Lean-based diagnosis and improvement for offsite construction factory manufacturing facilities

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Abstract –

In current practice, manufacturing companies have daily outputs that are expected to meet the company's targeted production level. In construction, there is an increasing trend toward buildings being manufactured off-site rather than through traditional stick-built methods on site. This trend has created a demand for construction companies to subcontract work and to seek new efficiencies in their operations. In reference to the production line, regardless of how hard an employee works, there are certain limitations that impede a worker's productivity. To reduce or remove these limitations, many companies have begun to implement Lean methodologies in order to reduce waste in the production process. However, before improving the productivity of the production line, an analysis of the entire manufacturing process must be conducted. This paper introduces the methodologies that can be used to evaluate the production process on both weekly and monthly bases to ensure a consistent productivity rate; this research can be implemented in a variety of manufacturing settings. As a case study, it is implemented at Fortis LGS Structures Inc., an Edmonton-based offsite construction company that produces light gauge steel wall panels; Fortis has been working closely with researchers at the University of Alberta to identify areas of waste and improvements which can be implemented to help increase the productivity of future projects.

Keywords –

Offsite construction; Light gauge steel; Modular construction; Lean manufacturing; Waste elimination.

1 Introduction

Modular construction derives its root from the manufacturing industry: entire stick-built construction projects are broken down into components that are easy to manufacture on factory production lines. Various concepts and knowledge have been borrowed from the manufacturing industry and implemented into modular construction over the past decades. Different levels of automation can be observed in the construction field to achieve high efficiency. Bock (2015) provides a review of the past and current tendencies in construction automation. Despite some technology limits, automation has been seen and proven in various construction activities: robotic infrastructure production; robotic transportation systems; general manufacturing industry, and so on. A concept of building component manufacturing (BCM) is introduced in Bock's work, which refers to a robotic industrialization trend based on concrete, brickwork, wood, and steel as building materials and large-scale prefabrication to deliver complex building components and products. Similar review and survey is also provided by Everett and Slocum (1994) and Vaha et al. (2013). For onsite construction, robotic-oriented thinking is also being targeted to reduce human components and errors in the process, such as a steel beam automatic assembly system (Chu et al. 2013; Jung et al. 2013).

Apart from the academic value of industrialization in construction, there is also an economical potential behind this trend, particularly in areas where construction labor is expensive and the outdoor construction environment is not comfortable due to the harsh weather. As an example, modular construction is being implemented for industrial construction projects in remote areas in Canada (Lei et al. 2013); and in the residential and commercial industry, the industrialization concept is being used to manufacture wall panels or modules for multi-story buildings/single-family houses (Yu et al. 2013; Sang et al. 2011). Wood and light gauge steel are two common materials used in this area. However, compared to European practice in modularization, the North American market is smaller due to the low level of acceptance of this method by the market and the technology readiness in North America. Some leading technologies in modular construction can be seen in Europe, such as WEINMANN and Randek machinery, which are attempting to maximize the usage of machinery in factory construction. To fully maximize the potential of machinery, other technologies/knowledge are required (particularly as the scale of production increases, the integration between different systems/technologies becomes necessary). "Industry 4.0" originates from the strategic project by the German government and was first used in 2011, which emphasizes a number of integrated automation, data exchange, and manufacturing technologies. A Cyber-Physical System (CPS) concept was developed to describe transformative theologies for managing interconnected systems between physical assets and capabilities (Brettel et al. 2014; Lee et al. 2015). On a more detailed level, the direct implementation of information-driven systems in modular construction is observed. For example, Altaf et al. (2015) introduce an RFID-based online simulation system for simulating a wood wall-panel production line. CAD-based production has also become a trend to achieve the communication between the design and the machines. In addition, industrial engineering concepts are a valuable contribution to modular construction. Various Lean-based improvements are being carried out in the construction industry. Fortis LGS Structures Inc. is a light gauge steel modular construction company located in Edmonton, Alberta, Canada; over the past decade, Fortis has developed its own method of wall panel production and unique structure detail designs. Their projects mainly focus on residential and commercial buildings. In recent years, Fortis has been seeking higher efficiency and a more cost-effective method in delivering quality products to the construction market, and bottlenecks have been noticed in the production causing ineffectiveness and waste. This paper introduces an initiative which began in 2015, marking the beginning of the company's industrial engineering journey, which involves the development of a method to capture and analyze the company's production line using some Lean-thinking ideas. This also leads to an implementation of a bar-code based tracking system into the factory for better material inventory and management. Case studies will be discussed in this paper to illustrate this transition.

