Case Study

Lean Transformation in a Modular Building Company: A Case for Implementation

Haitao Yu[1]; Mohamed Al-Hussein, M.ASCE[2]; Saad Al-Jibouri[3]; and Avi Telyas[4]

Abstract: Encouraged by the remarkable productivity improvements in the manufacturing sector, the construction industry has a long history of trying to garner the benefits of manufacturing technologies. Whereas industrialized construction methods, such as modular and manufactured buildings, have evolved over decades, core techniques used in prefabrication plants vary only slightly from those employed in traditional site-built construction. The objective of this research was to develop and implement a production system for the effective application of lean tools in building components prefabrication. To overcome the prevalent skepticism among middle management, the lean journey started with a pilot project involving one production line. Over a six-month period, lean tools such as 5S (sort, straighten, shine, standardize, and sustain), standardized work, takt time planning, variation management, and value stream mapping were implemented to a communication shelter production line. The implementation successfully won the support of the middle managers and established the foundation for expanding lean practices to other parts of the factory and applying relevant lean tools and techniques. **DOI: 10.1061/(ASCE)ME.1943-5479.0000115.** *© 2013 American Society of Civil Engineers.*

CE Database subject headings: Manufacturing; Lean construction; Productivity; Case studies; Construction industry.

Author keywords: Manufacturing; Lean construction; Production management; Productivity.

Introduction

For decades, construction practitioners have been enticed by the idea of modeling construction after manufacturing, which experienced significant productivity improvement in the past century (Crowley 1998). In general, two strategies have been used for industrializing construction. The product approach aims at minimizing on-site construction activities by turning buildings into products that can be manufactured in a factory environment, whereas the process approach focuses on applying a manufacturing management model to the current construction process. The product approach had a strong impact on design and construction in the 1960s, with the evolution of a building system that was underpinned by three principles: standardization, prefabrication, and dimensional coordination. Prefabrication of building components on a large scale changed a substantial part of the construction from craft to manufacturing. As a result, productivity in the construction industry went up over a short span of years in some European countries that adopted the prefabrication method. However, when the buying power increased in the 1970s, the market asked for more individuality, and construction, to a great extent, went back into being a craft. There have been significant debates around modeling construction after manufacturing (Winch 2003). The particularities of the construction process, such as a one-of-a-kind product, on-site construction, temporary supply chain, and trade-based workforce (Bertelsen 2003), were regarded as evidence that the management principles and techniques used in manufacturing were not applicable in construction.

The manufacturing model regained the attention of the construction industry in the early 1990s, when the lean production system became a new manufacturing paradigm. An important step in that was the work described by Koskela (1992), who introduced a tripartite view of the construction process as transformation, flow, and value generation (also termed the TFV theory of production). The concept was further elaborated upon in his dissertation (Koskela 2000). Another important milestone in lean construction is the work carried out by Ballard and Howell on construction workflow variability (Ballard 1993; Ballard and Howell 1994b). Their work led to a lean-based construction workflow planning and management tool, the last planner system (LPS) (Ballard 2000). Other research efforts on the transfer of lean manufacturing techniques to construction included the use of 5S (sort, straighten, shine, standardize, and sustain) to increase site visualization (Dos Santos et al. 1998), establishing a fail-safe (Poka-yoke) system to ensure first-time quality compliance (Milberg and Tommelein 2003), using Kanban to control on-site material inventory (Arbulu et al. 2003), and applying the PDCA (plan, do, check, and act) cycle to redesign critical assignment (Ballard and Howell 1994a). Salem et al. (2006) summarized previous research efforts in the area of lean construction and assessed the impact of these techniques on project performance by a designed case study. Although the research literature suggested positive results from the application of lean theory to the construction process (process approach), the inherent differences between construction and manufacturing impeded achieving the full potential of the lean production system (Salem et al. 2006).

Recently, there has been a tendency for the two aforementioned approaches to converge in the format of modularization, in which modules are individually designed, produced, and assembled with

---

[1] Senior Researcher, Landmark Group of Builders, 9765 54 Ave., Edmonton, AB T6E 5J4, Canada (corresponding author). E-mail: haitaoy@landmarkgroup.ca

[2] Associate Professor, Dept. of Civil and Environmental Engineering, Univ. of Alberta, Edmonton, AB, Canada.

[3] Associate Professor, Dept. of Civil Engineering, Univ. of Twente, Enschede, Netherlands.

[4] CEO, Kullman Building Corporate, Lebanon, NJ.

Note. This manuscript was submitted on November 5, 2010; approved on December 9, 2011; published online on December 12, 2011. Discussion period open until June 1, 2013; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Management in Engineering***, Vol. 29, No. 1, January 1, 2013. © ASCE, ISSN 0742-597X/2013/1-103-111/$25.00.

the efficiency of industrialization (Bertelsen 2005). Modular construction has been used by the construction industry for years, but the potential benefits of modularization have not been realized because most modular producers have failed to take advantage of modern manufacturing technologies to improve their production process [Manufactured Housing Research Alliance (MHRA) 2005]. The manufactured housing industry seized the value of lean manufacturing on process improvement. Two major streams of research in this area were plant layouts optimization based on lean principles and lean implementation plan development using simulation (Senghore et al. 2004; Mehrotra et al. 2005; Jeong et al. 2006).

This paper describes a lean implementation initiative in a U.S.-based modular building company, Kullman Building Corporate (KBC). In collaboration with the University of Alberta, a modular production line that was relatively easy to control was selected as a lean pilot project, and a number of lean production techniques were tailored and implemented. The lean journey started with 5S and standardized work. This was followed by using the value stream mapping technique to analyze current practice, formulate a lean production model, and develop a kaizen plan. The implementation results were documented in detail to verify the effectiveness of the lean production model. Through the lean transformation of the production line, middle management was convinced that lean production was workable and could remarkably improve productivity and reduce waste. The success also led to the lean implementation in other parts of the factory and management's long-term commitment to a lean culture.

