INVESTIGATING THE BARRIERS AND POTENTIALS OF APPLYING LEAN PRINCIPLES IN THE EGYPTIAN CONSTRUCTION INDUSTRY: AN ACTION RESEARCH APPROACH FOR APPLYING VALUE STREAM MAPPING

Ahmed Hamdy[1], Mohamed R. Ali[1], and Omar H. El Anwar[2, 3]
[1] Graduate Research Assistant, Structural Engineering Department, Cairo University, Egypt
[2] Lecturer of Construction Management at Cairo University, Egypt
[3] oh.elanwar@cu.edu.eg

Abstract: Lean construction principles are not yet well known to the Egyptian construction industry. Introducing lean principles is often reported to be faced with considerable resistance to change. In this research, the authors follow the action research methodology to apply some lean construction tools on an ongoing construction operation in Giza, Egypt. The operation at hand is the manufacturing and installation of steel fences and gates in a new residential complex. The operation involves material procurement, off site manufacturing, off-site finishing, transportation, installation and on-site finishing activities. The investigated sample includes four steel workshops, two painting workshops, and an on-site installation crew. The lean construction tool applied is value stream mapping. The main challenges faced by this operation are costumer's demand fluctuation and a resisting crafts-men culture. The customer demand unforeseeable fluctuations (1) affect the subcontractors' ability to order large quantities of materials from the suppliers with sufficient lead-time; (2) results in an unstable cash flow to the subcontractors; and (3) generates an unbalanced workload distribution among the on-site and off-site crews. The supervisors of the workshops and on-site crews attempted to adopt some operation plans that according to their experience is best suited for mass production. These plans incorporated many wastes and needed significant modifications to respond in time to the fluctuation of the customer's demands. Hence, value stream mapping is investigated as a possible solution to the aforementioned challenges. The authors succeeded to change and improve the operations of some participants, cutting the response time to customer demands by half in some cases. However, the authors failed with other participants, mainly because the crafts-men and their supervisors showed a significant resistance to change their operations design. This paper describes the lean construction initiatives, their results, and the main barriers and potentials identified through this research project.

1 INTRODUCTION

Lean construction seeks to maximize the generation of customer value by driving out all forms of waste, ensuring 'right first time' quality, reducing timescales and minimizing cost (Koskela 2004). Lean thinking offers an alternative method of project management to the construction industry. Lean construction is more efficient on complex projects with high uncertainties as well as fast track projects. There are several differences between the lean construction management approach and traditional project management. Following are some of these differences (Sicat 2012):

- The role of control in lean construction is to maintain a reliable flow, in contrary to the traditional after-the-fact variance detection,

- Lean management focuses on the whole process to maximize value rather than optimizing each activity in isolation,
- Lean construction utilizes a pull planning approach, and
- Lean construction focuses on reducing variations at an early stage.

A key principle of lean thinking is the identification and systematic elimination of process waste at every stage of the value chain (Koskela 2004). Generally, the work done in any process to provide a product or service is classified as one of three activity types: (1) value adding; (2) essential but non-value adding, which is only needed because of current practice constraints; and (3) non-value adding, which is pure waste and should be eliminated immediately.

To identify the level and type of waste within a process, eight categories of waste can be defined, as follows (Koskela 2004):

1. **Transportation**, unnecessary movement and handling of goods,
2. **Inventory**, poor planning and control of inventory leading to excessive stocks,
3. **Motion**, excessive or unnecessary movement of people, and poor layout of tools,
4. **Waiting,** idle resources (people and/or plant) waiting for information or other resources,
5. **Over-production**, producing more than is required and/or ahead of time,
6. **Over-processing**, double handling of items, materials, etc.,
7. **Defects**, non-‘right first time’ quality requiring rework, and introducing extra time, and
8. **Skill misuse**, wasting or not effectively tapping into available skills, expertise, and knowledge.

Lean construction principles and applications are new to the Egyptian construction industry. A recent survey conducted in Egypt showed a current lack of awareness of lean construction, where 55% of the respondents are almost not aware of lean construction and 40% were at best only moderately aware (Gamal 2013). On the other hand, there is a great potential for adopting lean principles, where 55% of the respondents reported high potentials to use new management techniques.