2 Light Gauge Steel Panelization Process

Fortis LGS Structures Inc. has adopted a modular construction method for constructing their buildings using light gauge steel material. Before producing the panels in the factory, the design drawings (e.g., architecture, structure drawings, etc.) are converted into shop drawings, which can be easily understood by the workers in the factory; and the production line is divided into several stations (see Figure 1). Currently the production line consists of the four stations as follows. (1) Assembly Table: where all the raw light gauge steel materials (steel studs, headers, and footers) are sorted and assembled together in bundles and passed to the next station. (2) Framing Table: where the light gauge steel materials are put together as wall components. On this table, semi-automated machines are used to assist the workers to achieve high efficiency and reduce the human components. (3) Sheathing Table: in this case the walls are exterior walls, thus drywall is sheathed to the wall frames with automated nailing guns. (4) Panel Racks: the sheathed walls are hung on the racks for exterior finishing such as stucco or bricks. After this station is completed, the wall panels are shipped to site for onsite assembly. Washroom units are also pre-assembled with plumbing finishing in the factory before shipment (Figure 2 pictures the products).

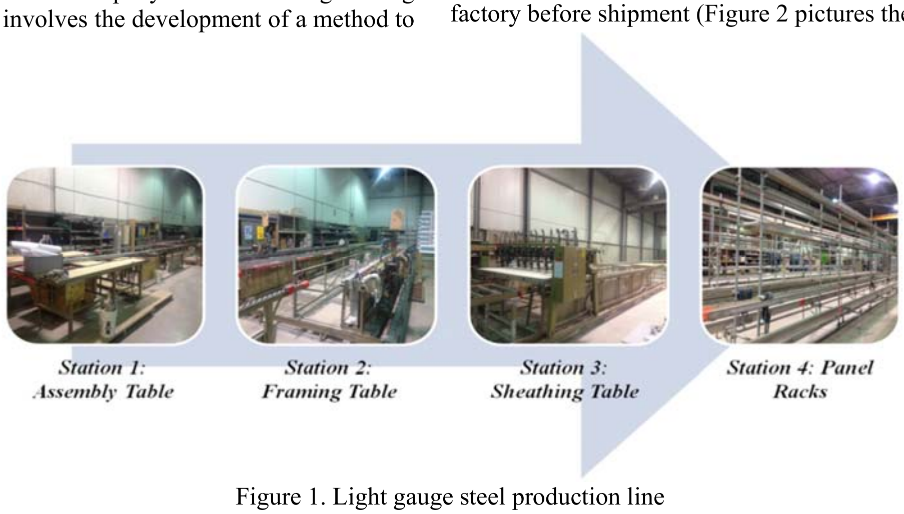


Figure 1. Light gauge steel production line

(*i*) LGS panel wall	(*ii*) Washroom unit

Figure 2. (*i*) Light gauge steel wall, and (*ii*) unit product

3 Production Line Diagnosis Approach

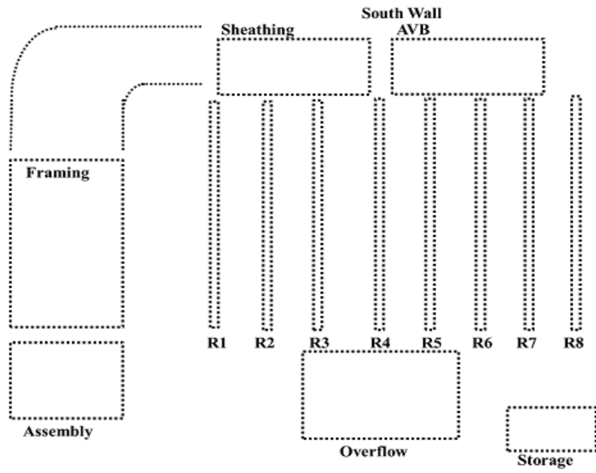
Production analysis for the current state based on the time study is the first step toward identifying/quantifying the company's existing problems. For offsite construction manufacturing—panelized or modular—there exist various approaches to achieve this. Yu et al. (2009) apply Value Stream Mapping (VSM) as the tool for current stage study based on the collected data base for house construction. Yet, the construction utilizes the stick-built methodology where the lead time between activities plays a large role on overall operation time. Shafai (2012) implements a time study for panelized manufacturing by collecting targeted work stations cycle time. The process efficiency is then studied by simulation using a regression model which is generated by statistical analysis. However, in order to achieve this, the quality of the collected data becomes critical. For factories that have limited automated data-collection systems, the procurement of accurate data for each individual operation process still poses a challenge. Considering the aforementioned issues, a less sophisticated but effective way for data-collection is used in this study. Although there is no large data set involved, the level of data collection correlates to the purpose of identifying the key issues on the current production line.

