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INTEGRATING LEAN INTO MODULAR CONSTRUCTION: A DETAILED CASE STUDY OF COMPANY X

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ABSTRACT

Value stream mapping is a valuable tool in the lean toolbox that truly uncovers hidden waste in a process. Recent researches have focused on process improvement in various construction domains, but more research need to address precast concrete operations at the plant. This paper seeks to investigate the integration of lean principles in the fabrication phase of modular construction by using value stream mapping. The research focuses on the plant processes used to produce precast concrete pre-slabs and on means of improvement. It presents results from a case study of Company X’s precast plant. Data describing the current state of pre-slab casting was collected from plant visits, the current value stream map is drawn, and a future state map is then recommended. Indeed, alongside some effective lean concepts that are applied at the plant such as preventive maintenance and autonomation, some weaknesses are identified such as sizeable raw material storage, large batch sizes, considerable final product inventory and lack of “shine”. Appropriate remedial measures are recommended such as reducing batch and inventory size, creating FIFO lanes as well as applying 5S across the plant.

KEY WORDS

Value stream mapping, lean principles, modular construction, precast operations.

INTRODUCTION

For the past three decades the construction industry has been adopting successful practices from the manufacturing industry in an attempt to achieve a quicker, cheaper, and better quality construction. The principles of the Toyota Production System (TPS) were welcomed by modular construction academics, and the consequent research on lean construction has been paving the way for smarter methods of construction. One of the links between the TPS and the modular construction industry is that a lot of the items needed on site are manufactured in factories and delivered just in time. This process, therefore, highly resembles the production process of any built-to-order item similar to the process used by Dell computers, where each product is created according to customer’s specifications.

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In markets where loans are low, manufacturing size is small, and customers are hesitant, contractors become hesitant about stocking any pre-fabricated items due to the low and unstable demand. Initially, large companies would be comforted by their economies of scale, but smaller companies would feel the need to take drastic changes to reduce their stock and adopt smarter methods of production and delivery in order to reduce waste (Nahmens, I., & Mullens, M. A. 2011).

Hence, lean manufacturing principles have been integrated into the field of modular construction at a decent rate. Several researchers have targeted the benefits that could be drawn from such a step. Early work by Ballard, Harper, and Zabelle (2002) aimed at illustrating the impact of applying lean concepts to the fabrication of precast concrete. Their experiment showed noticeable improvements in demand management, cycle time, productivity, workforce involvement, revenue, and profitability. These improvements were realized using existing technology and operations with little capital investment emphasizing the high efficiency of lean processes.

A more recent pilot study conducted by Manufactured Housing Research Alliance (2007) proved that lean techniques incorporated in factory home building could significantly increase efficiency and quality. The study subsumed nine different home manufacturing plants each of which has witnessed remarkable improvements in various areas. Over 100% increases in efficiency were recorded in some production departments. As for quality, an 85% overall reduction in defects was achieved in a certain process. Different plants also experienced ameliorations in work moral and communication between management and workers.

One way to efficiently implement lean principles in modular construction would be to first map material and information flows, the value stream. In fact, value stream mapping (VSM), a tool that has been frequently used in the manufacturing industry, was used in a few construction related research. Simonsson et al (2012) showed how VSM can help visualize the workflow in a construction project and the effects of the improvements or modifications made to the workflow. In another study in a Brazilian construction company, VSM allowed detecting problems and identifying the proper actions for improving the masonry process in construction using lean tools (Pasqualini & Zawislak, 2005).

This paper uses Company X as a case study to explore the process of modular lean construction. This company is currently producing precast pre-slabs for the construction of a big mall. The paper will seek to evaluate where the company stands from a lean perspective by drawing the current value stream map. Then, the study will seek to further enhance the company's performance by drawing an appropriate future state map and providing pertinent recommendations. Further recommendations will be provided for a more advanced lean process in the far future.

