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Redesign Production Process in Housing Using Lean Principles and Value Stream Mapping



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Redesign Production Process in Housing Using Lean Principles and Value Stream Mapping



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Summary

Lean construction has recently attracted considerable attention in the home building industry. Lengthy delivery time and significant waste in the construction process have caused many homebuilders to seek a more effective production model that will increase process reliability, reduce total lead time and improve overall product quality. Although housing construction provides the closest analogy to manufacturing, a high level of variability prevents the direct transplantation of lean paradigm and techniques. Supported by CMHC, and in collaboration with a local homebuilder, researchers developed a systematic approach using Value Stream Mapping (VSM) techniques to analyze the current process and to formulate a lean production model. After an 18-month implementation, significant improvement has been seen in terms of cycle time, process reliability and product quality.

Résumé

Depuis tout récemment, les constructeurs d'habitations s'intéressent beaucoup à la construction dite « allégée ». En effet, les longs délais de livraison et le volume important de déchets produit par le processus de construction incitent de nombreux entrepreneurs à rechercher un modèle de production plus efficace pouvant accroître la fiabilité du processus, réduire les délais de production totaux et améliorer la qualité générale du produit. Bien que la construction résidentielle et la production manufacturière aient beaucoup de points en commun, la grande variabilité propre à la première empêche l'adoption directe de tous les paradigmes et techniques d'allégement mis en œuvre pour la seconde. Bénéficiant du soutien de la SCHL et en collaboration avec un constructeur d'habitations local, des chercheurs ont mis au point une méthode systématique pour analyser le processus actuel et élaborer un modèle de production allégé au moyen des techniques de cartographie de la chaîne de valeur (CCV). Après une période de mise en œuvre de 18 mois, des améliorations considérables ont pu être constatées au chapitre du temps de cycle, de la fiabilité du processus et de la qualité du produit.

Acknowledgments

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1.0 Introduction

In North America, the home building industry has changed little since the 1920s, when the wood platform-frame structure emerged as the standard building technology. While advances in tools and materials have led to some incremental improvements, the fundamentals of the construction process remain almost identical and no significant improvements in productivity have been observed ^[1]. In contrast, other industries have experienced remarkable productivity improvements through the application of innovative technologies and operation management tools. A recent example is the automobile industry, where manufacturers have dramatically improved productivity through the adoption of a new production philosophy which has led to the ‘lean production system’. Popularized by Womack’s book, *The Machine That Changed the World* ^[2], ‘lean theory’ has been widely employed by a range of industrial sectors in the past decade.

Research on the implementation of lean theory in construction began in the early 1990s, when Koskela wrote a groundbreaking paper, “Application of the New Production Philosophy to Construction” ^[3]. This notion quickly attracted the attention of researchers in residential construction. Gann and Barlow et al. compared industrialized housing with automobile manufacturing in Japan, highlighting the similarities existing in their production strategies, but the focus of the papers was on product development, supply-chain coordination, marketing and sales, rather than on fundamental construction practices ^{[4][5]}. Zhang et al. proposed a waste-based management approach that considered all process inputs, including labour, equipment, materials, data and information, work space and time, as potential sources of waste ^[1]. Two case studies in housing construction were presented to demonstrate that minimizing resources waste would significantly improve productivity and quality. Ballard suggested that variability was the major source of waste in construction and that even flow production could increase the reliability of work flow and thus reduce cycle time in home building ^[6]. Bashford et al. further discussed implications of even flow production and concluded that the strategy had minor impact on construction duration, but could significantly reduce workflow variability ^[7].

The research presented in the report continues Ballard and Bashford’s efforts on house production flow management, but proposes a new lean production model by utilizing Value Stream Mapping (VSM). VSM, referred to at Toyota as Material and Information Flow Mapping, is the most commonly used tool in lean planning. It helps lean system practitioners to think about

flow instead of isolated wastes and to implement a lean system instead of individual lean techniques. Some research has been done in the application of VSM to construction, but these efforts have either focused on macro-process levels, such as supply chains ^[8] ^[9] and project delivery ^[10], or on single operations, such as masonry ^[11] and components manufacturing ^[12]. No report has yet been found on the use of VSM for fundamental construction process improvement.

A number of factors impede the application of VSM to the main construction stream at the operational level. First, an underlying prerequisite for VSM is the repetition of the production process. In manufacturing, hundreds of thousands of products in a product family pass through similar processing steps, so it is favourable to develop and implement a lean system to continually improve that process. A construction project, in contrast, presents a unique design, specifications and context and thus must be constructed accordingly, following a unique construction process (value stream). Since VSM requires diligent management commitment coupled with massive efforts in systematic data capture and analysis, lean training, core implementation team assembly and working process transformation, practitioners have been hesitant to invest such efforts to improve a process that may not recur. Second, VSM is a quantitative tool that uses a list of process data to depict the current state of the process and to determine what the future state will be. Construction companies, however, generally do not fully track construction processes. Moreover, most of the construction steps are lengthy and subject to numerous variables. Site investigation is useful to assist researchers in understanding the process, but it has proven nearly impossible to collect statistically meaningful data in a short time period. Third, key concepts/elements used in VSM, such as cycle time, change-over time, up-time and inventory, are defined in the context of manufacturing and seem non-applicable to construction.

Although the construction industry as a whole is defined very differently from manufacturing, homebuilding, as a unique sector in construction, provides the closest analogy to automobile production ^[13]. Its distinctive features, including high production volume (repetitiveness), controllable production flow and large inventory of work in process, make the application of VSM here favourable ^[14]. In the research, a four-phase methodology was adopted to develop the lean production model.

- 1) Work with representatives from construction management and all major subcontractors to draw a process flowchart of the entire homebuilding process. A VSM session conducted at

this level can identify the areas where wastes have accumulated and problems with handoffs occur over and over.

- 2) Five workgroups consisting of construction managers and related subcontractors work on five construction stages to map the current state of each construction stage. Mapping is conducted at construction activity level and data collected in the production tracking system are used to calculate the key attributes of tasks. This type of VSM pinpoints hidden problems and existing wastes.
- 3) A future state map is created by each working group. The major challenge of this phase is how to apply lean principles into the homebuilding process and identify the lean tools and the improvement methods. The future state map shows where these tools and methods are to be used.
- 4) Compile five future state maps into a future process chart, which becomes the overarching goal of company's lean implementation.

2.0 Flowchart of the Current Homebuilding Process

Landmark Homes started the lean production model development project with two 2-day sessions, which gathered all the company's management, construction managers, site managers and representatives from major subtrades. Each session targeted half of the homebuilding process. An external lean expert facilitated the session, and the author provided technical support, including documenting the discussion results and validating the flowchart with actual operations data. Figure 1 shows the second session where Landmark Homes' construction/site managers and related trade representatives mapped the second half of the homebuilding process, from Electrical Rough Finish to Pre-possession Orientation.

A process flowchart, instead of Value Stream Map, was selected as the first step in lean production model development due to the following three reasons:

- Process flowchart is a common type of chart used widely in engineering and business to document, analyze and manage processes. The chart is self-explanatory: it shows steps as various boxes and shows their order by connecting those boxes with arrows. No training is needed to understand or develop the flowchart.
- The focus of the flowchart is to document a process flow. It provides a big picture of the process, but does not involve a detailed description of each step. This feature makes it an

ideal tool for large group mapping sessions, where actual operations data are not always available.

- As a high-level process map, it facilitates communication between all stakeholders by carrying overall objectives and a focus on the initial areas of improvement.



Figure 1: The Process Flowcharting Session

Figures 2 and 3 show the process chart that was developed in the sessions. The focus of the mapping was on labor flow with each box in the map representing a construction task. The duration of each task and waiting time between the tasks were estimated based on the experience of site managers and related subtrades representatives. As shown in Table 1, the estimate in the flowchart provided a better description of the actual situation than the standard schedule had. The difference can be explained by the tendency of people to exclude abnormal situations, which leads to high deviation and longer construction times (see Table 2). At the end of each session, a team consisting of site managers and representatives of major subtrades was assigned to each construction stage to verify the corresponding section of the flowchart and to further develop the

value stream maps and improvement plans for each stage. The author joined the lean teams that targeted Stages 1 and 2 and who were responsible for providing technical support for all the lean teams. Support included historical operations data, cross-examination of value stream maps developed by each team and compiling all maps into an overall process map.

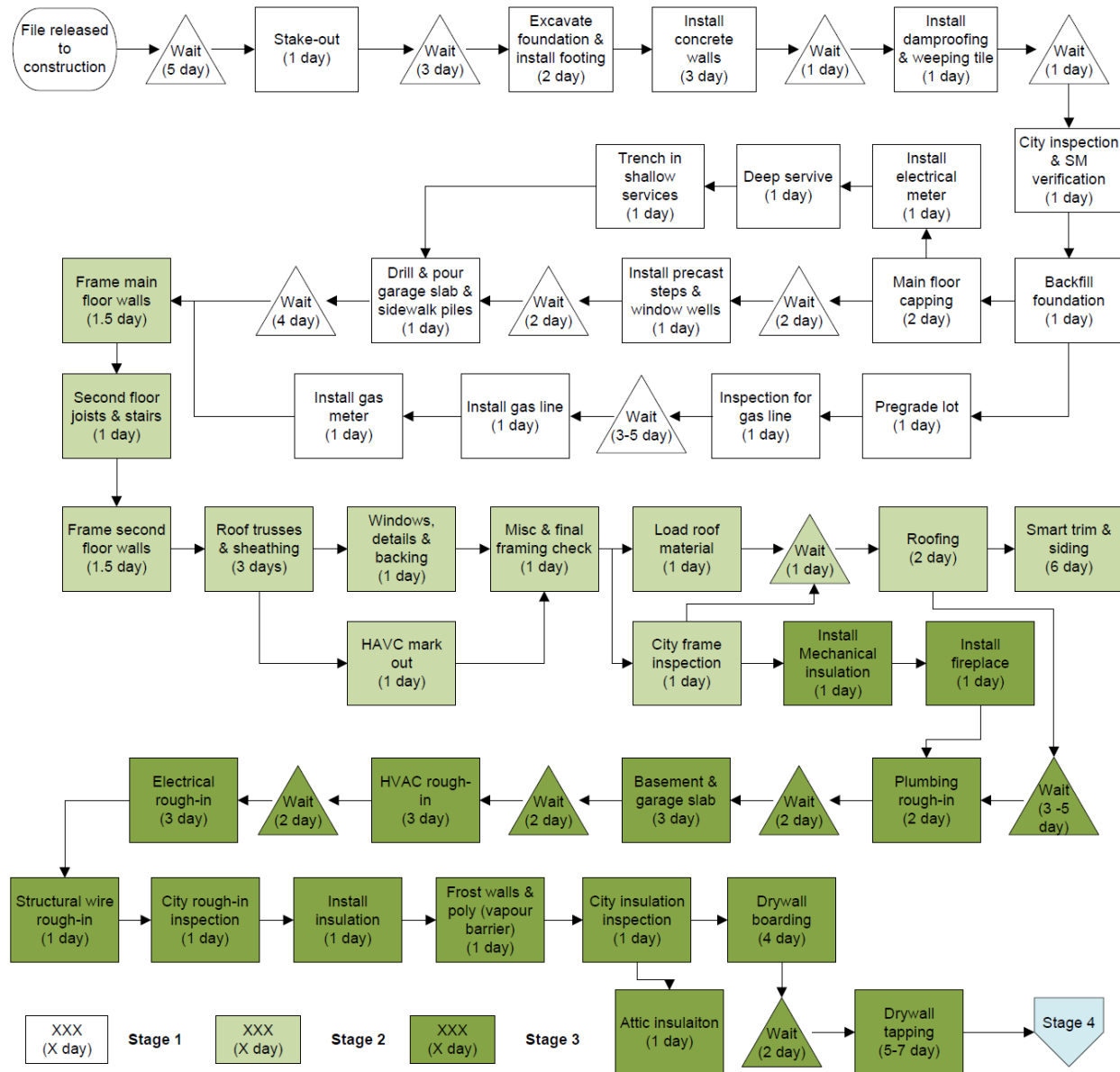


Figure 2: Homebuilding Process Flowchart (Stages 1-3)

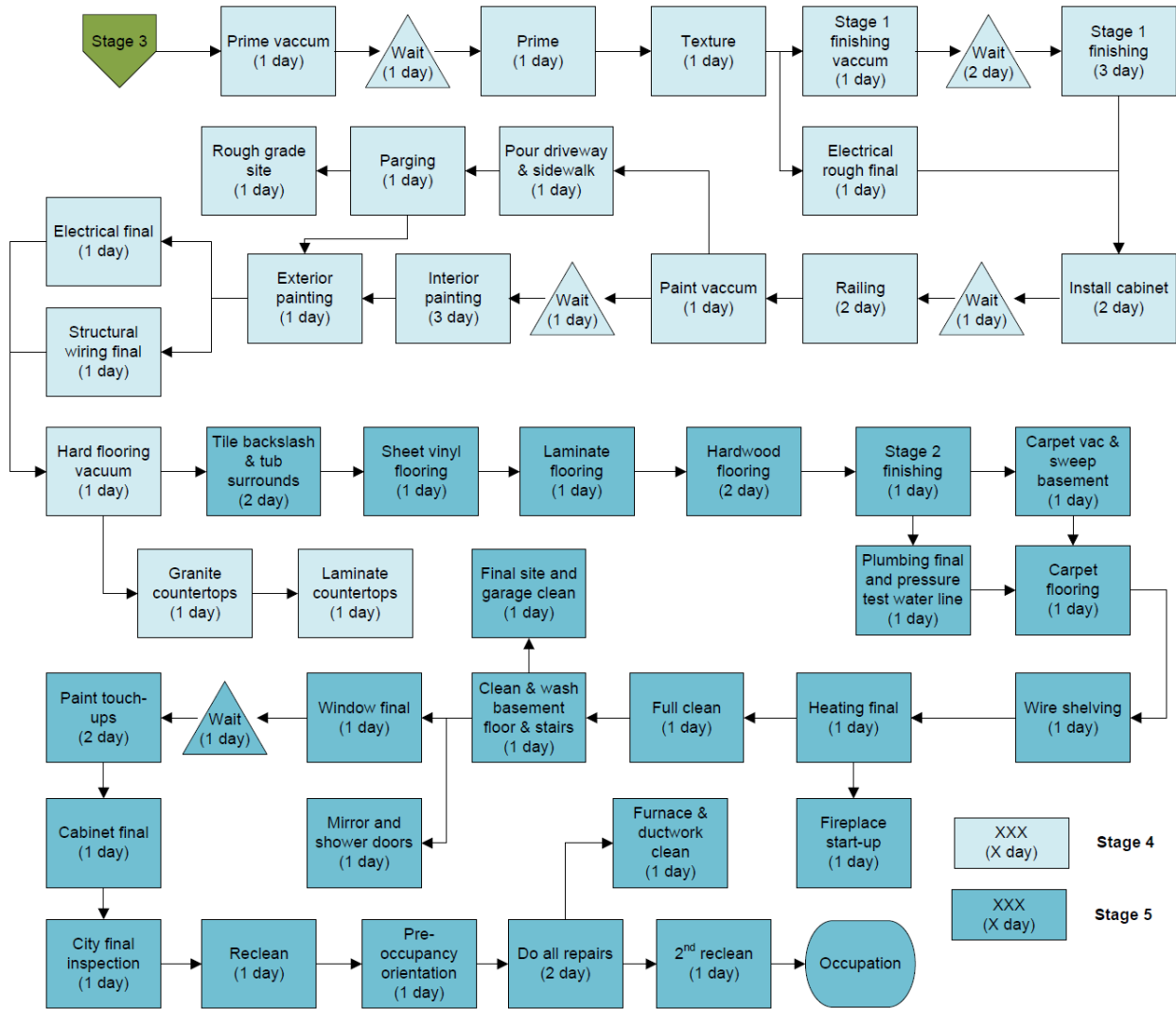


Figure 3: Homebuilding Process Flowchart (Stages 4 and 5)

Table 1: Construction Cycle Time Comparison

	Stage 1 Foundation	Stage 2 Lock-up	Stage 3 Rough-in & Drywall	Stage 4 Pre-finals	Stage 5 Finals	Total
Estimated Construction Time (working day)	31	18	36	23	23	131
Estimated Construction Time (calendar day)	43	25	50	32	32	182
Actual Construction Time Average (calendar day)	75	31	54	42	26	228
Construction Time in Standard Schedule(calendar day)	22	25	22	18	16	103

Table 2: Construction Stages and Descriptive Statistics (2007 Data)

	Stage 1 Foundation	Stage 2 Lock-up	Stage 3 Rough-in & Drywall	Stage 4 Pre-finals	Stage 5 Finals
Start Task	Stake out	Main floor capping	Plumbing rough-in	Prime vacuum	Tile flooring
End Task	Drill and pour garage & sidewalk piles	Roofing	Drywall taping	Hard floor vacuum	Occupation
Number of Tasks on main stream	9	10	11	13	20
Actual Duration Average (calendar day)	73	31	54	42	26
Standard Deviation	35	14	20	14	7
Coefficient of Variation	48%	45%	37%	33%	27%
Scheduled Duration (calendar day)	20	25	22	18	16
Difference (Actual - Schedule)	53	6	32	24	10

3.0 Data Collection and Key Measurements of Value Stream Mapping

As a quantitative tool, VSM uses a list of descriptive statistics to depict the current state of the process and to determine what the future state will be. In VSM exercises, one of the most important steps is to get detailed, real-time data related to the value stream. A common rule is to bring a stopwatch while walking along the actual pathways of material and information flow and to rely only on information obtained firsthand. However, most of the construction tasks are lengthy and have high variability in task durations and queuing times. Complexities in the construction process make it virtually impossible for an individual researcher to collect sufficient data merely through site observations.