Lean Production and the Modular Building Industry

Although in the past 30 years lean production has been studied and introduced into numerous workplaces regardless of industrial field or scale, there have always been arguments by the construction practitioners that construction is distinct from auto manufacturing and that lean production is not applicable. A high level of customization in building design makes building modules mostly one-of-a-kind products. The need for variety has been regarded by many as a major reason that a lean production system is not feasible for modular production, but ironically, variety is in fact the soil in which the lean production system was cultivated and the very reason that lean production surpasses conventional mass production in effectiveness. A major factor that drove Toyota to conceive lean production was the reality that the Japanese automobile market in the postwar period required the production of small quantities of many varieties under conditions of low demand. There were more than 200,000 cars per month that came off the assembly lines in a virtually infinite number of varieties. The number of varieties reached to the thousands just by considering the combinations of car size and style, body type, engine size, and transmission method. If colors and combinations of various options were included, it was rare to see two completely identical cars (Ohno 1998).

Moreover, an automobile, like a building modular, is made of thousands of parts; the number of processes involved is immense. It is extremely difficult to apply just-in-time (JIT) to a production plan of every process in an orderly way. An upset in prediction, a mistake in the paperwork, defective products and rework, trouble with the equipment, absenteeism—the problems that could arise are countless. A problem early in the process always results in a defect product later. Stops and changes in the production process will happen regardless of planning.

Background of Case Study

The case study company, KBC, is one of the leading modular building manufacturers in the U.S. The company was founded in 1927 by a young salesperson to provide turn-key, portable diners that served a market seeking fast, low-cost, home-cooked meals. After 80 years of growth, KBC now has over 200 employees and has expanded its market to produce a variety of building types, including equipment shelters, schools, dormitories and multistory residential buildings, correctional facilities, healthcare facilities, and U.S. embassies. The company coined the term accelerated construction to describe a building process free from uncertainties of weather, site conditions, and contractor relations. While modularization provides KBC significant competitive advantages in terms of site construction time, quality control, and predictability, the company has not yet realized its full potential. Considering the cost of transportation and installation, KBC's products were typically 10–20% more expensive than their counterparts built on-site. As a result, its customers were limited primarily to wireless providers, education institutes, and government, which are less cost

Fig. 1. Module production of a 3-story dormitory project

constrained. A fundamental reason for the high cost was that KBC, like other modular manufacturers, still "stick build under the roof," and failed to take advantage of modern manufacturing technologies that could significantly improve their production process (Nasereddin et al. 2007). Fig. 1 shows the production of a dormitory project that consisted of five 3-story buildings, which were built in the factory in modules and shipped to the site. In this example, the modules were stocked inside the factory and various trades and materials went to the building in sequence, similar to the on-site construction.

Both the KBC chief executive officer (CEO) and the chief operating officer (COO) came from the semiconductor industry and had profound knowledge in lean manufacturing; both of them believed that modularization would be the future of construction and had a passion to transform KBC from a traditional construction company to a lean manufacturer. The company had two vice presidents (VP), including VP of personnel, accounting, and project management, and VP of sales.

The KBC organization had a conventional hierarchical structure, with a manager for each functional area. The head of production was a plant manager who reported to the CEO. The production planning and workforce on the floor were managed by a production control manager, assisted by five line managers. A logistics manager was responsible for the procurement and storage of all materials and tools. All middle managers in the production department were company veterans, having been with the company for more than ten years. Although most of them had taken Lean 101 training, they did not have any experience in manufacturing and showed little interest in lean implementation at the beginning of the project.

The frontline workforce of KBC consisted of 110 full-time employees and temporary workers from two agencies. These workers represented a wide variety of trade disciplines: carpentry, welding, electrical, painting, plumbing, rigging, and computer numerical control machine operation. The KBC employees were unionized, with an average of four years of tenure. Frontline workers had also taken Lean 101 training provided by an external consultant, but they were generally reluctant to change. Skepticism was prevalent because of concerns that eliminating waste might result in increased work intensity and workforce reduction.

Lean Pilot Project and 5S

Lean transformation requires complete commitment from top management, but the biggest challenge and key success factor is to let the middle management and frontline workers see the necessity of change and the effectiveness of lean production. In KBC, this was done by focusing the lean implementation on a pilot project and 5S campaign.

The communication shelter production line, a discrete assembly line with a continuous work flow, was selected as the demonstration area of lean transformation. Because 95% of the communication shelters were 3.7 × 9.1 m (12 × 30 ft) or 3.7 × 6.1 m (12 × 20 ft) standard modules with similar configurations, standardization of the production process was relatively easy. Meanwhile, as a major production line generating 40% of the overall revenue of the company, it was highly visible. Backed by the top management, a top-down approach was adopted, and the objectives of the project were defined as synchronizing the production line to takt time, reducing average labor hours per module by 20%, and controlling overtime under 10% of total labor hours. The duration of the pilot project was scheduled as six months, and the first step was planned to be the process documentation of the communication shelter line and a 5S campaign.

The 5S plan has been recommended by many lean experts as the starting point of lean transformation (Productivity Press 2006), because compared to other lean tools, 5S, which focuses on cleaning and organizing the workplace, is easier to get workers to buy-in and it produces immediate visible results. More importantly, effective cleaning and efforts to sustain a better organized workplace involve many key lean principles and methods, such as standardized work and visual management. The 5S plan can help people that have no lean production experience build teamwork, discipline, and a culture of continuous improvement, which are the cornerstones of lean implementation.

After shop floor observation, a series of workshops were held with frontline workers to review the findings. At each workshop, the basic concepts of 5S and seven types of wastes were explained, pictures like Fig. 2(a) were presented, and examples of workplace management at some world-class lean enterprises were introduced. Following these, a brainstorming session was conducted to identify three top areas of waste and to develop a team action plan with possible solutions, completion deadline, and persons responsible. The production manager and line managers also attended these workshops to show their commitment and support to the initiatives.