VALUE STREAM MAPPING (VSM)

A value stream map (VSM) is the visualization of all the processes involved in the production of a certain product. It takes into consideration a range spreading from the time the order is made by the customer till the time the product is received, also included in this range are the aspects of design from concept to operation. Value Stream mapping mainly consists of information gathering, current state map drawing, and future state map drawing followed by an implementation plan (Rother & Shook, 1999).

The advantage of a VSM is the ability to focus on the problems hindering progress from a broad perspective and, accordingly, improve the system as a whole by tackling the root causes, instead of only tackling the problems by independently optimizing stations.

The "door-to-door" analogy is used in VSMs to show how processes are separated and how transitions occur between working stations/departments. This enables process planners to make further connections between suppliers and working stations. It may also eliminate other doors by merging several processes to achieve a rhythmic flow.

This process is mainly aimed at optimizing the flow through finding the sources of waste, linking all manufacturing processes to one visual language, and enabling companies to learn from each other. It also links the flow of information and material and allows the manager to create a visual representation of the production process while on site (*Rother, M., & Shook, J. 1999*). This leads to the desired future state map that would show beforehand the effect of making these changes on the production speed and efficiency. Furthermore it creates a roadmap that would direct towards a more efficient process in the future. A key to continuous improvement would be then to go through this process of information gathering, current state map drawing, future state map drawing, and implantation plan setting in a continuous cycle

METHODOLOGY

First of all, the study identifies the actual state of the system through a current state map. The authors conducted visits to the Company X's factory (the Gemba). Observing the processes alongside meeting with the workers and managers, the authors gathered information on the production process. On one hand data is gathered describing information and material flows in the factory (internal flow), mainly focusing on the following parameters: equipment and tools, number of people, available working time, uptime, cycle time, storage time, and inventory (raw material, WIP, and finished goods)

On the other hand, information on the factory's customer demand and material procurement (external flow) is collected describing the following:

Material requirement planning

Customer demand (size and rate)

Product delivery (size and rate)

After collecting the required data, the current state map is drawn focusing on both material and information flow.

In order to take the exercise to its full-fledged goal, the authors then identify waste in the system and seek to improve the process. A future state map is then drawn incorporating waste eliminations as well as system improvements. Finally, long term future recommendations are proposed with the goal of making the process even more lean.

CURRENT STATE MAP (CSM)

The scope of the value stream map will be limited to the Company X plant, starting from the materials storage and ending at the finished product inventory, while incorporating nonetheless materials supply as well as customer demand.

FINAL PRODUCT DEMAND AND MATERIAL SUPPLY

First of all, the VSM starts with Y Enterprise who contracts Company X for the fabrication of 600 m^2 of 0.1 m thick pre-slabs/day.

After being contracted by the client, the production control unit in Company X's plant office contacts material suppliers. For fine and coarse aggregates as well as for cement suppliers, it provides a monthly forecast (since they have daily deliveries). Production control also makes daily orders of fines and coarse aggregates, bi-daily orders of cement (since their suppliers are local) and steel coil orders once every 5 months (since the supplier is overseas). The quantity of fines, cement and coarse aggregates ordered is based on keeping a material storage that is enough for the upcoming 30 days, using a "Go See" mechanism. Therefore, material storage is closer to a supermarket approach than to a "push" schedule. Nonetheless, material storage is considerably high, but it is required in order to keep the plant running in spite of material shortages.

GENERAL FRAMEWORK

While ensuring the required raw material, production control also specifies the weekly schedule that is communicated to the general foreman at the plant who then schedules placement and pre-tensioning, pouring and curing in order to meet the set deadlines. The plant operates from 7:00 AM till 4:00 PM, with a l-hour lunch break at noon, and so the calculated total work time is 28,800 sec. The unit of flow in our VSM was taken to be 1 m2 of surface area.