Landmark Homes has an intranet-based production tracking system in which site managers record the booking date, confirmed start date, actual start date and actual finish date of every task in the construction process (Figure 4). Based on the data exported from the tracking system, the author developed a data analysis tool to calculate basic operations measurements. Figure 5 shows the system structure of the developed data processing tool. Operational data are extracted from LGB's intranet through open database connectivity (ODBC) and saved in a raw data table. The analysis module calculates the statistical attributes required by VSM, such as cycle time (CT), lead time (LT), waiting time between tasks (WT) and percent started on schedule (PSS). The system provides the capacity to calculate the descriptive statistics of data in any given time period or geographical area as shown in Figure 6. This system is now used by managers of Landmark Homes to monitor the current projects in construction and evaluate the performance of site managers.

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9461 - 219 Street NW - J1-07-005
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 Base Start: 02-May-07 Base Finish: 04-Oct-07 Base Duration: 156 day(s) Deficiency Maintenance Outstanding Deficiency

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Job detail	PO	Task Name	Email Print	Resources	Base Duration	Booking Date	Requested start date	Confirmed start date	Actual Start	Actual Finish	Project Start	Project Finish	Base Start	Base Finish	Task Delay	Task No
40	-	for foundation														
41		3 - Backfill & Shallow Trenching	E B		1	25-Jun-07		27-Jun-07	27-Jun-07	27-Jun-07	27-Jun-07	27-Jun-07	22-May-07	22-May-07		
43		Backfill Foundation	E B		2	25-Jun-07		27-Jun-07	27-Jun-07	27-Jun-07	27-Jun-07	27-Jun-07	22-May-07	22-May-07		
45		Shallow Services	E B		1	28-Jun-07		05-Jul-07	05-Jul-07	05-Jul-07	05-Jul-07	05-Jul-07	23-May-07	23-May-07		
46		Drill & place piles	E B		1	25-Jun-07		25-Jul-07	25-Jul-07	25-Jul-07	29-Jun-07	29-Jun-07	24-May-07	24-May-07		
47		Precast products	E B		1	27-Jun-07		03-Jul-07	04-Jul-07	04-Jul-07	04-Jul-07	04-Jul-07	24-May-07	24-May-07		
48		Window wells	E B		1	N/A	N/A	N/A	N/A	N/A	28-Jun-07	28-Jun-07	23-May-07	23-May-07		
54		Booking & Ordering #2	E B		1	N/A	N/A	N/A	N/A	N/A	28-Jun-07	28-Jun-07	23-May-07	23-May-07		
55		Gas Line Site Readiness Inspection	E B	Atco Gas	1	28-Nov-07	28-Nov-07	28-Nov-07	28-Nov-07	28-Nov-07	02-Jul-07	02-Jul-07	25-May-07	25-May-07		
56		Underground gas line installation	E B		1	28-Nov-07	30-Nov-07		06-Dec-07	06-Dec-07	12-Jul-07	12-Jul-07	06-Jun-07	06-Jun-07		
57		4 - Capping & Shallow Services	E B		1	18-Jul-07		24-Jul-07	24-Jul-07	24-Jul-07	02-Jul-07	02-Jul-07	25-May-07	25-May-07		
58		Main floor joists & subfloor package	E B		1	24-Jul-07		25-Jul-07	30-Jul-07	03-Aug-07	02-Jul-07	02-Jul-07	25-May-07	25-May-07		KTC Construction

Trusted sites 100%

Figure 4: LGB's Construction Production Tracking System

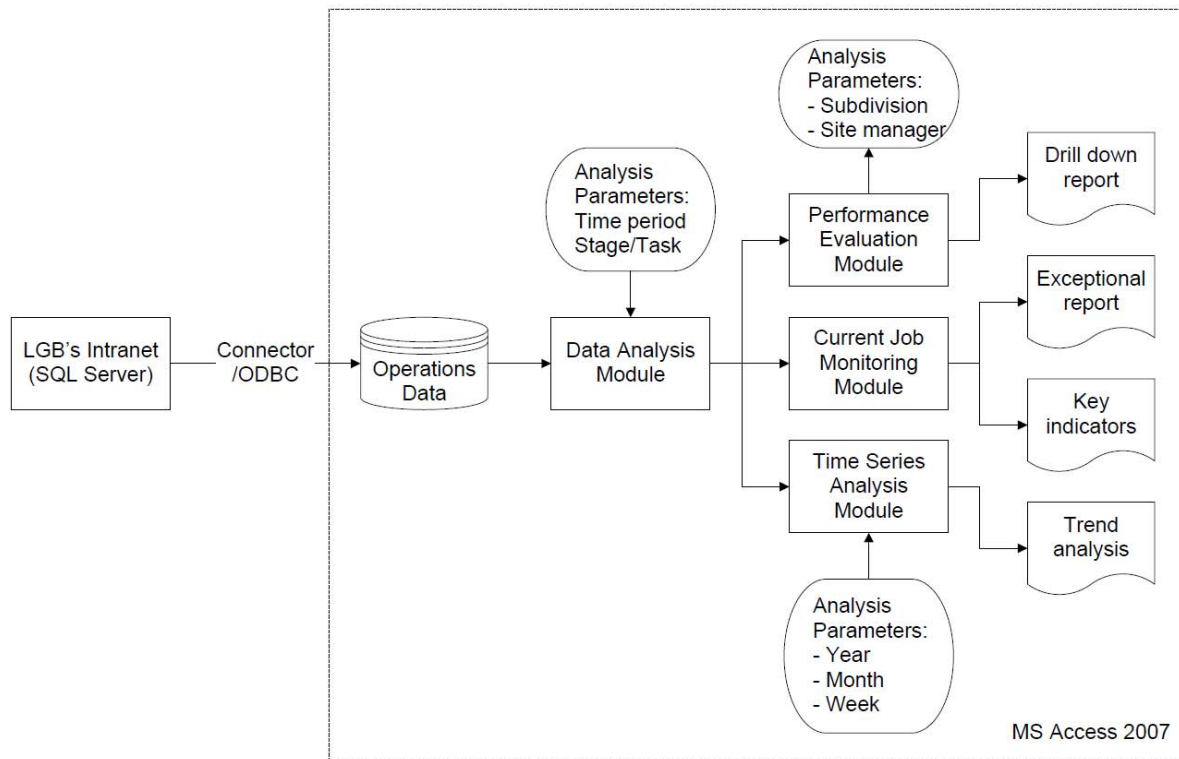


Figure 5: Data Analysis System Structure

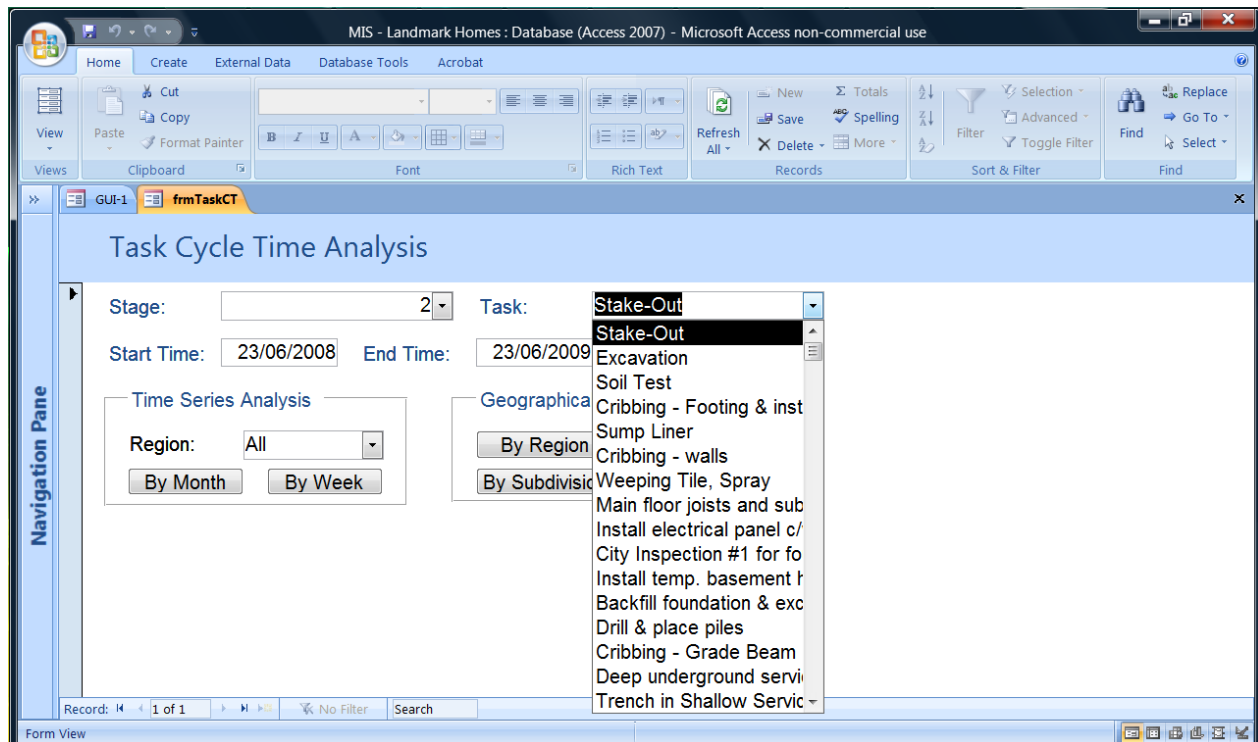


Figure 6: User Interface of Task Cycle Time Calculaiton

A major factor impeding the application of VSM to the main construction stream at the operational level is that key concepts/elements used in VSM, such as cycle time, change-over time, up-time and inventory, are defined in the context of manufacturing and seem non-applicable to construction. To apply VSM in construction, the author redefined most of the concepts used in traditional VSM and designed two new measurements, booking time (BT) and percent schedule started (PSS), as shown in Table 3. After discussion, the management of the company and core lean implementation team selected six key attributes, including cycle time (CT), changeover time (CO), lead time (LT), yield rate (Y), percent schedule started (PPS) and waiting time (WT). Since no historical record is available on changeover time and yield rate, they were estimated by site managers and related subtrades through group discussion. The other four attributes were calculated by the author using a data analysis system.

Table 3: VSM Key Elements ^[15]

Key Concepts	Definitions	Formula
Cycle Time (CT)	The duration that a sub-trade needs to complete its work package.	$CT = \text{Actual finish date} - \text{Actual start date}$
Lead Time (LT)	The time that a sub-trade needs to deploy its crew to a given job.	$LT = \text{Confirmed start date} - \text{Booking date}$
Waiting Time (WT)	The time that elapses between one task being completed to the next task being started. In lean system, WT serves as a time buffer to shield downstream crews from upstream variability.	$WT = \text{Actual start date of task } i+1 - \text{Actual finish date of task } i$
Available Production Time (APT)	The number of workdays available for trade contractors doing the construction.	$APT = 365 - \text{Weekends} - \text{Holidays}$
Changeover Time	The time that a crew needs to switch from working at one house to another, including demobilization and mobilization.	
Uptime	A measure of the proportion of APT that is actually used on construction, in percentage.	$\text{Uptime} = (\text{APT} - \text{Bad weather days} - \text{Changeover time}) / \text{APT}$
Work-in-process (WIP)	Number of uncompleted houses in the value stream, including the houses in construction and those standing idle waiting for sub-trades.	
In-process inventory / Supermarket	The backlog of ready houses that stands idle waiting for the start of a given task. In lean system, it serves as a buffer to protect the continuous workflow of downstream crews.	$\text{Number of houses in inventory (NOI)} = WT / \text{Operational takt time}$
Yield	The percentage of houses that go through an operation correctly, without any rework.	
Takt time	Takt time is the rate at which a homebuilder must build houses to satisfy customer demand.	
Operational takt time	It is the actual takt time used in process leveling. It considers the influences of system problems, such as bad weather, rework, changeover, and so on.	$\text{Operational takt time} = \text{Takt time} / \text{Uptime}$
Number of crews (NOC)	The number of teams that are working parallelly on the same task.	$\text{NOC} = CT / \text{Operational takt time}$
Percent Schedule Started (PSS)	A measure of the proportion of start-date promises made by sub-trades that are delivered on time, in percentage.	$\text{PSS} = \text{Number of tasks started on schedule} / \text{Total number of tasks}$

4.0 Value Stream Mapping (Case A – Stage 1)

Stage 1 is the most problematic segment. The scheduled duration of Stage 1 is 20 days, but houses actually spend an average of 73 days (365% of the scheduled duration) in this stage. In addition, a large standard deviation (35 days) indicates that the construction process in Stage 1 was not effectively controlled and that a high potential exists to reduce construction time by redesigning the process.

Figure 7 is the current state map of Stage 1, which was drawn up in July 2007. The conventional approach of residential construction management is based upon a management model which views the construction process as a series of tasks to be completed in sequence ^[16], and each house is scheduled and managed individually as a small project using a Gantt chart or Critical Path Method (CPM). The map shows the main flow of Stage 1 where 11 trade crews (represented by activity boxes) are involved. VSM provided an opportunity to view the construction process in a whole new light. Each trade can be seen as a workstation, and the

construction process becomes a production line. Instead of tasks occurring at an individual house in sequence, houses go through a set of operations performed by subtrades.

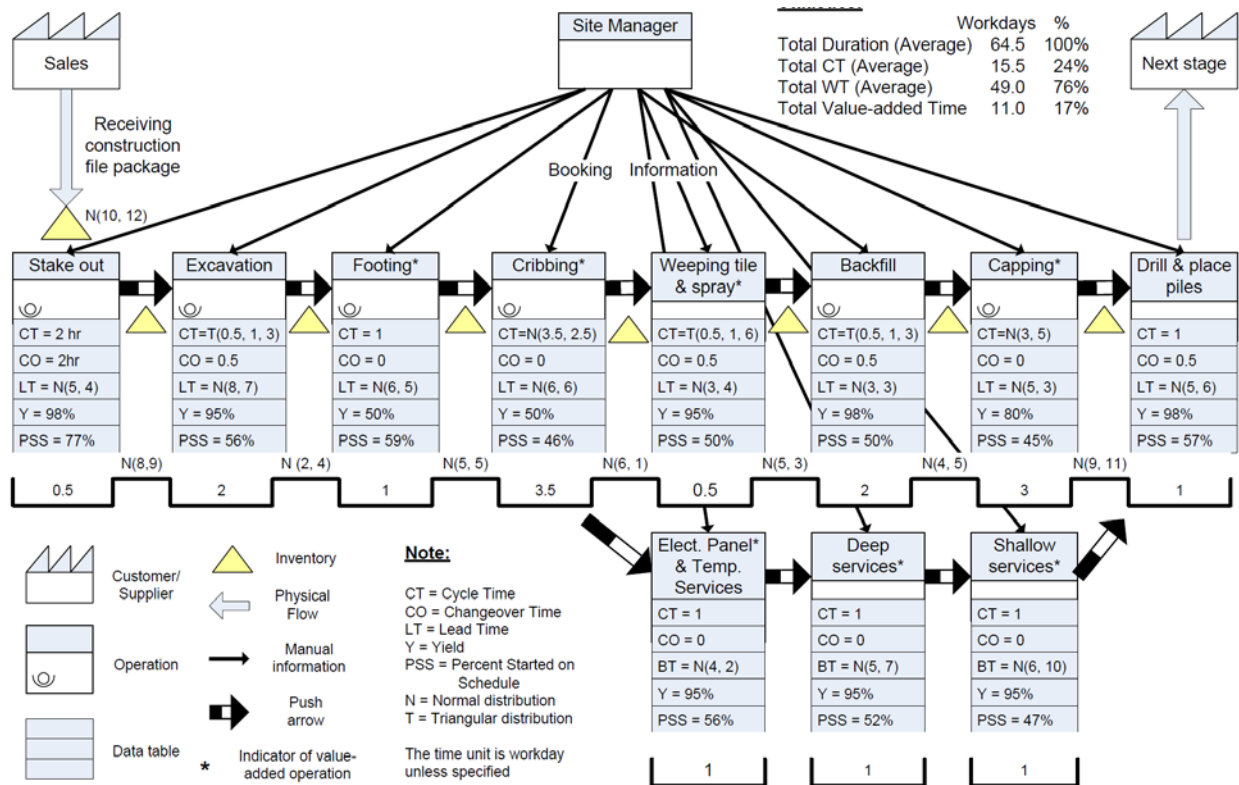


Figure 7: Current State Map of Home Building Process (Stage 1)

Unlike typical value stream maps used in the manufacturing industry, attributes of each task are not a constant, but are expressed in the form of distribution in order to reflect high variability in the construction process. Site managers are the center of production control. Due to the unpredictability of both the market and the construction process, home building is essentially a “make-to-order” business. No overall production schedule exists in the home building company, and construction is triggered when the file of a new house is released by sales. Subsequently, the responsible site manager starts booking material and sub-trades and tries to push the process as quickly as possible. Meanwhile, no look-ahead schedule is available for trade contractors. The booking information is generally issued by site managers via phone or fax on a task-by-task basis.