In two weeks, workers at the communication shelter line were organized into eight workgroups, each with its own 5S action plan and biweekly 5S meetings. The working condition of the shop floor was remarkably improved, as shown in Fig. 2(b). One advantage of starting a lean journey with 5S was that people could see the results


(a) (b)

Fig. 2. Work area of station 3: (a) before 5S; (b) after 5S

in a relatively short period of time and become excited about the progress and improvement. Moreover, 5S efforts soon went beyond cleaning activities to other lean implementations. In 5S meetings, a repeatedly asked question was "Where is the best place to put this material (or equipment)?" The answer was always "At the place where they are used." This led to the establishment of on-station inventory and the development of Kanban, a scheduling system used in lean to achieve JIT. Meanwhile, standardized work became a natural choice, because a given task should always be performed at a designated location so that required materials and equipment could be put next to that location. Comparing the two states shown in Fig. 2, the second one was not only much cleaner, but held all the materials and equipment required by the operations at station 3.

Standardized Work and Variation Management

Standardized work is regarded as the backbone of lean processes and the basis for continuous improvement and quality. If a process is always shifting, then any effort for improvement just creates one more variation that is occasionally used and mostly ignored (Liker 2004). One common problem in construction is that most construction tasks are done by trades people based on their skill and experience. Although the production of communication shelters in KBC was on an assembly line, the production process was highly unpredictable. The line manager dynamically assigned workers to tasks on a daily or hourly basis, and the line was moved when most of the tasks had been done. As a result, the production process varied and people did not know which state was normal.

The first step of standardized work was to determine takt time, the maximum time allowed for a modular to stay in a station. According to its definition, takt time can be calculated using the following formula:

$$T = \frac{T_a}{T_d} \tag{1}$$

where T = takt time; T_a = net time available to work; and T_d = customer demand. Based on a time series analysis of the historical data of customer orders and demand forecast provided by customers, takt time was determined as seven hours in months two to four and six hours in months five to seven. Because the average production cycle time in the current month (month one) was eight hours, to synchronize the production line to the takt time target meant a 25% improvement in production capacity in three months.

Operation standardization was done through a standard worksheet that consisted of two elements. A work combination table (Fig. 3) determined the task sequence and workforce requirements at a given station and clarified the work scope for which a crew was responsible. For each task, a standard work procedure (Fig. 4) provided step-by-step instructions to ensure workers follow the best practice. Because all workers had been trained to perform the operation in a standardized way before they were released to the job, they did not have to refer to standard worksheets during their operation. However, the combination table and standard work procedures were posted at each station to provide a visual reference for management to check adherence to the standard. Any deviation from the standard meant an abnormal situation, usually caused by problems. The role of management was to recognize the deviation, uncover the root causes, ensure that they were corrected quickly, and reestablish the standardized work.

One unique characteristic of construction is the high level of customization; it is rare to see two identical buildings. The production of communication shelters faced the same challenge. Some of the modules were so different that workloads in one or two stations changed dramatically. For example, compared to a standard 3.7 × 9.1 m (12 × 30 ft) module with a single interior gypsum board and exterior stenni finish, a module with double-layer interior and exterior boarding, waterproofing, and hand-laid brick almost doubled the carpenters' workloads at station 2 and station 3. The extra workload for one task might have a remarkable impact on the overall work sequence. When there was only one layer of interior gypsum board, the interior finishing crew started its work one hour after the start of the installation of interior boarding so they could both complete their job within takt time. However, if there were two layers of interior boarding, the interior finishing crew could not start until the entire first layer and 20% of the second layer of interior boards had been completed. To maintain the synchronization of the production process, measures had to be taken to accommodate workload fluctuation.

The two most commonly used methods for this purpose are overtime and workforce pool, but they need to be used in a systematic way to minimize waste. In KBC, different standard work sequences for each station were developed to deal with the different module types and takt time requirements. For instance, the work combination table shown in Fig. 3 was an 8-h takt time work sequence for a 3.7 × 9.1 m (12 × 30 ft) module with double interior and exterior gypsum board, which accounts for 35% of modules passing through the station. There were separate work

