large amount of parts, and lack of quality throughout the assembly process.

4.3 Future State Map and Proposed Improvements

With the completion of the current state map, and the identification of its waste, the preparation of the future state map for the chassis and the semi-trailer was begun, leading to the following suggested improvements:

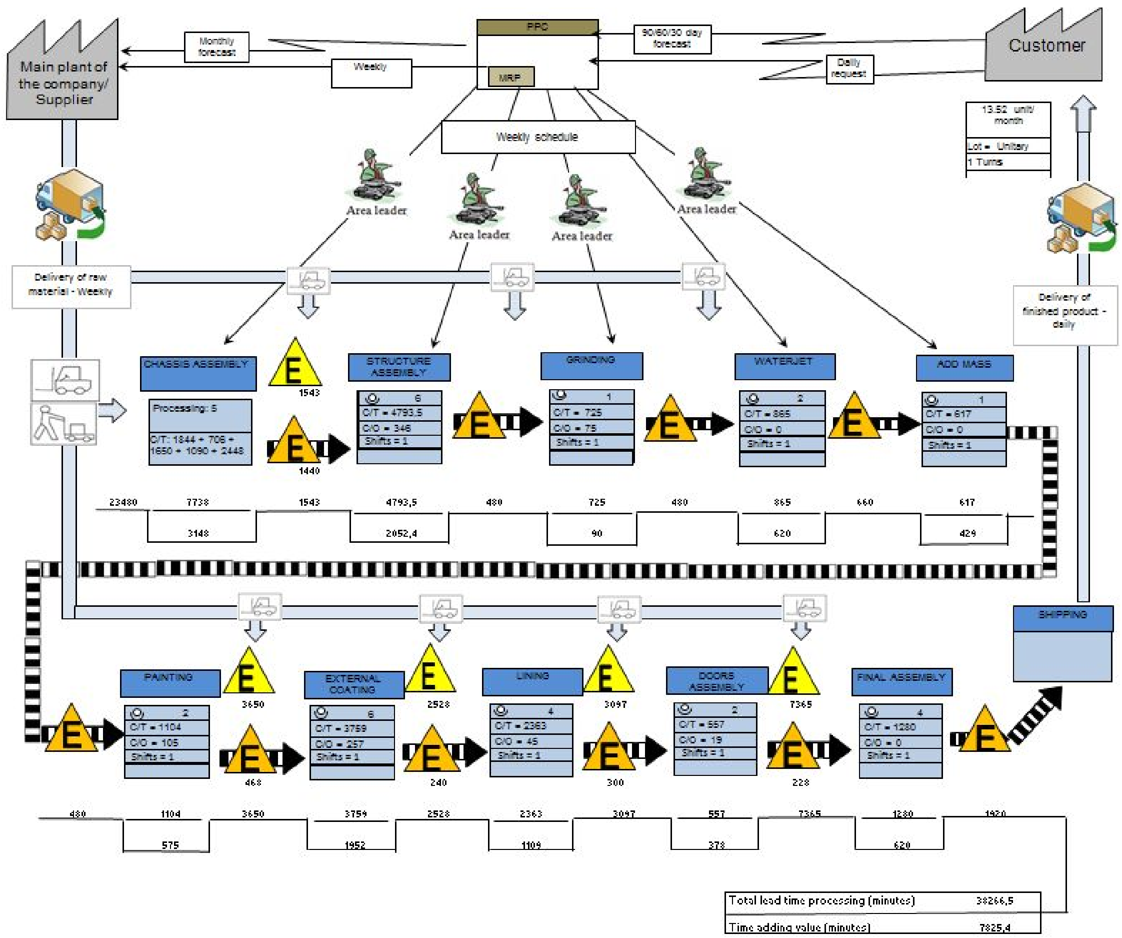

Figure 3. Current state map of the semi-trailer.