The first objective of the study is to diagnose Fortis's production line and expose the bottlenecks and potential areas for improvement. The study is carried out during a peak production period when the factory is active with a high production volume. The diagnosis procedure consists of the following steps:

- Process mapping and time study: to gather information to obtain the entire picture of the production; based on the process map, processing time is collected for each particular working station; the value stream map is created based on collected data.
- Waste identification and improvement action plan: to identify the waste in production from a high-level and detailed level; potential improvements are then proposed based on the defined wastes/bottlenecks.

3.1 Time study and process mapping

In this study, a floor process diagram is first created, as shown in Figure 3, to describe the production flow. The diagram shows the floor layout of the production facility with description. A time study is then conducted for each individual station to collect processing time. Figure 4 shows a typical time study sheet used for data collection. The key is to relate the time data with characteristics of the product being produced (e.g., dimensions of walls, number of door/window openings) and find the time distribution for each station. After the time study, the VSM is used to document, analyze, and improve the flow of information or product in a production process. However, the VSM in this study focuses on the manufacturing production flow, which is the cycle time for each work station, other than the process between different activities.



Production process order	Key material	Key tools	General crew required
Assembly	steel, clips, screws, insulation	…	3
Framing	screws	…	3
Sheathing	drywall, screws	…	3
AVB	cement, meshes	…	2
Foam (on racks)	foam	…	2
Rasping (on racks)	-	…	2
Basecoat (on racks)	cement	…	2
Primer (on racks)	-	…	2
Finish coat (on racks)	finishing material (stucco)	…	2
Loading	-	…	2