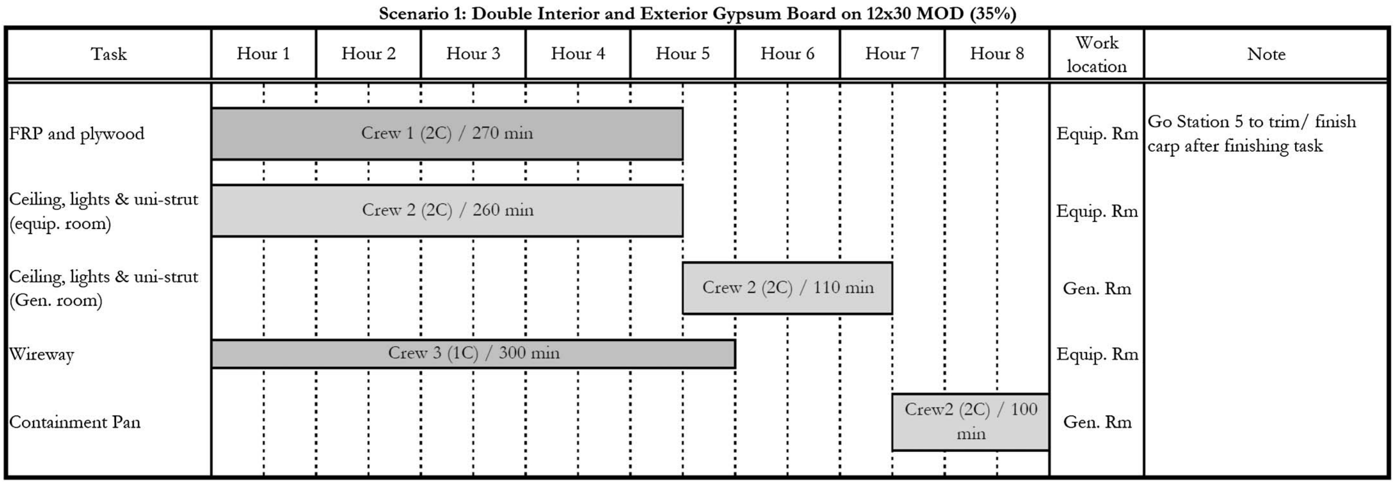
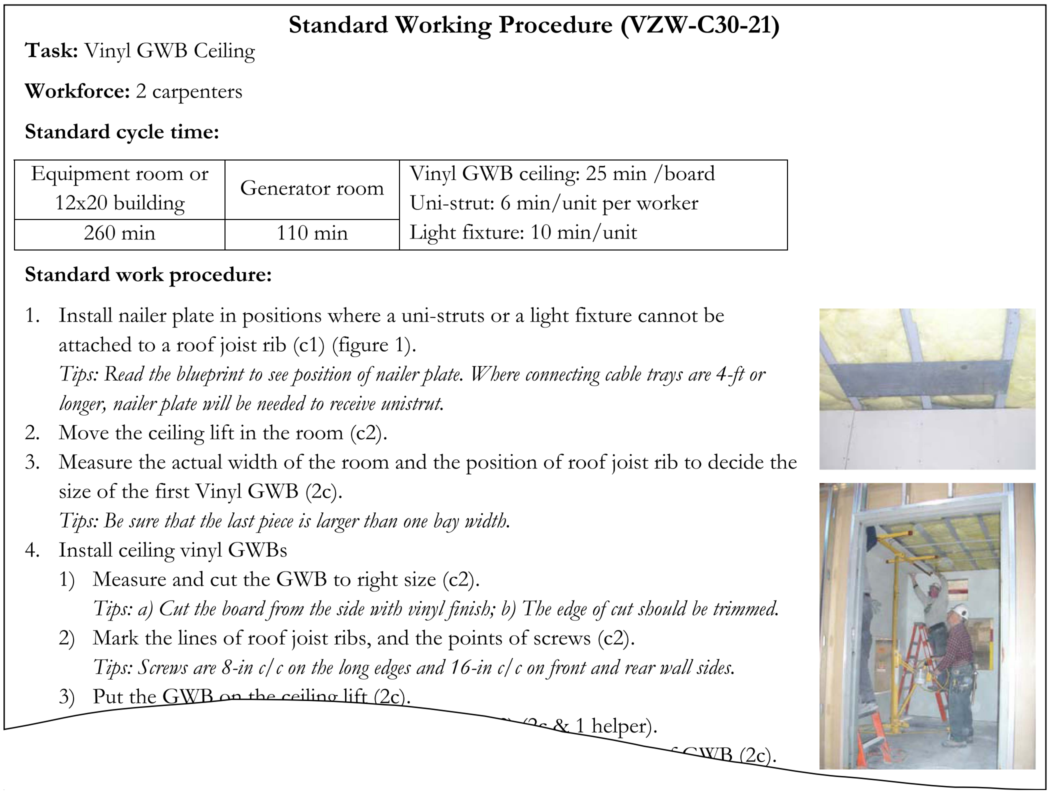


Fig. 3. Work combination table of station 3 (takt time = 8 h)



Standard Working Procedure (VZW-C30-21)

Task: Vinyl GWB Ceiling

Workforce: 2 carpenters

Standard cycle time:

Equipment room or 12x20 building	Generator room	Vinyl GWB ceiling: 25 min /board Uni-strut: 6 min/unit per worker Light fixture: 10 min/unit
260 min	110 min	

Standard work procedure:

1. Install nailer plate in positions where a uni-struts or a light fixture cannot be attached to a roof joist rib (c1) (figure 1).
   Tips: Read the blueprint to see position of nailer plate. Where connecting cable trays are 4-ft or longer, nailer plate will be needed to receive unistrut.
2. Move the ceiling lift in the room (c2).
3. Measure the actual width of the room and the position of roof joist rib to decide the size of the first Vinyl GWB (2c).
   Tips: Be sure that the last piece is larger than one bay width.
4. Install ceiling vinyl GWBs
   1) Measure and cut the GWB to right size (c2).
      Tips: a) Cut the board from the side with vinyl finish; b) The edge of cut should be trimmed.
   2) Mark the lines of roof joist ribs, and the points of screws (c2).
      Tips: Screws are 8-in c/c on the long edges and 16-in c/c on front and rear wall sides.
   3) Put the GWB on the ceiling lift (2c).

(2c & 1 helper).

GWB (2c).

Fig. 4. Example of standard work procedure

combination tables for the 3.7 × 9.1 m (12 × 30 ft) modules with single or no boarding and the 3.7 × 6.1 m (12 × 20 ft) modules. Float workforce, which did not belong to any work station, was used to deal with the extra workload for different module types, schedule delays, workers' vacations, and absenteeism. In normal situations, the float workforce worked on an off-line module, which was usually a special module with significant workload variation that could not be accommodated at the production line.

Value Stream Mapping

Standardized work is a great tool to stabilize the process and help people identify problems that lead to abnormal situations. However, a standardized procedure is not necessarily the best practice, and the current process often needs to be adjusted to meet the changed requirements. In the case of KBC, a new production model was needed to reduce the takt time of the communication shield line from eight hours to six hours. To achieve this goal, value stream mapping (VSM), a widely used lean planning tool, was selected because of its process view and the ability to link lean initiatives into a whole. Based on standardized work, a four-step method was adopted to develop the future lean production model: (1) current-state mapping; (2) existing practice analysis; (3) formulation of a future production model; and (4) laboratory testing of the model using simulation.

Prior to the commencement of VSM, two management decisions must be made: (1) select a value stream; and (2) decide the level of mapping. In this research, those two decisions were interrelated. When the door-to-door production flow was looked at as a value stream, the mapping could only be done at the station level, because a single map encompassing all tasks conducted within each station would be too large and cumbersome for a VSM team to handle. A high-level value stream map like the one shown in Fig. 5 provided a big picture of the process, but showed little detail of the operations; it could not be used for root cause analysis and future map formulation. In contrast, a station could be seen as a value stream with the preceding station as the supplier and the following station as the customer, as shown in Fig. 6. The problem with mapping the process at this level was that the value stream was not stable, because it might be necessary to move a task from one station to another to optimize the production line or to achieve a different takt time. In this research, maps at two levels were used simultaneously for waste identification and solution development.

