Mass Customization Strategies And Their Relationship To Lean Production In The Homebuilding Industry

Isabelina Nahmens
University of Central Florida

MASS CUSTOMIZATION STRATEGIES AND THEIR RELATIONSHIP TO LEAN PRODUCTION IN THE HOMEBUILDING INDUSTRY

by

ISABELINA NAHMENS
B.S. University of Central Florida, 2001
M.S. University of Central Florida, 2003

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Industrial Engineering and Management Systems
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Summer Term
2007

Major Professor: Michael Mullens

ABSTRACT

Current housing trends point to an increasing interest from homebuyers to demand houses that reflect their personal and unique styles, and which are individually configured according to these needs (NAHB, 2004). These homebuyers in turn are unwilling to settle for standard models that sacrifice what they really want in a home. At the same time this creates pressure on builders who are reluctant to sacrifice production efficiencies by deviating from standard models. Such customization desired by demanding customers can disrupt the entire estimating, production, delivery and management process, making it even more difficult to manage homebuilding efficiently and effectively. The question faced by homebuilders in this conditions is, how to manage this trade-off and deliver exactly what homebuyers want, at reasonable prices and lead times with minimal disruptions in efficiencies. Mass Customization (MC) is an emerging production paradigm that seeks to manage the trade-offs between product variety and mass efficiency, while fulfilling individual customer requirements.

The general purpose of this research is to improve the effectiveness and efficiency of housing production through the implementation of mass customization strategies. More specifically, this research focuses on the study of the production system through the application of *lean production* principles, as an approach to enable mass customization. This study first characterizes how much product choice is currently being offered by U.S. homebuilders and what is the impact of customization on production efficiency; and then focuses on the evaluation of the relationships between mass customization and lean production principles.

Results revealed that homebuilders offering increased product choice are likely to suffer poorer labor productivity, greater inventory, higher production costs, more quality issues, less

satisfied homebuyers, and lower space efficiency. In general, operational performance deteriorated with an increase in product choice. Therefore, industrialized housing manufacturers have not reached the ideal of mass customization and are paying a price for offering more choices to their customers. Homebuilders could mitigate these challenges by using lean concepts. In general, case studies showed that product choice does not necessarily make the implementation of lean concepts more difficult. Some lean concepts, like workload balancing and standardizing tasks, clearly facilitated the handling of product choice. Other lean concepts, like creating a continuous process flow, can be made to work well, even with increased choice. Case study results suggested that good concepts for lean (e.g., efficient continuous flow, effective pull system, workload leveling, defect-free processes, standard tasks, good visual controls, and reliable technology) were also good concepts for (or easily accommodated) handling a range of product choice.

ACKNOWLEDGEMENTS

Thank you God, for blessing me with this opportunity and for the opportunity to meet the people that I have met during this endeavor. I would like to also thank my parents for all of their support and assistance throughout my life and education; this accomplishment would have not been possible without them. I especially thank to my husband, Kensett for his support and for putting up with my long hours and emotional roller coasters and Stephan, our son, who give me the strength and motivation to endure and complete this work.

I would like to thank my advisor, Professor Michael Mullens, for his support, guidance and invaluable comments that made this work possible. I would also like to thank the committee Professors Robert Armacost, Renee Butler, Raj Echambadi, and Robert Hoekstra, for their helpful reviews and comments during the creation of this work. I want to also thank to the IEMS Department at UCF, especially Professor Linda Malone for her advice and support.

Finally, I would like to thank the Manufactured Housing Research Alliance and the individual homebuilders that participated in this research; without their help this work would not have been possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

Introduction and Motivation

We are entering an era where one size no longer fits all or even a few. We are entering an era where One Size Fits One (Heil et al., 1997). In the housing industry, homebuyers are demanding houses that reflect their personal and unique style, houses that are individually configured according to their needs. Homebuyers do not want to buy a standard model and sacrifice what they really want in a home, but at the same time builders do not want to sacrifice production efficiencies by deviating from their standard models (NAHB, 2004). As a result, homebuyers can either choose from a limited number of standard products offered by large-scale production homebuilders or pay a premium for a custom home built by a smaller custom homebuilder. Mass Customization is an emerging production paradigm that seeks to design and manufacture customized products at mass production efficiency and speed (Pine, 1993). The concept has been proposed as a potential strategy for competitive advantage; however companywide implementation of mass customization is hindered by the lack of validated operational strategies to customize on a mass scale (Tseng and Piller, 2003). The general purpose of this research is to explore the utility of mass customization strategies in homebuilding. The ultimate envisioned outcome is a set of guidelines that will enable U.S. homebuilders to better meet homebuyer needs through mass customization.

Each customer could find exactly the custom house desired, if companies make their product-process choice strategy work (Kahn, 1998). The emerging paradigm, mass customization, could effectively manage the trade-offs between product variety, mass efficiency and time to market, while fulfilling individual customer requirements, with efficient operations.

Mass customization in the housing industry context, refers to the ability to design and manufacture customized houses at mass production efficiency and speed. Customized houses might imply changes of varying difficulty, ranging from change in the core concept, dimensional changes (e.g., floor plan), or change in features and/or finishes. Thus, the concept of mass customization relates to the ability to provide customized products through flexible processes and supply networks at reasonable cost.

Mass customization strategies have been categorized primarily by the point of initial customer involvement. Lampel and Mintzberg (1996) define a continuum of five strategies that extend from no involvement (pure standardization) to involvement starting in design (pure customization). At one extreme there is the pure standardized supply chain (equivalent to the ship to stock strategy) and at the other there is the pure customization supply chain, equivalent to the make to order scenario (Barlow et al., 2003). Barlow et al. (2003) use this approach to categorize the strategies used by five of Japan's leading homebuilders, all industrialized. For example, Toyota Home manufactures small standard modules that are shipped to the construction site where they are assembled to create a custom home. This strategy was categorized as segmented standardization, since homebuyer involvement does not start until after modules are assembled in the factory.

With all the technological advances and innovative homebuilding technologies available today, builders still face several challenges while trying to achieve mass customization. The first challenge is determining product offerings. Homebuyers may not want to pay for features built into a standard model. However, customization can incur an extra cost (NAHB, 2004). Builders also face the operational challenge of how to provide customization without impacting the basic efficiency of the production process. When a company offers several variants of a product, the product architecture is a key determinant of operational performance, of both the production process and the supply chain (Ulrich and Eppinger, 2004). There are few examples in the literature reporting on enabling strategies for mass customization for complex products like houses. This makes this area an appropriate area for research.

The concept of mass customization encompasses the dynamics and trade offs among three elements: product design, production system design and supply chain design (Guruswamy et al., 2004). It is in the overlapping of these factors that trade-offs between product variety, mass efficiency and time to market occur. For example, an examination of developments in the automobile industry reveals three trends: 1) product design - the standardization of the chassis, engine components, sensing, wiring harnesses, etc. across an entire product line (Pil and Holweg, 2004), 2) production system design - the mass customization of body parts, finishes, accessories, and other elements that customers want tailored, and 3) supply chain design - the use of "tier 1" suppliers who replace thousands of assembly line parts with integrated component assemblies (Alford et al., 2000). The success of any mass customization strategy depends on the operation of the value chain (Pil and Holweg, 2004), therefore production system factors have to be evaluated in conjunction with product and supply chain factors.

Interaction among Product, Production System and Supply Chain Design

Mass customization strategies have been explored from product, production system, and supply chain perspectives in a topical manner or have been focused on only one form of customization. The literature presents different successful mass customization strategies, but only a few strategies are addressed at a time. This implies that there is not one single strategy to mass customization. Strategies for achieving mass customization are well known for many consumer products. However, their applicability to complex products like housing is less well understood (Barlow et al., 2003). Several mass customized homebuilding strategies are emerging at the intersection of product design, supply chain design and production system design. Building systems use factory-made modular components to speed the assembly of new homes on the construction site (i.e. - wood/steel frame trusses, wood/steel frame panels, structural insulated panels (SIPs), pre-cast concrete panels, insulated concrete forms, and "modular" homebuilding). The most popular building systems use the same components and design as their site-built counterparts, but effectively consolidate or shorten the supply chain by the delivery of factory-made sub-assemblies to the construction site. Suppliers are increasingly able to use flexible manufacturing innovations to gain production economies, even with greater demands for customization (Mullens and Toleti, 1996).

Open Building is an innovative, postponement-like strategy that intersects product design, production system design and supply chain design. OB is an approach that facilitates the design and construction based on organizing buildings and their technical and decision-making processes according to levels (Kendall and Teicher, 2000). By disentangling the systems and sub-systems from each level, opportunities are increased for better organization, increased consistency, quality and more control and flexibility for the homeowner. OB divides the total process and product of house construction into two decision levels: shell and infill (Kendall, 2004). Shell is the result of design decisions specific to the site, and includes foundations, building structure and envelope, stairs, and main mechanical, electrical, plumbing and systems. The infill is the set of design decisions and products needed to make a shell habitable and changeable later without disturbing the shell. OB systems simultaneously enable efficient work processes and variety of products in housing (Kendall and Teicher, 2000). While optimizing efficiency (labor and process) through a systematic production and assembly process, OB also allows for customization and future changes. OB goes beyond simple postponement, providing continuing benefits for remodeling and retrofitting during the life cycle of the house. OB offers the best prospect for mass customized homebuilding because it allows construction developers to balance efficient production processes with higher levels of choice.

Research Question

- How can homebuilders use mass customization strategies to improve the effectiveness and efficiency of homebuilding?

Research Purpose and Objectives

The general purpose of this research is to improve the effectiveness and efficiency of housing production through the implementation of mass customization strategies. This research intends to develop a set of guidelines that can guide U.S. homebuilders to better meet homebuyer needs through mass customization. Mass customization strategies encompass three dimensions of product realization: product design, production system and supply chain. This research will focus on the production system. More specifically, the research will investigate the Toyota Production System (commonly referred to as lean production) and how it supports or hinders mass customization principles. This detailed study intends to fill a void in the existing literature by exploring relationships between lean production principles and mass customization principles.

Some of the important questions this research intends to address are:

- What choices do industrialized builders offer and how do they affect plant performance?
- How do mass customization principles affect lean principles and vice versa, in the housing industry?

The methodology of this research entails two phases: first, an industry-wide exploration of the current levels of customization and the impact of customization on production efficiency, and second, two case studies on specific homebuilder plants to analyze in detail the effects of mass customization on lean and vice versa. Common trend across case study plants were documented as industry guidelines for implementing the seven lean principles while maximizing product choice.

Research Contribution

The contribution of this research is two fold. First, this study identified the impacts of product choice offered by industrialized builders on their production efficiency. Second, this research intended to fill a void in the existing literature, by identifying effective mass customization strategies for the industrialized housing industry through the exploration of mass customization principles, lean production principles and their relationship.

This research provides useful guidelines for builders interested in better addressing specific customer needs, while managing the operational complexities resulting from product variety. For builders that have already implemented mass customization strategies, this research provides the opportunity to re-assess their approach.

CHAPTER 2: LITERATURE REVIEW

In the housing industry, homebuyers are demanding houses that reflect their personal and unique style, homes that are individually configured according to their needs. Builders know that homebuyers prefer to change standard floor plans, components, equipment and finishes. However, builders do not want to sacrifice production efficiency by deviating from their standard models (NAHB, 2004). Changes can disrupt the entire estimating, production, delivery and management process, making it even more difficult to manage homebuilding effectively. As a result, homebuyers are forced to choose from a limited number of standard products offered by large production builders or pay a substantial premium for a custom home built by a smaller custom builder.

Traditional offerings, designed for average requirements, create customer sacrifice gaps, which is the difference between a company's offering and what each customer truly desires (Pine & Gilmore, 1999). A mass customization strategy has the potential to solve this problem, by delivering homebuyers exactly what they want, at reasonable prices and lead time. Da Silveira et al. (2001) argue that mass customization can be a reality in today's world due to the availability of new flexible manufacturing and information technologies that enables production systems to deliver higher variety at lower cost. They also believe that the increasing demand for product variety, the shortening of product life cycles and expanding industrial competition promotes the application of mass customization strategies.