Figure 3. Process diagram and description

	A	B	C	M	N	O	P	Q	R	S	T	U	V
1	SHEPHERD`S GARDENS												
2	#	Floor	READY FOR PRODUCTION		electrical box install Dennis	Foam		Molding		FLASHING		Rasping (update Reveals)	
3				date		crew	date	crew	date	crew	date	crew	date
4		1	467-01	18-Jun-15		Omer, Tahsin	22-Jun-15	Emerson, Shanika	6-Jul-15		26-Jun-15	Victor, Jermaine	2-Jul-15
5	12	1	471-01	18-Jun-15	7-Jul-15	Aziz, Omer, Tahsin	23-Jun-15	Emerson, Shanika	6-Jul-15		25-Jun-15	Omer, Tahsin Victor, Jermaine	6/25/2015 6/30/2015
6	3	1	462-01	11-Jun-15	N/A			Forms Emerson, Shanika	6/27/2015 7/06/2015		26-Jun-15	Gersey, Andy, Francis, Andres, Joel	29-Jun-15
7	35	1	492-01	15-Jun-15	16-Jun-15	Aziz, Elex, Rob	20-Jun-15		27-Jun-15			Elex, Rob, Greg	4-Jul-15
8	5	1	464-01	22-Jun-15	22-Jun-15			Emerson, Shanika	6-Jul-15			Victor, Jermaine	4-Jul-15
9	37	1	494-01	16-Jun-15	N/A	Aziz, Elex, Rob Elex, Rob	6/19/2015 7/7/2015				26-Jun-15	Elex, Rob	7-Jul-15
10		1	519-01	22-Jun-15		Omer, Tahsin	22-Jun-15		25-Jun-15		25-Jun-15	Omer, Tahsin	26-Jun-15
11	70	1	521-01	18-Jun-15		Aziz, Omer, Tahsin	23-Jun-15		25-Jun-15		25-Jun-15	Omer, Tahsin	26-Jun-15
12	71	1	522-01	18-Jun-15		Aziz, Omer, Tahsin	23-Jun-15	Elex, Rob, Greg	3-Jul-15		25-Jun-15	Aziz,Omer,Tahsin	26-Jun-15
13	10	1	469-01	18-Jun-15					26-Jun-15		25-Jun-15	Rolando, Gersey, Andres, Andy, Francis, Amel, Louie, Shanika	30-Jun-15
14	84	2	541-02	22-Jun-15		Aziz, Elex, Rob	19-Jun-15	Emerson, Amel	5-Jul-15			Elex, Rob, Greg	24-Jun-15
15	85	2	542-02			Aziz, Elex, Rob	19-Jun-15	Emerson, Amel	5-Jul-15			Elex, Rob, Greg	25-Jun-15
16	86	2	543-02			Aziz, Elex, Rob	19-Jun-15	Emerson, Amel	5-Jul-15			Elex, Rob, Greg	25-Jun-15
17	14	1	473-01	6-Jul-15	7-Jul-15	Elex, Rob	7-Jul-15	Lorenzitto, Emerson	7-Jul-15	Lorenzitto, Emerson	7-Jul-15	Elex, Rob, Gregory	11-Jul-15
18	15	1	474-01	6-Jul-15	7-Jul-15	Elex, Rob Elex, Rob, Gregory	7/7/2015 7/11/2015	Jayson, Amel, Michael	14-Jul-15	Jayson	9-Jul-15		
19	16	1	475-01	3-Jul-15		Elex, Rob	7-Jul-15	Reagan, Rodel	7-Jul-15			Elex, Greg	9-Jul-15
20	17	1	476-01	3-Jul-15		Elex, Rob	7-Jul-15	Reagan, Rodel	7-Jul-15			Elex, Rob, Gregory Gregory	7/11/2015 7/15/2015
21	18	1	477-01	4-Jul-15	9-Jul-15	Victor, Jermaine	6-Jul-15	Lorenzitto, Emerson	7-Jul-15	Lorenzitto, Emerson	7-Jul-15	Victor, Jermaine	9-Jul-15

Figure 4. A sample time study sheet

3.2 Waste identification

To ensure the success of Lean implementation, it is necessary to quantify the waste/bottlenecks in the production by setting up some indicators. In this study, indicators are used to primarily capture the waste time in terms of lost products and wasted working hours. The “lost products” are defined as the products lost due to the production inefficiency compared to the calculated takt time. Material waste is also measured in terms of waste percentage. In addition, another typical waste identified in this study is over-production due to non-balanced production lines.

4 Implementation and Results

4.1 Existing problems identification

The first step toward implementing Lean manufacturing is to obtain a commitment from the company’s management team. This is achieved by holding a meeting with the management team and providing fundamental Lean training. The goal is to engage the management and assist them in realizing the need for change and improvement. Following this, a two-week plan is provided for the company in order to conduct all the necessary analysis. Figure 5(i) shows a time study sheet filled out by the workers at the assembly station to record the processing time for that station. The collected data is correlated with various product parameters; for example, Figure 5(ii) shows the relationship between the produced wall surface area and its processing time on the assembly table. This can help the management team to identify products that take relatively more time to build, and obtain a rough idea about their production rate. The key findings from these scatter figures include:

(1) There is a wide range of variation in the working durations, which indicates a non-standardized working procedure.
(2) The size of the openings on the panel influences the time duration for assembly, framing, and sheathing stations, yet has very little impact at the AVB and foaming stations.
(3) Approximately 50% of wall panels are designed with specific length and working area range with a similar duration; however, the remaining 50% perform with a large range of variation.