PROCESS STEPS

The different process steps are as follows:

Cable Placement and Pre-tensioning at the plant of Company X is preformed using standardized formwork which is 140 m long, 1.2 m wide and 0.1 m thick (168 m^2 of surface). A single form allows the production of a batch of slabs. The steel cables are placed using a machine, operated by 2 workers, that was tailor-made for the process at the Company X's workshop adjacent to the precast plant. After placement, the cables are tensioned. Then, pieces of wood and cork are installed transversely at certain points throughout the 140 m long slab in order to decompose it into slabs of smaller spans (i.e. to prevent the concrete from being poured monolithically by providing a discontinuity). All in all, this takes around 21 sec/m^2, back-calculated from measuring the total time of about 60 min that was required for the whole (168 m^2) slab. At the plant, the concept of preventative maintenance is well followed. Consequently, the pre-tensioning machine has an uptime of 100%, with very rare breakdowns.

Concrete mixing is completed in batches of 0.5 m^3, which covers an area of 5 m^2 (since slab thickness is 0.1 m). Then, the batch is transported from the mixer to the formwork location in a movable metal basket automated on elevated rails (also made in-house). The process of mixing and transporting the batch to the pouring location requires about 3 min. by calculating the time required for 1 m^2, we obtain a cycle time of 36 sec. This 5 m^2 batch will be considered Work-in-Progress (WIP) during its transport phase.

Concrete Pouring is then done by a machine that moves along the 140 m formwork and pours the concrete inside the mold at a specified rate. After repetitive mixing, transport, and pouring, the 140 m pre-slab is cast.

Measuring the time required to pour the whole slab (2 hours), the cycle time for 1 m^2 is 43 sec. However, in spite of the preventive maintenance, the pouring machine still breaks down in some rare instances and needs repair, resulting in an uptime of 98%. Moreover, pouring in the plant is messy since some concrete spills over the formwork and, along with the rubble laying around in the plant, it has serious drawbacks. In the plant, several lines of formwork are available for parallel use. However, a team will only move from one line to another once it has finished its work on the previous line. Hence, each team moves to the 2^{nd} line after finishing the 1^{st} line, and this process is then repeated.

Accelerated Curing is preformed to speed up the production in the plant. Using steam curing, only 12 hours are required for concrete to reach the required strength, and only 2 workers are needed for the process. However, a certain setting time is required before curing can start in order to preserve the concrete mix's water-cement ratio. After pouring 3 slabs, curing is done for the 1^{st} one, and there are usually 2 shifts of workers that monitor curing. Uptime is usually 100%.

Cable Loosening and Cutting is done after curing. After curing, 2 workers remove the wood and cork separating different spans, and the pre-tensioned cables are slowly released. Finally, the steel cables still connecting separate spans are cut. This requires around 20 min for the whole 168 m^2 slab surface.

Staging is the final process in the plant. The finished product is moved by a crane to the storage area for delivery or customer pick up. However, the storage area is excessively full with around 5000 m^2 of finished pre-slabs equivalent to 8.3 days of production. Because of contractors delay in pick up, several pre-slabs may be left in storage for months before they are actually withdrawn. Unfortunately, this causes serious waste. Not only do they occupy space and result in storage costs, but they can be damaged due to weather conditions or to storage loads (since they are piled up on each other). This makes the pre-slabs unusable, thus leading to rework or waste.

The current state map is displayed on the following page. Lead time is 1288 hrs. while processing time is 12.4 hrs.

