Lean Homebuilding using Modular Technology

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Abstract

This paper describes an effort to apply the principles of lean production to modular homebuilding. To organize the effort, a kaizen blitz was used in a brief, but intense attack on construction waste and inefficiency. Several factors made this effort unique. First, the homebuilder used factory-built modules, which suggested that the improvement team must be extended up the supply chain to include both the modular manufacturer and builder and down the supply chain to include sub-contractors. Second, conventional concepts of continuous flow and batch production were extended to a project oriented construction environment. This paper describes how these issues were resolved and presents actual results. Results included substantial reductions in construction cycle time and significant improvements in safety, quality, productivity and energy efficiency.

1. Introduction

Modular construction is a promising new industrialized homebuilding technology that uses large, factory-produced modules (Figure 1) to construct homes (Figures 2 & 3). The approach differs from conventional stick-built construction, which uses smaller, elemental building components that are fabricated and assembled on the construction site. The primary advantage of modular construction is that most production operations are performed in the factory, allowing the builder/manufacturer to control the building environment and take advantage of modern manufacturing processes. Ideally, modular construction should produce a higher quality home delivered to the customer faster at lower cost.

Figure 1. Setting a typical module

Not all modular homebuilding processes can be moved inside the factory. Modules must still be set on the foundation, joined structurally and made watertight. Site-built structures such as garages and decks must be added. Utilities must be connected between modules and with the main service. HVAC systems must be installed. Local inspectors must ensure code compliance. Interior and exterior marriage joints must be finished. These on-site processes are often thought (and marketed) to be much simpler than conventional stick building. The reality, however, is that these operations are not trivial and can be a source of quality problems, delivery delays, and cost overruns.

Figure 2. Typical modular cape home

Figure 3. Large modular custom home

To address these challenges, a multi-disciplinary group of housing researchers is leading an effort to apply lean production principles to on-site finish operations. The objective of lean production is simple: to use less of everything to design and produce products economically at lower volumes with fewer errors [1]. Five principles have been recognized as fundamental to lean production [1]. These principles and their implications for modular homebuilders are summarized below.

1. Identify what the customer values – modular homebuilders must give their customers flexibility, providing a rich product mix and allowing homebuyers to customize their homes.
2. Identify the value stream (the steps necessary to create value for the customer) and challenge all wasted steps – modular homebuilders have taken an important first step to reduce waste, reconfiguring their supply chains by turning to large Tier 2 suppliers (module manufacturers). These modular manufacturers, in turn, use lean production techniques in their factories to reduce waste and maximize value to the homebuilder. When modules are delivered to the construction site, modular homebuilders must continue to challenge all waste including scrapped materials, delays, rework, and excess labor.
3. Produce the product when the customer wants it and, once started, keep the product flowing continuously through the value stream – this is difficult for modular homebuilders, and even more so for conventional builders. Builders typically rely heavily on independent sub-contractors and building inspectors. To maintain continuous flow, homebuilders must develop partnerships with reliable and flexible subs, accurately schedule activities, and strive to maintain the overall building schedule.
4. Introduce *pull* between all steps where continuous flow is impossible – modular homebuilders must pull subs and inspectors onto the job site when they are needed. Because subs and

inspectors cannot build inventory by producing in advance, scheduling is important to minimize scheduling conflicts and their resulting delays.

5. Manage toward perfection – modular homebuilders must continuously assess their performance, adjust strategies and improve.

To apply these lean production principles, the research group organized and led a kaizen blitz. Kaizen can be defined as "the planned, organized and systematic process of on-going, incremental and company-wide change of existing practices aimed at improving company performance" [2]. In contrast to scientific management approaches that split employees into 'thinkers' and 'doers', kaizen assumes that all employees can make a contribution to problem solving and innovation [3]. The kaizen blitz takes the same improvement philosophy and applies it in a brief, but intense attack on production waste and inefficiency [4]. Both the continuous and blitz forms of kaizen are key elements of lean manufacturing and six sigma production systems [5]. A high quality, high volume modular builder (80-100 homes per year) agreed to serve as the test bed for the effort. This paper describes the approach used, actual results, recommendations, conclusions and future research directions.

2. The Kaizen Blitz Approach

The kaizen blitz was accomplished in three phases, pre-blitz planning, blitz and blitz follow-up.