Upon drawing up the current state map, several wastes can be identified immediately. In this case, the first observation was that waiting times were very lengthy. The total duration of Stage 1 was 64.5 workdays, but waiting time accounted for 49 workdays. This means that houses in construction stood idle about 76% of the time, with no construction activity on site. According to

a study done in the U.S., on average, every day a house sits empty costs \$291 ^[17]. One apparent cause of the long waiting time was the high level of variability of the process. The lead times and cycle times of tasks in the map vary greatly. Six of 11 tasks have lead times with a standard deviation in excess of five days, and the cycle times of five tasks must be described using statistical distributions. In the current practice, site managers booked the downstream subtrade immediately following confirmation of the start date of the upstream tasks. The intention of this practice was to shorten construction duration by overlapping lead time and task cycle time, but the actual result was that nearly half of the tasks could not begin on the scheduled start date (the average PSS on the current state map is 54%). The temporary nature of the contract relationship between the homebuilder and trade contractors magnified any delay in the schedule through a ripple effect. For example, bad weather (e.g. heavy rain) prevents the excavation from commencing on the confirmed date for a given house. Since the excavation subtrade has already scheduled other jobs in consecutive days for other homebuilders, the delayed job has to be rescheduled to the end of its working schedule. Moreover, since the downstream task (in this example, pouring of footings) cannot begin until the excavation is complete, the site manager has to cancel original bookings and attempt to get new commitments based on the newly scheduled excavation date. However, from the perspective of the footing contractor, a sudden schedule change means that it must find a new job fitting for that time slot in a very short period of time. Then, over-booking (i.e. sub-trades accept jobs exceeding their capacity) has become common practice. Consequently, a greater number of tasks fail to begin on the scheduled start date and lead time becomes even more unpredictable.

Second, variations in cycle time were relatively high, especially for tasks whose cycle times were described in distributions. Site managers had reported that the major cause of high variation was not workload differences between house models, but the manner in which sub-trades carried out their respective jobs. They had the tendency to deploy their crews continuously on new jobs where large quantities of work were available, leaving uncompleted, minor details to rework crews. These rework crews followed separate working schedules and usually arrived several days later to finish the job. Quality problems were another cause of high variation in cycle time. It had not been rare, for example, that the crews who installed the main floor spent one day cleaning the beam pockets and leveling the top of the foundation walls.

Based on the analysis of current practice, the workgroup determined that the lean initiative goal for Stage 1 were increasing productivity by stabilizing the process, reducing lead time and eliminating defects. Accordingly, the lean metrics shown in Table 4 were developed in order to clarify the goal and track progress.

Table 4: Lean Metrics (Stage 1)

Metrics	Baseline	Goal*
Variation of production CT (workdays)	Up to 5	1
Total waiting time (workdays)	50	25
Value-added ratio	17%	25%
Average percent started at schedule (PSS)	45% - 77%	90%
Yield	50% - 98%	100%

* Goal was decided after future state mapping.

The focus of future state mapping is to eliminate the root causes of wastes and to link the value stream in a smooth flow. Unlike manufacturing, where the fundamental problem is overproduction caused by “batch and push” ^[18], the home building industry suffers most from variability. Unpredictability of the process causes all kinds of waste, not just of long lead times and excess inventory. Uncompleted houses are vulnerable to weather, requiring temporary protection; to pilferage, requiring security and extra materials; and to vandalism, causing rework. Variability also results in fluctuation of the production flow. This means that homebuilders need to sustain a large workforce pool and cannot provide stable work flows to trade contractors. In order to reduce the variability of the process, the following four measures were taken in the future state mapping (Figure 8): establishing a production flow and synchronizing it to takt time (the maximum time per house allowed to complete a task in order to meet demand); leveling production at pacemaker task; restructuring work; and improving operation reliability with work standardization and total quality management.

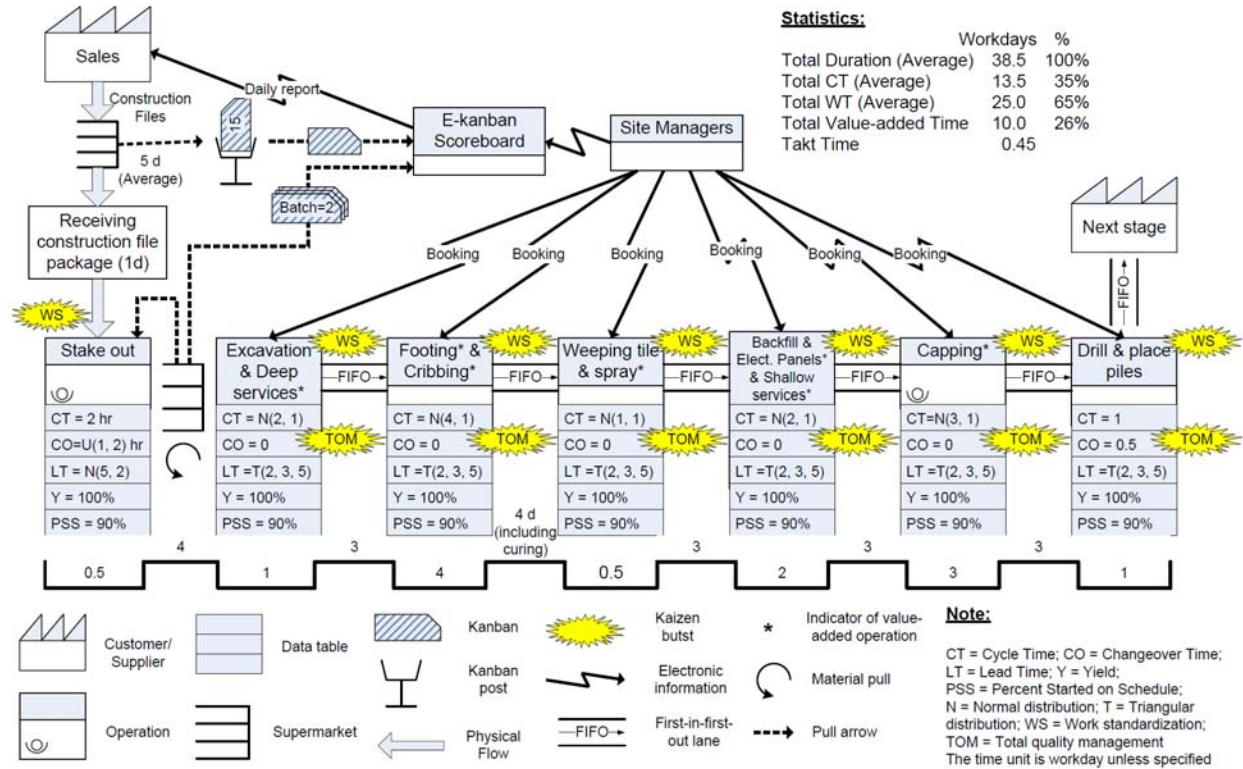


Figure 8: Future State Map of Home Building Process (Stage 1)

4.1 FIFO-Lane-Based Flow and Its Synchronization

In manufacturing, continuous flow forms the centerpiece of the lean production system and is regarded as the most effective way of production. Nevertheless, the production system built on continuous flow can only be used for a reliable process. As the system is fully synchronized, any small delay or breakdown in one operation will result in halting the entire system. Housing construction is a site-based production (as opposed to factory-based manufacturing). Weather and site conditions have a significant impact on the execution of construction activities, so variation in task duration is unavoidable. In addition, the housing construction process is a long process involving more than 60 work “packages” (tasks). Connecting all the tasks into a continuous flow would make the system very fragile. Finally, construction work is performed by various trade contractors who have individual interests and are almost exclusively concerned with the efficient execution of their individual tasks^[19]. Therefore, keeping an excess capacity buffer to overcome minor flow fluctuation is not practical for homebuilders.

Another important lean tool, supermarket-based pull flow, is also non-applicable in house construction. A pull-flow system is controlled by the pacemaker task, where customer orders

enter the production system. In manufacturing, the pacemaker is typically the most downstream task in the value stream, and the production pace of all upstream tasks is “pulled” by the pacemaker. The pacemaker acts at the beginning of the process. In order to develop a stable flow from the pacemaker task to the downstream end of the value stream, a FIFO-lane-based flow system is proposed based on the theory of last planner described by Ballard ^[20].

With the help of statistical analysis, the construction manager of the company can predict with great certainty the total number of houses that will enter the production system in the course of a given month, but it is virtually impossible for site managers to know with any certainty what the state of a given house will be more than a week into the future; there are simply too many variables that can affect the readiness of a particular job: weather, work progress, material supply, trade availability for preceding tasks, neighbouring construction activities, etc. The fundamental idea of the proposed system is to stabilize and reduce lead time by guaranteeing trade contractors’ working load. In practice, this is realized using agreed capacity, a commitment between a homebuilder and its trade partner on the number of jobs (kanban slots) that a sub-trade will perform each week. For example, a homebuilder might predict that about 40 houses would enter the production system next month, and it might have two trade partners working for a given task. Next, a trade booking agreement is signed between the company and each trade partner. Assuming that one trade contractor has agreed to provide six kanban slots weekly, and the other four, a typical booking scenario would be one such as shown in Figure 9. Site managers release specific job information following the completion of the preceding task and load a kanban slot. The capacity agreement in fact forms a FIFO lane, and the jobs released are the inventory on the lane. This way, the FIFO lane links two separate tasks into a stable flow. In the future state map, the cycle time (CT) and changeover time (CO) of each task remain the same as those in the current state map, and the waiting time (WT) reflects the length of the FIFO lane.

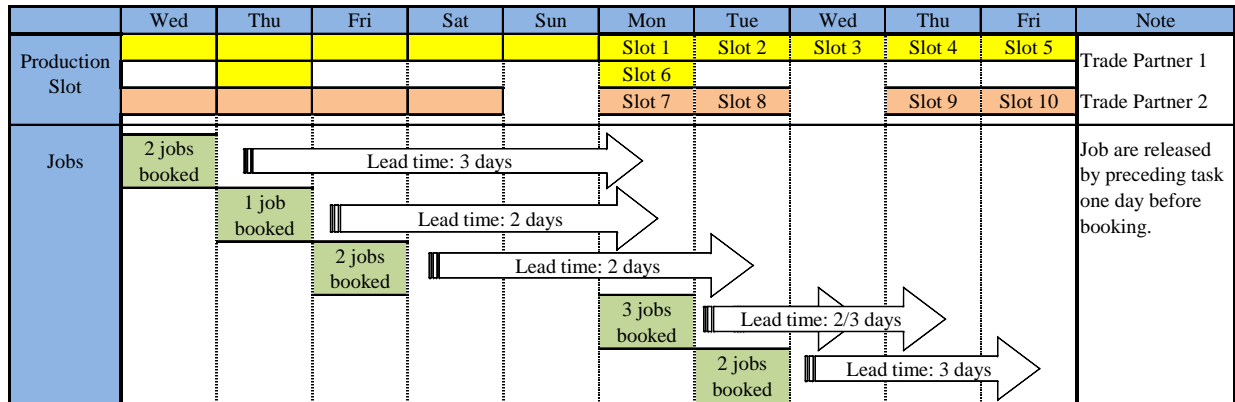


Figure 9: A Typical Scenario of Lean Booking

The number of kanban slots is decided by takt time, which is a function of customer demand. In the cooperating company, it usually takes 30 to 45 days from the customer signing the purchase agreement to the release of the file package to construction, so the average volume of sales in the past two months is used to determine the takt time of the system. In the first two months of 2007, the sales volumes of the company, including pre-sales and spec houses, were 47 and 42 respectively. Since 22 workdays are available in March, the takt time is 0.49 workdays. In practice, the downtime was estimated as 5%, and the agreed capacity of each task was designated as 10. By reserving the same number of kanban slots for each of the tasks in the value stream, the production paces of working stations are synchronized.

The FIFO-lane-based approach is different from other scheduling techniques for repetitive construction activities, such as LOB (Line-of-Balance), due to its ability to deal with the dynamic work flow — i.e., new houses can enter into the production system continuously — and high variation in productivity. In this system, consecutive tasks are de-coupled by the FIFO lane so that each task only deals with variations caused by the preceding task, which can be accommodated by adding a time buffer (WT) between tasks. For instance, the task called “Excavation and deep service” has a one-day standard deviation in cycle time and a possible two-day delay in booking time; thus, a three-day waiting time for the next task can effectively control the flow fluctuations caused by variations in the present task. In addition, the system is very flexible. Either party can change the agreed capacity from time to time, provided that advanced notice is given (in practice, the agreed upon notice time for capacity change is two weeks).

4.2 Production Leveling

In the conventional production management approach, the volume of jobs performed typically occurs unevenly over time. Figure 10(a) shows the monthly volume of files released to construction in 2006, and Figure 10(b) shows a typical record of the number of released files over a one-month period. The causes of this large fluctuation were unpredictability of sales and a pushed production management. Flow fluctuation causes several problems for a synchronized production system:

- There is no sense of takt time, and it is difficult to decide the capacity requirement.
- When peaks and valleys frequently appear, filling the agreed kanban slots consistently becomes a heavy burden.
- An erratic flow makes the production difficult to monitor – “Is the situation normal or not?”

In order to avoid these problems, the production control must lower the peaks and raise the valleys in the workload as much as possible so that the flow surface is smooth. This practice is referred to as production leveling or “even production flow.”

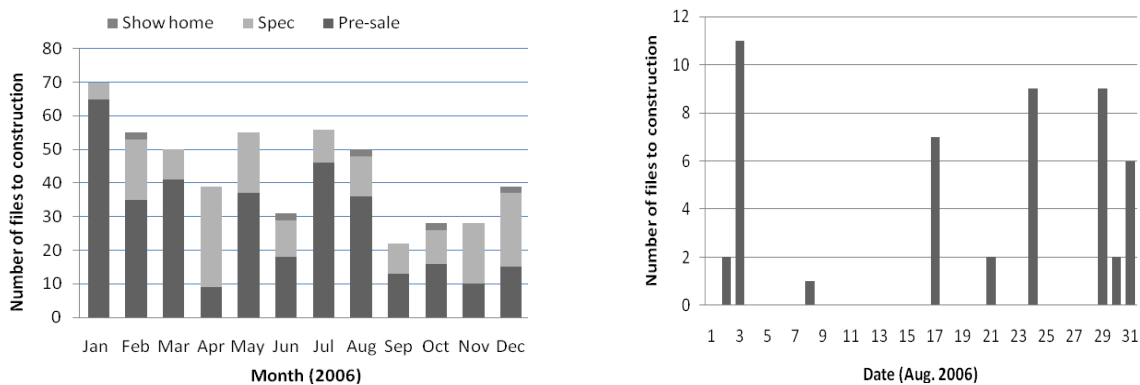


Figure 10: Typical Record of Files Released to Construction

Bashford et al.^[21] has described two common even-production-flow strategies (activity-based and start-based) and discussed their implications for the housing industry using simulation. In this research, these two strategies were combined and implemented in an innovative way. On the one hand, tasks connected by the FIFO-based lanes form an activity-based even-flow system. Unlike fixed schedules, where a long duration for each task must be chosen to ensure that the time will not be exceeded, a booking system based on the agreed capacity had the capability to accommodate minor variations so that time buffers between construction tasks were significantly reduced. On the other hand, a supermarket-based pull system was established between the pacemaker task (excavation) and sales as a decoupling buffer^[22]. The sales department typically

releases the files of pre-sale houses to the first supermarket, while the downstream task withdraws the files. Once the number of files in the supermarket reaches the upper limit, the sales must stop releasing; when the number reaches the lower limit, the sales releases the files of show homes and spec houses in small and consistent quantities until the files of pre-sale houses are available. The upper and lower limits are decided based on the historical analysis of sales variability. In this research, they were set to 15 and five homes (7.5 and 2.5 workdays inventory) respectively.