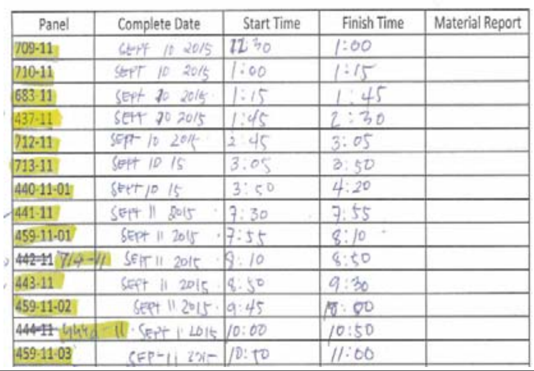
Based on the collected data, a VSM is created to represent the current state of the production line, as shown in Figure 6; and the following drawbacks of the production line are summarized:

(1) Large standard deviation contributes to an unstable production line flow. Variations in work duration on each station indicate the necessity of standardized work procedure.
(2) Work stations in a manufacturing plant should all target a constant cycle time to meet the customer requirement. However, the VSM shows a non-balanced production line where the AVB and potential foaming station interfere the flow of the line.
(3) Lean principles focus on value adding as well as eliminating waste. Regardless of the work efficiency on the station itself, the assembly station can be identified as a non-value added activity which consume close to 30 minutes for every panel that must be built.

The findings from VSM affirm the observations in the factory; areas are identified in the production line that potentially contribute to over-production. For example, the conveyor between the framing station and sheathing station is selected as a target area. The idle time of the products on this conveyor is collected, and an average of 20 hr of idle time is found for the products that are considered as waste from a Lean perspective. Figure 7 depicts that the wall panels are stacked on top of each other due to the non-balance of the production line, which causes the workers to spend time and effort to locate the correct panel to process. This is a typical situation known as a “push” system rather than a “pull” system. The workers’ productivity is also measured by calculating the wasted working time, which is conducted by means of monitoring from the company’s camera. At 60 minute intervals, an average of wasted time due to non-value added activities (e.g., walking around searching for material) is recorded, and according to the collected data, an average of 33% wasted working time is usual in a daily production.

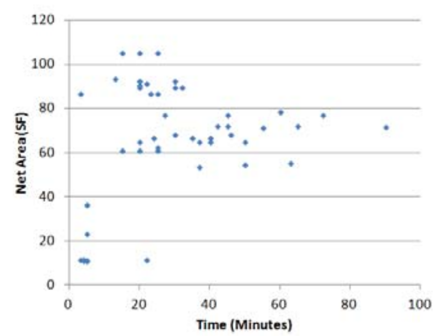
4.2 Potential solutions and future improvement

Previous findings in this study lead to various Lean strategies, including 5S and Kaizen, in order to achieve a clean and organized work environment. Regarding the implementation of 5S, this study reveals that specific target areas should be selected for improvement, and that it is easier to gain employee buy-in by beginning in an easy-to-improve area; the employees are more likely to be motivated if results are visual (Figure 8 shows an “after” state of the assembly station where 5S was performed). After obtaining employee buy-in, Kaizen sessions are conducted to identify the waste, and solutions are generated through brainstorm sessions. Some of the identified waste includes: (1) unnecessary inventories between framing and sheathing stations; (2) defects occur often, which result from improper material dimension and low production accuracy; (3) shop drawings are not supplied to the factory in a timely manner; and (4) workers are called off their work station by the factory manager from time to time. In general, the management has realized that the root of these causes arises from miscommunications and the solution is to assist employees in realizing their value and making them accountable for their work. From another perspective, Standard Operation Procedures (SOPs) are necessary for producing quality panels. Figure 9 shows a sample SOP created for the assembly station. From the production line flow perspective, the goal is to create work stations with congruent cycle times. In consideration of these observations, two solutions are proposed: (1) eliminate the work at the assembly station by proper machinery support or beforehand planning. Therefore, one extra station is being created. It is also important not to increase the cycle time at the second work station in order to maintain the production line balance; and (2) as the last two activities each use double the cycle time of the previous work station, work should be broken down further to allow the cycle time to be maintained at an approximately constant level. Cycle time, based on the working hours divided by the number of work stations, can be calculated to shorten the current duration, either to decrease the working hours with manpower or machine support, or increase the number of work stations by creating space from non-value added activities.