In order to demonstrate the relevance of this research the background and previous related work are described in this chapter, including mass customization principles and strategies, product design, production systems design (focusing in Lean production principles) and supply chain design as they relate to mass customization and their application in the housing industry.

Mass Customization

What is Mass Customization?

The term mass customization was coined by Davis in 1987 in his seminal book, Future Perfect (Davis, 1987). The concept of mass customization as a manufacturing strategy was popularized by Pine (Pine, 1993). Pine describes the manufacturing aspects of mass customization by mapping the progression from mass production to mass customization. Mass customization is the next paradigm, following the century-old mass production paradigm. Mass customization is the ability to design and manufacture customized products at mass production efficiency and speed (Pine, 1993). In a broader context, mass customization is the ability to provide individually designed products and services to every customer through high process agility, flexibility and integration (Davis, 1989). Thus, the concept of mass customization relates to the ability to supply customized products through flexible processes and supply networks at reasonably low costs. Guruswamy et al., 2004 proposed a unified framework aimed at supporting mass customization from a three dimensional perspective: product design, production process design and supply chain design. A mass customization strategy encompasses the dynamics and trade offs among those three factors (Figure 1). It is in the overlapping of these factors that trade-offs between product variety, mass efficiency and time to market occur.

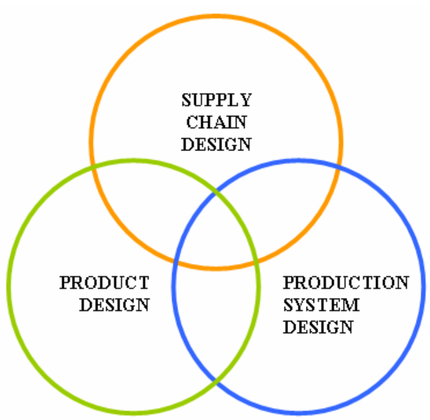

Figure 1- Mass Customization Components

From a manufacturer perspective, mass customization is viewed as another customer demand that challenges their capability to maintain the cost, quality and speed of operation. Qiao et al. (2003) argue that manufacturers view mass customization as their ability to produce and deliver customized products rapidly while keeping costs at the mass production level. For manufacturers the success of mass customization is dependent on the effective and efficient alignment of internal capabilities with external opportunities.

From a customer perspective, mass customization provides superior customer value by producing goods and delivering services that meet individual customer needs with near mass production efficiency (Tseng and Jiao, 2001). This definition implies that the goal is to detect customer needs first and then to fulfill these needs with efficiency that almost equals that of mass production. Mass customization is a customer-centric approach, consequently it is a value chain-based concept (Da Silveira et al., 2001). There is also a cost component that supplements this definition, requiring no price premium be added to the customized product. However, mass customization practice shows that consumers are frequently willing to pay a price premium for customization to reflect the added value of customer satisfaction due to individualized solutions

(Tseng and Piller, 2003). The added value causes an increment of utility, customers gain from a product that better fits their needs than the best standard product available. Therefore, the value customers give to a customized product is an important element in the definition of mass customization.

Mass customization in the housing industry context, refers to the ability to design and build customized houses at mass production efficiency and speed. These houses have been individually configured according to customer specifications. In some cases, builders allow homebuyers to customize their house floor plan, to add custom features, components and finishes, for a price premium. However, there are restrictions on the choices offered to homebuyers. Apart from the constraints imposed by the size and shape of the plot and building and planning regulation, builders try to limit the level of choice in order to achieve efficiencies in the construction process (Barlow et al. 2003). Furthermore, the type of building system used affects the ability to offer choice.

There is a wide variety of understandings and meanings of mass customization. In order to address the implementations issues of mass customization, a working definition was adopted as “the technologies and systems to deliver goods and services that meet individual customer’s needs with near mass production efficiency” (Tseng and Jiao, 2001).

Application of Mass Customization in Industry

Many companies and industries are adopting mass customization strategies to better meet customer requirements. There are many examples of industries that are pursuing a mass customization strategy:

- Apparel- Levi's Company offers custom jeans, called "cut-to-fit" jeans. Customers can order their jeans according to their specification (i.e. fabric, style and size); the company receives the order and makes the jeans, which then is delivered to the customer's store. These custom jeans are made possible through the use of flexible manufacturing processes. Unique patterns re-built upon a traditional style pair of jeans that is altered to specific customer specifications (Duray et al., 2000).
- Cellular phones and pager- Motorola Company offers highly customized communication devices, allowing customers to choose from a variety of features including language options, colors, and accessories to meet their specific needs. Motorola uses a sophisticated information system to help customers select feature from options that cover many combinations (Duray and Glen, 1999).
- Computer- Dell Computer Company provides customization of personal computers through interchangeability of parts. Computers systems are assembled according to customer requirements by adding or subtracting components from one of the several base systems (Duray and Milligan, 1999). Customer can customize the configuration of their personal computer by choosing from a variety of hard drive, chips, storage media and accessories.
- Bicycle- in bicycles, the frame fabrication processes, tube cutting and welding, presents the critical technology decisions to customization. For example, Cannondale uses a system combining laser cutting with the slot-and-tab assembly scheme, which allows any type of frame geometry to run through its production process in any sequence with very little set-up. Bicycles are extremely modular; components are commonly interchanged with frames from different models. Because of the modularity built into their design, VooDoo and National bicycles can outsource their front suspension component to a third party.
- Automotive- manufacturers offer all their vehicles in many body styles, power trains, and combinations of interior trim and exterior paint. Manufacturers also are offering an increasing number of options that allows drivers to tailor cars to their liking. For example, Buick allows drivers to choose between a soft or sport suspension. Some manufactures are beginning to build vehicles to specific end customer orders (Holweg and Pil, 2004). For example, Toyota in Japan, offers five day delivery, from the time the customer personally designs his/her own, customized car (from modular options) on CAD system, through order processing, scheduling, manufacture, testing and delivery. Some of the mass customizations methodologies successfully used by Toyota include lean manufacturing processes and supply chain management, as well as some other advanced technologies (Alford et al., 2000). However, there are some negative impacts of variety on the value chain, Pil and Holweg (2004) proposed strategies such as mutable support structures (e.g., interchangeable), modularity, option bundling, and late configuration for mitigating the impact of variety in the manufacturing.
- Construction- Babcock & Wilcox Construction Company had the opportunity to benefit from designing for constructability and has experienced productivity improvements (Hines et al., 2001). Hence, the ultimate goals of constructability (planning, predictability and consistency) were realized.

As the literature indicates, mass customizers represent a vast array of products, industries and manufacturing systems with different mass customization strategies. Although industries might vary, there are some success factors in the implementation of a mass customization strategy that remain valid across industries.

Mass Customization Strategies

Mass customization strategies have been explored from product, production system and supply chain perspectives in a topical manner or have been focused on only one form of customization. The literature presents different successful mass customization strategies, but only a few strategies are addressed at a time. This implies that there is not one single strategy to mass customization. In order to provide an overall comprehension about mass customization strategies, a summary of relevant research is compiled below.

Mass customization strategies have been categorized primarily by the point of initial customer involvement. Lampel and Mintzberg (1996) define a continuum of five strategies that extend from no involvement (pure standardization) to involvement starting in design (pure customization) (Figure 2). The five mass customizing strategies include: pure standardization, segmented standardization, customized standardization, tailored customization, and pure customization. Pure standardization refers to the case in which all product is the same and where the customer does not get involved before taking possession of the product. In segmented standardization, firms respond to the needs of different clusters of buyers, but each cluster remains aggregated and the product produced for the cluster is the same. In customized standardization, products are made to order from standardized components. Tailored customization requires a basic product that can be customized in the fabrication stage. In pure customization, the product is customized from scratch. However, there has to be some initial standard configuration, otherwise this strategy corresponds to prototyping rather than customizing.

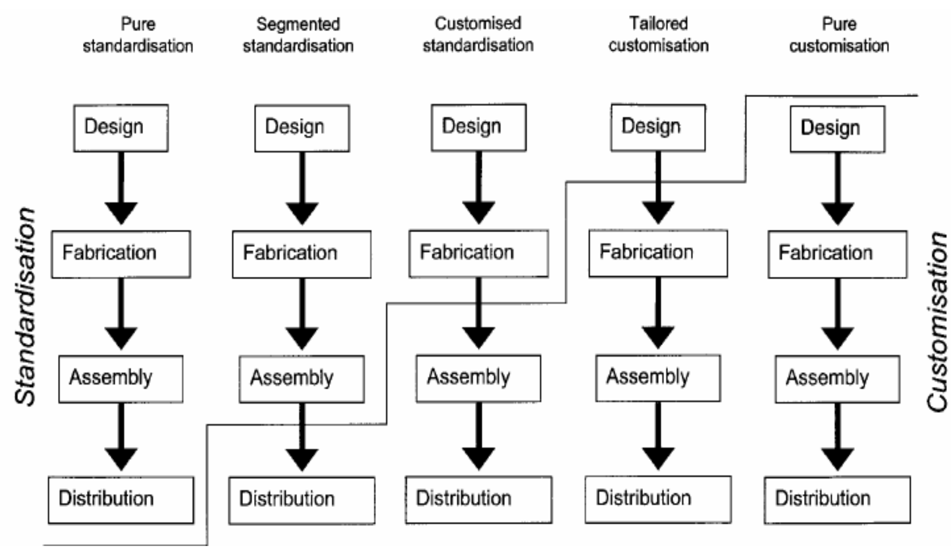

Figure 2- Continuum of Five Mass Customizing Strategies (Lampel and Mintzberg, 1996)

Barlow et al. (2003) used Lampel and Mintzberg's continuum approach to categorize the strategies used by five of Japan's leading homebuilders, all industrialized. For example, Toyota Home manufactures small standard modules that are shipped to the construction site where they are assembled to create a custom home. This strategy was categorized as segmented standardization, since homebuyer involvement does not start until after modules are assembled in the factory.

Pine and Gilmore (1999) introduce a taxonomy to classify suppliers who pursue mass customization based on customer needs and classify mass customization based on the capability of avoiding a specific customer sacrifice. The authors defines customer sacrifice as "the difference between what a customer accepts and what he/she really needs, even if the customer doesn't know what that is or can't articulate it" (Pine and Gilmore, 1999). In this context, they identified four distinct approaches to mass customization: collaborative, adaptive, cosmetic and transparent (Figure 3). In collaborative customization, customers select from predetermined components, and then the product is custom made. In adaptive customization, only one customizable product is offered and the product is designed so that users can alter it themselves. Cosmetic customization, presents a standard product differently to different customers. Transparent customization provides individual customers with unique goods or services without letting them know explicitly that those products and services have been customized for them. Typically, this type approach requires long term relationship between manufacturer and customers. Pursuing any type of the mass customization strategies presented by Pine and Gilmore (1999) will have an impact on product, production process and supply chain.

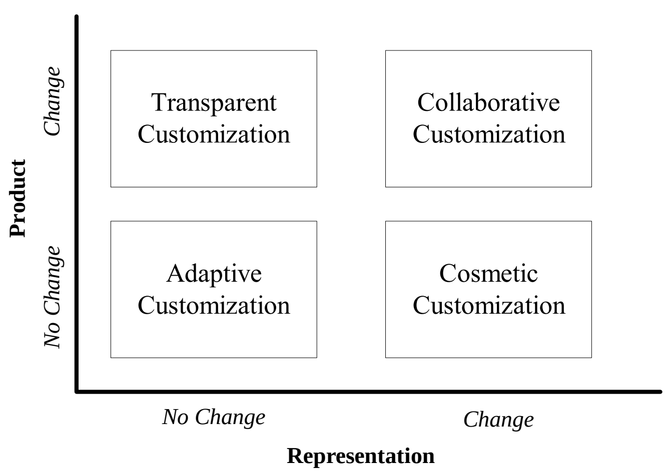

Figure 3- The Four Approaches to Mass Customization as a Response to the Customers' Sacrifice by Pine and Gilmore (1999)

Pine and Gilmore's (1999) conceptualization of mass customization strategy focuses on the customer and his/her sacrifice. Duray et al. (2000) focus on an operations perspective to mass customization. They present a classification of mass customization based on two dimensions: point of customer involvement and type of modularity. These dimensions are evaluated in relation to the production cycle consisting of the design, fabrication, assembly and use phases. Duray (2002) concurs that the point of customer involvement in the production cycle is a key indicator of the degree or type of customization provided. If customers are involved in the early design stages of the production cycle, a product could be highly customized. If customer preferences are included only at the final assembly stages, the degree of customization will be less. In this manner, the point of customer involvement provides a practical indicator of the relative degree of product customization. Duray et al. juxtaposed both dimensions, customer involvement and modularity, resulting in four different archetypes: fabricators, involvers, modularizer, and assemblers (Figure 4). Fabricators are willing to use common components, but they may also tailor or design new components to meet customer requirements. Involvers allow customers to take part in the design and fabrication process, and the customization is done during the assembly phase by combining standard components. Modularizers use common components in many product lines, and customization is done in the assembly or use phase. Assemblers use standard components and allow customers to take part in the late stages of the production cycle.