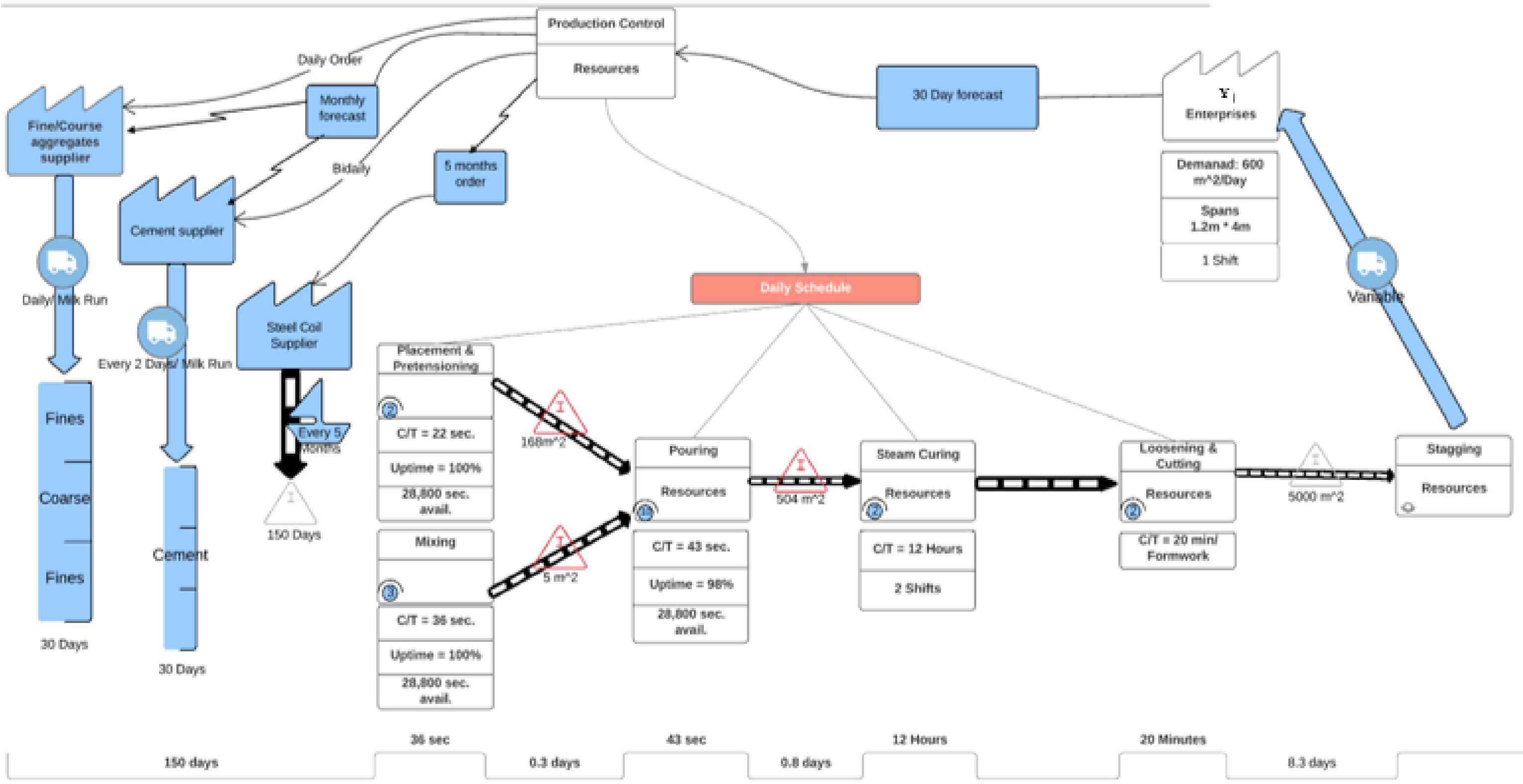

Figure 2. Current State Map

FUTURE STATE MAP (FSM)

After analyzing the CSM, a FSM is developed incorporating modifications deemed necessary for a lean value stream. These modifications aim to optimize the system using existent technology, simple additional or modified tools, and lean principles. The aim of this exercise is to use lean principles in order to improve manufacturing process without incurring considerable costs.