4.3 Work Restructuring

It is apparent that waiting time can be effectively abated by reducing the number of handovers. In an extreme case, if the entire value stream could be completed by a single crew, the house would pass directly from one task to the next in a continuous flow, without any waiting time in between. The factor that prevents the same crew working continuously in a house throughout the value stream is that different tasks require different skills and equipment. Although multi-skilling and the use of cross-functional teams were shown to be effective in reducing variability, and thus improving flow ^[23], the reality is that the vast majority of trade contractors are specialized in one type of job.

A feasible solution is to examine adjacent tasks and consider the possibility of integrating them into one work package to be performed by a single working team. The footing and cribbing tasks, for instance, require a similar skill set (framing and concrete pouring) and can easily be completed by one crew. Historically, these two tasks have been performed separately, because it is more productive to pour footings in batch (where multiple footings are poured within a subdivision at one time), and wall forms are always moved around with the cribbing crew. On the future state map, these two tasks are combined into one work package with an expected cycle time of four workdays. Compared to a savings of three workdays of waiting time, the possible cost increase due to the small amount of concrete pouring and under-utilization of wall forms is minor. The same strategy was also used for electrical panel installation and shallow services which were both electrical jobs. In fact, this work package was further integrated with backfill tasks to be contracted to a cross-functional team. The electrical, cable and telephone (shallow service) lines are approximately three feet below finished grade. By installing them at the same time with backfill, trenching operation is eliminated, and the quality of backfill is ensured. A

similar consideration led to the integration of task excavation and deep services (water and sanitary) which are situated at approximately nine feet underground.

4.4 *Process Improvement Measures*

The production process on the future state map exhibits significant overall improvements. Total construction duration of the value stream decreases from 65.5 workdays to 38.5 workdays, amounting to a reduction of 27 workdays (or a little over five weeks). The percentage of waiting time drops from 76% to 65%, and the value-added ratio increases from 17% to 26%. However, achieving the material flow envisioned in the future state map requires that the amount of inventory on FIFO lanes ideally to be stabilized around six houses (i.e. three workdays lead time) and never less than four so as to ensure that subtrades receive notice at least two workdays ahead. Based on the statistical analysis, PSS needs to be improved from the current 45% to 77% range to an upward amount of 90% with standard deviation of cycle time for each task reduced to one workday, so that the probability that the cycle times of any two homes in a series of six are longer than the average cycle time by more than one workday is below 10%. Although the actual probability of a shortage of jobs in the FIFO lane to fill the kanban slots might be much lower due to possible completion of previous delayed jobs, focused attention on improving the reliability of the operation of sub-trades will be required. In practice, the following kaizen foci were proposed by the core lean team:

- Work standardization – The work scope and quality standards of each task are clarified in written documents and distributed to related sub-trades. The goal is “100% ready handover”.
- Total quality management – Trade contractors are required to control quality at the source, completing all repair work before workers leave the site, while site managers are required to check quality as the construction is in progress. The goal is “100% first-time-through.”
- Long-term partnership with trade contractors – Lean implementation involves significant behavioural changes in all parties linked to the system. It will take time to build up trust between parties, train workers and change the mindset of personnel.

These items are marked on the future state map using a kaizen lightening burst icon. An advantage of VSM is that the process improvement efforts become subordinate to the value stream design, as opposed to stand-alone improvement activities, so that the lean team can focus on the improvements that have real impact on overall process performance.

Information flow is another important issue in VSM. Without a fundamental change in information management, it would be very difficult to operate a lean value stream. Unlike a manufacturing production line, construction crews move from one house to another that may be located miles away. Visual control cannot be applied in housing construction the same way that it is in manufacturing. Using the concept of the heijunka box, the authors proposed an internet-based “e-kanban” system, with a column of kanban slots for each workday and a row of kanban slots for each trade contractor. Site managers place a kanban with the link of job information (detailed address and technical drawings) into a desired kanban slot when a job is ready. The corresponding trade contractor then withdraws this kanban via the internet and allocates a crew to the job. If a slot is not loaded two days prior to its start date, or if a kanban is not withdrawn until the start date, the construction manager will be aware of a production problem.

5.0 Value Stream Mapping (Case B – Stage 2)

Compared to Stage 1, Stage 2 is much simpler. 11 tasks in the flowchart involve only five trade contractors and thus can be grouped into four work packages: framing, roofing, trim work and siding. However, LGB had almost lost control of Stage 2 when the company was doing VSM in 2007. Since 2002, Alberta had experienced robust economic growth driven by high energy prices and resource development. Rapid increases in population and peoples’ income boosted the demand for housing. In late 2006 and early 2007, the Alberta housing market reached its peak. The new-housing starts in Edmonton metropolitan area hit a historical high of 14,970 units in 2006 and 14,888 units in 2007, almost twice the number in 2001 ^[24]. This volume severely strained the capacity of trade contractors and the supply of construction labour force. Bashford et al. ^[25] studied the relationship between production system loading and project cycle time in residential construction. In reality, the situation was much worse than that predicted using the mathematical model. Part of the reason is that the housing production system is not an isolated system. The high-paying jobs in the oil sands industry attracted workers moving from residential construction to industrial construction projects. As shown in Figure 11, the current state map drawn in August 2007 using the data of 292 single-family houses that were constructed by Landmark Homes in the first 7 months of 2007, the duration of Stage 2 (50 workdays) doubled compared to 2005 and 2006 (31 calendar days as shown in Table 1).

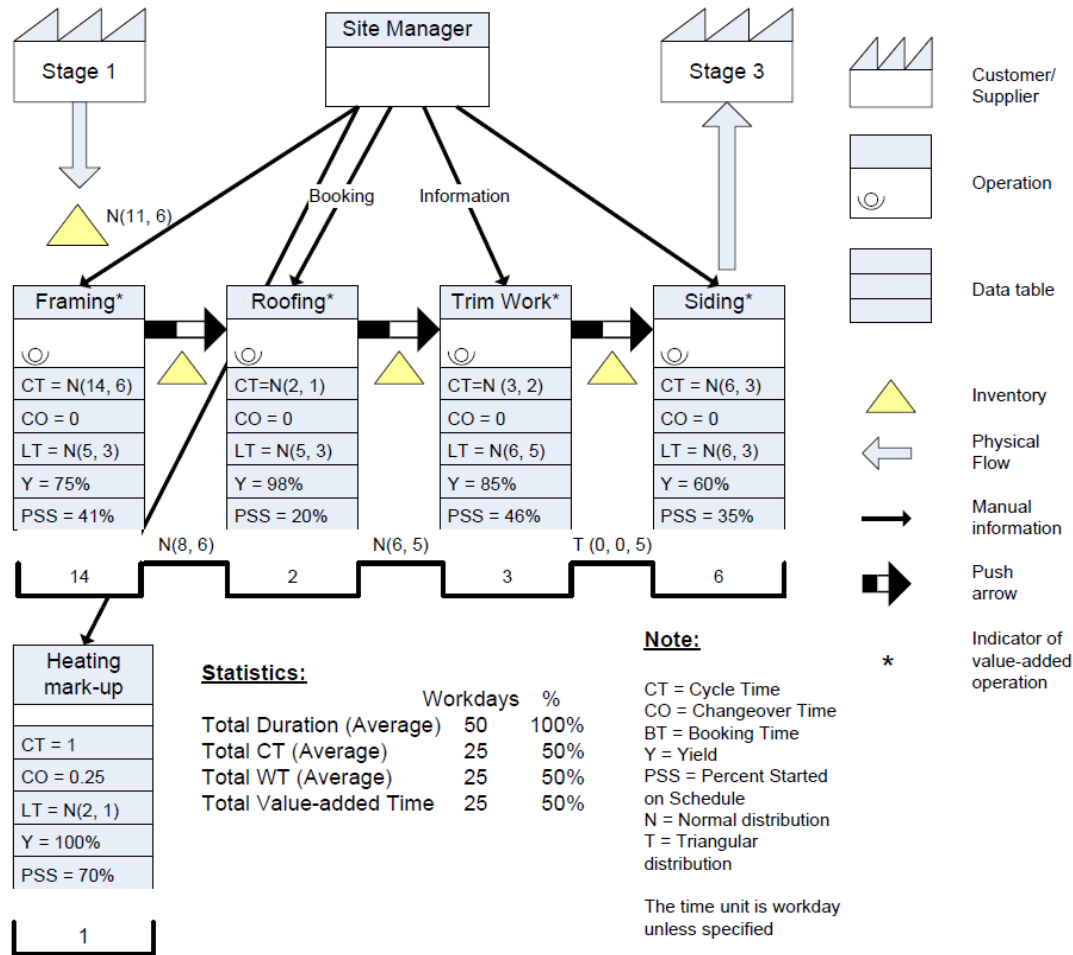


Figure 11: Current State Map of Home Building Process (Stage 2)

An obvious reason for the prolonged stage duration was the long waiting time that accounted for 50% of the total duration (or 25 workdays). The discussion at the Stage 2 workgroup VSM session had the same conclusion as that of Stage 1 workgroup: the root cause of long waiting time was the high variability of the construction process. Landmark Homes' site managers further pointed out that although the average lead time was one week, the variation of lead time was high and only less than half the jobs had started according to the confirmed schedule date. The actual start time of a task of a given job was virtually unpredictable. In order to ensure the site was ready when the next crew came to the job, site managers booked the next trade after a task had started. For long duration tasks, such as framing and siding, since the variation of cycle time were several days, the working request of the next task was generally issued in the last two or three days before completion. The statistics obtained from data analysis proved the site managers

comments: the waiting time after roofing was the same with the lead time of trim work and siding, and the waiting time after framing was three days longer than the lead time of roofing.

Wastes also existed in the task's cycle time. The average cycle time of framing was 14 workdays, but the estimated duration of framing was nine workdays (see Figure 2). In order to maximize their interests and reduce the risk of being idle, subcontractors always intend to receive bookings at or even more than their capacity. In a booming market, they often started a new job before the job that they had been doing was completed. Working two or more jobs simultaneously causes long cycle time and high variation. Therefore, the actual value-added-ratio of the process is much lower than 50%, the number shown in the map.

Quality was also a big issue here, especially for framing and siding. The 75% yield rate of framing did not mean that only 25% of jobs had defects. In fact, every job had defects, and the 75% yield rate meant that on average 25% of items in framing checks failed. The Landmark Homes' standard framing checklist has 237 items (Figure 12). A fail rate of 25% means that on average 59 errors were found on every framing job. Low quality led to significant wastes in the process. In general, the site manager had to do framing checks two or three times for every job, and framing crews had to go back to the job and spend another one or two days to repair the errors found in the framing check.

Landmark Homes (Edmonton)

Framing Checklist			
CAPPING			
Job Address			Site Manager:
Job Number:		Framing Contractor:	
Date Inspected:		Date Re-Inspected:	
Area of Home	Framers Check	Site Manager	Description
Basement			
Teleposts correct type in proper locations, centered on beam & plumb. No more than 3" of thread showing.No less than 1".			
Beams are level & straight.			
Beam pockets are filled with solid blocking			
Solid point load blocking through joist space to beam and foundation wall. (Under doors and large windows)			
Headers above basement windows (required for windows over 4 feet)as per joist layout			
Main Floor Joist System			
Beams are sized as per plan.			
Engineered joist & beam package installed as per manufacturers layout. Check for plumbing hits.			
Joist hangars installed as per manufacturers detail, joists glued in seat and screwed. Excess glue cleaned off.			
Backer blocking installed at all joist hanger locations as per manufacturers detail.			
Squash blocks installed, one on each side of EVERY joist where it bears on a beam or at point load.			
Floor sheathing glued and screwed			
Lateral bracing installed as per manufacturers specifications shown on blueprint and/or layout			
2x6 cantilever blocking installed on flat for insulation			
Sand/concrete access location & size as per blueprint (if applicable)			
Stairwell correct size & location.			
If walk-out, ensure correct window RO's and in correct location, all sheathing nailed, walls level, plumb and square.			
Install cantilever insulated pan.			
Basement stairs installed securely and properly with poly between stair and frost wall.			
2"x8" Handrail backing installed at 28" o/c from nosing.			
Bearing walls triple plated wrapped in poly on footing.			
Proper backing for drywall in stairwell			
Headroom 6'-8" when possible otherwise minimum 6'-5".			
Backing for baseboard in between all studs.			

Signed: _____
(Site Manager)

Signed: _____
(Framing Contractor)

Date: _____

Figure 12: Landmark Homes' Framing Checklist (Page 1)

In the VSM session, new ideas, like preventive quality control, “100% ready 100% of the time” and continuous workflow to dedicated crews, were proposed to reduce stage cycle time and improve product quality. The basic idea of preventive quality control is that site managers check quality when crews are working at site. For instance, the site manager checks the main floor walls and second floor system when the crew is framing the 2nd floor walls, checks the 2nd floor walls when the crew is constructing the roof and checks the roof when the crew is installing backings. Preventive quality control increases the times of quality checks and thus the workload of site managers, but the quality problems are identified and corrected when crews are still working on site, so it may save crews’ time on rework. The “100% ready 100% of the time” uses the same rule of the Last Planner System: site managers only book the jobs that will be 100% ready (site, materials, etc.) for sub-trades by the scheduled start dates, and thus, the downstream task is shielded from the variability of upstream process. When trade partners can trust that Landmark Homes will only book trades into jobs that are 100% ready, they will pre-schedule their crew for the job and stop overbooking for that time slot. The goal of providing continuous work flow is to establish long-term partnership with subcontractors. Landmark Homes will commit to provide continuous work to selective trade crews, and those crews will work exclusively for Landmark Homes. Dedicated crews will ensure the availability of workforce and improve product quality and process reliability.

While those ideas are promising, the workgroup and the management of the company realized that for long-term improvement, radical changes in construction technology and work structure were necessary. Two such initiatives were prefabrication and job integration. As a production homebuilder that provides a broad spectrum of housing products, from multiple-family row houses, to starter housing, to mainstream single-family houses, to high-end customized mansions, Landmark Group of Builders (LGB) believed that a panelized building system was the only way to meet such diverse needs in the market. Although the practices of industrialized housing in Japan and Western Europe provide useful lessons and prove the effectiveness of the technology, all those successes were achieved in different market situations and with different products. How to integrate panelized construction into LGB’s building process was a big challenge. No success story in North America had been reported in this area. A few large production homebuilders in the U.S. adopted similar approaches ^[26], but no operation details were available.

Following the lean principle that any new technology must be thoroughly evaluated and proven through direct experimentation in a pilot area before it is used in the present process (Liker 2004), LGB developed a three-phase plan as a guideline for implementing the technology.

- Phase I: A pilot plant will be established to produce wood-frame open wall panels, floor panels and roof segments. All houses built by Landmark Homes (Edmonton) will use the panelized system. The impact of the new technology to the existing process will be analyzed, and the improved process will be standardized.
- Phase II: A production division will be established based on the pilot plant. The division will produce insulated open panels and perform all major construction tasks in Stage 2, including framing, roofing and siding. The idea of job integration came from the concept of sequential procedure ^[27], which regarded the construction process as a successive realization of an autonomous sequence. Each sequence is a large work package containing the tasks grouped by functions of the building. A few super-subcontractors performing large packages of continuous work without interference will improve the reliability of the process and reduce the management overhead.
- Phase III: The production division will produce a closed-wall panel system, and thus electrical rough-in, smart wiring and drywall will be integrated into its work scope. All LGB members will use the panelized system and a standard process for building envelop construction.