Type of Modularity

Point of Customer Involvement	Design	Fabrication	Assembly	Use
Design / Fabrication	Fabricators		Involvers	
Assembly / Use	Modularizers		Assemblers	

Figure 4- Matrix Grouping of Mass Customization Configurations by Duray et al. (2000)

Da Silveira et al. (2001), building on previous research, introduced a classification framework of eight generic mass customization strategies:

- Design- in this mass customization strategy, customers interact with suppliers with the objective to design a particular product that fulfills particular requirements (e.g. residential architecture). This strategy allows for customer involvement.
- Fabrication- this mass customization strategy includes customized product using basic predefined design, and allows customer to modify the product building block (e.g. Motorola's Bandit pager).
- Assembly- this mass customization strategy refers to the use of standard models that can be combined into different product variants in order to meet particular customer requirements (e.g. Hewlett-Packard products). This strategy allows for customer involvement.
- Additional Custom Work- in this strategy, mass customization is achieved by adding custom work (e.g. Ikea's furniture) to standard product, often at the point of delivery.
- Additional Services- in this strategy, mass customization is achieved by adding services (e.g. Burger King's hamburger) to standard service, often at the point of delivery.
- Package and Distribution- this mass customization strategy refers to delivery or packaging similar products in different ways (e.g. Wal-Mart's peanuts).
- Usage- in this mass customization strategy, usage occurs only after delivery, through products that can be adapted to different functions or situations (e.g. Lutron's lighting systems).

- Standardization- this mass customization strategy relates to customizing products which self adapts to specific customer needs.

In the homebuilding sector there are different mass customization strategies that are delivering a wide range of custom houses. Investigating Japan's industrialized housing industry, Barlow et al. (2003) identified examples of Lampel and Mintzberg's five mass customizing strategies. For example, Sekisui House manufactures standardized components and subassemblies that are shipped to the construction site where they are configured and assembled based on customer's requirements. This strategy was categorized as tailored customization, since homebuyer involvement starts at the fabrication stage, before the modules are assembled in the factory. This strategy also allows for more design and specification choices to be offered.

There is evidence in the literature, that there is a wide array of industries using different types of mass customization strategies with good business results. This implies that there is not one single strategy to mass customization. Kahn (1998) argues that successful strategy resides in companies making their product-process choice strategy work, "each customer finds exactly the option he or she desires" (Kahn, 1998). Furthermore, the success of mass customization depends on the industry's product, production process and supply chain factors. However, existing literature on mass customization has mainly focused on manufacturing operations (Da Silveira et al., 2001). In addition, critical enablers of mass customization are rarely discussed. The next section introduces critical enabler from the literature and the industry.

Mass Customization Enablers

In order to select the best strategy for mass customization, there is a need to identify enabling factors. Mass customization enablers are classified into technology and methodology, which supports the development of the production system (Da Silveira et al., 2001). In general, Chandra and Grabis (2004) argue that the organizational and cultural aspects of the mass customization implementation address the methodology enablers, whereas the technology enablers address manufacturing aspects.

- Mass customization methodologies – refer to organizational and cultural aspects of mass customization. For example, supply chain management is a mass customization enabler methodology. Supply chain management has been referred to as the binding glue that holds together all the activities performed for mass customization success (Gooley, 1998). The main purpose of supply chain management is to coordinate interactions with customers, distribution of customized products, manufacturing, and purchasing of materials from suppliers. This mass customization methodology will be described further in the next section.
- Mass customization technologies- refer to technologies that enable mass customization such as computer-aided design (CAD), computer-integrated manufacturing (CIM), and flexible manufacturing systems (FMS). Communication and network technologies enable direct links between manufactures and suppliers, which improve the response time to customer requirements. Agile manufacturing practices are characterized by their ability to prosper in rapidly changing environments, changes introduced by customer's demand. Rapidly changing environments requires re-programmable and re-configurable production systems that are able to economically operate with very small lot sizes (Da Silveira et al., 2001). Duguay (1997) believes that there are certain interactions between agility and lean manufacturing. Each mass customization technology will be described further in the next section.

Mass Customization Components

Mass customization strategies encompass three dimensions of product realization: product design, production system and supply chain. Although this research focuses on the production system (lean production) and how it supports or hinders mass customization principles, consideration is also given to the other two mass customization components. Below is a summary of the latest literature on all three mass customization components to better understand their dynamics.

Product Design for Mass Customization

Before considering a mass customization strategy, the “product should be customizable” (Da Siveira, Borentein and Fogliatto, 2001). Thus, there are certain product factors that could enable or hinder mass customization. Mass customization is only applicable to those products for which the value of customization, to the extent that customers are willing to pay for it, exceeds the cost of customizing (Tseng and Piller, 2003). A customized product is designed specifically to meet the needs of a particular customer. Pine and Gilmore (1999) distinguish between a customized product and product variety. Whereas customization strives for fulfilling individual customer’s needs, variety simply involves more choice from which the customer is able to choose. It is important to realize that the availability of hundreds of varieties probably limits the market appeal of customized products for most customers (Duray, 2000). However, product variety is not equivalent to customization. This distinction is important because customization implies that customers must be involved in specifying the product design.

Since each customer has individual tastes and preferences, there should be many possible designs available to the customers. From a product design perspective, having all possible variations of a product might be feasible. However, from a production and logistical point of view, design choices should be restricted to as few as possible, to achieve cost efficiencies (Blecker et al., 2005). This situation is true in the housing sector, where builders try to limit the level of choice in order to achieve economies of scale in construction process (Barlow et al., 2003). Furthermore, the type of building system used by the builders affect their ability to provide product variety. Therefore, the problem of product design for mass customization translates into the development of product variants that can be efficiently manufactured.

Customized products are a slight variation of standard configurations and are typically developed in response to a specific order by customer (Ulrich and Eppinger, 2004). Thus, the existence of an initial product configuration is required to realize customization. A customized product can be seen as a generic product which then is modified by customer needs, like a car with a list of optional extras (Duray, 2000). Or it can be seen as a special product made of standard or customized modules assembled based on customer needs, like a prefabricated house. The adaptability of a product to customization largely depends on its architecture - the assignment of functional elements to the physical building blocks of the product (Ulrich and Eppinger, 2004). Architectural considerations that can facilitate customization include product platform and modularity. The motivation behind both approaches is to make it easier to create product variety and achieve customization.

Product Platform

One of the characteristics of a product's architecture is the product platform. A platform is a set of product elements and interfaces that are common to different final models (Muffatto, 1999). Product customization can take place by adding options to a common platform or by mixing and matching modules to achieve different product characteristics (Mikkola and Larsen, 2004). The motivation behind the use of modular components and common platforms is to create product variety and achieve customization at low costs.

Modularity

Mass customization requires that special products be provided in a cost effective manner. A number of researchers suggest that modularity is the key to achieving low cost customization. Pine (1993) argues that modularity is a key to achieving mass customization. Modular architecture refers to both, the tightness of coupling between components and the degree to which the rules of the system architecture enable or prohibit the mix-and-match of components (Schilling, 2000). In the housing industry, modular and panelized homebuilding systems are examples of modular architecture. A modular approach can reduce the variety of components while offering a greater range of end products. Another advantage of modularity is that it allows part of the product to be made in volume as standard modules with product customization achieved through combination or modification of the modules. While modularity has several advantages from a design perspective, it also reduces complexity from a manufacturing perspective. This is evident in industries manufacturing products such as computers and bicycles.

Production Process Design for Mass Customization

For most of the last century, mass production was the key manufacturing strategy in efficiently producing products and services at very low cost. Mass production systems are characterized by their ability to produce large volumes of standardized products at low cost, achieved through repetitive operations and long running production lines. Product is pushed through the line based on sales forecasts and material inventory levels. However, with customers' changing needs and rapid change in today's market, mass production systems are not capable of responding quickly in meeting customers' changing needs. As a result, there is the need for radical changes to methods used to operate traditional manufacturing enterprises. Pine

(1993) proposed that the proper strategic response is to enter the new frontier in business competition and shift to mass customization as a way of doing business. In recent years, mass customization has become an established manufacturing strategy. Furthermore, it has evolved beyond the initial promise of being the exclusive alternative to mass production. In literature and industry, it has been recognized that mass customization should be adopted only in response to real customer demand for customized products (Chandra and Kamrani, 2004). Thus, companies should evaluate their customers' needs and market before shifting to mass customization.

Since 1990 companies have used mass customization as a manufacturing strategy to supply customized good and services to their customers. However, it is evident from the literature, that while industries have made tremendous progress in initiating mass customization strategies, there are still two challenges, maintaining the lowest possible cost and lead times. Thus, this research presents manufacturing strategies that could lessen those mass customization challenges.

Researchers have examined ways to determine optimum variety levels (Ho and Tang, 1998). They developed three predictive indexes (commonality index, differentiation index, and setup index) based on data from high-tech companies. These indices can help companies quantify costs of delivering a certain level of product variety. However, research has yielded no definitive conclusions on product customization's impact on manufacturing operations (MacDuffie et al., 1996). It is almost certain that product design and supply chain initiatives that support mass customization will impact manufacturing. For example, designing and outsourcing large-scale, modular, integrated components will have a profound effect on fabrication, sub-assembly and final assembly processes. Some solutions proposed to mitigate any negative impact that customization may have on manufacturing relates to production process innovations, such as agile manufacturing, flexible manufacturing and advance technologies.

Agile Manufacturing

Some authors equate agility with mass customization, based on their ability to produce an almost unlimited variety of products in small quantities, even single customized items (Sheridan, 1993). Agility refers to the ability to change the processing facility to cope with product variety and customization. As stated by Voss (1994), "the essence of an agile corporation is the ability to reconfigure the plant facility itself." Where reconfigure means the ability to change production capabilities (what processes can be performed in the facility) and production capacity (the capacity available for performing each process). Agile manufacturing is concerned with many facets of an enterprise: processes, people, management and organizational structures, vendor relationships, business strategies, etc. Agility refers to the manufacturer utilizing resources and people which can be changed, or reconfigured, quickly and easily for coping with variability and uncertainty (Shewchuk, 1998). Agile manufacturing practices are characterized by their ability to prosper in rapidly changing environments, changes introduced by customer demand. Rapidly changing environments requires reprogrammable and reconfigurable production systems that are able to economically operate with very small lot sizes (Da Silveira et al., 2001). Duguay (1997) believes that there are certain interactions between agility and lean manufacturing.

Lean Production System

This research focuses on the production system. More specifically, the research will investigate the lean production and how it supports or hinders mass customization principles. The lean production system started with the Toyota Production System (Ohno, 1988). Lean production is based on five fundamental principles: 1) identify what the customer values, 2) identify the value stream and challenge all wasted steps, 3) produce the product when the customer wants it and, once started, keep the product flowing continuously through the value stream, 4) introduce pull between all steps where continuous flow is impossible, and 5) manage toward perfection (Womack and Jones, 1996). Lean manufacturing systems operate as a "pull" system, in which downstream processes call for parts via "Kanbans" (information communication cards) from their predecessor processes when needed (Lu and Gross, 2001). Lean production principles and impact in product choice are described below.