Value stream mapping (VSM) is one of the essential lean practices, which has resulted in significant improvements in the manufacturing, military, and healthcare sectors, and has recently attracted interest in the software engineering community (Khurum 2014). VSM visualizes the entire production process throughout the enterprise. It represents both the materials and information flows. As defined by Rother (1999), value stream is the collection of all the activities required to bring a group of products through the main flow from raw materials to the end user. Furthermore, VSM enables documenting the relations between the activities and controls.

There are a number of reported attempts to leverage value stream mapping to improve construction processes. For instance, Roberto Arbulu et al. (2003) presented a case study within which VSM was used to re-engineer the construction supply chain for pipe supports used in power plants. Haitao Yu et al. (2009) developed a systematic approach that is based on VSM to analyze and formulate a lean production model for the home building industry. Chein-Ho Ko, and Shun-Chi Li (2014) used VSM to enhance submittal reviews for public construction projects by proposing a pull system instead of the traditional push system. Rosenbaum et al. (2014) used VSM to simultaneously assess production and environmental wastes over the execution stage of construction projects, and presented a case study of a reinforced concrete hospital in order to improve its production and environmental performance. Banawi and Belic (2014) used VSM as part of their delay analysis framework, in order to improve exterior construction processes. They applied their model to a case study of 53 residential units. Frandson et al. (2012) used VSM as one of the documentation tools in their study to analyze the workflow of complex projects.

In this paper, we attempt to use VSM to model and improve a number of processes in steel and painting workshops for manufacturing and painting steel products, including metal fences and gates. The studied construction operation involves material procurement, off-site manufacturing, off-site finishing, transportation, and on-site installation and finishing activities. The motivation to apply VSM to this operation was the reported long response times to the customer needs. Due the nature of the case study project, the customer demand was unpredictable and fluctuating. This unpredictable demand affected the subcontractors' ability to order large quantities of materials from the suppliers with sufficient lead-time, while the subcontractor's mass production approach required large batches of materials to reduce the products unit costs. The demand fluctuations also resulted in an unstable cash flow to the subcontractor and generated an unbalanced workload distribution among the on-site and off-site crews. The following section describes the adopted research methodology to address this challenge.

2 RESEARCH METHODOLOGY

The studied project in this paper is a residential compound developed in Giza, Egypt. This paper focuses on the operation of manufacturing and painting steel products, which include side chain linked fence panels, back fence panels, and metal gates. The subcontractor responsible for this operation is Rawasy. The objective of this study is to propose and implement operational improvements that would reduce the subcontractor's response time to meet the developer's needs.

In order to achieve this objective, this research project adopted a four-phased action research methodology, which starts by developing a current state VSM for these processes that depicts the supply of raw materials, manufacturing processes in steel workshops, painting processes in painting workshops, and assembly on site. Second, the wastes within these processes are identified, and the process performance in terms of response time, cycle time, and inventory is reported. Third, a future state VSM is proposed and applied in order to eliminate processes wastes. Finally, the research findings are analyzed and discussed.

Table 1 shows the components and symbols of the VSM models developed to analyze this operation. The following subsections present the developed current and future state maps.

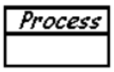
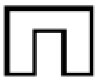
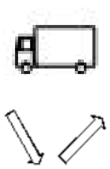
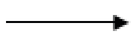
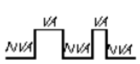
3 CURRENT STATE VSM

The objective of the current state VSM is to represent the actual state of the studied operation. This includes identifying and assessing the constituent processes/task, inventories between these tasks, crews and equipment, raw and manufactured materials transportation, and information flows. As shown in Figure 1, the current state VSM represents three lines of production, which are required to produce three product families; fencing side chain linked panels, fencing back panels, and pairs of steel gates. The production of each product family is sequentially conducted at three sites; the steel workshops, painting workshops, and on-site assembly locations. The production is distributed among four steel workshops, two painting workshops, and one on-site assembly team. Further, there are four suppliers and vendors providing the needed materials to the workshops and the on-site team. These materials include steel, wire mesh, accessories, and painting materials.

The customer sends monthly installation schedules to the subcontractor, who in turn uses these schedules to determine the required response time to meet the client's needs. Accordingly, the subcontractor translates those schedules into weekly manufacturing schedules to the suppliers, workshops, and on-site assembly team. The steel workshops start the operation by conducting the three tasks of cutting, assembling, and mesh finishing, as shown in Figure 1.