Considering that the time frame for implementing the future state map was 18 months, the Stage 2 future map was developed based on plan Phase II, as shown in Figure 13.

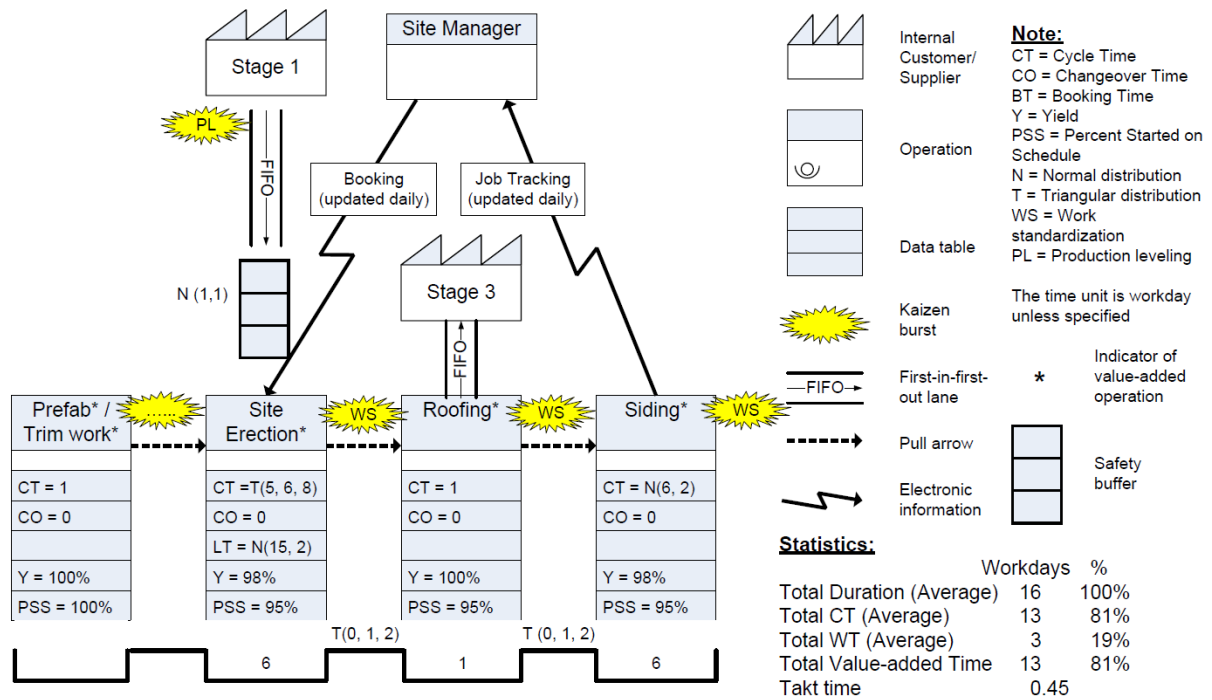


Figure 13: Future State Map of Home Building Process (Stage 2)

In the new process, Stage 2 is one work package. Site managers inform the production division the date that a job can be ready for framing start. After receiving the framing request, the production scheduler checks the production schedules and puts the job into the closest available time slots. Then he or she sends the confirmed schedule date to the site manager and books all required materials and equipment. Once the erection date has been set up, the production schedule of the job is fixed. The wall and floor panels and roof segments are generally prefabricated in the shop one day before erection, and the house is erected on the framing start day. All windows, doors and trim work are installed in the factory. The HAVC openings are also cut in the plant according to drawings, and thus heating mark-out (a non-value-added activity) is eliminated. It is estimated that a three-person crew can complete the framing of a 2,000 square feet single-family house in six workdays, including one day of erection. Roof shingles are loaded onto the roof on the seventh workday, and roofers show up on the eighth workday and siding starts on the tenth workday. The cycle time of Stage 2 is three weeks. The process is triggered by the framing start date, but pulled by the completion date of siding. A one-day buffer is scheduled between the on-site tasks to accommodate possible delays caused by weather, equipment breakdown, rework, etc. Theoretical analysis showed that prefabrication could effectively mitigate construction peculiarities and thus bring the construction process to the same starting

point as manufacturing. A stable and reliable process allows the direct application of lean principles and tools, which will significantly reduce wastes and improve productivity. Table 5 summarize the current situation and goals of lean initiatives.

Table 5: Lean Metrics (Stage 2)

Metrics	Baseline	Goal*
Variation of production CT (workdays)	Up to 6	< 2
Total stage duration (workdays)	50	16
Total waiting time (workdays)	25	3
Average percent started at schedule (PSS)	20% - 46%	> 95%
Yield	60% - 98%	> 98%

Some concepts and lean tools used in Stage 2 have already been discussed in the last section, and more details will be introduced in the next chapter. A factory-based sub-process (Stage 2) completely changes the rules of construction management and asks for higher levels of process control. For instance, all construction activities in Stage 2 are triggered by a framing request, but the lead time of framing start is three weeks. A longer lead time is necessary for prefabrication, because the lead times for materials like windows, doors and trusses are 10-12 workdays, and the plant needs time to adjust its capacity based on demand fluctuation. However, long lead times mean high levels of process control – site managers need to know the exact date when the site can be ready for framing just after the foundation is poured. Once the framing start date is confirmed and the job is located in the production schedule, that date cannot be changed. Since all the schedules, including schedules of wall production, floor production, roof production, crane, truck and trailers, field framing crew, roofing crew and siding crew, are balanced and synchronized, the change in one job will disturb the entire system and result in a non-continuous work flow. For that reason, the prefabrication plant has a two-week frozen production window. If the framing start date of one job is delayed for whatever reason, the wall and floor panels and roof segments will be produced according to the schedule and stored in the yard, and the site work will be taken out from the crane, transportation and field crews' work schedules. Remarkable wastes are caused by double handling finished products and the idle time of equipments and field crews.

6.0 Future State Flow Chart and Kaizen Plan

VSM is a powerful tool for lean planning and communication for management, but it is too complex for workers and most small-trade contractors. In order to make sure that everyone involved in the process knows what is happening and why, Landmark Homes created a future state flowchart to visually show the goal of lean transformation and developed an 18-month kaizen plan to guide and coordinate efforts to improve the value stream.

6.1 Future State Flowchart

The future state flowchart is a simplified summary of the future value stream maps of five stages. It shows the time standard for every major construction activity and the relationship between and work sequence of those activities. Thus, site managers and trade contractors can have a big picture of the entire process and know what the ideal or normal situation should be.

The future state flowchart, as shown in Figures 14 and 15, targeted to reduce the overall duration of the construction process to 149 calendar days (106.5 workdays or 5 months). Compared to the current process flowchart, the construction duration was reduced by 19% (25 workdays), mostly from eliminating waiting time. The target seemed quite conservative, but considering the real situation of early 2007, the improvement was actually substantial. Due to the soaring housing market and lack of skilled trades, the average duration of 213 single-family homes completed by Landmark Homes in the first six months of 2007 was 294 days. Thus, Landmark Homes was in fact targeting a duration reduction of 49%.

The focus of Stages 3 to 5 was increasing process reliability through production control. After roofing and siding (Stage 2) are completed, the house becomes a controlled environment; the biggest unpredictable and uncontrollable factor in on-site construction – weather – is not an issue any more. In addition, most tasks in Stages 3 to 5 take less than one day to finish, and the size of the house does not have a big impact on the cycle time. Now the key to eliminate waiting time is to ensure that trades show up on the job at the scheduled day. The following three factors were critical to achieve this goal:

- Make sure that the site is 100% ready 100% of the time. After confidence has been built, trades will not overbook jobs to avoid idle time caused by sudden schedule changes.

- Standardize the construction process to increase predictability, so site managers can book trades two to three weeks ahead to ensure the availability of a workforce.
- Even production flow to create continuous workflow for regular trade contractors who have long-term partnerships with the company.

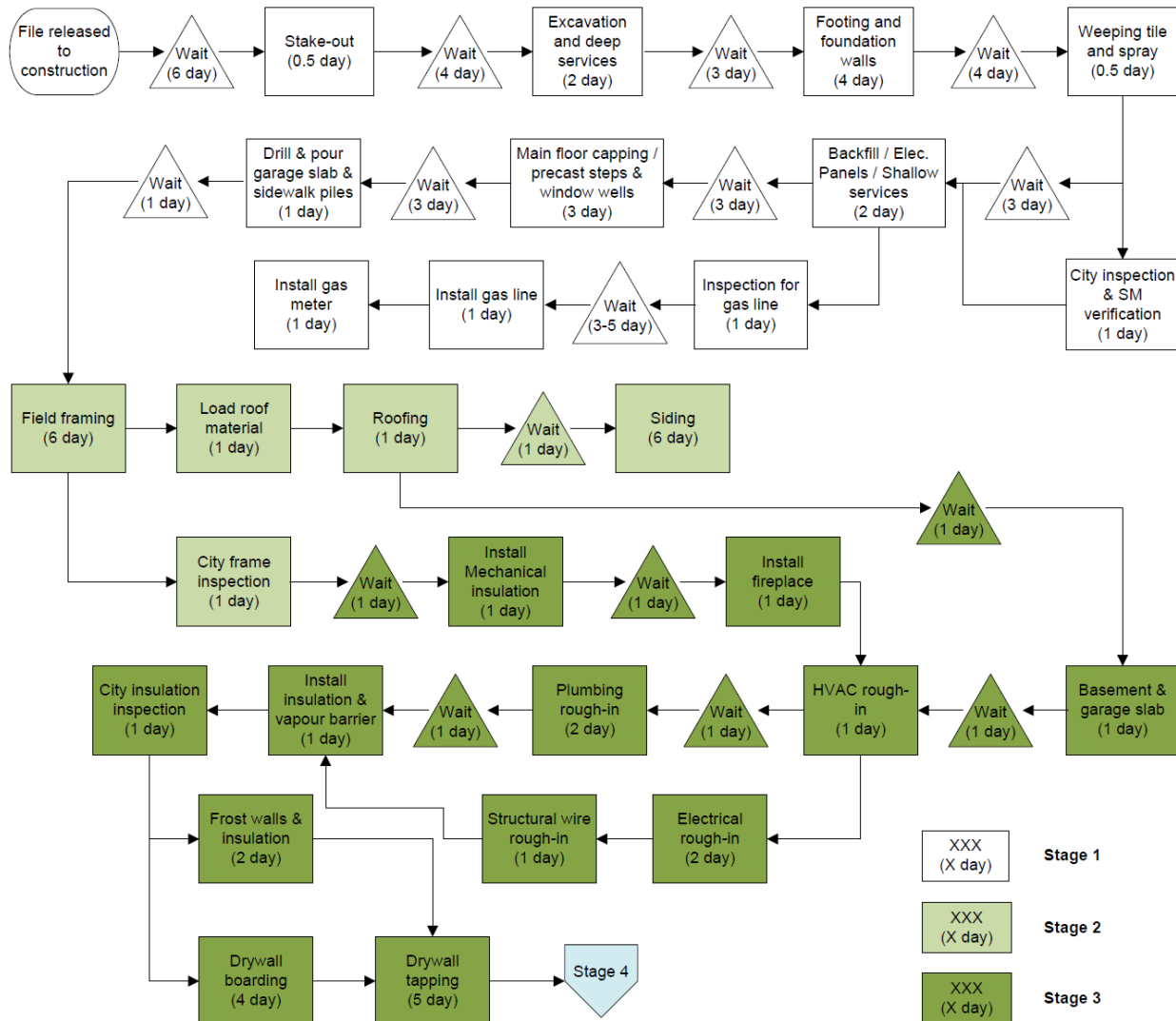


Figure 14: Future Stage Flowchart (Stages 1 to 3)

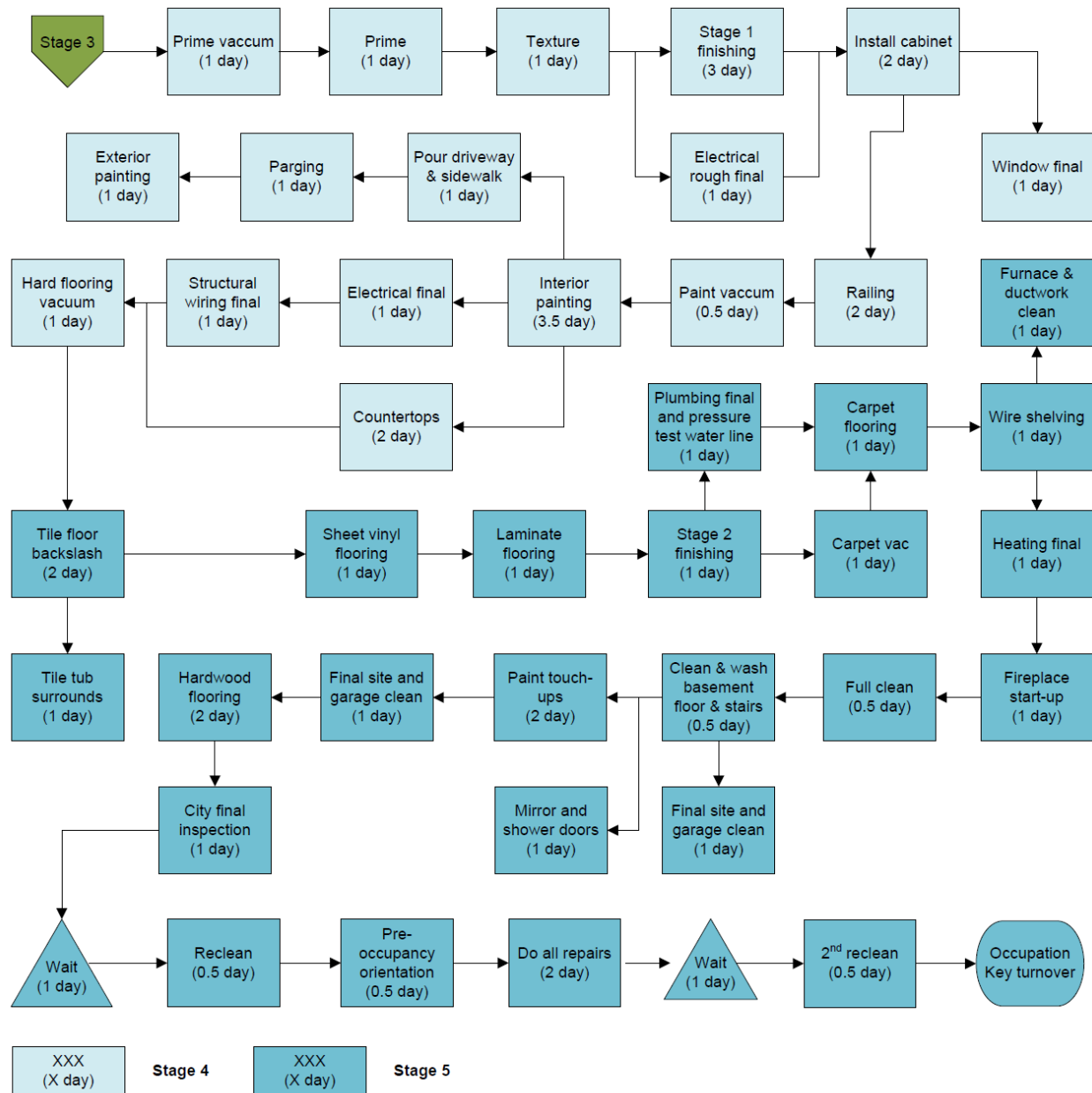


Figure 15: Future Stage Flowchart (Stages 4 & 5)

6.2 Kaizen (Continuous Improvement) Plans

The future state process flowchart had set a clear goal for lean improvement. After a series of company and trade meetings, “5-month delivery cycle” was understood and accepted by everyone in the company and all trade contractors. However, lean implementation is a long-term job, and the concepts shown in the future state map cannot be implemented all at once. A

comprehensive planning is necessary to break the implementation into steps and to set milestones of improvements.

The five workgroups worked separately to create a kaizen plan for their target stage. Instead of focusing on implementing techniques identified in VSM sessions, the workgroups were required to envision the planning process as building a series of connected flow and to find the best answers to the following three questions:

- How to create a continuous process flow.
- How to improve the flow reliability.
- How to level production.

A four-step process recommended by Tapping et al. ^[28] was adopted by all five workgroups in their kaizen planning.