In Construction the application of the lean production model stems from a discussion of Koskela's work (1993), which emphasized the importance of the production process flow, as well as aspects related to converting inputs into finished products as an important element to the creation of value over the life of the project. Factory configuration plays an important role in production flow, particularly when there is considerable product variation. Queuing availability and the flexibility for work to migrate upstream/downstream can mitigate some of the inefficiencies resulting from high product variation (Mullens, 2004). Information technology can enable better planning and management under conditions of high product variation.

Salem and Zimmer (2005) identified five major lean principles applicable in the housing industry: customer focus, culture/people, workplace standardization, waste elimination and continuous improvement/built in quality. Picchi and Granja (2004) presented five lean principles used in the construction industry: value, value stream, flow, pull and perfection. Value- value as perceived by the homebuyer; Value stream- mapping of materials and information; Flow- creating continuous flow; Pull- refers to pulling services, components and materials just when necessary, and Perfection- refers to quality systems designed for immediate detection of problems. Liker's seven lean principles, that are key facets of a lean production systems and significant for the industrialized housing industry, were used as guidelines in this study.

Flexible Manufacturing

Often the term agile manufacturing is confused with flexible manufacturing; however, there is a distinction between the two. Flexibility refers to the ability to change a manufacturing system from within, whereas agility refers to the ability to change (reconfigure) a manufacturing system from the outside, i.e., externally (Shewchuk,1998). A flexible manufacturing system is very flexible for what it was designed to do. However, flexible manufacturing systems are rarely agile: they are extremely rigid systems which take a lot of time and effort to change (i.e., from the outside) once they are in place and running (Daghestani, 1998).

Davis (1989) states that mass customization is facilitated by production processes that are flexible and integrated. Qiao et al. (2004) find that flexible manufacturing systems can support mass customization, producing more part varieties and handling manufacturing requirement changes. A flexible manufacturing system typically consists of computer numerically controlled (CNC) machines, linked by an automated material handling and storage system, all under the control of an integrated computer control system. Flexible manufacturing systems typically have flexibility in four dimensions: volume, manufacturing processes, product mix, and delivery (Koste and Malhotra, 1998) (Figure 5). This flexibility allows companies to satisfy demands for a relatively diverse range of products with a small to medium batch size. Thus, in a mass customization environment, a manufacturing production system should possess sufficient flexibility and rapid response capability to deal with complex manufacturing situations. For example, flexible manufacturing systems should have certain degree of flexibility to manufacture assorted products with the same group of machines that are linked by automated material handling systems (Lau, 1995).

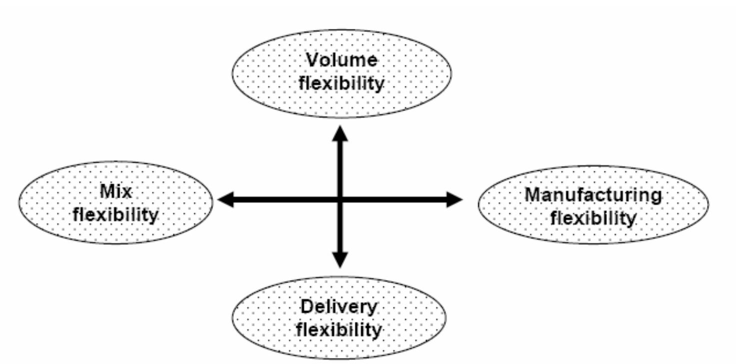

Figure 5- Flexibility Major Components (Koste and Malhotra, 1998)

The key to successfully adjusting a manufacturing system for the production of customized products is to develop the capability of swiftly reconfigurable operations and processes with respect to customers' individual needs and dynamic manufacturing requirements (Qiao et al., 2004). In a mass customized environment, the quality of the manufacturing process is particularly important. The success of any production system strategy, to effectively achieve mass customization, depends on the operation of the value chain and therefore cannot be discussed or evaluated in isolation (Pil and Holweg, 2004).

Supply Chain Design for Mass Customization

The implementation of mass customization strategy affects the entire enterprise. Therefore, it is imperative that the strategy be reflected in the design of supply chain, from sourcing to final distribution or product (Chandra and Kamrani, 2004). Supply chain configuration involves determining the location of suppliers, component warehouses, manufacturing facilities, distribution centers and establishing flows among supply chain members (Chandra and Grabis, 2004). Hence, efficient logistics and supply chain management are one of the key preconditions for adopting mass customization strategies.

Postponement

Postponement or late configuration is one of the dominant strategies used to address mass customization issues. The postponement strategy implies that differentiation of products is delayed to the latest possible point in the supply chain (Bowersox and Morash, 1989), locating the decoupling point closer to the customer. A critical decision in any supply chain is determining how production will be linked with actual demand (Fisher, 1997). Decouple point is define in this research as the point in a supply chain where a specific customer's order is associated with a specific product. Ideally, the decouple point would be located before the point in the supply chain where the product is customized. Ulrich et al. (2004) identify the ideal process dynamics in a customization environment by analyzing operations upstream and downstream of the decoupling point. Ideally, operations upstream of the decouple point operate in a make-to-stock mode and fill inventories of partially completed goods, while operations downstream of the decouple point operate in a make-to-order mode and produce good associated with specific customer orders. This approach buffers the upstream operations form unpredictable fluctuations in end customer demand.

The use of the decoupling point in housing supply chains has been suggested by Naim and Barlow (2003), as a way to manage customization. Barlow et al. (2003) explored Japan's industrialized housing industry approaches to customization, based on Lampel and Mintzberg's continuum of five mass customizing strategies. They study several Japanese housing companies, including Toyota Home (segmented standardization), Sekisui Heim (customized standardization) and Sekisui House (tailored customization). This exploration demonstrated that mass customization, in the housing industry, could be supported by several generic supply-chain models.

Postponement allows standardization prior to the decoupling point, where customer orders are received. Postponement has been found to be a powerful mean to improve supply chain performance in the production of customized products (Whang and Lee, 1998; Feitzinger and Lee, 1997). This strategy could take different forms. Postponement can take place in the manufacturing by delaying final assembly, labeling and packaging. It can also take place in distribution by delaying decision on final manufacturing activities. For example, in the auto sector, Honda-Europe configures body kits, alarms, and trim accessories in the distribution centers, based on customer orders.

One postponement strategy proposed for housing construction is Open Building (OB) (Habraken, 1976; Kendall, 2004). OB is an innovative approach to design and construction based on organizing buildings and their technical and decision-making processes according to levels (Kendall and Teicher, 2000). By disentangling the systems and sub-systems from each level, opportunities are increased for better organization, increased consistency, quality and more control and flexibility for the homeowner. OB goes beyond simple postponement, providing continuing benefits for remodeling and retrofitting during the life cycle of the house. While optimizing efficiency and using a systematic production and assembly approach during the construction, OB also allows customization and future changes.

Supply Chain Configuration

Supply chain configuration relates to the facility location problem applied across all tiers of the supply chain (Chandra and Grabis, 2004). The primary objective of supply chain configuration is to determine location of suppliers, manufacturing facilities, distribution centers and to establish flows among supply chain members. Since a mass customization strategy affects the entire enterprise. Therefore, it is imperative that the strategy be reflected in the design of supply chain, from sourcing to final distribution or product (Chandra and Kamrani, 2004). The main factors consider in the supply chain configuration includes costs related to fixed investment in facilities, processing, procurement, transportation and capacity constrains. For example, Motorola arranged its supply chain configuration to successfully produce a customized product, by consolidating the sub-assembly and final assembly of the Bandit pager at one location to save manufacturing lead time.

The homebuilding supply chain is unusually large and complex (Mullens and Hastak, 2004). Product suppliers provide a wide range of stock materials (e.g., insulation, roofing) and custom components (e.g., trusses, cabinets), with delivery times ranging from hours to months. Managing the product side of the supply chain involves ensuring specified materials are on-site when needed (and not before), staged in the proper location, protected from theft and damage, and, of course, provided at the overall best value to the homebuyer. The services side of the homebuilding supply chain presents an even greater challenge. Most homebuilders who build more than 50 homes per month perform no construction work (Bashford et al., 2003). Instead, they rely on 25-30 independent trade contractors who actually build the house. Difficulties arise in coordinating the numerous independent contractors with a series of complicating factors: multiplicity of interactions between contractors, workflow variability in a long, sequential production system, and repetition of this problem across multiple homes simultaneously under construction. Mullens and Hastak (2004) suggest that the supply chain might be simplified by 1) creating value-added partnerships or simply adding additional value at a supplier or 2) increasing cooperation or better integrating suppliers, perhaps through technology (Bernold, 2005).

Inventory Management

Due to customization, demand for components can be unevenly distributed (Chandra and Kamrani, 2004). These components that have erratic demand require different approaches to inventory management. Chandra and Grabis (2004) proposed the following inventory management approaches to mitigate the effects of mass customization: MRP-based policies can be used for managing components with variable demand. Re-ordering point policies can be used for managing globally sourced components with steady stochastic demand. JIT policies can be used for managing locally sourced components with steady demand. Thus, these strategies demonstrate interrelationships between inventory management and supply chain configuration. Another challenge is to synchronize all the components in order to achieve the desired level for customized products. Usually, customized products are built to order and so no end product is kept.

Another alternative would be considering an inventory system with service level depending upon complexity of product configuration, where the service level is measured by delivery time (Chandra and Grabis, 2004). Therefore, if a customer demands a rarely demanded component, a longer delivery time is offered. This is the case of the on-line bookstore, where popular books are kept in stock while others have longer delivery times. However, the value of the customized product and customer willingness to wait should also be considered.

Third Party Logistics

Companies can outsource their logistic operations including material sourcing and product distribution to third party logistic providers. Gooley (1998) advocates third party logistics as an important factor enabling mass customization by providing flexibility and proximity to the final customer without incurring fixed costs. Outsourcing selected elements of the supply chain can sometimes provide greater flexibility. Outsourcing candidates include components (Mikkola and Larsen, 2004) and logistics (Gooley, (1998).Chandra and Grabis (2004) argue that third party providers can reduce costs of mass customization by 1) transporting and warehousing materials and products, and 2) providing add-on services, such as final customization.

Information Technologies

In mass customization, the role of information technology has been well defined by Andel (2002): "mass customization requires mass communication". Information technology can be a powerful integrating force across the supply chain, providing a common source of information on sales, inventory levels, supplier orders, and shipping status. Information technology contributes by eliminating delays associated with processing of orders and managing product information, across the supply chain. Hence, it can facilitate customization by providing efficient and accurate exchange of product requirements between customer and manufacturer and between manufacturer and supplier.

In the housing industry much research has been conducted in the application of advanced technologies such as Integrated Wireless Site (IWS) (Bernold, 2004), and Enterprise Resource Planning (ERP) (Jeong, 2003).

Mass Customization and Lean Production Principles

In an environment of high and stable demand level, lean production is a very efficient organizational method. However, in environment where the product mix changes irregularly and drastically, downstream processes require randomly customized parts on flexible schedules to be supplied to their matching predecessor processes on short notice. Hence, extra inventory, equipment, and labor are needed to compensate for product and order variations. Therefore, Qiao et al. (2004) argues that efficiency gains of the lean production system are diminished. Chandra and Grabis (2004), however, argue that lean manufacturing can be an effective strategy for customized products with stable demand. A number of lean principles support mass customization. Minimizing set-up times and reducing lot size increases the opportunity for continuous flow. Cellular manufacturing (Bedworth, Henderson, and Wolfe, 1991) with its flexible workplace and flexible workforce enable the efficient production of a family of products on the same line. Thus, there are some benefits to be realized from the use of lean manufacturing systems in a mass customization environment.