Upon drawing up the current-state map, several wastes could be identified immediately. For a linear assembly line, a basic lean principle is to balance the workload and synchronize the station cycle time to takt time. This may be common sense, but in practice it is not an easy job for production management. From the data in Fig. 5, it is easy to see that the production cycle times (C/T) of some stations were much lower than the takt time, which was 480 min in the current-state map. That meant the production capacities of those stations were higher than the demand. Conversely, the percentage of completion (Completion), which was defined as the percentage of modules with all tasks completed at the time of being moved to the next station, were quite low, even at the stations with a much lower cycle time. For instance, the average station cycle time of station 3 was 400 min, approximately 17% lower than the takt time, but the percentage of completion at station 3 was only 80%; one of every five modules moved to the next station had unfinished tasks. For stations with a cycle time close to the takt time, the incompletion rates were much higher. In the case of station 5, almost half of the modules were moved out of the station unfinished. The ripple effect of unfinished tasks disturbed the production pace and led to significant wastes. For instance, if the electricians at station 4 did not finish the rough conduit

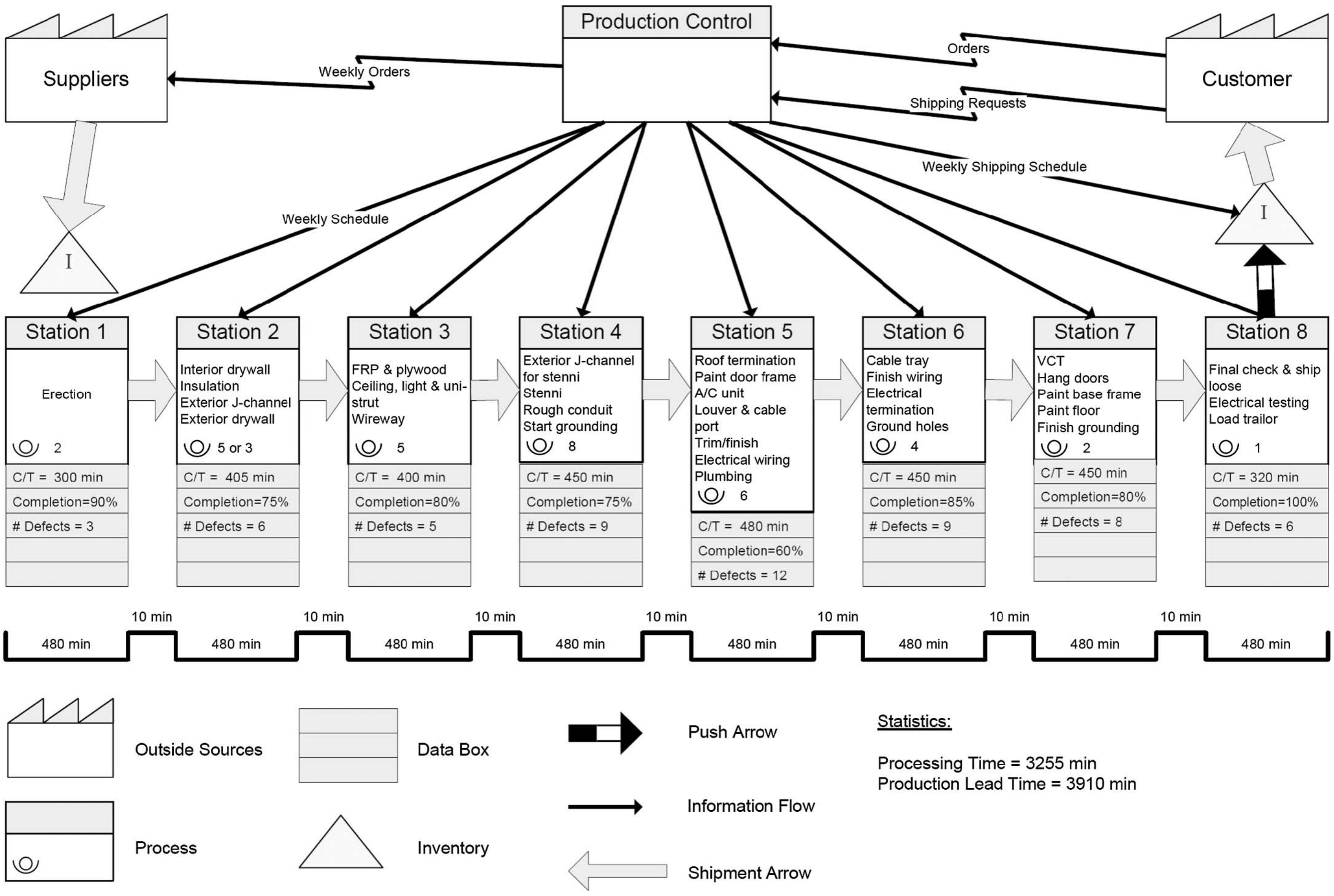


Fig. 5. Current-state map (high level)