- 5) Review the future state map and create a yearly kaizen plan.
- 6) Determine milestones (start and finish dates) for each main improvement event and develop a kaizen milestone chart.
- 7) Complete the VSM storyboard. (In the case of LGB, the VSM storyboard was made on the company level for the entire construction process. The storyboard was posted in the board room of the company as shown in Figure 16.)
- 8) Present the kaizen plan to management and obtain approval.

The objective of yearly kaizen plans is to provide a high-level structure for lean application. The workgroup started with defining major lean implementation elements required to accomplish the improvement, and then the implementing sequence of these elements were decided. After this, the start and finish dates were assigned to each element, and the timeframe was presented in a kaizen milestone chart using predefined symbols. Figure 17 shows the yearly kaizen milestone chart developed by workgroup 1 (Stage 1). In Landmark Homes, the kaizen milestone chart was reviewed every two weeks by the workgroup to monitor the progress of lean implementation. Open triangles would be added on the chart to indicate actual start dates and closed triangles to signify actual completion dates.

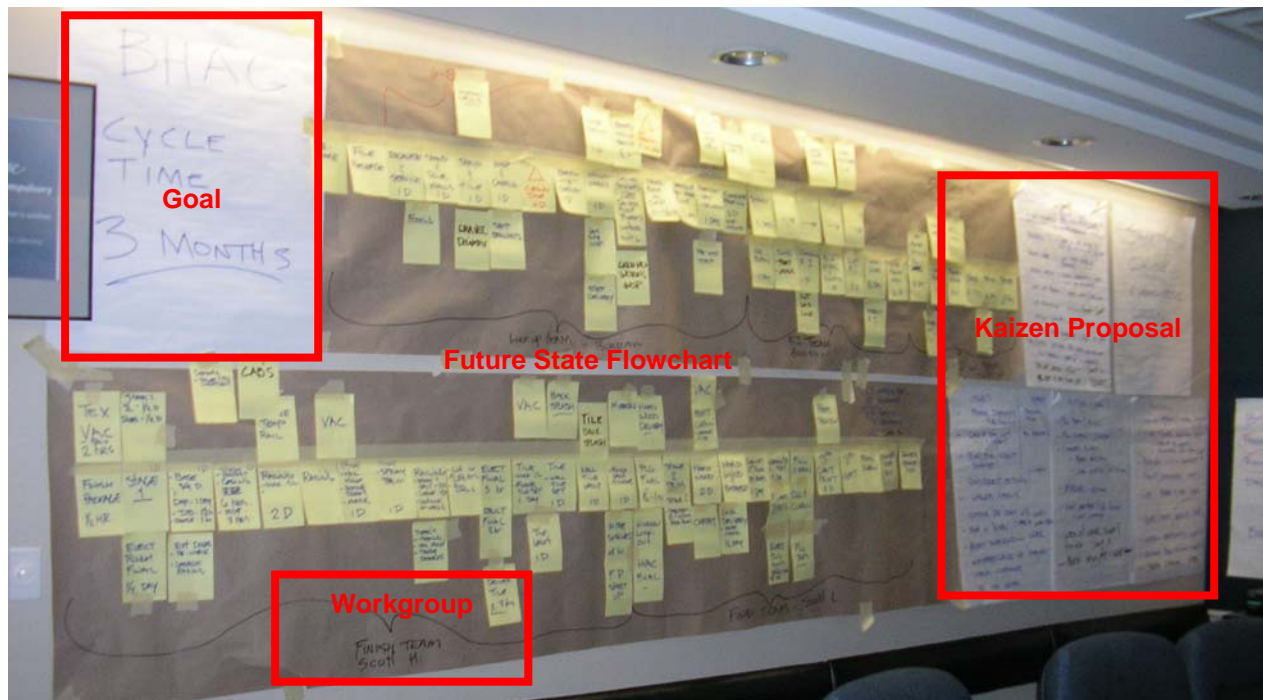


Figure 16: Lean Implementation Story Board (Landmark Homes 2009)

YEARLY KAIZEN PLAN														
Value Stream: Stage 1			Value Stream Team: Bohdan, Slav, Ali, Barry, Haitao									Date: Aug 10, 07		Page 1 of 1
Item	Task	Goal	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
	Continuous Flow													
1	Takt time development		---	---										
2	FIFO-lane-based flow	All trades	---	---	---	---	---	---	---	---	---	---	---	---
3	E-kanban storeboard			---	---									
4	Capacity adjustment mechanism	All trades		---	---	---	---	---	---	---	---	---	---	---
5	Waiting time reduction	< 25 days						---	---	---	---	---	---	---
	Flow reliability	PSS>90%												
6	Standardized work package	All tasks					---	---	---	---	---	---	---	---
7	Work restructure	One super contractor							---	---	---	---	---	---
8	Total quality control	Yield > 95%					---	---	---	---	---	---	---	---
9	Cycle time reduction	90% within time standard								---	---	---	---	---
	Production leveling	Variation<20%												
10	Supermarket-based pull flow (file release-excavation)			---	---	---	---	---	---	---	---	---	---	---
△ = Start Date			----- = Expected			▲ = Completed								

Figure 17: Yearly Kaizen Plan (Workgroup 1)

7.0 Lean Implementation

Lean implementation leads to significant changes in the working process and in the production organization. These changes affect virtually everyone in the company and all the trade

contractors. Change – even change for the better – is difficult for most people. Lean experts in manufacturing talk about and understand the importance of driving fear from the workplace and motivating people to change their working habits ^[28]. In the construction industry, which has relied on and been characterized by the traditional construction project culture for decades, communication and gaining the support of all stakeholders for lean initiatives is difficult, but important. Based on a study on lean application in the Swedish industrialized housing industry, Hook and Stehn ^[29] summarized the fundamental impact of current construction culture on lean application as:

- low motivation and awareness of build-in quality, standardized work, flow and continuous improvement;
- problems are solved based on experience, seldom thoroughly analyzed and documented; and
- ad hoc solutions and a low responsibility for production process and system.

As a production homebuilder with 30 years of history, Landmark Homers experienced the same type of difficulties in lean transformation (i.e. the hard-to-change project culture and mentality of workers and managers).

For many people, lean implementation seems like another short-term program, but it is not. Toyota spent over 30 years developing a lean manufacturing system, and they continue to perfect it. The success of lean implementation depends on the long-term commitment of top management. “The most important factors for success are patience, a focus on long-term rather than short-term results, reinvestment in people, product, and plant, and an unforgiving commitment to quality,” says Robert McCurry, former executive V.P. of Toyota Motor Company. Landmark Homes’ management shows its commitment to lean implementation by:

- Allocating sufficient time and resources for lean training.
- Engaging external lean consultants to facilitate the VSM process.
- Managers spending time to lead lean activities.
- Including lean activities into construction managers and site managers’ work scope.
- Investing on lean techniques, such as a panel prefabrication plant, e-kanban scoreboard, etc.
- Sharing the benefit of lean implementation with trade contractors.

7.1 *Developing People and Partners*

In the preface of *The Toyota Way* ^[30], the author quoted Fujio Cho, president of Toyota Motor Company, to explain the uniqueness of the lean production system. Mr. Cho said, “The key to the Toyota Way and what makes Toyota stand out is not any of the individual elements. ... But what is important is having all the elements together as a system. It must be practiced every day in a very consistent manner – not in spurts.”

Obviously, the Toyota Way cannot be achieved by hiring an external lean expert to conduct several lean workshops and facilitate VSM sessions or by appointing a lean champion to be responsible for lean events and value stream map implementation. Developing people who live with the lean philosophy and cultivating an environment of learning and continuous improvement are the key.

Landmark Homes kicked off its lean implementation journey with a series of lean training. First, key management personnel of the company attended a one-day training session (Lean 101) led by an external lean expert. The session introduced basic concepts of lean, such as eight types of wastes and flow, and explained commonly used lean tools, including standardized work, 5S, visual control, workforce practices, quick changeover, takt time management, quality at the source, pull flow (JIT), kanban, production leveling and total production maintenance. This session also served as the kick-off meeting to solicit organizational buy-in. Then, all employees in the company were required to take Lean 101 training to get familiar with lean concepts and principles. A simulation airplane game that tied together key lean concepts was an important part of this training.

The training of construction managers and site superintendents is extremely important, because the process and system are ultimately supported and managed by them. Their role is much more than that of a supervisor; they need to lead the way. Lean production has much higher expectations for mid-level managers. They must not only have the knowledge and skills to manage and coordinate construction jobs, but also have the ability to solve problems, facilitate team work, encourage continuous improvement and teach others. Those “soft” skills cannot be taught in the classroom and have to be learned by doing it. In six months, the lean expert had attended weekly lean meeting and numerous workgroup meetings to coach people on how to observe a process, define problems, find out root causes, communicate, facilitate meetings, work

in a team, develop standards and so on. External experts have their limitations. They do not have the necessary job knowledge and normally do not have the time to be involved in day-to-day operations and problem solving. They are outsiders of the company and are not in the management loop. Because of these limitations, the external lean experts cannot provide a lean solution for the company or take the leading role in lean implementation. Their role in lean transformation is mostly as a coach and advisor who helps in training people and kicking off the lean initiatives. However, in the early stage of lean transformation, significant investment in lean consulting is necessary due to the lack of lean knowledge and skills inside the organization.

Getting buy-in from subcontractors is indispensable for lean transformation of production homebuilders. Since all construction works are virtually performed by various subcontractors, mapping and planning are worthless unless consensus with subcontractors can be achieved. At the beginning of the one-day flowcharting session, the lean expert quickly went through the key concepts of lean and introduced the VSM technique so that the representatives of major subcontractors knew what was happening in the meeting. Since a majority of trades only had temporary relationships with Landmark Homes and the turnover rate was high, it was difficult to justify the investment on providing training to subcontractors. Moreover, lean production is different with current project-based practice in many ways. It was not easy to persuade subcontractors to follow a new system while the entire industry was still on the old track. A solution is to grow super-subcontractors that live with the same lean philosophies.

A good example of this strategy is the Great Canadian Renovation and Construction Corporation. In early 2007, Great Canadian Roofing Corporation was one of the 43 major subcontractors working with Landmark Homes. It took about 80% of roofing, 40% of framing and 35% of siding jobs of Landmark Homes. At that time, Landmark Homes was subcontracting jobs to five framing, two roofing and six siding companies in its 31 subdivisions. In late 2007, LGB formed a strategic partnership with Great Canadian Roofing Corporation and established a joint venture company, Great Canadian Renovation and Construction Corporation, which specialized in panelized construction. Now Great Canadian has become a super-subcontractor for the group and carries all the framing, siding and roofing jobs of three major group companies. Seeing Great Canadian as an extension of the company, LGB invested heavily on integrating the working processes of two companies and providing support for Great Canadian's lean initiatives. In fact, the second author, working as a senior researcher of LGB, currently spends 50% of his

time working in Great Canadian as a lean analyst. So far, Landmark Homes has five super-subcontractors carrying restructured work packages: excavation-foundation, framing-roofing-siding, plumbing, electrical-structural wiring and insulation-drywall.

Following lean principles to develop partners and suppliers involves fundamental change in mentality. Conventionally, homebuilders maintain a large subcontractor pool and contract works to the lowest bidder. It is believed that subcontractors have an inherent motivation to improve their processes and productivity to survive and grow in competitive market. In fact, this belief is simply wrong for the following reasons:

- Most of the trade contractors are founded and led by people who used to be trade workers. They know the industry well and have good technical skills, but lack training in management required for process improvement.
- The vast majority of subcontractors are small companies. They do not have the necessary resources for long-term improvement efforts nor the ability to take the risk of innovation.
- Trade contractors are basically service providers. Any innovation or change must get buy-in from homebuilders. Without a mentality change in the management of homebuilding companies, changes like work restructuring and super-subcontracting cannot happen.

The key to build long-term partnerships is that the homebuilders cannot look at trade-contractors as external service providers. Rather, they should be viewed as an extension of the homebuilding company, and the company would work with them to develop an integrated production system. The construction works then are not commodities to be sourced on the market through open bidding, but services provided by high capable suppliers that have the same company culture and are working in one production system. In *The Toyota Way*, Liker^[31] suggested a supply chain needs hierarchy as shown in Figure 18. Currently, Landmark Homes has established a stable relationship with all its trade contractors with fair business relationships, stable processes and clear expectations. For super-subcontractors, Landmark Homes is working to achieve a higher level in the hierarchy – to develop enabling systems and to learn together as an enterprise.

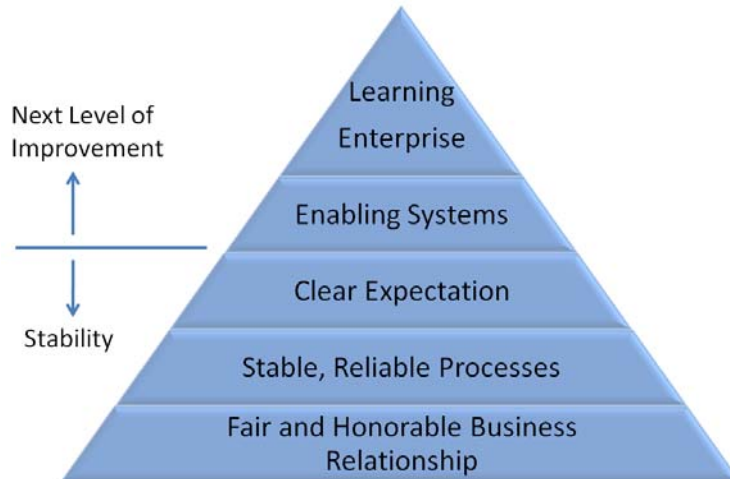


Figure 18: Supply Chain Needs Hierarchy (Liker 2004)

7.2 *Base Management Decision on Long-Term Thinking*

Principle #1 in the Toyota Way is to “base your management decisions on a long-term philosophy, even at the expense of short-term financial goals” ^[31]. Long-term thinking is considered as the foundation of the Toyota Way (see Figure 19). Management must recognize that the lean implementation journey is an adventure involving many unforeseen problems and short-term pains. It is critical to keep the big picture in mind and not to let the problems and failures stop the process.

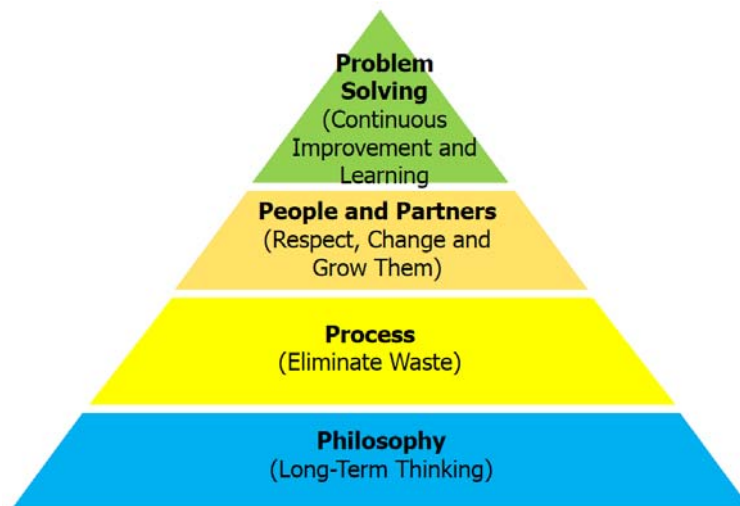


Figure 19: “4 P” Model of the Toyota Way ^[31]

Lean implementation in Landmark Homes also confronted numerous difficulties and even failures. Due to significant differences between the homebuilding and manufacturing industries

and lack of examples of precedents in the industry, Landmark Homes' lean initiatives had to adopt a trial-and-error approach. Each kaizen event was an experiment. People learned from mistakes and revised the kaizen plans to try again. In fact, most of the kaizen plans has been revised several times in the 18-month lean implementation period, and the ultimate process and the future state map were quite different. However, the management's commitment to lean implementation and the five-month delivery cycle goal never changed. The top management of the company has a clear vision that lean production through industrialization is the future of housing production and the only approach to improve customer service to another level – three-month delivery and “net-zero ready” houses. The 18-month lean implementation is only the first stage towards this goal.

The global economic meltdown was a serious test on Landmark Homes' commitment toward lean implementation and its long-term thinking philosophy. In the second half of 2007, the Edmonton housing market started cooling down. In 2008, the situation severely deteriorated. Landmark Homes' sales dropped more than 60% from its 2006 level. Due to significant decrease in the number of new house starts, the house construction market turned from a buyer's market to seller's market in the middle of 2008. As shown in Figure 20, the framing labour price had fallen almost 40% in six months (the blue line represents the market price). At that time, Great Canadian just started its wall panel prefabrication plant. Lack of experience and high fixed costs made the real costs of prefabrication much higher than the market price. The green line in the chart represents the actual labour costs of factory-based framing. Great Canadian had lost half of a million dollars on framing in the first eight months of 2008 and ran out of cash in September.