Liker (2004) identified 14 principles in the book The Toyota Way and these principles drive the techniques and tools of lean production. The 14 principles are divided in four sections: 1) Long-term philosophy (principle 1), 2) The right process will produce the right results (principle 2 to 8), 3) Add value to the organization by developing your people and partners (principle 9 to 11); and 4) Continuously solving root problems drives organizational learning (principle 12 to 14). The principles that directly relate to the production system are principles two to eight, described below:

Principle 1: Create Continuous Process Flow to Bring Problems to the Surface

Continuous process flow is one of the core elements of lean production systems to achieve the removal of waste. It is related to the ideal of flowing value without interruptions, eliminating waste and reducing lead time of generating new products or services (Womack and Jones, 1996). In order to create continuous process flow, processes are usually redesigned and improved by removing waste (muda). The process is redesigned through a Kaizen or “continuous improvement”. Kaizen is a method that strives toward perfection by eliminating waste – non-value added activities from the perspective of the customer. The seven wastes that are evaluated and removed are: overproduction, excessive inventory, unnecessary conveyance, over processing, excessive motion, waiting and corrections/re-work. Lean principle 1 tries to achieve the following characteristics: 1) One piece flow, 2) Adding value without interruption, 3)

Standardize work to stabilize flow, 4) Synchronize flows, 5) Flow oriented layout, 6) Inventory buffers in the right places and 7) Reduced cycle time.

Build in quality (Jidoka) in the production process is facilitated by the one piece flow. Every operator is an inspector and works to fix any problems in their station before passing them on to the next station (Liker, 2004). Defect detection is faster in smaller batches. While creating one piece flow, waste in all forms are reduced or eliminated, which creates higher productivity, frees up floor space, improve safety, improve employees morale and reduces the cost of inventory.

In construction, creating continuous process flow in construction sites is a huge challenge due to its fragmented nature, low standardization patterns of activities, one of a kind features of construction's products, etc. (Koskela, 2000). Further, product customization introduces variation of cycle times which makes continuous process flow more difficult. An approach to mitigate these challenges is to allow for controlled inventory between activities or operation where fluctuation of cycle time occurs. Rother and Shook (1999) recommended to "Flow where you can, pull where you must" when designing lean production systems. Liker (2004) supports their recommendation and believes that where it is not possible to create one piece flow, the next best thing is to design a pull system with some inventory.

Principle 2: Use "Pull" Systems to Avoid Overproduction

Pull and flow are the core characteristics of lean production systems and are cornerstones for the elimination of waste. Pull system is a method to signal a predecessor process for more material or to produce a part. Production should be pull from the customer end, including both internal and external customers, to avoid overproduction. In a pull system the resources are pulled based on immediate customer demand. The ideal state of a pull system is JIT (just in time) approach: giving the customer (which may be the next step in the production process) what he/she wants, when he/she wants it, and in the amount he/she wants (Liker, 2004). Supermarkets and Kanban are two elements of a pull system. Supermarkets are controlled inventory with some connection to customer orders, used to schedule production at an upstream process. Ohno (1988) created the concept of supermarkets or small stores as a compromise between the ideal of one piece flow and push. When one specific item is taken by the customer from the supermarket, it gets replenished; otherwise the item remains in the supermarket and it is not replenished. Thus, overproduction is avoided. Kanban is a system of visual signals (e.g., cards, empty bins, empty carts, etc) that formalizes customers' requests and synchronizes suppliers and customers both inside and outside the plant. When pure one piece flow is not possible because processes are far apart or the cycle times to perform the operations vary a great deal (due to customization), the next best is Kanban systems.

Principle 3: Level Out the Workload (Heijunka)

Dennis (2002) argues that stability in production orders is critical for processes to produce the right part in the right quantity at the right time. This stability can be reached by leveling production (Heijunka) by distributing the production volume and mix evenly over time. This approach does not build products according to the actual flow of customer orders, but accumulate the orders in a period and levels them out so that the same amount and mix are being made each day. Leveling out the workload aids to achieve the goal of minimizing or eliminating waste (Muda), eliminate overburden to people and equipment (Muri) and eliminates the unevenness in the production levels (Mura).

Principle 4: Build a Culture of Stopping to Fix Problems, to Get Quality Right the First Time

This principle refers to employee empowerment and their role in quality. All employees are allowed to stop production, to signal and fix a quality problem. The goal is to achieve and deliver perfect first time quality. Lean tools such as Poke Yoke and Jidoka are used. Poka Yoke is an inexpensive robust device that eliminates the possibility of a defect by alerting the operator that an error has occurred (Dennis, 2002). This device can either detect deviations from standards before they occur, or once they occur, stop the activity to prevent the defects. The Japanese word Jidoka was defined by Toyota as “automation with a human mind”, which implies intelligent workers and machines identifying errors and taking quick countermeasures. Jidoka applications entail developing processes with both high capability (few defect made) and containment (defects contained in the zone).

Principle 5: Standardized Tasks Are the Foundation for Continuous Improvement and Employee Empowerment

This principle includes the development of standard procedures. Standard procedures should include specific takt time, sequence of processes and required inventory. Takt time is the rate of demand frequency, it illustrates the frequency by which product should be produced based on customer demands. While standards need to be specific to be used as guidelines, they should also be general enough to allow for some flexibility (Liker, 2002). This is particularly important in a customization environment. Standardized work provides great benefits such as process stability, identifies clearly stop and start points for each process, organizational learning preserving the know-how and expertise, audit quality problems allowing to assess current condition and identify problem, and employee involvement.

Employees should participate in the writing of standard procedure. This will empowered employees to participate in the improvement and growth of the company. Henry Ford's (1988) wrote that "today's standards are best for today but which is to be improved tomorrow". Standardization is the basis for future improvements.

Principle 6: Use Visual Control So No Problems are Hidden

This principle includes the 5Ss: 1) *Sort* through items and dispose of rarely used items by red tagging, 2) *Straighten* by organizing and labeling a place for each item kept, 3) *Shine* by cleaning the work area, 4) *Standardize* by developing procedures to maintain and monitor the first three S's, and 5) *Sustain* using management audits to stay disciplined. 5S's accomplishes a clean, organized workplace that is visual and serves as the foundation of improvement. This tool helps to make the work place efficient and productive.

Visual controls is any communication device used in the work environment that tells workers at a glance how work should be done and whether it is deviating form the standard. In Toyota, visual control goes beyond capturing deviations from a target it integrated to the value added work to improve flow (Liker, 2002). Visual controls allow workers to look at the processes, equipment, inventory or another worker performing a task and immediately see the standard being used and if there is any deviation from the standard.

Principle 7: Use Only Reliable, Thoroughly Tested Technology That Serves Your People and Processes

Technology should be use to support people, process and values. The technology used must be flexible to accommodate process improvement as business changes.

CHAPTER 3: RESEARCH METHODOLOGY

Introduction

This is an exploratory study on mass customization strategies specific to the homebuilding industry and the impact of product choice on plant production efficiency. This study focused on the homebuilding production system and lean as an approach to achieve mass customization. The general purpose of this research is to improve the effectiveness and efficiency of housing production through the implementation of mass customization strategies. Considering that homebuyers do not want to sacrifice what they really want in a home, and the importance of builders' production efficiencies, this study proposes to develop a better understanding of the dynamic among mass customization and lean principles:

1. By identifying mass customization and lean principles, representative of the housing industry through a literature review of relevant research and trade publications.
2. By characterizing how much product choice is currently being offered by U.S. homebuilders and the impact of customization on plant production efficiency, through an industry-wide survey.
3. By assessing the relationship between mass customization and lean production principles, in the housing industry.
   a. Documenting lean implementation in two plants.
   b. Evaluating effects of product choice on lean principles implemented.

With those findings, this research intends to develop guidelines which will enable U.S. homebuilders to better meet homebuyer needs through mass customization, without sacrificing production efficiencies. In addition, the detailed study at the production level intends to fill a void in the existing literature by exploring relationships between lean production principles and mass customization principles, in the housing industry.

Theoretical Foundation

The housing industry is faced with homebuyers demanding houses that reflect their personal and unique style, homes that are individually configured according to their needs. Builders know that homebuyers prefer to change standard floor plans, components, equipment and finishes. However, builders do not want to sacrifice production efficiency by deviating from their standard models (NAHB, 2004). Changes can disrupt the entire estimating, production, delivery and management process, making it even more difficult to manage homebuilding effectively. The problem faced by homebuilders is how can they deliver exactly what homebuyers want, at reasonable prices and lead times. The literature suggests that companies might be able to achieve this efficiency and product variety through mass customization. Thus, by definition mass customization is the ability to design and manufacture customized products at mass production efficiency and speed (Pine, 1993) (Figure 6). This research intent is to explore mass customization principles that could enable homebuilders to better meet customer needs, without sacrificing their production efficiency.

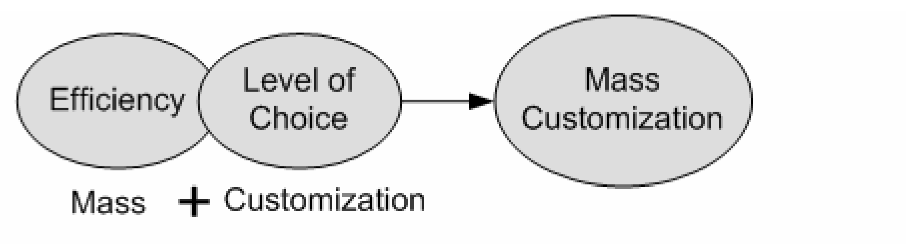

Figure 6- Mass Customization Definition

The theoretical foundation for this research was established through a literature search of relevant research, peer reviewed journals and trade publications. Priority was given to the more recent studies. Among the many mass customization enabling factors identified in the literature, lean production represents a particularly interesting topic for research due to its application challenges in a mass customization environment. The literature identifies continuous improvement as a shared principle in both lean and mass customization concepts. Thus, lean production could be an instrument for homebuilders to achieve and maintain continuous improvement at the operational and enterprise level. Tu et al. (2001) and Da Silveira et.al. (2001) argue that lean production is an important factor that supports mass customization. Conversely, Qiao et al. (2004) argue that the efficiency of lean is diminished in an environment where product mix changes irregularly and drastically and where downstream processes require randomly customized parts on flexible schedules to be supplied from their predecessor processes on short notice. Under these conditions, they argue that extra inventory, equipment, and labor are needed to compensate for product and order variations. Chandra and Grabis (2004), however, argue that lean production can be an effective strategy for customized products with stable demand. For example, cellular manufacturing (Bedworth, Henderson, and Wolfe, 1991), a lean production technique, uses a flexible workplace and flexible workforce to enable the efficient production of a family of products on the same line. Thus, there are some benefits to be realized from the use of some lean principles in a mass customization environment. Although the goal of both mass customization and lean production is to reach mass production efficiencies, lean principles are not necessary concerned with increasing product variety.

In construction the application of the lean production stems from a discussion of Koskela's work (1993), which emphasized the importance of the production process flow, as well as aspects related to converting inputs into finished products as an important element to the creation of value over the life of the project. Maintaining a balanced flow and creating value to the customer are also important factors in mass customization principles. Factory configuration plays an important role in production flow, particularly when there is considerable product variation. Characterizing the modular housing factory, Mullens (2004) found that queuing availability and the flexibility for work to migrate upstream/downstream can mitigate some of the inefficiencies resulting from high product variation. Information technology can enable better planning and management under conditions of high product variation.

Research Scope

Mass customization and lean production are important innovations being considered by industrialized homebuilders. However, the literature shows a controversy about the concurrent use of both mass customization and lean production. The scope of this research has two levels, aiming to cover both topics. First, an industry-wide exploration of the current levels of customization and the impact of customization on production efficiency is undertaken. In order to understand the relationship among mass customization strategies and lean production, the research will then narrow its scope, using case studies on specific plants to analyze in detail the effects of mass customization on lean and vice versa.

Research Design

The research approach combined an industry-wide survey of industrialized home producers with the identification and evaluation of lean production techniques at two plants. The research entails two phases: empirical study and case study. The case study includes a common trend analysis among participating plants, considering the product choice offered and its impact on each lean principle (Figure 7). Both phases are described in more detail in the following sections.