2.1 Pre-blitz Planning

To prepare for the kaizen blitz, key players met four weeks prior to the event. Participants included the president and project manager from the homebuilder, an engineer from the modular manufacturer, a lean consultant and a housing researcher. The team agreed upon objectives (Table 1), scope, and the preliminary schedule. To focus the effort, project scope was limited to finish activities occurring after the modules are set, the roof is raised and the home is made watertight. These first three activities are typically completed in 1-2 days and are generally considered highly efficient. Dates were finalized. The consultant also led the group in a review of lean production concepts, focusing on the value stream, waste (or muda) and single piece, continuous flow.

Table 1. Kaizen blitz objectives

Benchmark	Units	Target
Productivity	Hr./sq.ft.	Increase 20%
Quality	Repair hr./sq.ft.	Decrease 50%
Cycle time	Days	Decrease 50%
Energy	BTU/sq.ft.	Decrease 50%

2.2 The Kaizen Blitz

The kaizen blitz took place during the week of August 6-10, 2001, in the builder's headquarters and on various construction sites. Full time participants included the builder's president and project manager, the modular manufacturer's production manager and production engineer, the consultant, and three housing researchers.

The first two days were spent on one construction site observing early finish activities for a four-module colonial home. The team initially focused on quality issues, since discrepancies from manufacturing, shipping and set must be identified and repaired before true value-adding activities can begin. Based on observations and discussions with the builder's construction crew, the team developed a list of common quality problems, estimated average repair times and identified likely root causes. Average repair time totaled about 64 man-hours per home. The majority (78%) of these repairs were attributed to transport. Racking and motion caused a large number of drywall cracks as well as nail pops and repainting needs. The factory was responsible for some defects in cabinetry, electrical, window alignment and drywall taping. Factory representatives on the team indicated that most of the manufacturing discrepancies and shipping damage could be avoided by changing factory processes and agreed to follow-up. They also suggested that the builder switch to a faster drying drywall compound to reduce drying time after each of the three coats. Other recommended quality improvements included using metal grates at home entry to reduce dirt tracked inside, changing flashing detail on exterior doors, letting in the dado on all exterior walls, and putting dye in drywall compound for visual detection.

A critical element of home quality is the energy performance of the home, which impacts indoor air quality, comfort and energy costs. The team identified a number of opportunities including uninsulated areas, ineffective gaskets and air barriers, and poor procedures for air sealing at module connections and windows. Recommendations included: 1) insulate the foundation walls rather than the ceiling above the basement, 2) double seal marriage joints with gaskets and foam, with the gasket serving as a backer for the foam, 3) have the factory caulk the electrical outlets and light switches or install a sealed and gasketed box, 4) have the factory seal around the window with foam instead of fiberglass, 5) have the factory install bath and kitchen fans with higher quality dampers to prevent air infiltration, and 6) change band joist insulation to better fill cavities. These changes are expected to cut energy costs by over 40%.

The team discovered several opportunities to improve safety on the construction site, including the use of portable stairs to enter the home (instead of a board), the immediate removal of ship-loose siding to eliminate a tripping hazard, and the use of temporary covers to cover open bulkheads.

The team observed numerous opportunities for improving supervision on the construction site. Workers arrived on site at 7:30 AM, but no drywall work could begin until materials arrived. Daily set-up and tear-down time for carpenters was substantial. Since there were no bathroom facilities or coffee on site, workers left the site for breaks, typically taking more than 45 minutes for each break. Productivity was further reduced by a delay in electrical service. In summary, the team agreed that the project manager should focus on 1) planning and supervising the work so that the right resources (workers, materials, tools, utilities) are available when needed and 2) keeping the workers on the job and working efficiently. More specifically, the team recommended that a Porta-Potty, dumpster, generator and job box be placed on each jobsite.

Also apparent were inefficiencies related to ship-loose materials. Stacks of material were moved repeatedly (up to 12 times) to access one wall and then another. Lost time is estimated at over 2 man-hours. Stepping over the materials created a safety hazard. During the kaizen, the builder and manufacturer agreed on optimal placement of shiploose materials. For example, the manufacturer agreed to place electrical fixtures in the closet closest to the kitchen.