Panel	Complete Date	Start Time	Finish Time	Material Report
709-11	SEPT 10 2015	12:30	1:00	
710-11	SEPT 10 2015	1:00	1:15	
683-11	SEPT 10 2015	1:15	1:45	
437-11	SEPT 10 2015	1:45	2:30	
712-11	SEPT 10 2015	2:45	3:05	
713-11	SEPT 10 15	3:05	3:50	
440-11-01	SEPT 10 15	3:50	4:20	
441-11	SEPT 11 2015	7:30	7:55	
459-11-01	SEPT 11 2015	7:55	8:10	
~~442-11~~ 7/4-11	SEPT 11 2015	8:10	8:50	
443-11	SEPT 11 2015	8:50	9:30	
459-11-02	SEPT 11 2015	9:45	10:00	
~~444-11~~ 444-11	SEPT 11 2015	10:00	10:50	
459-11-03	SEPT 11 2015	10:50	11:00	

(i) Time study



(ii) Relation of the wall SF and processing time

Figure 5. Time study and data analysis

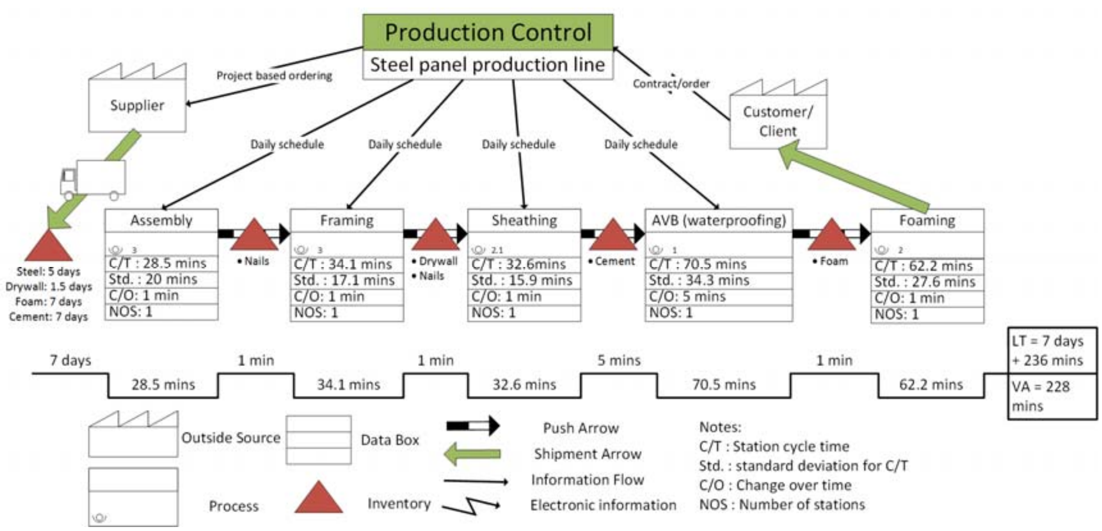


Figure 6. Value stream mapping (VSM) for the production line

Figure 7. Workers searching for the correct panel due to non-balanced line

Figure 8. 5S implementation results

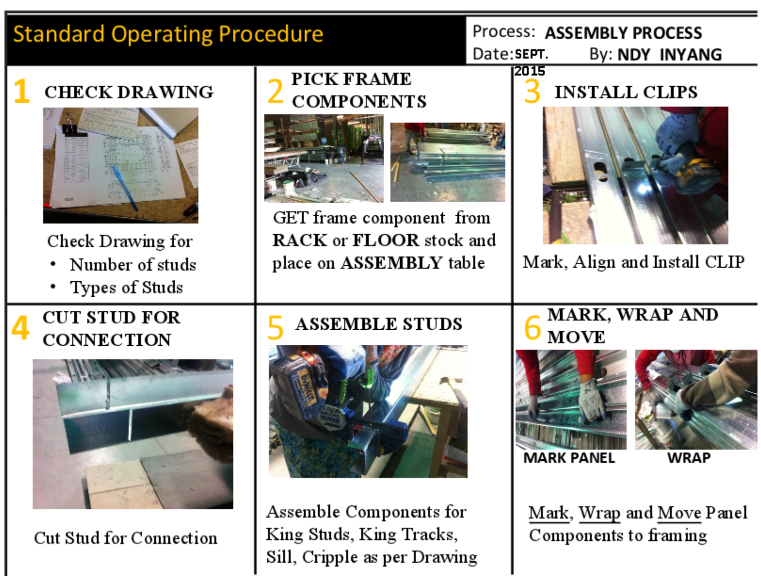


Figure 9. Standard operation procedure (SOP) for assembly station

5 Conclusions and Future Work

This study identifies the values of using Lean manufacturing concepts in a factory-based production line. The objective is to assist the company to realize the areas of waste in their production, and identify key areas for improvement. Time study is proven as the key for the analysis, based on which VSM is created to visualize the bottlenecks of production. The Lean tools are applied to the factory production line to assist in adding value to the production process. Typical tools include 5S, Kaizen, and JIT, etc. This research reveals that it is important to gain the employee/management buy-in in order to achieve Lean improvement. A culture change of the company is required for a continuous improvement process. For future work, the authors see the potential of implementing a real-time tracking system to the production line in order to better control the inventory and production. To achieve a highly balanced flow, immediate information feedback from the floor to the office is mandatory. This can be achieved through many available technologies, such as the barcode system or Radio-frequency identification (RFID) system (Altaf et al. 2015). Digital Kanban systems can also be helpful to the productivity improvement and defects control.

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References

[1] Altaf, M. S., Liu, H., Yu, H., and Al-Hussein, M. Online simulation modeling of prefabricated wall panel production using RFID system. Proceedings of 2015 Winter Simulation Conference, pages 3379 – 3390, Huntington Beach, California, USA, 2015.