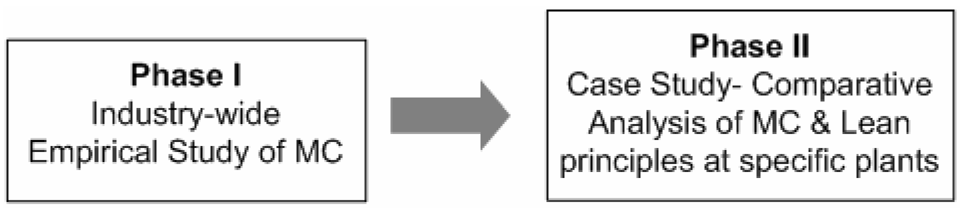

Figure 7- Research Design

PHASE I- Industry-wide Empirical Study of MC

The purpose of the first phase is to characterize how much product choice is currently being offered by U.S. homebuilders and the impact of customization on plant production efficiency. Product choice has two main dimensions: the number of home models offered (variety) and the degree of customization (e.g., dimensional changes, finishes) permitted. For instance, a plant might offer a large number of home models, but limit the degree of customization to a predetermined set of options (e.g. raw material or/and component substitution). These two dimensions of product choice and its impact on production efficiency were evaluated in Chapter #4.

Phase 1 explored mass customization based on plant performance. Figure 8 is a mass customization model that displays the relationship of efficiency (mass) and level of choice (customization). The ideal combination of customization and efficiency lies in quadrant QII (high efficiency and high customization).

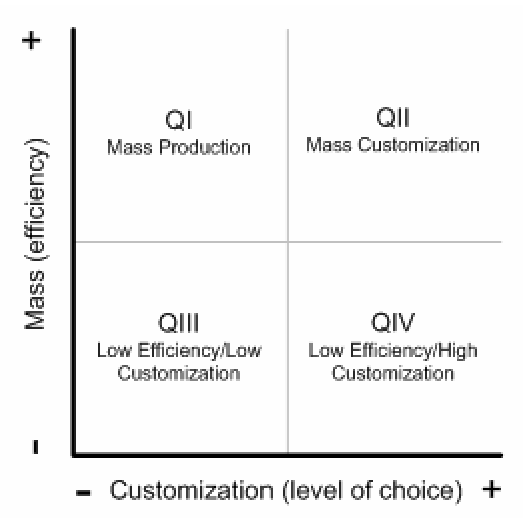

Figure 8- Mass Customization Model

This first phase of this research seeks to answer the following question:

- What choices do industrialized builders offer and how do they affect plant performance?

Data Collection Plan

The information for Phase I is provided by the Manufactured Housing Research Alliance (MHRA) and includes results from a large scale survey of industrialized housing producers, primarily HUD Code and modular manufacturers. The survey was distributed to the participating plants and collected during Summer of 2005. The survey, developed by MHRA in collaboration with UCF researchers, includes various measures of the level of choice offered and plant performance. A copy of the Industry-wide Survey is shown in Appendix A.

The level of product choice offered was documented by the following questions.

- Q2- Product Type: percentage of homes produced in the following categories: HUD Code, Modular, Commercial and Other.
- Q3- Product Mix: how many models are offered in the current marketing literature that are actually produced.

- Q4- Degree of Customization: percentage of homes produced that allowed for different degrees of customization (e.g. no customization, minor floor plan changes, extensive floor plan change and totally custom/new sheet of paper).
- Q5- Product Premium: percentage of homes produced with different levels of finished drywall as a Premium feature (e.g. no finished drywall, limited finished drywall and whole house finished drywall).
- Q6- Product Design: percentage of homes produced by number of modules/home (e.g. one module, two modules, three modules, four modules or more).

A broad range of plant characteristics and operational performance indicators were also documented for each participating plant. These included annual sales dollars, number of orders in backlog, plant configuration (e.g. number of stations, plant size, etc), quality, customer satisfaction, employee satisfaction, safety, and labor productivity. Metrics capturing plant efficiency were calculated using these plant performance indicators.

Data Analysis Plan

Participating plants recorded their answers for each survey question in a spreadsheet. If a plant left any question unanswered, this plant was not included in the analysis that pertains to the blank answer. Because the data set includes plants with two distinct home types, HUD code and modular, a separate analysis was performed for each type. The analysis of the industry-wide survey was conducted with the SPSS® (Statistical Package for Social Science) software.

Data from the survey was processed and the following variables were documented and/or calculated for each category: product choice offered (Question #2-7), plant characteristics (Questions #9-16 and 28) and operational performance metrics:

Product Choice Offered

- Primary type of homes produced- the type of home with the highest percentage
- Number of models in the marketing literature that are produced.
- Number of models representing 90% of actual production.
- Primary level of customization provided (e.g. no customization, minor changes, extensive changes and totally custom)- the level of customization with the highest percentage.
- Primary level of drywall finish (e.g. none finished, limited and whole house finished drywall) - the level of drywall finish with the highest percentage.
- Primary number of modules per home (e.g., single, two, three, four or more modules per home) - the category with the highest percentage.

Plant Characteristics

- Plant size (sqft)
- Number of main-line workstations
- Plant capacity (modules/week)
- Modules produced per year
- Homes produced per year
- Annual sales dollars ($M)
- Total annual labor cost ($M)
- Number of modules in backlog
- Annual number of accidents
- Annual labor turnover (%)
- Annual service cost ($M)

Operational Performance Metrics

- Plant size per current weekly production (sqft/modules produced per week) - reflects the plant's space efficiency.
- Number of production stations per current weekly production (stations/modules produced per week) - reflects the efficiency of the workstations on the plant's main line.
- Material inventory turns per year- reflects the efficiency of the inventory carried by the plant.

- Sales dollars per module - indicates the overall revenue per module produced. This metric suggests the value of the module as well as the overall cost, including labor, materials and profit.
- Labor cost (% of sales) – a widely used measure of labor productivity.
- Labor cost per module - reflects labor productivity.
- Current production (modules/week) - describes the physical product flow, suggesting the overall scale and pace of the operation.
- Capacity utilization - reflects the general condition of the market as well as the effectiveness of the plant in generating orders.
- Backlog (% of annual production) – indicates the balance between sales and production.
- Accidents per module - reflects the safety of the plant relative to production level.
- Customer Satisfaction – indicates how well the plant satisfies their customers, both in terms of product and service. This metric is commonly collected by plants (the customer satisfaction survey format is similar across industry), internally analyzed and reported.
- Service cost per module - indicates how much the plant spends to resolve discrepancies identified after the home has been delivered to the customer. It is a key measure of quality and also reflects the efficiency of labor on getting it right the first time.

The data analysis had three major sections: 1) Descriptive characteristics including basic statistics of the survey, 2) Analysis of the impact of product choice on plant production efficiency, and 3) Analysis to explore the quantitative relationship between product choice and operational performance metrics.

Descriptive Characteristics

In order to characterize the product choice offered, operational performance, and plant operating characteristics, basic statistics characterizing all responses were calculated for each question.

Analysis of the Impact of Product Choice on Production Efficiency

Hypothesis testing was performed to identify significant differences in operational performance between various levels of product choice. The alternate hypotheses were stated as follows:

- H1: Operational performance differs with the number of standard models produced.
- H2: Operational performance differs with the level of customization offered.

A normality test was conducted to check the distribution of the data. Since the data was not normally distributed, nonparametric statistical techniques were used for the data analysis. The hypotheses were tested by conducting a Kruskal-Wallis Test, which is similar to the ANOVA for nonparametric data. If a significant difference (p-value<0.05) was noted, a post hoc test (Dunn) was conducted to identify the specific groups that were significantly different, followed by a box plot graph to visualize their relationships.

Analysis to Explore the Relationship among Product Choice and Operational Performance Metrics

Spearman's correlation analysis was performed among the product variables and the operational performance metrics. The main purpose of this analysis was to identify the magnitude and orientation of the relationship among product choice variables and the operational performance metrics (Figure 9).

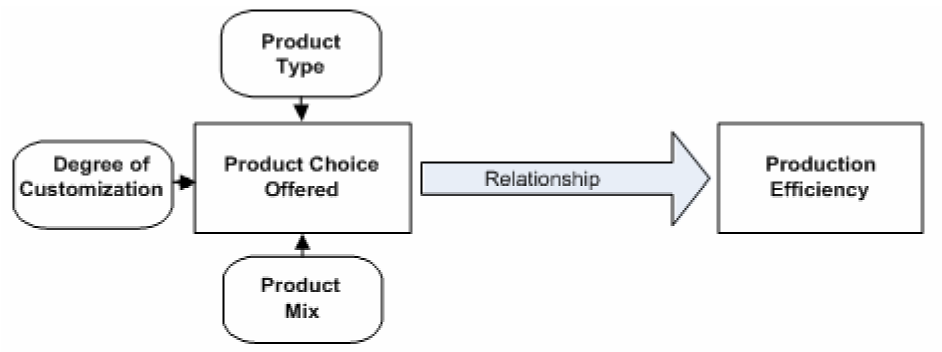

Figure 9- Customization and Operational Performance Relationship Model

The outcomes of Phase I were: 1. baselines of current industry performance; 2. identification of operational performance differences based on the degree of customization offered; and 3. a table that identifies the quantitative relationship between product choice and operational performance. Outcomes 2. and 3. were summarized and displayed in a cause and effect diagram in Chapter #4.

PHASE II: Case Study- Common Trend Analysis across Plants

Phase II focuses on the interaction between lean production principles and mass customization principles. Due to the controversy found in the literature about concurrent practices of mass customization and lean production, Phase II intends to explore in detail how they are related. The purpose of this phase is to conceptually investigate the impact of product choice on lean principles to better understand the dynamic among the two. This phase seeks to answer the following question:

- How do mass customization principles affect lean principles and vice versa, in the housing industry?

This research uses a case study of two plants to analyze the detailed effects of mass customization on lean and vice versa. The target population for these case studies was a group of nine industrialized housing plants that initiated lean production efforts in 2006. Since these plants were new to lean concepts, the implementation was focused on a particular area or department. The two plants were selected for inclusion in the case study based on their accessibility and the researcher's personal participation in the lean implementation efforts. The primary purpose of the case study was to develop an understanding of how product choice influences lean principles, and vice versa. Each case study has three major steps:

- Plant level: document the company's background and product choice offered.
- Department level: document and analyze the outcome of the lean implementation
- Department level: evaluate the effects of product choice on the implementation of lean principles.

Common trends were then documented and used to develop guidelines for an effective mass customization strategy (Figure 10).