On the third and fourth days of the kaizen blitz, team members moved into the builder's office. Here they estimated labor requirements and developed scenarios for continuous flow. The average value-added labor (man-hours) required to complete each activity was estimated by the builder's project manager and refined by team members. These labor estimates were then allocated to the builder's six-person construction crew, subcontractors and inspectors based on current practices. A summary of the results for the builder's crew is shown in Figure 4. Several points should be noted. First, each crewmember is assigned a variety of tasks, both within and outside of his/her trade, based on previous experience and skills. Second, there is a large variance in the labor hours assigned to each crewmember. This suggests that crewmembers with shorter assignments will be idle as they wait for those with longer assignments. Third, the TAKT time (or demand cycle) was calculated using peak summer sales as shown in Equation 1.

TAKT time = 65 working days / (15 homes / 2 crews) = 8.6 working days / home / crew (1)

In other words, each crew must complete an average of one home every 8.6 working days (68.8 hours) in order to meet average customer demand. This is dramatically less than 13 week (65 working day) delivery time currently promised by the builder, indicating a substantial opportunity to reduce cycle time and related waste. Fourth, optimal construction crew size can be calculated as shown in Equation 2.

Construction crew size = 208 total crew labor hours per house / 68.8 clock hours per house (2)
= 3 crew members

The optimal 3-person crew size is significantly less than the current 5-person crew (plus the supervisor) and is based on several key assumptions: 1) the non-value added activities discussed earlier have been completely eliminated and 2) crew members are sufficiently cross-trained to equally balance the workload.

Figure 4. Average value-added labor per home by crewmember (builder employees only)

Much of the waste in the finish process can be attributed to the batch construction scheduling strategy (Figure 5) employed by the builder. The builder uses two 5-person construction crews. Each crew has up to eight homes under construction at the same time. The builder promises customers that their homes will be completed within 13 weeks (65 working days) from module set. The builder routinely delivers within several days of the promised delivery date. Note that the home is idle for most of the 13 week construction cycle. This clearly violates the third principle of lean production – keep the product flowing through the value stream. In the context of finishing the modular home, this principle suggests single home flow - starting and completing one house at a time (Figure 6). This impacts both cycle time and productivity. Using single home flow, far less time will be spent traveling between multiple construction sites and setting-up/tearing-down equipment. No longer will construction inefficiencies be masked by moving the crew to another home, creating travel-related inefficiencies. For example, a delay caused by an electrical subcontractor not completing the rough-in is masked by the carpenters (who cannot finish the drywall until the wiring is completed) moving to another site. Single home flow exposes problems so that they can be addressed immediately. The extended cycle time resulting from batch construction also permits other problems to develop. Customers may simply change their minds, damage can occur and the home must be cleaned.