These products are then shipped to the painting workshops, which conduct five tasks, including stocking, sanding, first coat application, second coat application, and wrapping. The finished products are then shipped to the work site for installation, finishing, and inspection. The current state map shows the cycle times of each task and the inventory durations as well as the response time as the key performance indicator for each of the three product families. For example, the batch size for the side chain linked panels (the first product family) is 100 panels and manufacturing response time is 8.1 working days. These achieved response times could not meet the customer's needs. Accordingly, process improvements were required to the current state (for instance, as represented by the two Kaizen Bursts in the first product family). The proposed and implemented improvements are reported in the following subsection; the future state VSM.

Table1: VSM Operation Components and Symbols

Symbol	Description
	Customer/Supplier icon: The customer for this operation is the developer of the residential compound. Suppliers are the steel suppliers, wire mesh vendors, steel accessories vendor and paint vendor.
	Dedicated Process flow Icon: Represents a process/task conducted by (Rawasy) with a continuous, internal fixed flow.
	Work cell Icon: indicates that multiple processes are integrated in a manufacturing work cell.
	Inventory Icons: Represents inventory between two processes/tasks.
	Shipments Icon: Represents movement of raw materials from suppliers to the receiving dock/s of the subcontractor workshops, or the movement of finished goods from the shipping dock/s of the workshops to the customer.
	Connector: Represents non-electronic information a flow.
	Push Arrow Icon: Represents the “pushing” of material from one process to the next.
	Spark Connector: Electronic information flow
	Supermarket Icon: an inventory “supermarket” (Kanban stock point)
	Material Pull Icon: Supermarkets connect to downstream processes with this "Pull" icon that indicates physical removal.
	Kaizen Burst Icon: Highlight improvement needs and planned kaizen workshops for specific processes that are critical to achieving the operation Future State Map.
	Timeline Icon: Shows the value added times (cycle times) and non-value added (wait) times.