- Reduced variation in optional inventory (commercial items), standardizing the available models;
- Standardization of parts manufactured in the company, without influencing the optional sizes offered to the customer;
- Reduction in the quantity and increase in frequency of supply of parts and sub-assemblies to the assembly line, using transport and storage devices, reducing inventories and increasing the turnover of parts;
- Processing along a continuous and single stream;
- Production schedule is informed to the chassis assembly operation and the assembly of the structure over the chassis. In subsequent operations programming follows a FIFO (First In First Out) sequence;
- Reduction in handling time between assembly areas because there is no need for the product to move so often in parallel assembly areas;
- Development of devices for positioning and assembling parts, ensuring speed and quality of operations;
- Development of devices to align the chassis and the metal frame over the chassis at each area change, reducing the setup time in each operation;
- Formation of assembly cells to eliminate unnecessary movements, reducing waiting, setup and lead times;
- Changes in layout and the location of parts and materials inventory;
- Cleanliness, organization and identification of parts and assembly equipment;
- Standardization of drawings, assembly procedures, and conducting employee training;
- Structuring quality control, preventive maintenance, 5S, and continuous improvement.

From these proposed improvements, future state maps for the chassis (Figure 4) and the semi-trailer (Figure 5) were prepared.

In order to achieve the future state maps for the product considered, the following activities were carried out: (a) training the staff involved with the changes, (b) change in layout, (c) cleaning and organizing the assembly line, (d) planning the warehouse for managing commercial products and items produced at the company's main manufacturing plant, (e) labeling of materials, (f) delimiting and highlighting sectors and circulation areas, (g) installation of lifts for assembly areas, (h) reduction of setup times of various operations.

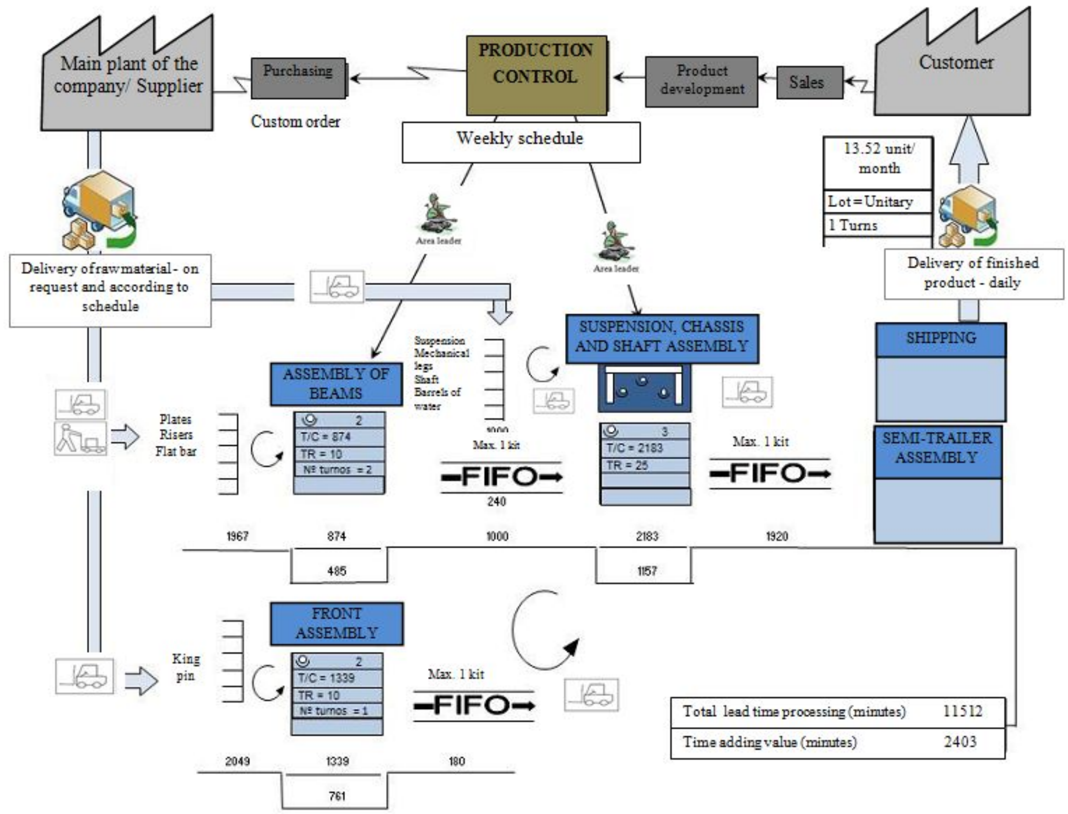

Figure 4. Future state map of the chassis.