The top management team of LGB had to make choice: they had to either make use of the low prices in the construction market to further reduce costs or invest more money into the prefab business. The first choice was good for LGB's short-term financial goal – cutting prices to survive in the harsh housing market – but the failure of the prefabrication plant would be a heavy blow to its long-term strategy in industrialization and lean production. In contrast, the second choice supported the company's long-term goals, but would reduce LGB's already seriously narrowed profit margin.

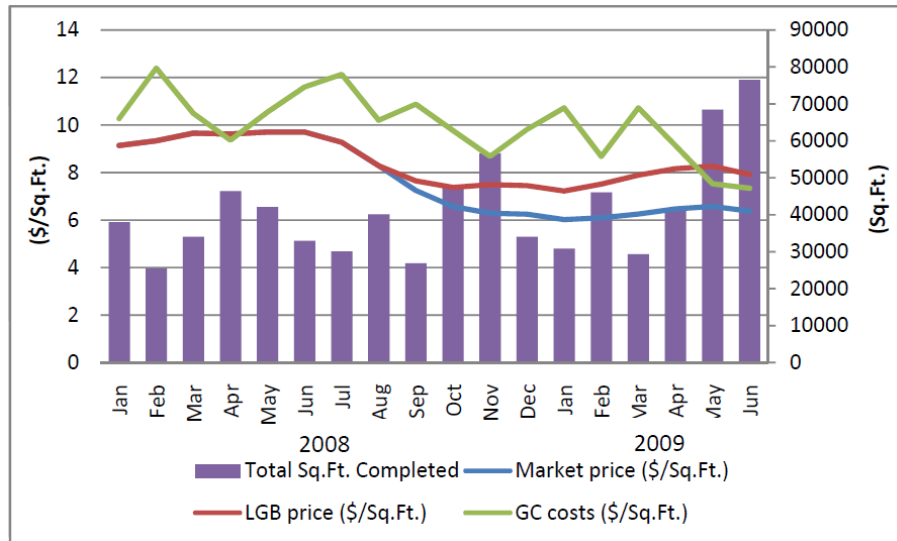


Figure 20: Great Canadian Prefabrication Costs vs. Price (Framing Labor)

After a series of debates and a thorough study on the benefits that prefabrication had and would provide to the company, the top management team decided to pay Great Canadian a \$1.20/sq.ft. premium on top of market price, which was the value of direct benefits that prefab framing brought to the company. The red line in Figure 20 shows LGB's framing labour price for Great Canadian. The premium started from September 2008 and was increased to \$1.85/sq.ft. in March 2009. In addition, LGB decided to inject \$100,000 every month to Great Canadian Renovation and Construction Corporation to solve its cash flow difficulties. LGB's decision was quite risky during the bottom of economic recession, but it is an excellent example of the lean principle – "base your management decisions on a long-term philosophy, even at the expense of short-term financial goals." LGB's efforts started to pay-off when the housing market sharply rose from the second quarter of 2009.

8.0 Lean Implementation Result

In VSM sessions, each workgroup developed its lean metrics, and Landmark Homes' management set a goal of five-month delivery for lean implementation. After 18 months of lean application, Landmark Homes (Edmonton) remapped its homebuilding process in April 2009. Figure 21 is the new current state map for Stages 1 to 3. Compared to the current state map drawn in July 2007, the new current state shows significant improvements in terms of cycle time, process stability, waste elimination and product quality.

8.1 Cycle Time

The first direct benefit of lean implementation is the reduction of cycle time. In March 2009, 35 houses were delivered to customers by Landmark Homes (Edmonton). The average construction cycle time of those houses was 161 days. Although there was still a 10-day difference from the lean implementation goal – 150 days – it represents 48% improvement compared to the construction cycle time of 25 houses that were delivered to customers in July 2007. Figure 22 shows the time series curve of construction cycle time and number of houses delivered in the past 25 months. There is a clear descending trend after June 2008 when jobs that entered into production system after lean implementation reached possession. May 2009 was the first time that the average construction cycle time of possession houses was less than 150 days, achieving the lean implementation goal.

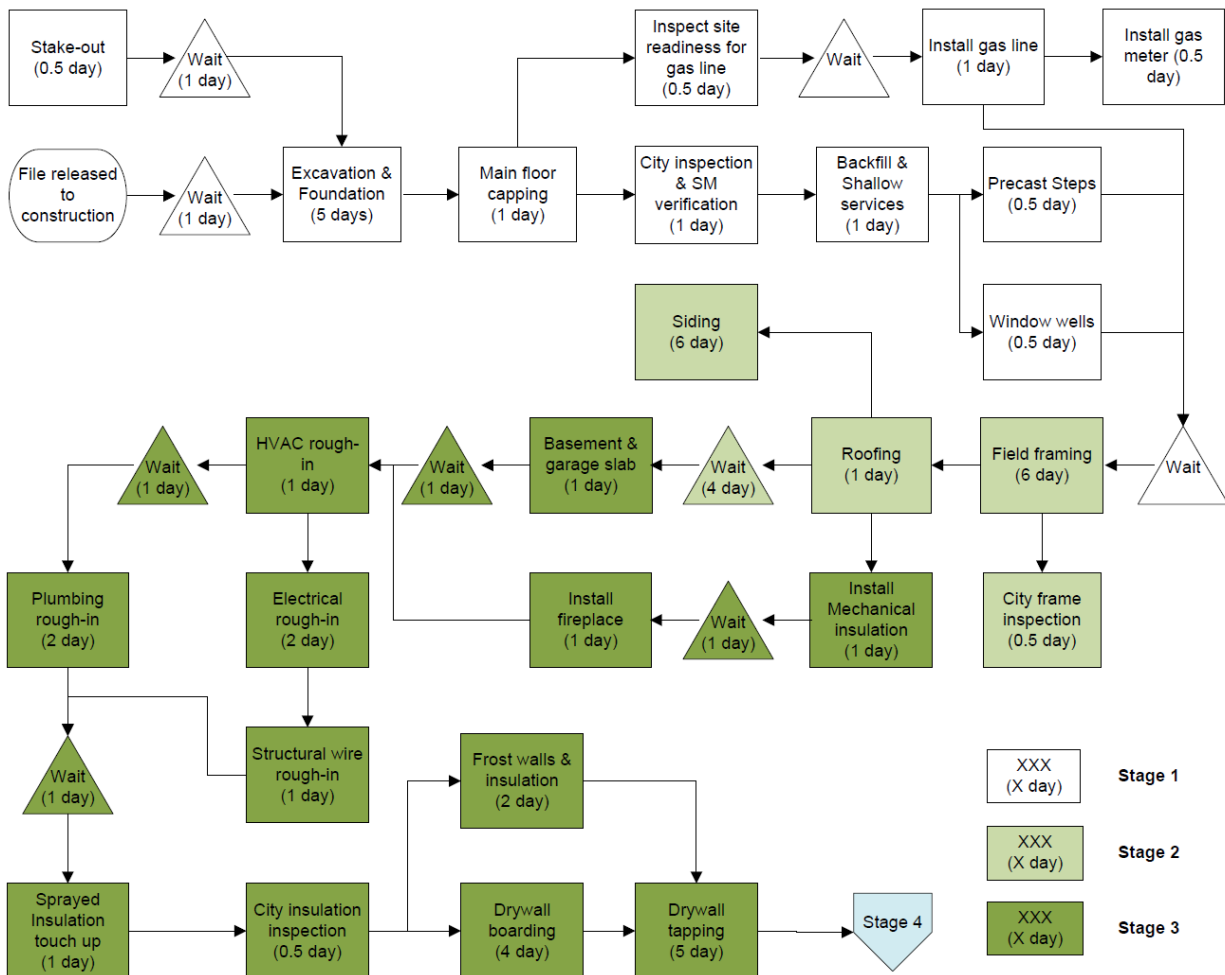


Figure 21: New Current State Flowchart (Stages 1 to 3)

Since houses generally take months from start construction to possession, total construction cycle time is a good indicator of overall lean improvement, but does not reflect the current cycle time situation. For example, the houses that were possessed in May 2009 were excavated the previous November and December. Thus, stage cycle times are a better description of up-to-date lean implementation results. Table 6 summarized the average stage cycle times of jobs that entered each stage in June 2009. Compared to the average cycle time of jobs that were completed in the first six months of 2007, significant improvements have been seen in the cycle times of Stages 1 and 2 with some improvements in the cycle times of Stages 3 and 4. The cycle time of Stage 5, however, was five days longer than before. A study on waiting time helped explain why lean implementation had different impacts on each stage. Due to limited available data, Table 7 only shows waiting time between construction tasks and does not include the waiting time during construction operation. It was common in 2006 and 2007 that a subcontractor started a construction activity, for example drywall taping, for one or two days and then stopped the work to go to other jobs, leaving the house idle for three days, and then came back to finish the job. That was a major reason why the cycle times of construction tasks were so variable at that time.

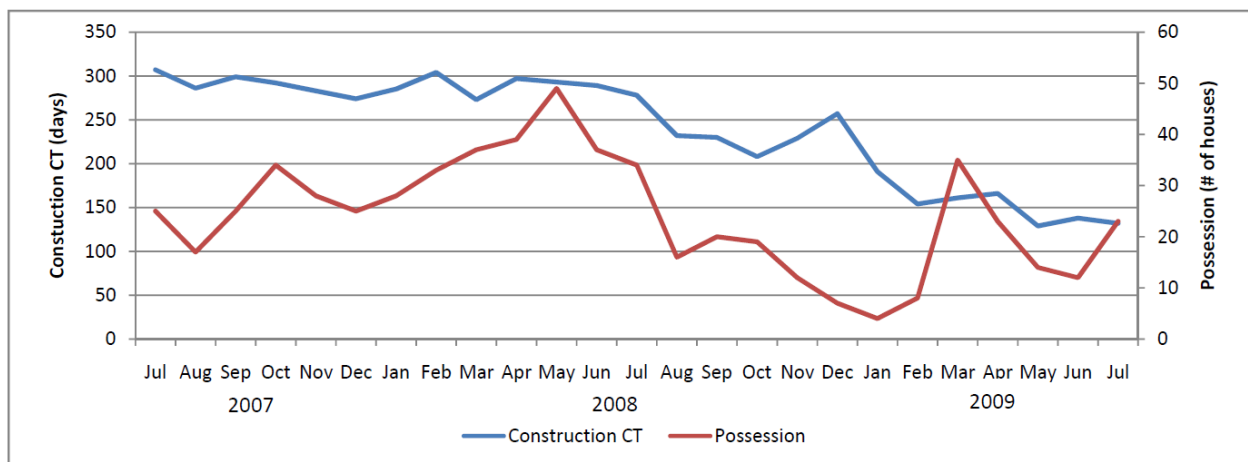


Figure 22: Construction Cycle Time and Possession (Landmark Homes)

Table 6: Construction Cycle Time Comparison

		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Average CT	Early 2007	75	31	54	42	26
	Jun-09	22	15	39	31	31
Reduction	Days	53	16	15	11	-5
	%	71%	52%	28%	26%	-19%

Table 7: Waiting Time between Construction Tasks

		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Value-Added Ratio
Waiting Time of A Typical Single-family house	Early 2007	46	1	25	11	6	53%
	Jun-09	2	0	1	3	10	82%
Reduction	Days	44	1	24	8	-4	
	%	96%	100%	96%	73%	-67%	

By comparing data in Tables 6 and 7, we can see about 85% of cycle time reduction in Stage 1 comes from reducing waiting time between construction tasks. Leveled production provides a continuous workflow and predictable workload, which are the prerequisites of building supersubcontractor. A single contractor that exclusively works for one homebuilder and carries all the major tasks in the stage ensures workforce availability and minimizes handovers and thus reduces waiting time.

The improvement in the cycle time in Stage 2 was through the reduction of task cycle time. Framing, roofing and siding are all long-cycle operations and can be overlapped. After a house frame was finished, the framing crew continued its work inside the house, while roofers worked on the roof and siding installers worked around the house. Therefore there was no waiting time between tasks, but the cycle time of each task highly depended on the availability and skills of small trade crews, and long idle time hid in the tasks. Factory-based construction and super-subcontractors provide the possibility to standardize the construction process, to train crews and to continuously improve its operation.

Stages 3 and 4 are both characterized with a large number of construction activities that do not have clear logical relationships to one another. The difference between them is that some major tasks in Stage 3 are long-duration tasks, such as rough-ins, drywall boarding and taping, and tasks in Stage 4 are mostly one-day jobs. Process reliability has been significantly improved after the implementation of lean production system, and the waiting time between tasks has been almost eliminated. The one-day and three-day waiting time in Stages 3 and 4 are mainly days when vacuum cleaning is taking in place. For one-day jobs, reducing task cycle time does not have an impact on overall cycle time since it is difficult to schedule jobs in terms of hours. Therefore, no matter whether the task cycle time is four hours, six hours or eight hours, it is counted as one day. The overall cycle time reduction of Stage 3 is less than the reduction on waiting time because in the new standardized process there is basically no task overlap: one day with one trade crew on site.

Stage 5 consists of a number of one-day tasks and some non-value-added activities, such as cleaning, inspections and repairs. In the old production system, the overall construction time was so long that at the end of the process, site managers and sales representatives normally pushed hard to finish the house and turn it over to the customer. Since the house was already delivered late, customers generally moved into the house as long as it was completed. The new process is standardized and a buffer of a few days is left between the completion of the house and key turnover date to shield possible delays and repairs of quality problems. Although the overall cycle time of Stage 5 is on average five days longer than that of two years ago, LGB is able to provide preliminary completion times when customers sign the purchase agreement as well as the exact occupation date 45 days ahead. In fact, LGB is the only homebuilder in the region that gives clear expectations on delivery time, which is extremely important for customers to make financial arrangements, to dispose of their current residence and to prepare for occupation.

8.2 *Process Variability*

Increasing construction process reliability and predictability are the central tenets of lean construction. The implementation of Landmark's lean production system not only remarkably reduced cycle time, but also reduced process variability. Table 8 shows a comparison of overall cycle time and its standard deviation for jobs started in February 2007 and February 2009. In two years, the house delivery time was improved by 55%, while the variability of the construction process reduced by 67%. A 19-day standard deviation allows LGB to give its customers a forecast of the house completion date at the time when customers sign the purchase agreement with reasonable accuracy.

Table 8: Overall Cycle Time and Its Standard Deviation

	# of Jobs Started	Average Total Cycle Time	Standard Deviation	Coefficient of Variation
February 2007	30	316	58	18%
February 2009	10	142	19	13%

The improvement on overall process reliability is built on efforts to increase operation consistency in every portion of the process. As shown in Table 9, substantial improvement on process reliability has been seen in all five stages. In a perfect lean production system, there should be no variation in stage cycle time. The production flow is leveled at the pace-maker task, and any possible delay was shielded by the FIFO lane at decouple points. In real practice, a

production homebuilder usually has hundreds of houses in construction at any given time. There are always jobs running into unexpected or unavoidable events. For instance, an in-fill site has no space around it to put the prefabricated roof, so the roof trusses have to be delivered after the house is erected, and the roof has to be framed in the air. This may lead to a two-day delay in framing. To accommodate such unavoidable delays in the process, while minimizing the usage of time buffers, projection tables are used to dynamically level and schedule production flow based on actual completion of upstream tasks. Although schedule adjustment means variability, it can effectively reduce the time buffer required to keep process stable and predictable.

Table 9: Standard Deviation of Stage Cycle Time

		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Standard Deviation of CT	Early 2007	35	14	20	14	7
	Jun-09	3.7	5.2	6.8	3.1	4.0
Reduction	Days	31.3	8.8	13.2	10.9	3.0
	%	89%	63%	66%	78%	43%

There is an optimal balance point of process reliability and overall cycle time reduction. Improvement in reliability increases the predictability of the process, and thus downstream subcontractors can be scheduled in advance to eliminate the waiting time between tasks. However, to ensure the prediction is reliable and the site is 100% ready 100% of the time, time buffers are necessary to accommodate the possible delay caused by unpredictable or unavoidable events, which increase the overall cycle time of the process. Lastly, this balance point is decided by operation reliability. In lean implementation, standardized work and total quality control have reduced the variation of each construction operation to less than one day for long-duration tasks (task cycle time longer than two days) and zero for one-day tasks, so that FIFO lanes and projection tables can be used to develop three-week production schedules and maintain PSS (Average Percent Started at Schedule) above 90%. In the second phase of Landmark Homes' lean initiative, a goal has been set to reduce the standard deviation of stage cycle time to two days. Then, those variations can be completely shielded by using small time buffers between stages. The entire construction process then can be standardized on the process level, which means the production flow can be leveled once at the beginning of the process, and the house delivery date can be decided exactly at the time when customers sign the purchase agreement. This will bring tremendous advantages in cost reduction and improve customer satisfaction.