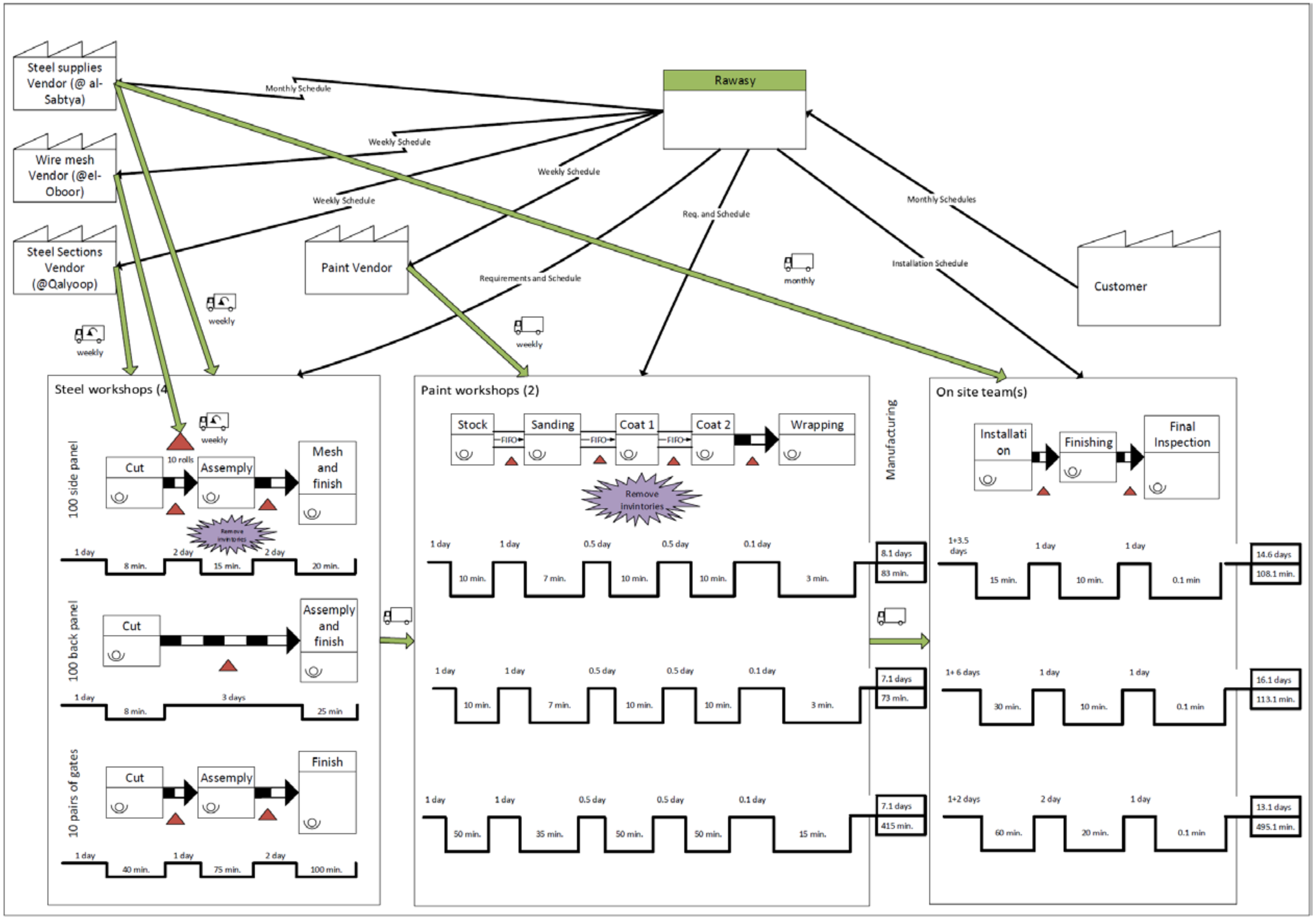


Figure 1: Current State VSM

4 FUTURE STATE VSM

The use of value stream mapping enables visualizing the materials and information flows and identifying sources of wastes. Accordingly, a series of process improvements were proposed and implemented in the three product families, as shown in the future state VSM in Figure 2. The developed future state VSM was proposed to half of the workshops (i.e. two steel workshops and one paint workshop), whereas the remaining workshops continued to adopt the current state VSM. All the changes in the manufacturing process were implemented and tested in two consecutive batches in these workshops.

For space considerations, this subsection will discuss the details of the improvements implemented for the side chain linked panel (the first product family), whereas the improvements in all product families are demonstrated in the future state VSM in Figure 2. For improving the response time for producing the side chain linked panel, five improvements were made based on analyzing the shortcomings of the current state VSM, as follows:

- Decrease the batch size of the side panels from 100 to 35 panels,
- Combine assembly and mesh production processes in the steel workshops into one work cell,
- Combine the stocking and sanding processes in the painting workshops into one work cell,
- Combine the two coating processes in the painting workshops into one work cell, and
- Eliminate the wrapping process in the painting workshops.

Current processes adopt a mass production approach characterized by production wastes, such as large work-in-progress inventories, which in turn result in long response times. The first change is designed to gradually move from the current mass production approach as close as possible to a one-piece flow approach in order to minimize the production wastes associated with mass production. To this end, the production batch size was reduced from 100 panels to 35 panels, which is the minimum batch size that assures no waste in both material and transportation.

In the current state, each process in the steel workshop used to process the 100 panels before moving them all to the following process, which delayed the production and created large in-process inventories. In the improved future state, the assembly and mesh production are combined into a single work cell, eliminating their in-process inventory. Further, a pull system is implemented between the processes in the steel workshop (as indicated in Figure 2), where each processed panel is moved right away to next process to minimize the lead time and in-process inventories. These modifications decrease the inventory time and inventory amount significantly, where the inventory was reduced from 5 days for entire 100 panels to 2.9 days for only 35 panels.

Similar improvements were implemented in the painting workshop, where the first four processes are combined into two work cells, as shown in the future state VSM, eliminating in-process inventories. A supermarket pull system was also introduced between these two work cells with an 80% threshold. Furthermore, the wrapping activity was removed, because it added no value to the customer. These changes decreased the inventory time and amount in the painting workshops from 3.1 days per 100 panels to 1.2 days per 35 panels with almost no additional cost.