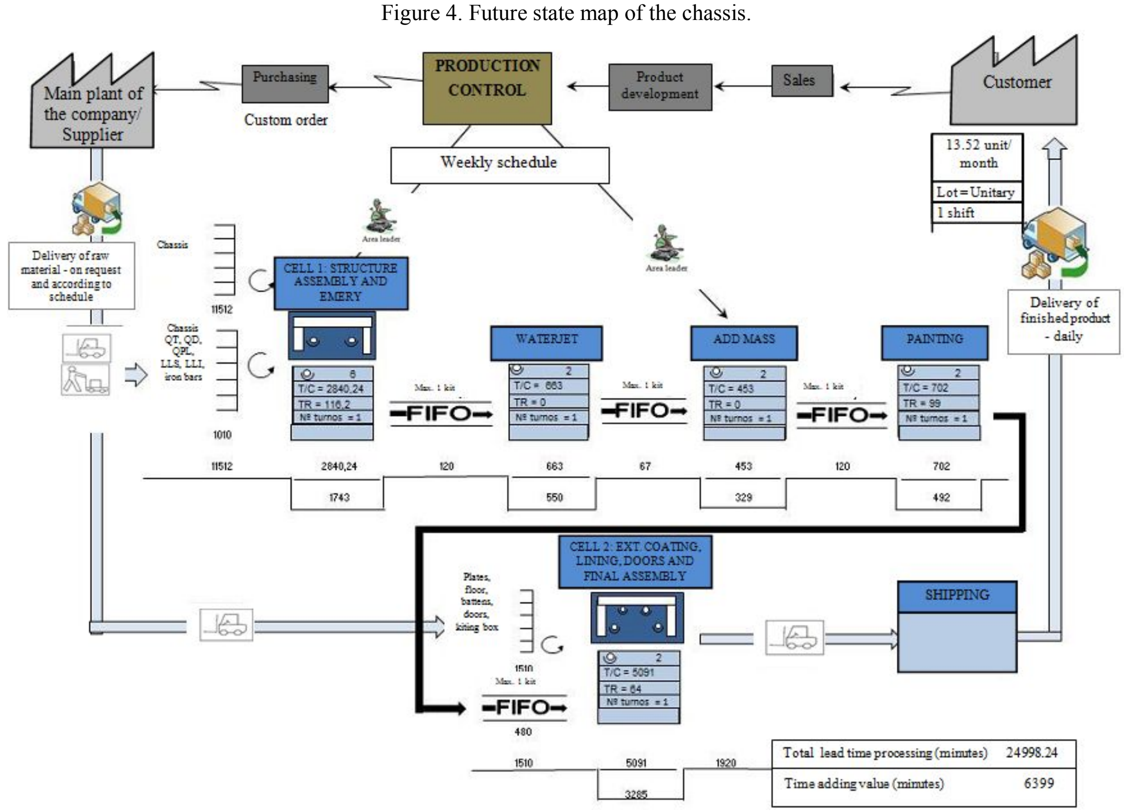

Figure 5. Future state map of the semi-trailer.

One example of the use of lifts in an assembly area of a semi-trailer is shown in Figure 6. In the previous assembly procedure of the semi-trailer there was the need to carry many wooden trestles and boards for assembling the external scaffolding (Figure 6a). After completing the assembly operations, it was necessary to disassemble everything, and reassemble again for the next product, and this generated much non-value added time and effort.

In order to solve this problem, independent elevators were developed, positioned on each side of the semi-trailer (Figure 6b). On the elevator platform, connectors for the air hoses were adapted, avoiding accumulation of hoses on the floor. The platform has the necessary width for allowing the movement of welding equipment, avoiding loss of time to place the device on the platform every new assembly. In addition, the platform height may be raised to the height of the operator.

(a) (b)

Figure 6. The assembly area before the installation of lifts is shown in (a), whereas the lifts are shown in (b).

5. Results Obtained

With the partial implementation of the future state maps of the chassis and semi-trailer, some results have been achieved in eliminating waste, improving quality of products and processes, reducing costs and reducing the product lead time, as shown in Table 1.

Table 1. Results obtained with the partial implementation of the suggested improvements.