As a first step, Takt time (customer demand rate) is determined in order to identify the pace at which the production process must be running (Rother & Shook, 1999). Takt time is calculated as follows:

$$Takt\ Time = \frac{Available\ Working\ Time\ per\ Day}{Customer\ Demand\ Rate\ per\ Day} = \frac{28800}{600} = 48\ sec$$

The CSM shows that all of the processes, except for curing, loosening and cutting cables, have a cycle time that is below Takt time. Yet a good practice is to try to reduce the difference between different cycle times and, consequently, reduce the quantity of work in progress (WIP). For this purpose and some others, discussed below, the following improvements are made to the current state map:

Kaizen-1: Knowing that there should be a certain quantity of mixed concrete ready to be poured, concrete mixing and concrete pouring cannot be incorporated into a one piece flow. However, we can run the two processes at equal rates (43 seconds) if we maintain a certain buffer between them. In this sense, concrete would be equally withdrawn and replenished. This would impose a limit on the quantity of mixed concrete.

Kaizen-2: In order to further control production of mixed concrete, FIFO (First in First Out) will be used. FIFO could be conceived as a lane that once gets full signals to the supplying process to stop producing (Rother & Shook, 1999). In this case, a part of the bucket of the pouring machine in which concrete is placed could function as a FIFO. If FIFO gets full under certain circumstances, the production of concrete is triggered to stop.

Kaizen-3: The cycle time of placing, pre-tensioning, and tying cables will be increased to match that of pouring (43 seconds). Slowing down this process would reduce the waiting time of the machines involved in this process but cannot reduce the amount of work pushed to the downstream process (Pouring). This is because pouring cannot start until cables along a whole formwork (140 m in length) have been tensioned. This inventory is conceived as necessary waste and cannot be reduced unless the length of formworks used is shortened.

Kaizen-4: The formworks will be made 30 m in length. Using 30 m long rather than 140 m long formworks (as an initial goal) would not only reduce the quantity of inventory between the processes but also time wasted while waiting for a prerequisite activity to finish. The quantity of inventory between cable tensioning and pouring would decrease from 168 m2 to 36 m2. A FIFO can be introduced between the two processes to ensure that the quantity of inventory does not exceed 36 m2, the minimum necessary waste (i.e. as soon as cabling is finished, pouring starts).

Kaizen-5: Considering a setting time of 4 hours and pouring time of two hours for a whole formwork, curing the first formwork cannot start until two other formworks are poured. Thus, under these conditions, the quantity of WIP (504 m2) between the two processes is deemed necessary and cannot be reduced since enough time must be devoted for concrete setting after pouring. Yet FIFO will be used to create a pull mechanism and prevent overproduction under any circumstances.

Kaizen-6: The variable final product inventory will be replaced by a FIFO lane that will limit its size and provide a pull rather than a push mechanism. The stock will match demand for 2 days, reducing the production lead time by 6.3 days. In order to achieve this goal, reliable promising and close communication are required with the contractor on site so that the exact time of pick up can be determined realistically. This would greatly reduce the quantity of product that might not be eventually sold due to damage or changes in customer demand. Consequently, rework and overproduction are reduced.

Kaizen-7: Although scheduling is a must when it comes to shipping material from one country to another, a lead time of 5 months is considered an excessively long period. We must reduce the size of the steel coils batch to overcome the problems resulting from storing steel for a long time. Instead of ordering 30 tons of steel coils every 5 months, we can order 15 tons every two and a half month.

Kaizen-8: In spite of the preventative maintenance procedures followed at the company, uptime of the concrete pouring machine must be increased to 100%. This could be done using the “5S programs.” These programs consist of eliminating waste that could result in defects and even injuries in the workplace (Liker, 2005). Particularly, shine (cleanliness), one of the 5S, reveal pre-failure conditions that cause machine failure. This will allow for a more efficient preventative maintenance. It will also ensure a safer working environment for workers.