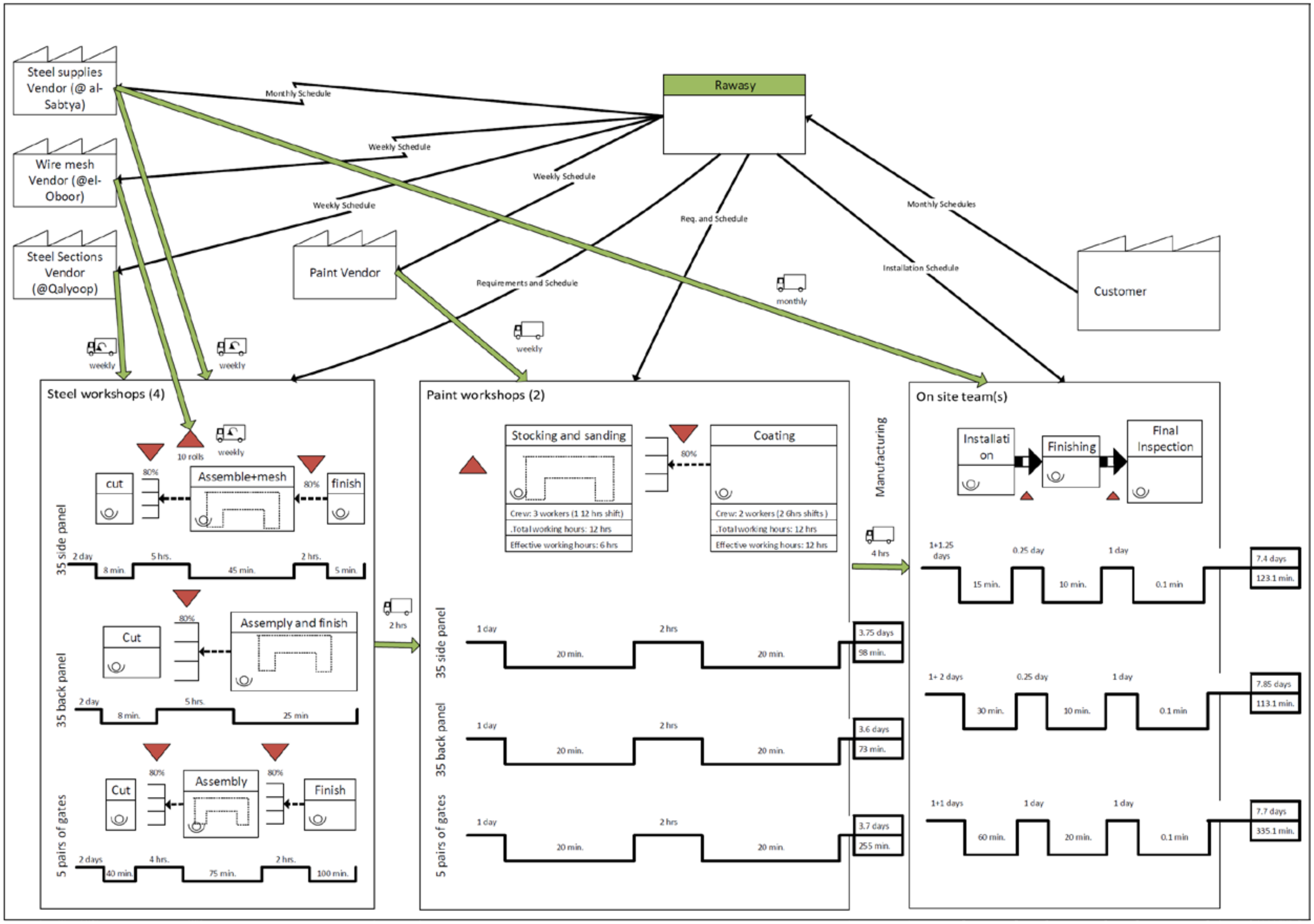


Figure 2: Future State VSM

5 DISCUSSION

In this study, the response time corresponds to the lead-time of producing a batch of the fence panels and gates. As shown in Figure 3, the abovementioned improvements resulted in reducing the response time by about 50% in the three product families, as follows:

- The side panels: The response time decreased from 8.1 days to 3.9 days,
- The back panels: The response time decreased from 7.1 days to 3.6 days, and
- The gates: The response time decreased from 7.1 days to 3.7 days.