[2] Bock, T. The future of construction automation: technological disruption and the upcoming ubiquity of robotics. Automation in Construction, 59, 113 – 121, 2015.

[3] Brettel, M., Friederishsen, N., Keller, M., and Rosenberg, M. How virtualization, decentralization and network building change the manufacturing landscape: an industry 4.0 perspective. International Journal of Mechanical, 8(1), 37 – 44, 2014.

[4] Chu, B., Jung, K., Lim, M., and Hong, D. Robot-based construction automation: an application to steel beam assembly (Part I). Automation in Construction, 32, 46 – 61, 2013.

[5] Everett, J. G., and Slocum, A. H. Automation and robotics opportunities: construction versus manufacturing. Journal of Construction Engineering and Management, 120(2), 443 – 452, 1994.

[6] Hyeok, S., Al-hussein, M., Al-jibouri, S., and Yu, H. (2012). "Automation in Construction Automated post-simulation visualization of modular building production assembly line." *Automation in Construction*, Elsevier B.V., 21, 229–236.

[7] Jung, K., Chu, B., and Hong, D. Robot-based construction automation: an application to steel beam assembly (Part II). Automation in Construction, 32, 62 – 79, 2013.

[8] Lee, J., Bagheri, B., and Kao, H. A cyber-physical systems architecture for Industry 4.0-based manufacturing systems. Manufacturing Letters, 3, 18 – 23, 2015.

[9] Lei, Z., Taghaddos, H., Ph, D., Olearczyk, J., Ph, D., Al-hussein, M., Ph, D., Asce, M., and Hermann, U. (2013). "Automated Method for Checking Crane Paths for Heavy Lifts in Industrial Projects." *Journal of Construction Engineering and Management*, 5(2003), 1–9.

[10] Randek, http://www.randek.com/, accessed on April 4th, 2016.

[11] Shafai, L. (2012). "Simulation Based Process Flow Improvement for Wood Framing Home Building Production Lines By."

[12] Vaha, P., Heikkila, T., Kilpelainen, P., Jarviluoma, M., and Gambao, E. Extending automation of building construction – Survey on potential sensor technologies and robotic applications. Automation in Construction, 36, 168 -178, 2013.

[13] WEINMANN machinery, http://www.weinmann-partner.com/, accessed on April 4th 2016.

[14] Yu, H., Al-hussein, M., Asce, M., Al-jibouri, S., and Telyas, A. (2013). "Lean Transformation in a Modular Building Company : A Case for Implementation." *Journal of Management in Engineering,* 29(January), 103–111.

[15] Yu, H., Tweed, T., Al-Hussein, M., and Nasseri, R. (2009). "Development of Lean Model for House Construction Using Value Stream Mapping." *Journal of Construction Engineering and Management*, 135(8), 782–790.