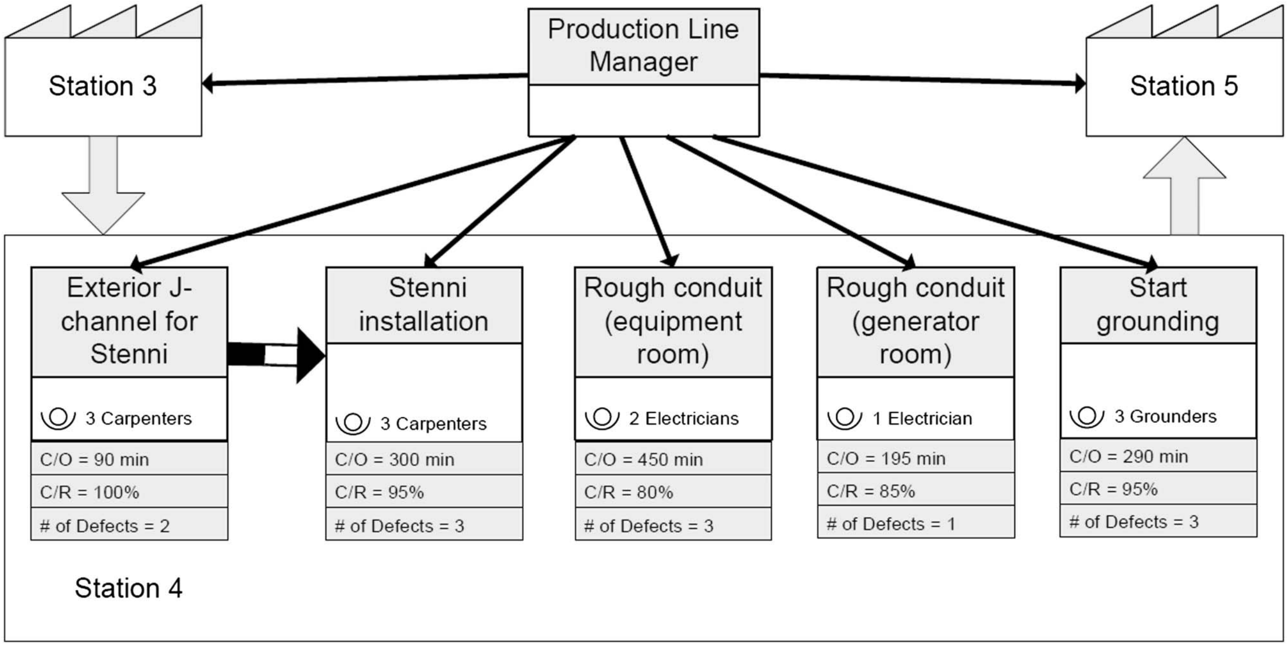


Fig. 6. Current-state map (station 4)

in the equipment room, they needed to continue their job at station 5. Then the workers who should pull electrical wires could not start their job on time, so they were idle at the beginning and had to hurry at the end to finish their job before the module moved to the next station. Moreover, installing rough conduits at station 5 meant that workers had to move back and forth between station 4 and station 5 to get tools and materials, and the more time they spent at station 5, the less time they had for the next module in station 4.

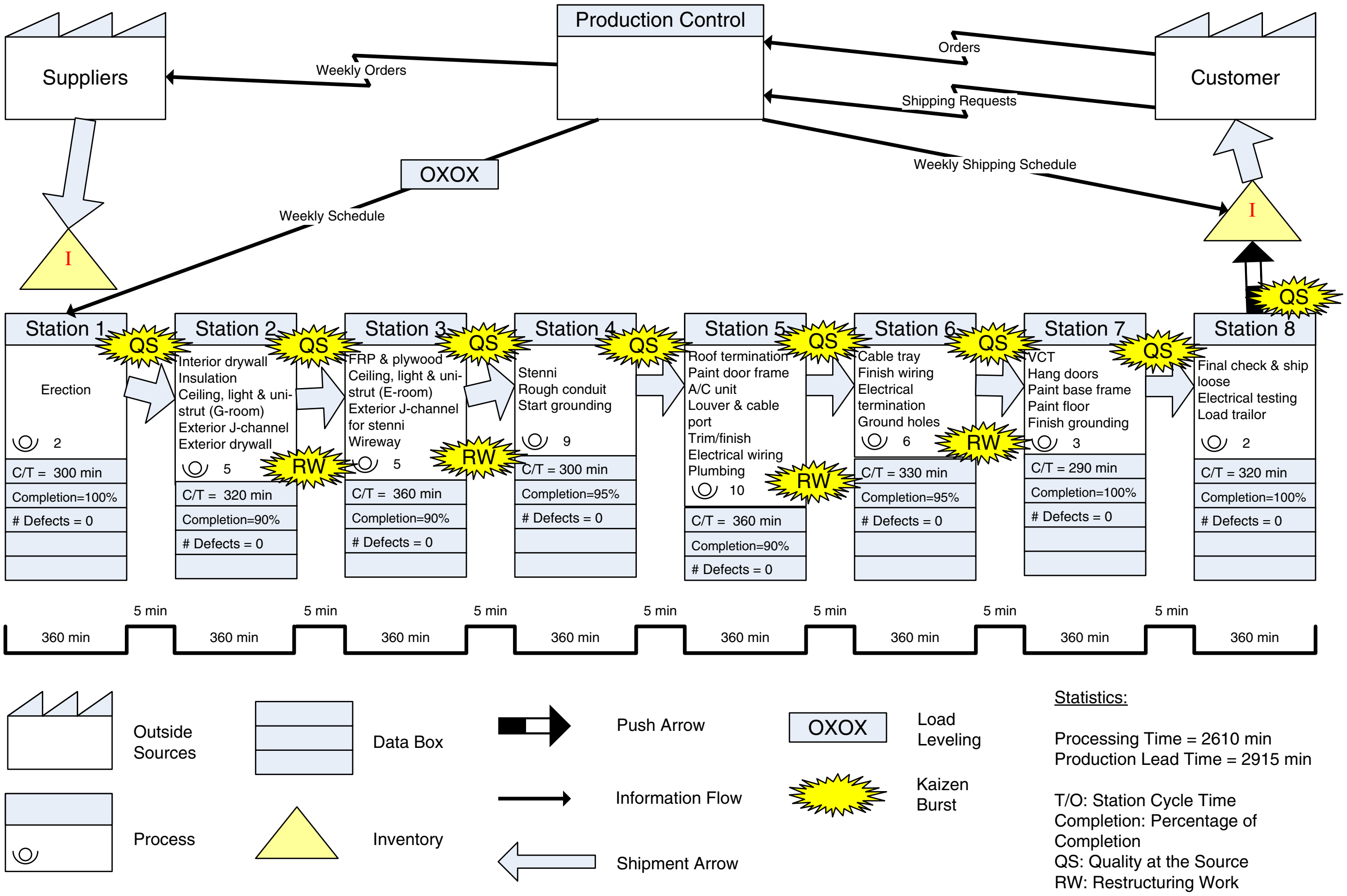


Fig. 7. Future-state map (high level)

A major reason for the low percentage of completion was the variation of workload caused by different module configurations. The average cycle time of station 2 was 405 min, but 35% of the modules were 3.7 × 9.1 m (13 × 30 ft) with double interior and exterior gypsum boards that needed 480 min to install. There was no time buffer in this case, and any delay would result in unfinished tasks. Although flexible workforce and overtime were effective tools to handle the workload variation, as explained in the previous section, a further measure was necessary to reduce the variation at the source. Quality problems were another cause of high variation in cycle time. It was quite common that a worker had to stop his or her work and go to a downstream station to fix defects.