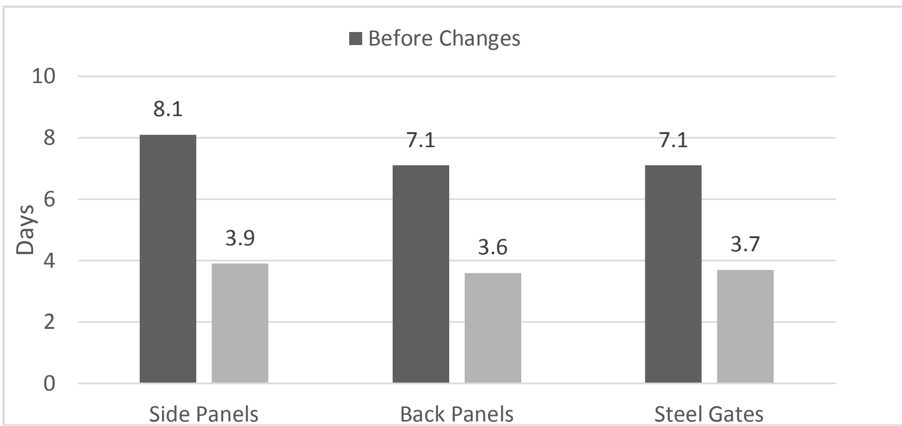


Figure 3. Response time before and after the improvements

The reported improved performance was achieved in one steel workshop and one painting workshop. However, the other steel workshop showed significant resistance to change as will be discussed in this section. The following paragraphs discuss (1) success factors; (2) observed barriers; and (3) reported impacts on other metrics.

First, based on the researchers' observations, there were three main factors of success; (1) setting clear goals and cascading them throughout the subcontractor's organization and to the workshops; (2) the willingness of the crews to accept change, which represents a learning culture; and (3) the nature of proposed changes, which was characterized by their low cost and no need for advanced technologies. Regarding the first factor, in the case study at hand, it was clear to the subcontractor's management that reducing the response time is a top priority. Accordingly, various processes needed to be changed to fit this organizational goal, as discussed in the previous section. As for the second factor, the two workshops that successfully adopted the proposed improvements were both characterized by a very skillful foreman and a crew of semi-skilled young workers, who showed complete obedience to their supervisor. For these two crews, the changes in the processes were designed and verified with their foremen's aid and consultancy, and the changes were then implemented with minimal resistance from the workers. Third, the proposed process improvements did not come at a noticeable cost and did not need the use of advance technology. This is an important aspect to facilitate the adoption of such changes in a relatively primitive and cost-conservative working environment.

The main observed barrier to implementing the proposed improvements was a culture of resistance to change, as experienced with the other steel workshop. It is noteworthy that the resisting crew is the one with the most skilled workers, which might explain why they showed the least cooperation and the most resistance to any change in their usual processes, especially that these changes were proposed from an outsider to the crew.

The implemented process improvements affected two other metrics; the products quality and manufacturing time per piece. First, the products quality generally improved. For instance, in the traditional mass production approach, defects might not be detected until a complete batch of 100 panels is produced. In the proposed approach, defects are identified and addressed early in the value stream. On the other hand, the manufacturing time per piece (unit lead-time) showed an increase by an average of 27% in the proposed approach, as follows (and as shown by Figure 4):

- Regarding the side panels: manufacturing time per piece increased from .65 hours to .89 hours,
- Regarding the back panels: manufacturing time per piece increased from .57 hours to .8 hours, and
- Regarding the gates: manufacturing time per piece increased from 5.7 hours to 5.9 hours.

Figure 4. Manufacturing time per piece before and after the changes

From the management perspective, the increase in the overall production time is an acceptable cost to the decrease in the response time in the operation at hand. This increase might be attributed to the learning curve effect, where the modified processes were only tested on two consecutive batches.

6 CONCLUSIONS

This paper presented an action research project, which involved designing, implementing, and testing an improved construction operation process using value stream mapping. The studied operation involved the production of three product families of fence panels and metal gates. A current state VSM was first developed based on actual observations. Second, sources of waste were identified and process improvements were proposed. Third, a future state VSM was developed to encompass and implement these changes. Fourth, the improved processes were evaluated. This research project represents the first attempt to apply value stream mapping to the Egyptian construction industry.

The results showed the superior performance of the improved process in terms of response time to customer’s needs (which is the main target of this research) and the products quality. On the other hand, the manufacturing time per piece showed an increase, especially in the fence panels production. It was observed that with a clear delineation of organizational goals and discussing them in a respectable and involving manner to the working crews, a valuable enhancement is achieved to the whole operation and to the relations among its members. It is noteworthy that most of the value added is achieved through the use of the most simple and inexpensive changes. However, a resisting culture to change remains a main barrier to such improvements.