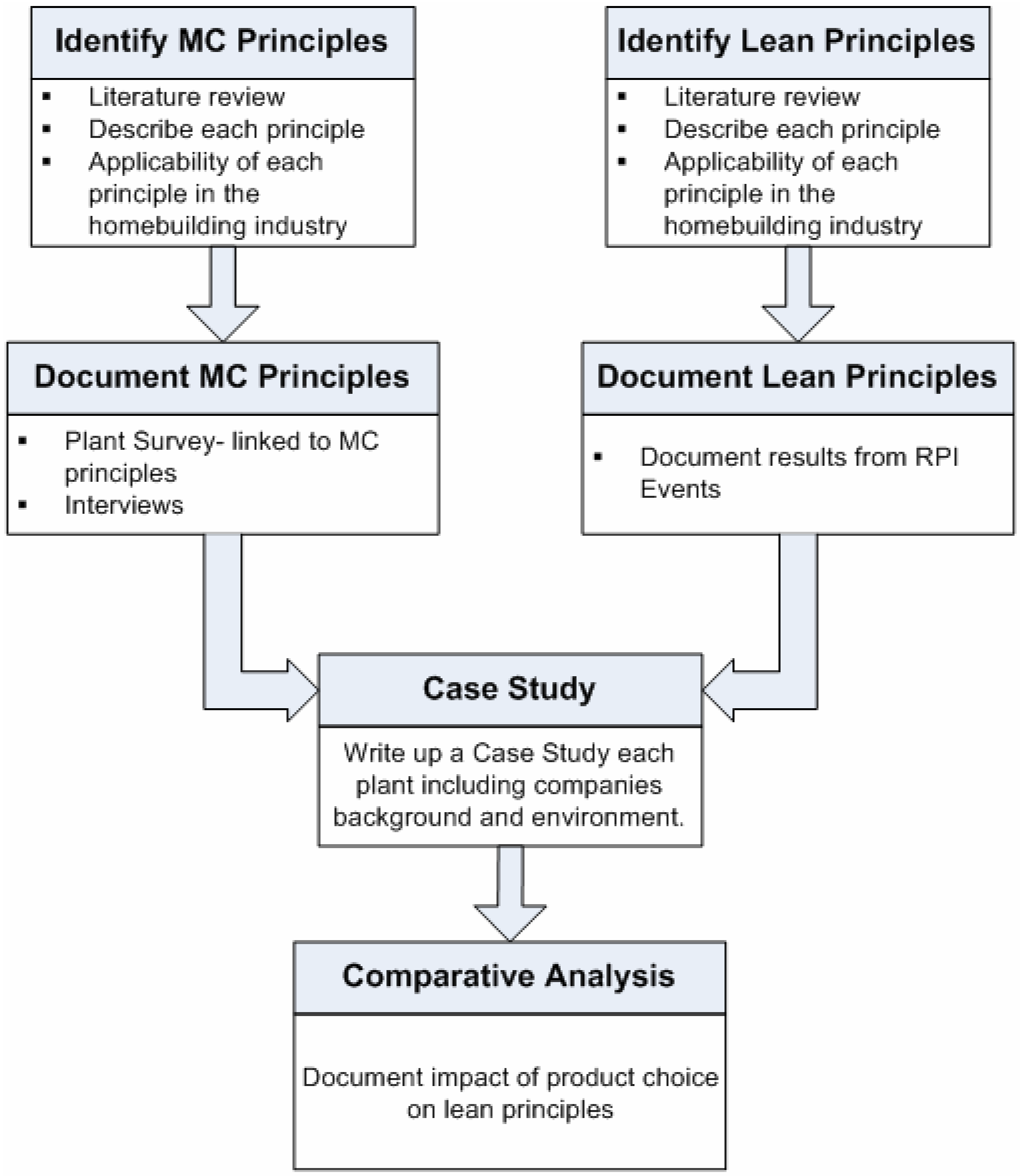

Figure 10- Phase II Methodology Flow Chart

Case Study

Sample

The target population for this case study was nine industrialized housing plants that initiated lean production efforts in 2006. These lean efforts were supported by MHRA and lean/industry experts from Senco Products and the University of Central Florida. Since these nine plants were new to lean concepts, plant staff participated in a one week lean training in April 2006. The training covered basic lean concepts and techniques including workplace organization (5S), takt time, continuous flow, pull/kanban replenishment, cellular manufacturing, value stream mapping, process observation analysis, waste discovery, cycle time/bottleneck analysis, line balancing/production leveling, standard work, visual control, rapid process improvement (RPI), etc. An RPI is a continuous improvement event targeted to an area and/or activity that involves workers from different areas/levels of the organization. The material in this training was tailored to the industrialized housing industry and addressed the challenges of implementing lean in the industry. During the training, each plant was represented by two or three key staff members as their lean advocates. The intensive training equipped advocates with the knowledge to identify waste, to develop new lean approaches to reduce waste, and to implement and sustain change.

Participating plants began lean implementation in Summer 2006, conducting RPI events on problematic areas identified during plant-level value stream mapping. Two of the nine plants were selected for the case study.

- Company A- primarily a modular producer, the plant offers a large range of configurations. Starting from 101 different home models, customers can customize their own home.

- Company B – a HUD-code producer, the plant offers 47 different models in configurations of single, double or triple wides. Floorplans range from 737 to 2,458 square feet, 2 to 6 bedrooms and 1 to 3 bathrooms. This company limits customization to a narrow, predetermined set of options.

Data Collection Plan

Three primary sources of information were used: observation, interviews and documents. A wide range of employees, from CEOs to trade workers, were interviewed. Mass customization and lean principles representative of the housing industry were identified from the literature:

1. Mass customization principles- to characterize mass customization principles at each plant, the literature was used as a starting point. The literature offers one generic mass customization strategy (Duray et al. 2000) and one mass customization strategy tailored to the housing industry (Barlow et al. 2003). Duray et al. (2000) investigated mass customization from a manufacturing point of view and her classification of mass customization strategies is based on the timing of customer involvement and the type of product modularity, evaluated along the production cycle: Design, Fabrication, Assembly and Use. In the housing industry context Barlow et al. (2003) developed mass customization strategies using Lampel and Mintzber's (1996) continuum of five degrees of customization. Barlow uses this approach to categorize the strategies used by five of Japan's leading homebuilders, all industrialized (Figure 11). For example, Toyota Home manufactures small standard modules that are shipped to the construction site where they are assembled to create a custom home. This strategy was categorized as segmented standardization, since homebuyer involvement does not have to start until after each module is assembled in the factory.

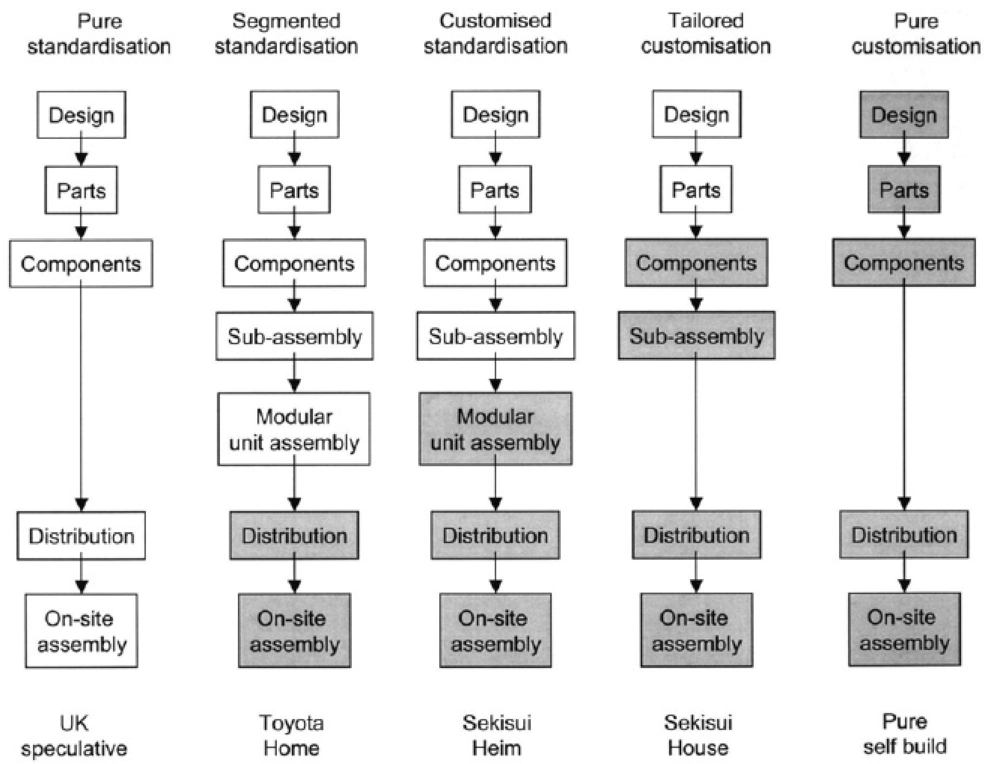

Figure 11- Customization Degrees Applied to the Housing Industry (Barlow et al., 2003)

This study identified mass customization principles meaningful for the housing industry using contributions from Duray and Barlow, supplemented by data collected from the case study plants (Table 1). A survey was developed reflecting these mass customization principles and then used to assess the case study plants. A copy of the interview questions for the mass customization principles is shown in Appendix B.

Table 1- Industrialized Housing Industry's Mass Customization Principles

Industrialized Housing Industry Mass Customization Principles	Description
Postpone where customization impacts the production process	• Delaying customization is a function of product architecture and process design. If the architecture permits a delay in customization, then it must be built into the production process. • This principle may be used in several ways: 1) component build-to-stock and then final product customize-to-order (provides benefits of process standardization and cycle time reduction), or 2) complete build-to-order (providing benefit of process standardization and flexibility for customer to continue customization during early production – note that this flexibility can rarely be exercised due to the short time window).
Use modular architecture and product platform designs with common components to achieve product customization	• Modularity/Commonality- refers to the tightness of coupling between components and the degree to which the rules of the system architecture enable or prohibit the mix-and-match of components. • MC encourages the use of a small set of standardized, plug compatible components to create this choice. • Changes in the core architecture of the product for each customized configuration, might limit the use of this principle.
Design the production process so that it can facilitate the production of a variety of products, while accommodating different product mix and volume	• Refers to the configuration of the production process and how it could support a given mass customization strategy. Process flexibility also defines the limitations of the factory. • Labor Flexibility- refers to the number and variety of activities that employees can perform without incurring higher cycle time or large changes in performance outcomes (i.e. cross-trained workforce). • Layout- refers to the arrangement of the area layout to facilitate the production of a variety of products (i.e. cellular production, queuing subassemblies, ability to perform activity upstream/downstream of preferred workstation – may be facilitated by equipment flexibility). • Equipment/tools- refers to the flexibility of equipment and tools to facilitate the production of a variety of products (i.e. a fixture that can accommodate a variety of sizes of window frame).

Documenting Mass Customization Principles

In order to document the mass customization principles represented in the case study plants, a two tier interview with each plant was conducted, following a pre-determined set of questions. This set of questions was aligned with the mass customization principles in Table 3. The two tier interview refers to an initial assessment and documentation of mass customization principles at the plant level and then at the department level where the RPI took place. The main purpose of this interview was to capture the level of choice offered and the mechanisms to accomplish it. A copy of the interview questions for the mass customization principles is shown in Appendix B.

2. Lean Production Principles- lean means getting the right things, to the right place, at the right time, in the right quantity while minimizing waste and being flexible and open to change (Womack, 2005). The overriding goal of a lean production system is to deliver value to all stakeholders- internal and external customers; and to eliminate waste- all activities that do not add value. Womack and Jones (1996) introduced five core concepts related to lean: 1) specify value in the eyes of the customer, 2) identify the value stream and eliminate waste, 3) make value flow at the pull of the customer, 4) involve and empower employees, and 5) continuously improve in pursuit of perfection. In general, Womack's core lean concepts could be implemented in any industry, but keeping in mind the industry's own characteristics.

The production system of an industrialized housing manufacturer has unique characteristics, such as: 1) complex product with large components, 2) few small and fixed stations located along side of the main production line (i.e. plumbing), 3) few large and fixed stations located along side of the main production line (i.e. wall build), 4) labor and material flow to the product while product flows continuously on the main production line, 5) some activities could stop the main line roll, because some activities need to happen at certain locations (i.e. large components need crane), 6) multi-operator teams perform specialty work (i.e. trades), making it difficult to measure work content and cycle time for each unit and 7) little inventory due to lack of space (Mullens, 2006). The special characteristics present in this industry dictated how lean principles were implemented.

Salem and Zimmer (2005) identified five major lean principles applicable in the housing industry: customer focus, culture/people, workplace standardization, waste elimination and continuous improvement/built in quality. Picchi and Granja (2004) presented five lean principles used in the construction industry: value (perceived by the customer), value stream (mapping of materials and information), flow (creating continuous flow), pull (pulling services, components and materials when necessary) and perfection (quality systems designed for immediate detection of problems). Liker (2004) identified 14 principles in the book the Toyota Way. These principles drive the techniques and tools of the Toyota Production System (TPS), also known as the lean production. The 14 principles are divided in four sections: 1. long-term philosophy (principle 1), 2. the right process will produce the right results (principles 2 to 8), 3. add value to the organization by developing your people and partners (principles 9 to 11), and 4. continuously solving root problems drives organizational learning (principles 12 to 14). Since the participating plants were new to lean production, their initial implementations focused on process changes. This study focused on these lean process concepts (Liker's lean principles 2. through 8.) as enablers of mass customization. These principles are renumbered and summarized in Table 2. These seven lean principles were used to structure the analysis of lean improvement in the two case study departments.