Finally, having a plant operated using FIFO, pull is prevalent all throughout the process. This eliminates the need for the daily schedules previously assigned to each process. Rather, the work will only need to be communicated to the first process, and the rest will flow. Incorporating these changes into the current state map, a future state map is presented below. The total lead time is 636 hours while processing time

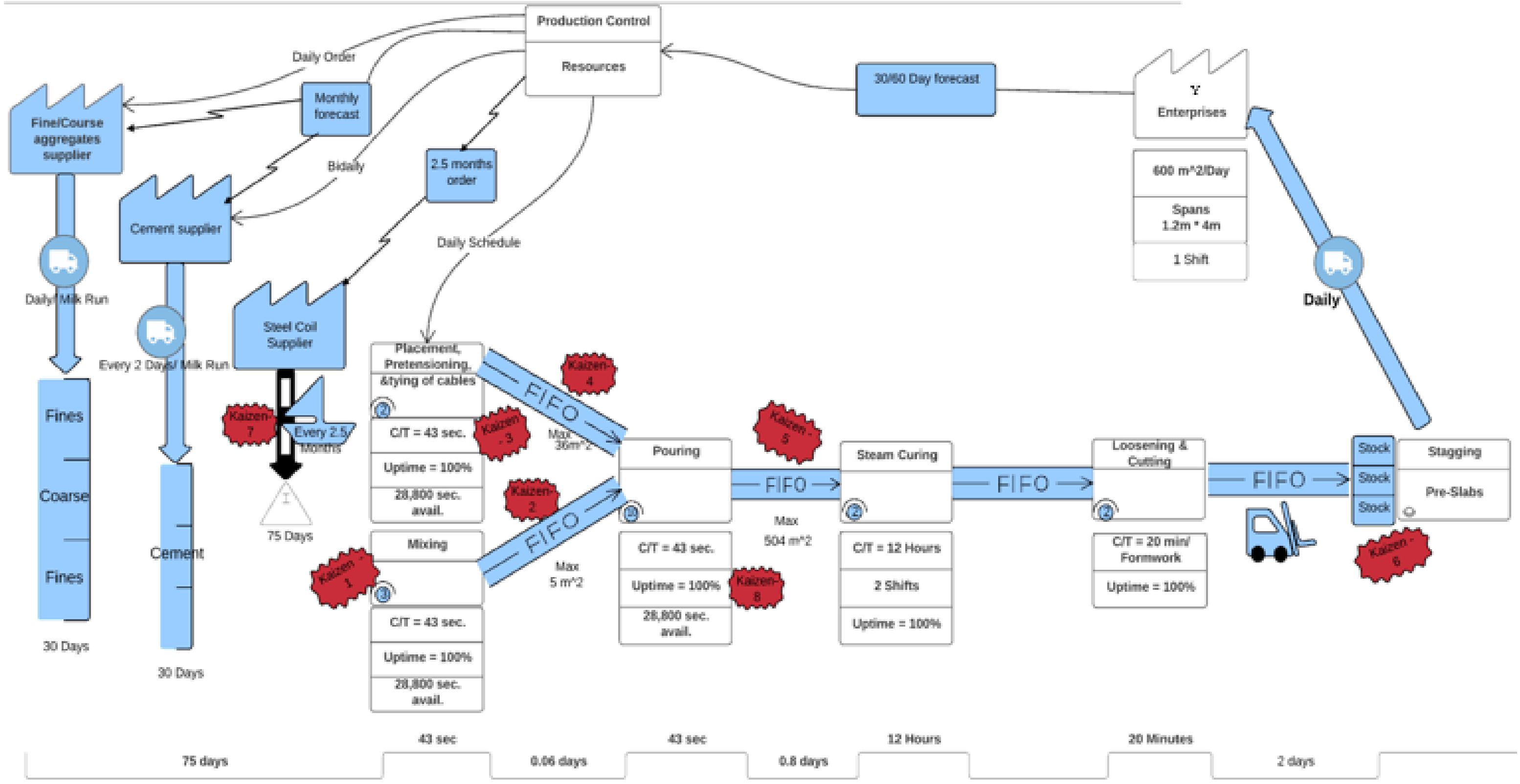

Figure 3. Future State Map

is 12.4 hours.