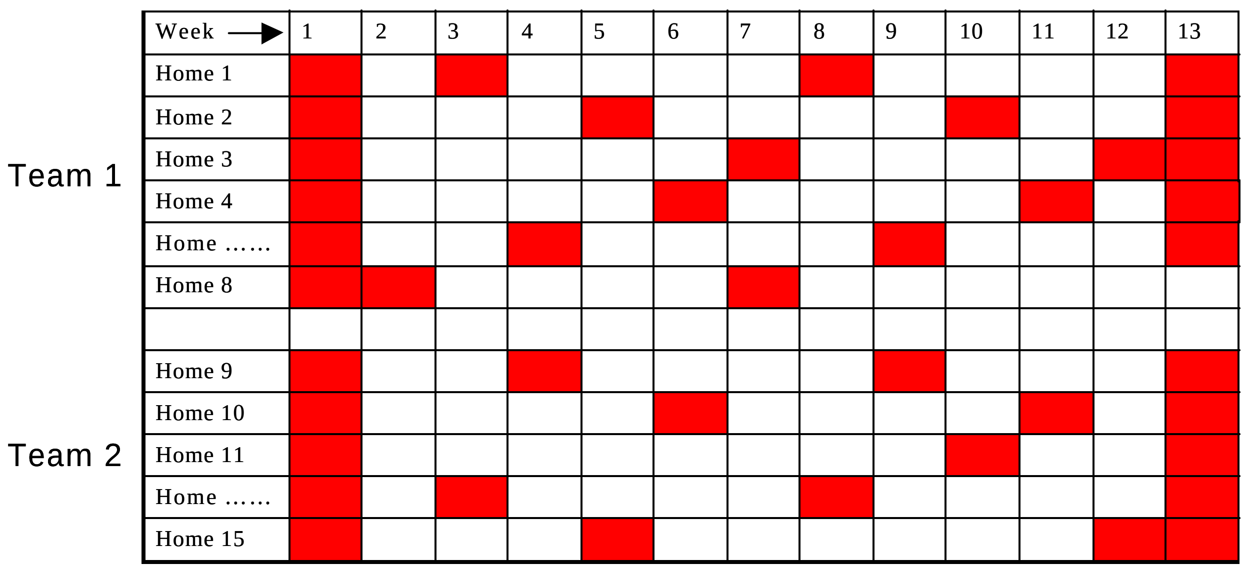

Figure 5. Current batch construction scheduling strategy

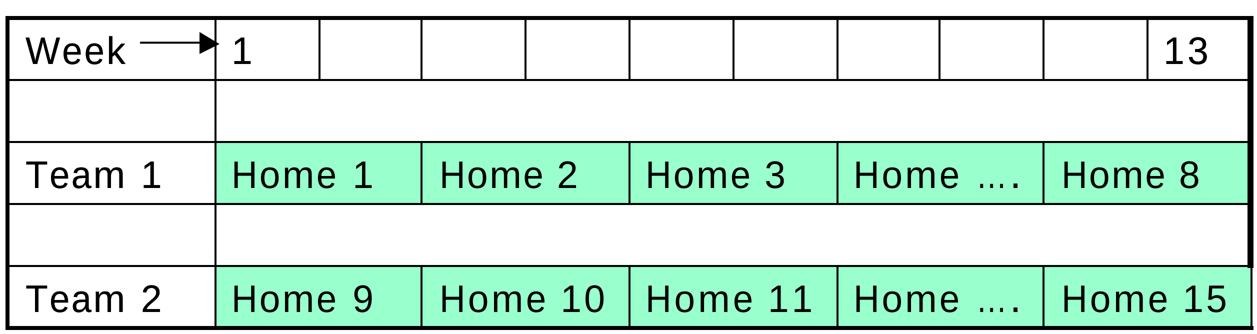

Figure 6. Single home construction approach recommended by the team

The team next developed a construction plan using MS PROJECT, assuming single home flow. Potential precedence relationships were identified and process times were estimated, assuming no non-value added tasks and a crew size of three. Subcontractors and building inspectors were included in the plan, using conservative estimates for their response times. A critical path analysis of the construction plan indicated that a typical home could be completed in about 10 working days.

On the final day of the kaizen blitz, the team summarized and presented findings and recommendations to the builder's staff. Using staff feedback, the team agreed to add another week to the cycle time to reflect delays inherent in the construction process (i.e., weather, building inspectors). After discussion, the builder committed to making most of the recommended changes.

2.3 Blitz Follow-up

In October 2001, reporting to a group of modular manufacturing executives, the president of the builder reported that they were making considerable progress and many new policies and scheduling changes had been applied. He noted that although they have only begun the process, they have already reduced cycle times from 13 weeks to 8 weeks per house. This progress was made by reducing some of the waste identified during the kaizen and by tighter scheduling. The builder did not attempt single home flow, citing a lack of confidence in the details of the recommended construction plan and in the willingness of subcontractors to comply. The builder also indicated that they were distracted by an increase in sales and the need to bring on a second module supplier due to excessive lead times.

Researchers conducted a 2-day follow-up visit to the builder in August 2002. The objective was to restart the builder's improvement process. The primary focus was the development of a more realistic construction plan, incorporating additional detail and refining precedence relationships between activities. In addition to the original participants, subcontractors were invited - to introduce them to the concept of single home flow and to gauge their commitment. Several key subs attended and all expressed a willingness to maintain a tight construction schedule, with sufficient advance notice. The resulting construction plan (Figure 7) yields a construction cycle of about 30 work days during the winter and about 20 days during the remainder of the year. During the cold winter months, the builder requires the heating system to be operational before finishing the drywall. The builder also decided to organize around a 4- person crew, the minimum considered practical. Note that all red tasks in the plan are on the critical path. The remaining blue tasks are non-critical with slack times shown to the right of the bars. Slack times indicate how long the task can be delayed without impacting the overall schedule.

3. Conclusions and Future Research

Modular homebuilders can apply the principles of lean production to achieve substantial improvements in safety, quality, cycle time, construction costs and energy performance. Transitioning from multi-home batch construction to single home flow is believed to be particularly important, since it is essential to cycle time reduction and related quality/cost improvements.