The focus of future-state mapping was to eliminate the root causes of wastes and to link the value stream in a smooth flow. As shown in Fig. 7, three measures, including workload-leveling, restructuring work, and in-station quality, were used to increase process reliability and achieve a 6-h takt time. The basic idea of workload leveling is to meet varying customer demand (a mix of modules with variations) without workload fluctuation in the manufacturing process. In typical manufacturing, load leveling is done through a heijunka box showing the quantity of a mix of products being produced over a specific time period. In modular production, the major method of load leveling is to establish an optimized production sequence to ensure that the delay in the completion of one module does not lead to the delay of the next module, and that crews shared by multiple tasks at different stations have enough time to perform all assigned tasks. As a part of lean production planning, the responsibility of deciding production sequence was moved from sales to production line managers. Every Wednesday, the sales department sent a tentative 2-week schedule to production based on the sequence of orders and customers' demanding dates, and the line manager adjusted the module sequence in the schedule based on a set of predefined rules. For instance, if there was a 3.7 × 9.1 m (12 × 30 ft) module with hand-laid bricks (Nailite) as exterior finishing in the schedule, two extra workers would be needed at station 4, because the labor hour of brick installation was almost 60% more than that of stenni installation. According to the production design, these two workers were crew 1 of station 2. The optimal production sequence was as shown in Fig. 8.

The purpose of restructuring work is to balance the production line so that the overall cycle time of each station can be as close to

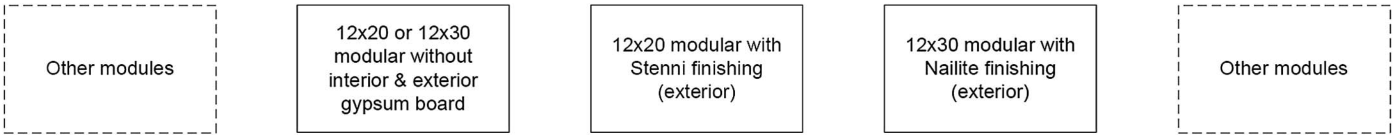


Fig. 8. Optimal production sequence after Nailite finishing module

the takt time as possible. However, the more the production line is synchronized to the takt time, the higher the risk that some tasks will not be completed within the takt time period. The process shown in the future-state map (Fig. 7) required high reliability of workers' operations and effective variation management measures. Standardized work and quality at the source were the keys to reduce operation variability.

Future-State Map Implementation

The changes brought by 5S and standardized work based on the current practice established a solid foundation for the lean pilot project. In fact, after one month of 5S initiatives, production management was eager for the next step of lean implantation. A task group that included the production manager, line managers, and station leaders was established to lead the implementation of the future-state map. The team met weekly to develop kaizen (improvement) plans, coordinate training, and review progress. After six months of implementation, the throughput of the production line improved from 1.1 modules per workday in July (8-h takt time) to 1.73 modules per workday (5-h takt time) in January, as shown in Fig. 9. There was a learning curve for KBC's production management to realize the importance of having a process view and following the kaizen plan, because any ad hoc adjustment based on improvement in one or two individual tasks did not improve the overall performance of the production line, but instead disturbed the flow. During this project, simulation played an important role to help researchers and production management guide the lean implementation process and develop interim lean models. The future-state map presented the ideal state at which the production line was expected to be in six months, but it would not be possible to implement the entire lean system at once, and in reality, the workers had disparate attitudes toward changes, which led to varying improvement progress. The management had to consistently adjust the lean implementation plan and develop interim lean models based on the real situation to keep the production line balanced and turn improvement on an individual task into the improvement of the entire process. Considering the complexity brought by a high variety of modules and its impact on workload and task cycle time, it was tedious and difficult to manually adjust the production line. Computer-based simulation provided a powerful tool for identifying the optimal model through scenario analysis and helping management to better understand the effect of changes. A detailed discussion of the simulation method and results is beyond the scope of this paper and will be reported in a subsequent paper.

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Workdays	23	21	21	23	20	23	20	17	22
Throughput	21	23	22	25	22	31	28	24	38
Productivity	0.91	1.10	1.05	1.09	1.10	1.35	1.40	1.41	1.73

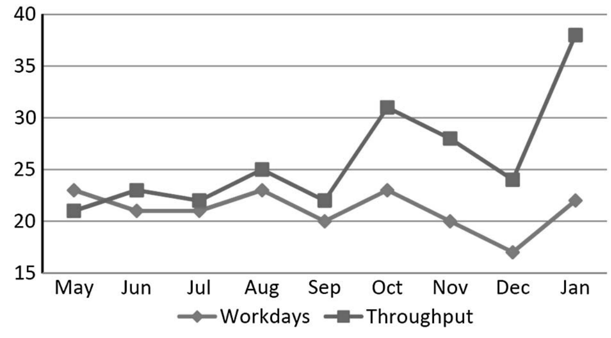


Fig. 9. Throughput of communication shelter production line

	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Average Workers Actually on Line	43	43	44	45	48	49	47	53
Average Absent %	15	17	14	10	5	2	6	4
Labor-hour/MOD	383	367	352	346	312	320	271	254
Overtime %	21	13	9	5	11	14	1	4

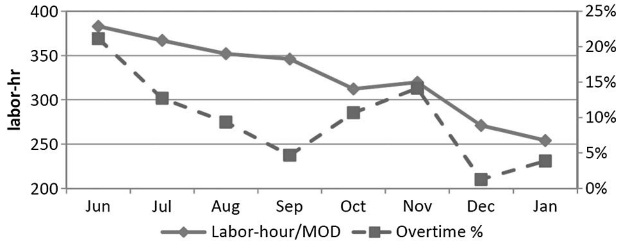


Fig. 10. Improvements on productivity and overtime

As pointed out by Ohno (1998), the goal of any lean improvement is cost reduction, and this can be done by either increasing the production quantity or by reducing the number of workers. However, the quantity is determined by sales, a number that cannot be increased arbitrarily. From May to September, the customer demands were quite stable around 22 modules per month. KBC's lean efforts focused on standardizing the production process and working procedure. In four months, the direct labor efficiency, measured by labor hours per module, was improved by 10%, and labor cost reduced by 18%. KBC did not lay off any workers, but reduced overtime from 20% of the total labor hours to 5%, as shown in Fig. 10. In October, the number of orders increased by almost 50%. Instead of hiring more people, KBC initiated a training campaign to reduce absenteeism and promote radical kaizen. The future-state map was used as a guideline to optimize the production process and to reduce takt time from eight hours in September to seven hours in October and to six hours in December. In January, five workers were added to the workforce on the communication shelter line to deal with the backlog from December and to reduce overtime. The average labor hours spent on one module was reduced to 254 hours, which meant a 34% decrease from the June level.