7 ACKNOWLEDGEMENT

The authors would like to acknowledge the support of the workshops foremen and their crews in designing and testing the proposed changes. The authors would like to express their gratitude to Mr. Abd Al-Hakeem Al-Soory, Mr. Magdy Hanna, and Mr. Hany Mahmoud.

8 REFERENCES

Abdulmalek FA, Rajgopal J. 2007. Analyzing the benefits of lean manufacturing and value stream mapping via simulation a process sector case study. *Int. J. Prod. Econ*. **107**(1):223–236.

Al-Sudairi AA. 2007. Evaluating the effect of construction process characteristics to the applicability of lean principles. *Constr. Innov*. **7**(1):99–121.

Banawi, A. and Bilec, M. 2014. Applying Lean, Green, and Six-Sigma Framework to Improve Exterior Construction Process in Saudi Arabia. *Journal of Construction Engineering and Project Management*, 10.6106/JCEPM.2014.4.2.012, 12-22.

Chien-Ho Ko, Sun-Chi Li .2014. Enhancing submittal review and construction inspection in public projects. *Automation in Construction*. **44**: 33-46

Frandson, A. and Alves, T. 2012. Analysis of the Work Flow in a Complex Project. *Construction Research Congress 2012*: pp. 268-277.

Gamal M. 2013. Improving Project Performance Using Lean Construction in Egypt: A Proposed Framework. M.Sc. thesis, School of Sciences and Engineering, The American University in Cairo, Egypt.

Garg D, Desmukh SG. 1999. JIT purchasing "literature review and implications for Indian industry". *Prod. Plan Control*, **10**(3):276–285.

Gopakumar B, Sundaram S, Shengyong Wang, Koli S, Srihari K. 2008. A simulation based approach for dock allocation in a food distribution center. *Simulation Conference 2008*., **10**: 2750–2755.

Grewal CS, Sareen KK. 2006. Development of model for lean improvement: a case study of automobile industry. *Ind. Eng. J. 35* (**5**):24–27.

Haitao Yu, Tarry Tweed, Mohamed Al-Hussein, Reza Nasseri 2009. Development of Lean Model for House Construction Using Value Stream Mapping. *J. Constr. Eng. Manage.*, **135**(8), 782–790.

Hsiao FH, Xu SD, Lin CY, Tsai ZR. 2008. Robustness design of fuzzy control for nonlinear multiple time-delay large-scale systems via neural-network-based approach. *IEEE Trans. Syst. Man.* **38**(1):244–251.

Huang CC, Liu SH. 2005. A novel approach to lean control for Taiwan funded enterprises in mainland China. *Int. J. Prod. Res.* **43**(12):2553– 2577.

Khurum M, Petersen K, Gorschek T. 2014. Extending value stream mapping through waste definition beyond customer perspective. *J. Softw. Evol. and Proc.2014*, **26**: 1074–1105.

Koskela L. 2004. Making Do – the eighth category of waste. IGLC 12, Elsinore, Denmark.

McDonald T, Van AEM, Rentes AF. 2002. Utilizing simulation to Enhance Value Stream Mapping a Manufacturing Case Application. *Int. J. Logistics Research Applications*, **5**(2):213–232.

Roberto Arbulua, Iris Tommeleinb, Kenneth Walshc, James Hershauerd. 2003. Value stream analysis of a re-engineered construction supply chain. *Building Research and Information*, **31**(2): 161-171

Rosenbaum, S., Toledo, M., and González, V. 2014. Improving Environmental and Production Performance in Construction Projects Using Value-Stream Mapping: Case Study. *J. Constr. Eng. Manage*., **140**(2), 04013045.

Rother M, Shook J. 1999. Learning to see, "value stream mapping to add value and eliminate MUDA". The Lean Enterprise Institute, Brookline, MA.

Sicat, S. 2012. The Lean Approach. Faithful Gould. Retrieved from http://www.fgould.com/north-america/articles/lean-approach/ last accessed on 16 February 2015.

Singh B, Surrender K. 2010. Value stream mapping: literature review and implications for Indian industry. *Int. J. Adv. Manuf. Technol.* (2011), (**53**):799–809.

Zheng Li, Xiao Jing, Hou F, Feng Wei, Li. Na. 2008. Cycle time reduction in assembly and test manufacturing factories A KPI driven methodology. *IEEE International Conference*:1234–1238.