Problem	Results Obtained
Large amount of raw materials	45% reduction in raw material inventory
Long product lead time	38% reduction in product lead time
Long movement and transport times of materials and products	73% reduction in distance traveled
	51% reduction in the time to transport materials and products
Long time for preparing the assembly area, jigs, and pieces of equipment	86% reduction in the time for preparing the assembly area
Long operation waiting times	65% reduction in the operation waiting times
Long time for positioning the parts and subassemblies	33% reduction in the time for positioning parts and subassemblies
Long processing times	12% reduction in the processing times
Non-conformances in final inspection	83% reduction in the non-conformances recorded in the final inspection

This reduction in waste was not fully completed as proposed in the future map, since some proposals for improvements were not fully implemented, while others have not yet been implemented due to strategic decisions by the company, lack of resources, and limited time.

6. Difficulties Encountered

Some difficulties were encountered throughout this work, and some of them were the following:

- Difficulty in applying the lean philosophy in the production environment of the company (ETO), since the demand is not predictable;
- Mapping of custom products, which have a lot of parts and subassemblies, resulting in unique products for each application;
- High variety of products within the same product family;
- Difficulty in developing jigs and devices that facilitate the assembly of any product variation;
- Craft-like operations;
- Inefficient production scheduling;
- Lack of knowledge and significant resistance of employees to apply concepts related to Lean Manufacturing.

7. CONCLUSIONS

This paper proposes the use of Value Stream Mapping (VSM) [4,5,11] in a manufacturer of custom products (ETO), with the aim of identifying the sources of waste in its production system. The current state map was prepared analyzing the door-to-door value stream of the assembly line of the semi-trailer. And the future state map was drawn after identifying the different wastes in the current state, proposing significant improvements to the assembly line in order to reduce or eliminate waste.

Despite the high variety of materials and options offered to the customer, it is inferred that, in order to add value to the ETO products, it was not necessary to draw a large amount of maps, which would be a difficult task, and it could impair the visibility of the value stream. The procedure used was to choose a product family that moved through similar processing steps and use common resources along the value-adding process, being suitable for the application of the lean philosophy. In addition to these reasons, the chosen product family is strategic the company considered.

The main results of this research were: 45% reduction in storage time of raw material, 38% reduction in product lead time, 73% reduction in distance traveled, 51% reduction in time for transporting materials and products, 86% reduction in preparation time of the assembly area, 65% reduction in waiting time, 33% reduction in the time of placement of parts and subassemblies, 12% reduction in product processing time, and 83% reduction in recorded non-conformances. These results show the potential application of the concepts of lean manufacturing in ETO environments.

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REFERENCES

[1] J. C. Chen, C.-H. Cheng and P. B. Huang: "Supply Chain Management with Lean Production and RFID Application: A Case Study", Expert Systems with Applications, Vol. 40, pp. 3389–3397, 2013

[2] S.R.L. Pires: "Strategic Manufacturing Management ", Editora UNIMEP, 1995 (in Portuguese).

[3] D.F. Tubino: "Production Planning and Control: Theory and Practice", 1st ed., São Paulo: Atlas, 2007 (in Portuguese).

[4] M. Rother and J. Shook: "Learning to See", Lean Enterprise Institute, 1999.

[5] J. C. Chen, Y. Li and B. D. Shady: "From Value Stream Mapping Toward a Lean/Sigma Continuous Improvement Process: an Industrial Case Study", International Journal of Production Research, Vol. 48, No. 4, pp. 1069–1086, 2010

[6] R.R. Nazareno, L.C. Silva, A.F. Rentes: "Value Stream Mapping for Products with a Wide Range of Parts", 23rd Encontro Nacional de Engenharia de Produção – ENEGEP – Ouro Preto, Brazil, 22 to 24 October 2003 (in Portuguese).

[7] J.P. Womack and D.T. Jones: "Lean Thinking", Free Press, 2003.

[8] T. Ohno: "Toyota Production System: Beyond Large-Scale Production", Productivity Press, 1988.

[9] S. Shingo: " Non-Stock Production: The Shingo System of Continuous Improvement", Productivity Press, 2006.

[10] N. Slack, S. Chambers and R. Johnston: "Operations Management", 6th ed., Financial Times/Prentice Hall, 2009.

[11] S. Vinod, M. Somanaathan and K. R. Arvind: "Development of Value Stream Map for Achieving Leanness in a Manufacturing Organization", Journal of Engineering, Design and Technology, Vol. 11, No. 2, pp. 129–141, 2013