NECESSARY IMPROVEMENTS FOR A MORE LEAN PROCESS

For Company X to achieve the material and information flows visualized in the FSM, the following improvements must be realized in the process:

- Reduction in the rates of concrete mixing and cables tensioning processes to match that of concrete pouring (43 seconds) by properly reallocating resources.
- Use of FIFO between different processes to control production and avoid unnecessary waste at each process.
- Reduction in the formwork length from 140m to 30m to considerably reduce batch size.
- Replacement of the final product stock with a 2 days FIFO lane, relying on reliable promises and close communication with the client.

Reduction in the batch size of steel coils from 30 tons ordered every 5 months to 15 tons ordered every 2 and a half months.

Integration of the 5S programs.

These modifications would have a minimal financial impact in the short term. Moreover, they would cut costs in the long term mainly as a result of reducing batch size and inventory. Hence, there should be no major challenges that could hinder the implementation of the FSM. This could be further emphasized by the fact that, during data collection, the managers acknowledged the deficiencies their process suffer from and the need for change.

LONG TERM FUTURE RECOMMENDATIONS

One of the most important lean principles is continuous improvement in the pursuit of perfection (Liker, 2005). Bearing this in mind, once the proposed future state map is properly implemented, great efforts must be dedicated to go through a more challenging value stream mapping cycle. The more one approaches perfection, the harder the identification of possible means becomes. Yet what is firmly determined is that the ideal goal is based on maximizing value in the eyes of the customer while eliminating waste (Liker, 2005).

In a more lean scenario at Company X, formwork could be constructed to tightly meet the specifications determined by the customer. In the case study described above for example, this imposes further reduction of formwork length to only 4 m. This would significantly reduce the amounts of necessary waste between different processes. Moreover, this could even eliminate the need for the cutting process. On another note, the available quantities of raw materials should be further reduced. Regarding steel coils, the company could search for another supplier that is geographically closer and requires less shipping time to deliver, maybe even a local one. This would allow the company to buy raw materials weekly or even bi-daily instead of buying very large batches and stocking them for months. By doing this, the company would not only reduce the total lead time by 73 days (in case of bi-daily delivery) and free up space in the plant but also save cost usually wasted on steel coils damaged due to storing. Hence, deeper analysis would continuously reveal room for improvement, advancing the lean aspect of Company X.

CONCLUSION

The state of Company X's manufacturing process is investigated in this paper using value stream maps that break down the sequence of ordering, manufacturing, and delivering into delimited processes in order to help visualize the entire progress of work. A detailed analysis of the company's current production process revealed certain lean aspects, including preventative maintenance, supermarkets of material supply (except for steel coils), and tailor-made equipment and tools. Yet room for improvement is also identified at the level of overall lean philosophy. With the aim of creating better flow of material and information, waste such as raw material inventory, work-in-progress and final goods inventory were tackled. Fundamental lean concepts and tools, specifically kaizen and continuous flow, were suggested: FIFO lanes, reliable promising and 5S programs are all suggested for inclusion throughout the process. Furthermore, previously imposed necessary waste is reduced by reducing formwork length.

As an outcome of the near future state map, production lead time is reduced by 50.6% from 1288 hours to 636 hours. Moreover, different types of waste including inventory, overproduction, waiting, and rework are reduced. Finally, safety is improved as a result of reducing health hazards. Cost savings and efficiency improvement are evident consequences of reducing waste and lead time and improving safety.

The case study of a successful company with 16 years of experience proved that there is always a definite possibility for continuous improvement and proved the importance of a new perspective to overcome the perceived optimum state. Long term improvements that were suggested prove this assertion, coming closer and closer to the lean ideal: Instant delivery with zero inventory in stores.

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