Conclusions

The lean implementation results show that lean production principles and techniques can be effectively applied in modular building production. Most modular building producers like KBC have a long tradition of operating as construction companies, and the management does not have the necessary training and knowledge of lean production. Although modules are built in the factory environment, the building methods and management tools used in modular production are the same as those used in conventional on-site construction. A detailed examination of the current practice, the way the production line was planned and managed, revealed that a jumbled process and unbalanced production line led to significant wastes, and that the production system could be improved through stabilizing the process and restructuring work.

The biggest challenge in applying a lean production system in construction is to get buy-in from middle management and frontline workers. In this research, 5S proved to be an effective way to get people involved in lean initiatives and enthused about lean by realizing immediate results. Moreover, the efforts to organize the workplace and sustain results involved the implementation of many other lean principles and techniques, such as standardized work and visual management, and established a solid foundation for lean production model implementation. The lean approach developed in this research was the result of viewing the entire production line as a whole, focusing on balancing the production line with process stability rather than solely on improving the productivity of each operation. Detailed production data were collected and used to describe the current practice and evaluate the lean implementation results. After six months of lean implementation, a dramatic improvement in terms of production throughput, productivity, and labor cost was observed.

The success of the pilot project won the support of middle management, and research on lean implementation at three other production lines in KBC is ongoing. The communication shelter line is unique in modular building production. The lean production model developed in the pilot project cannot be used for other production lines, but the lean implementation approach and key strategies presented in this paper could be generalized for the modular building industry and tailored for any particular modular production line. The fundamental implementation of this research is that the current practice of modular building production has large potential for improvement through the application of lean production principles and techniques.

References

Arbulu, R. J., Ballard, G., and Harper, N. (2003). “Kanban in construction.” *Proc., 11th Annual Conf. of the Int. Group for Lean Construction*, Blacksburg, VA.

Ballard, G. (1993). “Lean construction and EPC performance improvement.” *Lean construction*, L. Alarcon, ed., Balkema, Rotterdam, Netherlands, 79–91.

Ballard, G. (2000). “The last planner system of production control.” Ph.D. dissertation, Univ. of Birmingham, Birmingham, U.K.

Ballard, G., and Howell, G. (1994a). “Implementing lean construction: Improving downstream preference.” *Lean construction*, L. Alarcon, ed., Balkema, Rotterdam, Netherlands, 111–125.

Ballard, G., and Howell, G. (1994b). “Implementing lean construction: Stabilizing work flow.” *Proc., 2nd Annual Meeting of the Int. Group for Lean Construction*, Santiago, Chile.

Bertelsen, S. (2003). “Construction complexity analysis.” *Proc., 11th Annual Conf. of the Int. Group for Lean Construction*, Blacksburg, VA.

Bertelsen, S. (2005). “Modularisation: A third approach to making construction lean?” *Proc., 31st Annual Conf. of the Int. Group for Lean Construction*, Sydney, Australia.

Crowley, A. (1998). “Construction as a manufacturing process: Lessons from the automotive industry.” *Comput. Struct.*, 67, 389–400.

Dos Santos, A., Powell, J., Sharp, J., and Formoso, C. (1998). “Principle of transparency applied in construction.” *Proc., 6th Annual Conf. of the Int. Group for Lean Construction*, Guaruja, Brazil.

Jeong, J. G., Hastak, M., and Syal, M. (2006). “Supply chain simulation modeling for the manufactured housing industry.” *J. Urban Plann. Dev.*, 132(4), 217–225.

Koskela, L. (1992). “Application of the new production philosophy to construction.” *Technical Rep. #72*, Center for Integrated Facility Engineering, Dept. of Civil Engineering, Stanford Univ., CA.

Koskela, L. (2000). *An Exploration towards a Production Theory and Its Application to Construction*, VVT, Technical Research Centre of Finland, Espoo, Finland.

Liker, J. (2004). *The Toyota Way*, McGraw-Hill, New York.

Manufactured Housing Research Alliance (MHRA). (2005). *Getting lean: Assessing the benefits of lean production in factory built housing*, U.S. Dept. of Housing and Urban Development, Affordable Housing Research and Technology Division, Washington, DC.

Mehrotra, N., Syal, M., and Hastak, M. (2005). “Manufactured housing production layout design.” *J. Archit. Eng.*, 11(1), 25–34.

Milberg, C., and Tommelein, I. (2003). “Role of tolerances and process capability data in product and process design integration.” *Proc., 2003 Construction Research Congress*, ASCE, Reston, VA.

Nasereddin, M., Mullens, M., and Cope, D. (2007). “Automated simulation development: A strategy for modeling modular housing production.” *Autom. Constr.*, 16(2), 212–223.

Ohno, T. (1998). *Toyota production system: Beyond large-scale production*, Productivity, New York.

Productivity Press. (2006). *Visual tools: Collected practices and cases*, Productivity, New York.

Salem, O., Solomon, J., Genaidy, A., and Minkarah, I. (2006). “Lean construction: From theory to implementation.” *J. Manage. Eng.*, 22(4), 168–175.

Senghore, O., Hastak, M., Abdelhamid, T. S., AbuHammad, A., and Syal, M. G. (2004). “Production process for manufactured housing.” *J. Constr. Eng. Manage.*, 130(5), 708–718.

Winch, G. (2003). “Models of manufacturing and the construction process: The genesis of re-engineering construction.” *Build. Res. Inf.*, 31(2), 107–118.