Future research is likely to focus on several areas. First, the authors hope to continue to work with the builder, particularly in the area of subcontractor partnering. Electricians and plumbers are notoriously independent. Therefore their cooperation will be essential in achieving single home flow. Second, the lessons learned in this exercise must be documented and transferred to other builders through a training program. It is imperative that gains are consolidated and that energy efficiency improvements are closely coupled with any transfer of this technology to other builders.

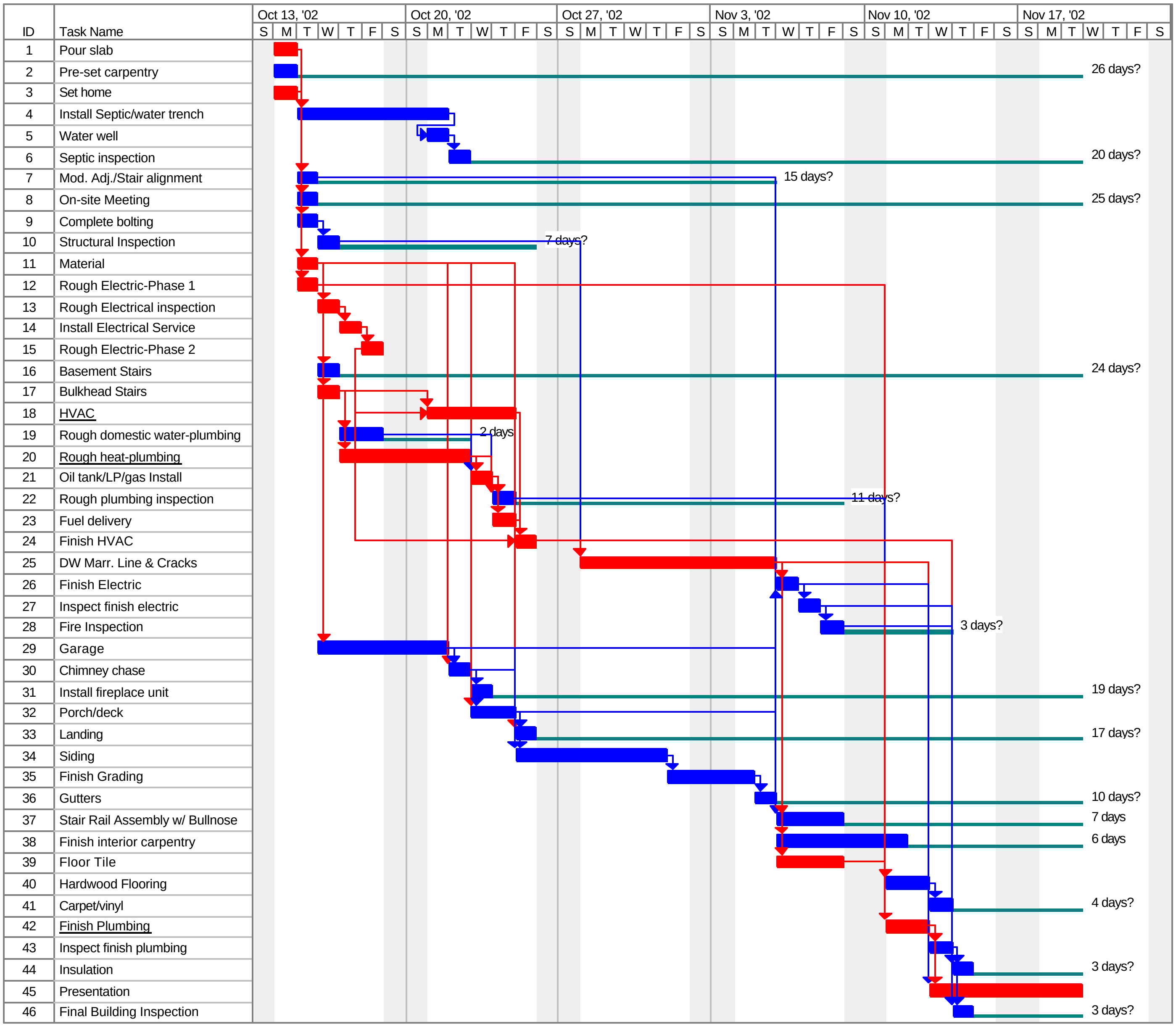

Figure 7. Typical construction plan for modular home finish during winter months

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