8.3 *Quality and Customer Satisfaction*

Jidoka (in-station quality) is one of two pillars of lean production. Building a culture of stopping to fix problems and getting quality right the first time is an important lean principle. In LGB's lean application, quality control systems have been developed in both the subcontracting and homebuilding companies. In the "Continuous Process Flow and Flow Reliability" section, the impact of standardized work and training on quality improvement has already been discussed. This section will focus on the result of the homebuilder's efforts and the consequence of quality improvement.

Figures 23 and 24 are the quality tracking reports for jobs that were occupied by customers in June 2008 and June 2009. In the report, "Ave # of Def" refers to the total number of defects that were identified in the construction process. "Ave # of Def Left" is the number of defects that subcontractors failed to repair within 48 hours. Three days before pre-occupation orientation, site managers checked the quality of the house, which is called "Qty Review." The defects found in the pre-occupation orientation are counted in the "Ave # of PreOcc Def," and defects found at and after possession are counted in "Possession Def."

Quality Tracking Report						
Possession Date		Possession Date				
From:		6/1/2008 12	To:	6/30/2008	Run Report	
Possession Jobs	Site Manager	Ave # of Def	Ave # of Def Left	Ave # of Qty Review Def	Ave # of PreOcc Def	Ave # of Possn Def
<u>37</u>	Total Jobs	33.16	1.03	12.86	1.86	11.22
<u>1</u>	Rick Clements	2.00	0	0	0	0
<u>2</u>	Billy Biendarra	29.50	1.00	21.50	0	2.00
<u>3</u>	Maclean Kumpula	7.67	0	3.67	0	2.33
<u>4</u>	Ali Sadiq	15.75	1.00	0.75	10.50	5.00
<u>1</u>	Suat Demirer	42.00	2.00	11.00	0	6.00
<u>3</u>	Marc Labbe	23.00	7.00	5.67	0	8.67
<u>6</u>	Phillip Hender	34.50	0	14.50	0	12.67
<u>2</u>	Rollin Kurka	113.00	1.50	68.00	0	13.50
<u>1</u>	Karol Kolodziejczyk	15.00	0	15.00	0	15.00
<u>6</u>	Corry Commandeur	49.67	0.67	19.33	4.17	15.17
<u>7</u>	John McKale	28.14	0.14	5.29	0.29	17.57
<u>1</u>	Randy Lund	26.00	1.00	0	0	20.00

Figure 23: Quality Tracking Report (Landmark Homes, June 2008)

Quality Tracking Report

Possession Date	Possession Date
From: 6/1/2009 12:00:00 PM	To: 6/30/2009 12:00:00 PM
Run Report	

Possession Jobs	Site Manager	Ave # of Def	Ave # of Def Left	Ave # of Qty Review Def	Ave # of PreOcc Def	Ave # of Possn Def
<u>12</u>	Total Jobs	82.75	2.08	32.83	12.83	2.92
<u>4</u>	Ali Sadiq	25.50	0.50	2.00	8.25	0.50
<u>2</u>	Corry Commandeur	89.50	1.00	46.00	11.00	1.00
<u>1</u>	Rollin Kurka	139.00	5.00	25.00	19.00	5.00
<u>5</u>	Phillip Hender	114.60	3.20	53.80	16.00	5.20

Figure 24: Quality Tracking Report (Landmark Homes, June 2009)

Comparing the two reports, it is interesting to find that in Figure 23 the numbers in the column of “Ave # of Def” varied substantially and much less than those in Figure 24. This does not mean that the operation quality in 2008 was much higher than that in 2009, but that site managers did not follow the standard to check construction quality. In fact, before October 2008 when the revised quality standard was issued, there was no clear instruction on when and how the defect should be recorded. Figure 25 shows an example of deficiency records for a job completed in June 2008. According to revised standards, there were two obvious problems in this quality detail report. First, there were no records of the deficiencies found during the construction process. All records were inserted after possession, although two of them were assigned the type of construction. Second, the record was not specific. For instance, the second item in the report is “Paint touch up required” on cabinets. But it did not specify location and how many points. In the new standard, every point of paint touch-up needs to be specified in the report and counted as a defect. That means if five points on cabinets requires painting touch-up, there should be five deficiency records and counted in quality tracking reports as five deficiencies.

Improved operation quality and tighter quality inspection standards resulted in higher quality of final products. The average number of deficiencies found in possessed homes has been significantly reduced from 11.2 in June 2008 to 2.9 in June 2009. As a combined effect of shorter cycle time and higher product quality, customers’ satisfaction level increased in the past 12 months as shown in Figure 26. From the chart, a clear correlation can be identified between the average number of deficiencies in possessed homes and the customers’ satisfaction rating. Since Figure 26 is based on a 30-day move-in loyalty survey designed to capture feedback from

homeowners who moved in Landmark Homes' houses in the previous month, the AVID curve lags behind the quality curve by one month.

Job	Address	Subdivision	Possession	Category	Deficiency	Insert Date	Completion Date	Deficiency Type
1-07-115	4055 Crowsnest Crescent	Lakeland Ridge	6/23/2008 12:00:00 AM	Cabinets	drawer at the left side of the sink to be fixed	6/24/2008 10:35:53 AM	7/4/2008 12:00:00 AM	Construction
1-07-115	4055 Crowsnest Crescent	Lakeland Ridge	6/23/2008 12:00:00 AM	Cabinets	Paint touch up required	6/24/2008 10:37:05 AM	7/4/2008 12:00:00 AM	Construction
1-07-115	4055 Crowsnest Crescent	Lakeland Ridge	6/23/2008 12:00:00 AM	Lighting	The glass of thr exterior light in the back yard to be replaced	6/24/2008 9:56:00 AM	7/1/2008 12:00:00 AM	Pre-Occ
1-07-115	4055 Crowsnest Crescent	Lakeland Ridge	6/23/2008 12:00:00 AM	Lighting	The light fixtures at both sides of the fireplace to be re-selecttd by the customer(no more spare in the store of Park lighting)	6/24/2008 9:57:43 AM		Pre-Occ
1-07-115	4055 Crowsnest Crescent	Lakeland Ridge	6/23/2008 12:00:00 AM	Windows/Doors	The chips in the exterior windows (from outside) to be	6/24/2008 10:00:10 AM	8/8/2008 12:00:00 AM	Pre-Occ

Figure 25: Example of Quality Deficiency Records (Landmark Homes)

AVID Ratings are a professional, third-party survey to assess homebuyers' satisfaction with homebuilders' service. As the biggest service provider in the customer loyalty management field, AVID Ratings Co. provides service for more than 400 builders in North America and conducts over 350,000 homebuyer surveys each year. Based on survey data, AVID publishes the average rating of the top 10% of homebuilders in North America. This allows its consumers to benchmark its organization with industry leaders. Before February 2009, the ratings of Landmark Homes were lower than the industry benchmark, but now the company has entered the top 10% and consistently has ratings above 80%.

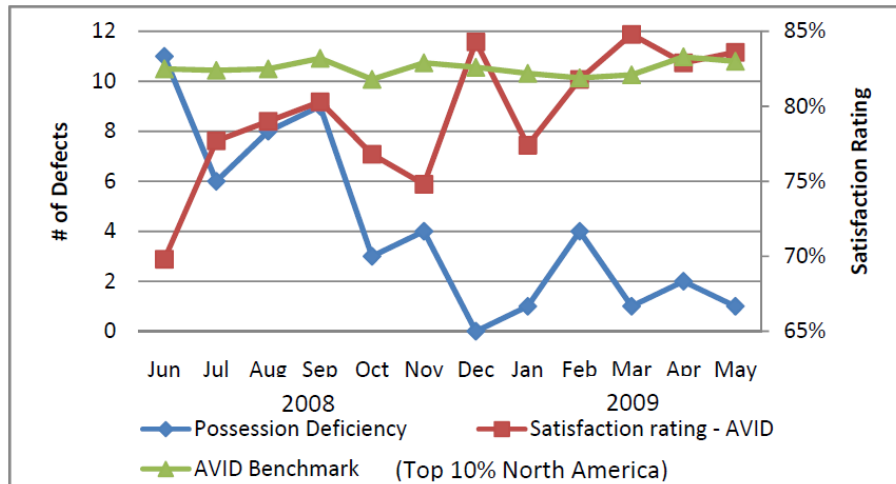


Figure 26: Quality and AVID Customer Satisfaction Survey (Landmark Homes)

9.0 Continuous Improvement

Phase I of Landmark Homes' lean implementation was 18 months and ended in February 2009. As discussed above, the lean implementation had achieved great success and the management team decided to commence Phase II immediately. In March and April, a series of VSM sessions were organized to map the current state of Landmark Homes' homebuilding process and formulate the future state map. The lean improvement goal for the next 18 months is to reduce the overall construction cycle time from 150 days (five-month delivery) to 90 days (three-month delivery). Table 10 summarizes the improvement objectives of each stage.

Table 10: Lean Improvement Objectives (Landmark Homes 2009)

		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Total
Current State	Cycle Time	22	15	39	31	31	138
	Standard Deviation	3.7	5.2	6.8	3.1	4.0	
Lean Improvement Goal	Cycle Time	14	8	25	14	29	90
	Standard Deviation	2.0	2.0	2.0	2.0	2.0	

In order to achieve the lean objectives, the following seven issues were identified in the VSM sessions as key kaizen elements:

- 1) Reducing foundation cycle time so the house can be backfilled in 2½ workdays. Precast concrete foundation system is considered as a promising technique to achieve this goal.

-
- The image shows a project management board with two sections. The top section is titled "BHAG" and "CYCLE TIME 3 MONTHS". It features a timeline with tasks like "File Review", "Design", "Test", and "Release", with durations ranging from 1D to 5D. The bottom section is titled "SCOTT H." and "CYCLE TIME 3 MONTHS". It features a timeline with tasks like "File Review", "Design", "Test", and "Release", with durations ranging from 1D to 5D. Both sections include a "5D DAYS" column and a "VAC" column.

4) Educating and helping subcontractors establish in-station quality control systems so they can take full responsibility of their work quality and protecting surrounding works. Homebuilder's site managers will only do spot checks during construction, and all quality steps will be eliminated from the process.

- 5) Developing a super-subcontractor for electrical and structural wiring operations and encouraging the formation of large crews.
- 6) Establishing an in-house cleaning team. All the cleaning works will be performed on work days with no separate days dedicated for “vacuuming.”
- 7) Cultivating a lean culture of stopping to fix the problem to continuously improve the working process.

In June 2009, Landmark Homes’ management published its long-term view of the homebuilding process (Figure 28). The design originated from the practice of a Japanese industrialized housing producer ^[31], but was modified to suit the market situation in North America. The process starts when a customer selects a basic model and makes decisions on the level of specification, exterior color and internal fit-outs (Figure 28, #1). This is an interactive process consisting of several sessions in show homes and in the design center. The final product is visualized to the customer via design catalogues, material samples and 3D animation. Once the purchase contract is signed, all customer selections are compiled into a job file package and sent to drafting and estimating departments for drawings and purchase orders (PO) preparation (#2). Meanwhile, the construction division is informed to generate a job schedule and level the flow. Then the drawings, POs and job schedule are sent to the production division (#3) and subcontractors (#4) who are responsible for providing all the resources and workforces required for completing the assigned construction tasks on site. The production division orders the job-specific materials (#5), such as roof trusses, windows, doors and stairs, and puts the job into a production schedule (#6). A three-week lead time and two-day flexibility on erection date are required by the production division to ensure material availability and to level the production flow. Common materials, like lumber, OSB, joists, engineering beams, insulation and drywall, are controlled by the kanban system. Suppliers replenish the material inventory in the prefabrication shop based on production kanbans (#7). Building components, including precast concrete foundation panels, floor panels and wall panels, are delivered to the site. The delivery is synchronized with the crane and field erection crew (#8). All divisions and subcontractors consistently adjust their capacity and resource allocation based on LGB’s forecast and strategic planning (#9).

A few strategic moves have already been in the planning stage including: 1) cooperation with a leading precast company in the region to produce precast foundation panels; 2) the construction

of an 85,000 square-foot facility to contain an automatic closed wall panel production system that has the capacity of producing panels for four houses per day; and 3) a research project with University of Alberta using building information systems (BIM) to link the entire homebuilding process, from house model development, to sales, to production, to site construction, to service.

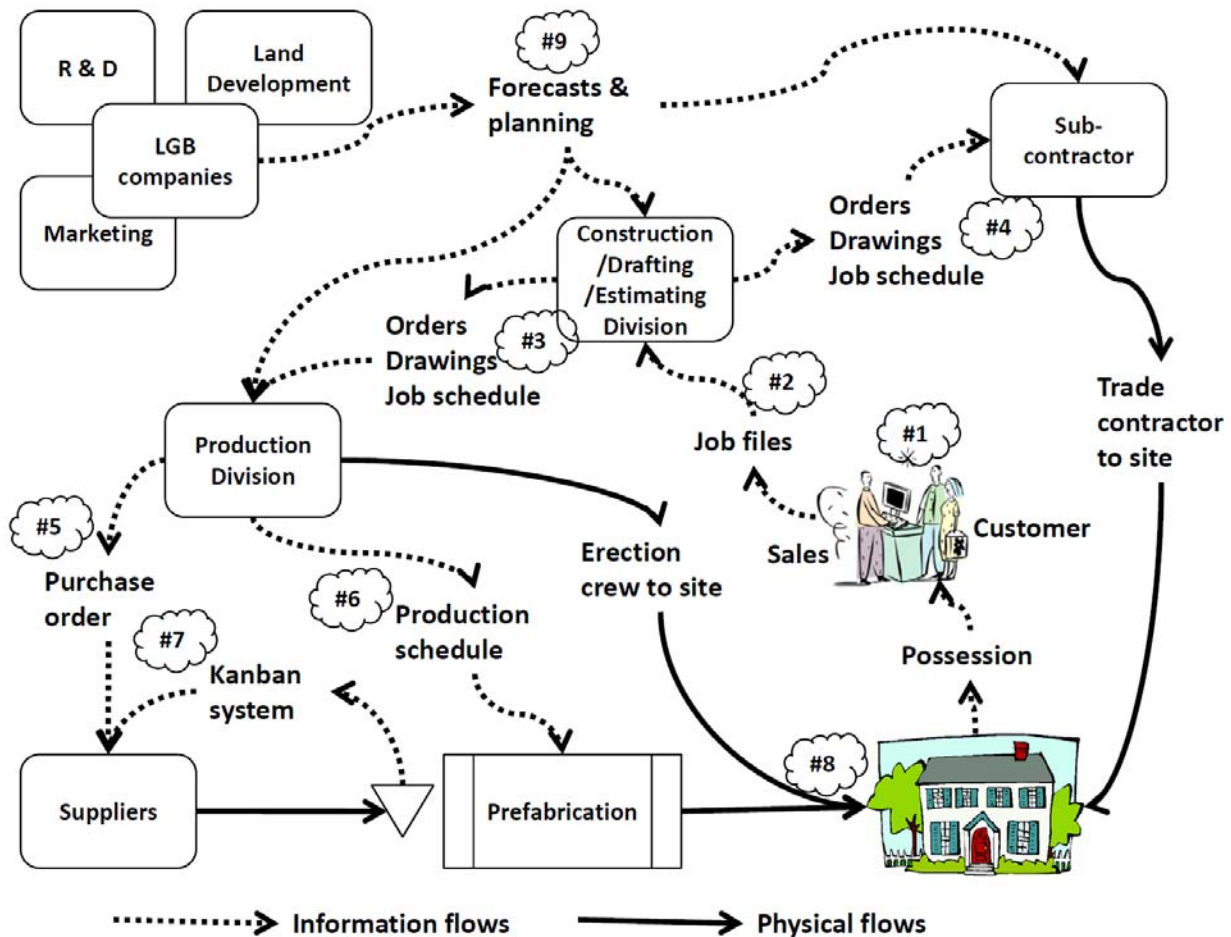


Figure 28: Landmark Homes' Homebuilding Process

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