Table 2- Industrialized Housing Industry Lean Principles

Industrialized Housing Industry Lean Principles	Description
1. Create continuous process flow to bring problems to the surface	• One-piece flow. • Once started, add value without interruption - create continuous flow. • Standardize work to stabilize flow. • Synchronize flows - synchronize production activities so that one does not start until the previous activity has finished. • Use flow oriented layout. • Use inventory buffers in the right places. • Reduce cycle time.
2. Use "pull" systems to avoid overproduction	• Pull from the customer end - including both internal and external customers. • Pull services, components and materials just when necessary. • Use "supermarkets"- controlled inventory. • Use visual control- kanban systems.
3. Level out the workload (Heijunka)	• Eliminate overburden to people and equipment (Muri). • Eliminate unevenness in the production schedule (Mura). • Level out the workload of all manufacturing and service process- a true balanced lean flow of work.
4. Build a culture of stopping to fix problems, to get quality right the first time	• Continuously improve - reveal and solve problems at the source, as they occur. • Deliver perfect first time quality- "build in quality" (i.e. poka yoke, Jidoka). • Keep quality control simple and involve team members. • Create culture - involve and empower employees to continuously improve.

Industrialized Housing Industry Lean Principles	Description
5. Standardized tasks are the foundation for continuous improvement and employee empowerment	• Standardized work- takt time, sequence of processes and standardized stock on hand- employees should participate in the writing of standard procedures. • Rules and procedures are used as enabling tools- performance standards are used in parallel with information on best practices for achieving them. • Supports organizational learning- "pilot teams" • Empowered employees. • Standardized work should allow customization to different levels of skill/experience and should guide flexible improvisation.
6. Use visual control so no problems are hidden	• Clean it up, Make it visual- use simple visual control systems (e.g. 5S). • Integrate the visual control systems to the value-added work- use visual control to improve flow. • Reduce reports to one piece of paper whenever possible.
7. Use only reliable, thoroughly tested technology that serves your people and processes	• Use technology to support people, process and values. • Technology must be flexible to accommodate process improvement as business changes. • Supplement the system information with "genchi genbutsu" (go look, go see). • Use tested technology that can improve flow- pilot tests.

Documenting Lean Implementation: Rapid Process Improvements (RPI)

After the lean training session in April 2006, the two plants included in the case study initiated efforts to apply the lean concepts and tools learned. The first step for each plant was to develop a value stream map, identify possible areas for improvement and implement several RPI events. An RPI event is a rapid form of Kaizen or "continuous improvement". Kaizen is a method that strives toward perfection by eliminating waste – non-value added activities from the perspective of the customer. Kaizen or RPI events help to eliminate waste by empowering employees with the responsibility, time, and tools/methodologies to uncover areas for improvement and to support change. This type of activity is team based and should involve employees from different levels of the organization. The purpose of the RPI is to continuously improve and install a lean culture in the company through the use of lean principles and tools. An RPI event provides focus on a process or an operation and helps to identify value and waste.

Each case study plant was unique in applying lean concepts in their plant, but each plant realized positive benefits. These benefits will be discussed in detail in Chapter #5. The RPI event at each plant was documented by gathering the following information: objective of the RPI, description of process targeted, description of current process and improved process, and accomplishment resulting for the RPI. A detailed questionnaire is shown in Appendix C. The information was gathered mainly through interview and on-site observation.

Data Analysis Plan

After gathering the case study data describing the company, their product choice offered and the lean implementation in each plant, the data was documented and analyzed. Descriptions of the old and improved processes (before and after lean implementation) in the two targeted departments were documented, as well as the quantitative RPI results reported by each plant. Product choice and its dimensions for each department were also described. Then, a detailed analysis of each RPI was performed, assessing the impact of each dimension of choice on each of the seven lean production principles, shown in Table 2. This assessment was performed on both the old and improved processes, which helped to highlight the significance of the lean solutions implemented. Although the MC principles shown in Table 3 were not used explicitly in this analysis they helped to guide the analysis of how lean concepts were able to accommodate the choice dimensions of the existing product design. A common trend analysis was then conducted to identify common and conflicting findings from the two case studies. Did the implementation of lean principles make it more difficult to offer product variety and, vice versa, did offering product choice make it more difficult to implement lean principles? The following negative propositions were used to frame the common trend analysis:

- *P1: Product choice makes continuous process flow more difficult*
- *P2: Product choice makes pull systems more difficult*
- *P3: Product choice makes leveling out the workload more difficult*
- *P4: Product choice makes the development of a quality culture more difficult*
- *P5: Product choice makes the development of standardized tasks more difficult*
- *P6: Product choice makes visual control more difficult*
- *P7: Product choice makes the use of technology (that serves people and process) more difficult*

Finally, findings from Phases I and II were brought together to develop guidelines to improve the effectiveness and efficiency of homebuilding, through mass customization. As discussed before, Phase I reveals the challenges of offering increased product choice by documenting the impact of different levels of choice on plant operational efficiencies. Phase II illustrates how to overcome some of these challenges through the application of lean principles. Together they may form the basis for a methodology that may result in a successful mass customization strategy. A summary of the resulting guidelines were included in Chapter 5.

CHAPTER 4: INDUSTRY-WIDE SURVEY ANALYSIS

This chapter presents results and statistical analysis from the survey of industrialized home producers. The goal of this analysis was the characterization of how much product choice is currently being offered by U.S. homebuilders and the impacts of product choice on plant operational performance. The presentation of the findings is grouped into two major sections, as follows:

- Descriptive characteristics including basic statistics of the survey.
- Analysis of the impact of product choice on production efficiencies.
    - Analysis of Product Choice vs. Operational Efficiency.
    - Relationship analysis: Product and Operational Performance metrics.

Sample

The target population for the survey was 150 industrialized home producers across the U.S. Together, they operate 275 plants, both HUD Code and modular. Surveys were distributed to a key decision maker at each company, usually the president or CEO. Surveys were distributed and results gathered during a four months period from January to April of 2005. 141 plants completed the survey, representing 51% of the 275 operating plants initially contacted.

Descriptive Characteristics

Of the 141 plants that completed the survey, 29 (21%) produced primarily modular homes and 112 (79%) produced primarily HUD-code homes. The plants were widely distributed geographically, representing 27 states and Canadian provinces. Because the data set includes plants with two distinct home types, HUD code and modular, a separate analysis is performed for each type.

Product Choice Offered:

A summary of product choice offered is displayed in Table 3.

Table 3. Summary of Product Choice Offered

	HUD Code plants	Modular plants
Models offered in literature (avg.)	92	82
Models produced (avg.)	29	35
Most common level of customization	None (42%) Minor (43%) Extensive (15%) Custom (1%)	None (7%) Minor (45%) Extensive (38%) Custom (10%)
Most common level of drywall finish	None (53%) Limited (5%) Whole house (43%)	None (3%) Limited (3%) Whole house (93%)
Most common home size	One module (11%) Two modules (88%) Three modules (1%)	One module (3%) Two modules (83%) Four modules (10%) > Four modules (3%)

Participating plants offered many more home models in their marketing literature than they actually produced. Offerings ranged from a minimum of 3 models for HUD-code plants and 34 models for modular plants to a maximum of 534 models for HUD-code plants and 300 models for modular plants. To characterize the range of models actually produced by each plant, participating plants were asked the number of models that accounted for 90% of their last year's production. Models produced ranged from a minimum of 1 model for HUD-code plants and 10 models for modular plants to a maximum of 109 models for HUD-code plants and 80 for modular. This variation represents the product mix that participating plants must accommodate. Larger product mix can affect productivity and quality, especially for less flexible production systems. Modular plants actually produce a larger portion of their models offered (43%) than HUD-code producers (32%). The distribution of models produced for each home type is shown in Figure 12.

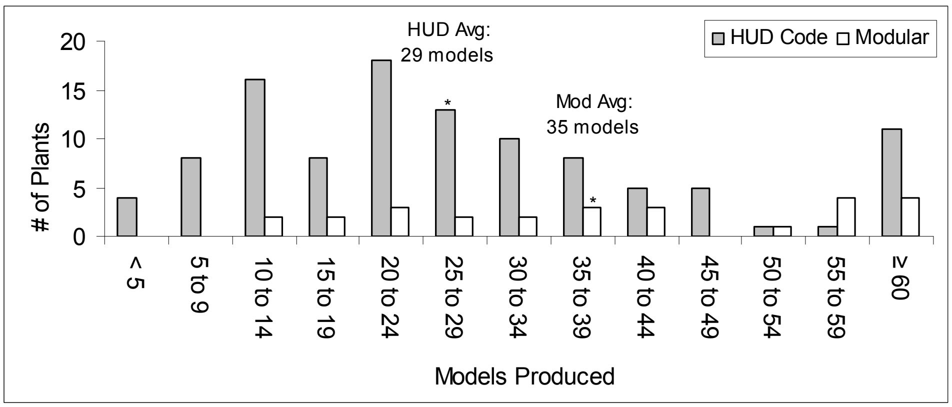

Figure 12- Distribution Of Models Produced

Participating plants were asked to describe their product based on the allowable level of customization (e.g. no customization, minor floor plan changes, extensive floor plan change and totally custom/new sheet of paper) offered. The distribution of the primary level of customization offered by participating plants is shown in Figure 13. 43 (42%) HUD-code plants offer no customization, 44 (43%) offer minor changes, 15 (15%) offer extensive changes and 1 (1%) offer totally custom. 2 (7%) modular plants offer no customization, 13 (45%) offer minor changes, 11 (38%) offer extensive changes and 3 (10%) offer totally custom. The primary level of customization for a plant refers to the category with the highest percentage. 9 (6%) plants were not included, because of a tie for primary level. HUD-code plants offer less customization than modular plants.

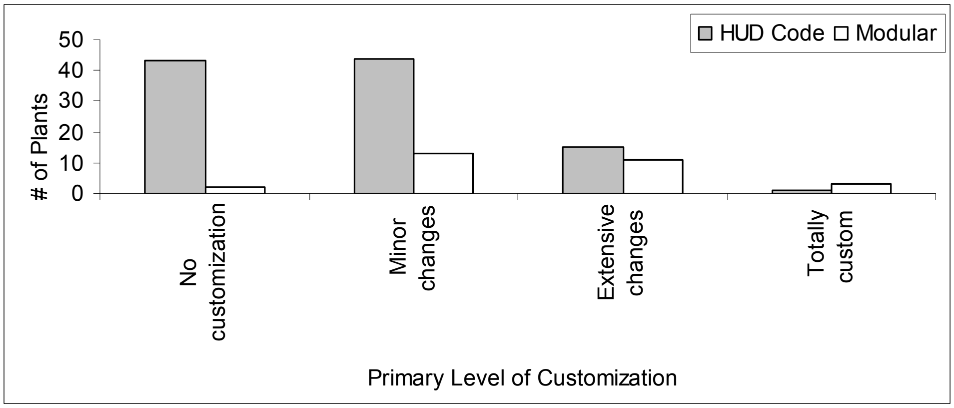

Figure 13- Primary Level of Customization Distribution

Plants were asked to describe their product based on the level of finished drywall in a home (e.g. none, limited and whole house). In this study, drywall finishing is considered a premium characteristic of the home. The primary level of finished drywall is distributed as follows (Figure 14): 57 (53%) HUD-code plants provided none, 5 (5%) provided limited, and 46 (43%) provided whole house. 1 (3%) modular plant provided none, 1 (3%) provided limited, and 43 (93%) provided whole house. 4 (3%) plants were not included, because of a tie for primary level. Most (93%) modular plants offer whole house finished drywall. HUD-code plants are roughly evenly divided among those that offer none or whole house finished drywall. The drywall finishing process includes three coats of mud, sanding and painting. This process is often a bottleneck to plant capacity and a source of quality problems. The distribution of finished drywall in HUD-code plants is somewhat misleading, indicating a relatively high percent of plants that primarily do “whole house” finished drywall. Further inquiry reveals that more than half of the HUD-code plants that reported “whole house” drywall finishing produce also produce modular homes (1% to 38% modular). Since modular homes are typically expected to have finished drywall, this could explain the high percentage of the participating HUD-code plants doing whole house drywall installation.

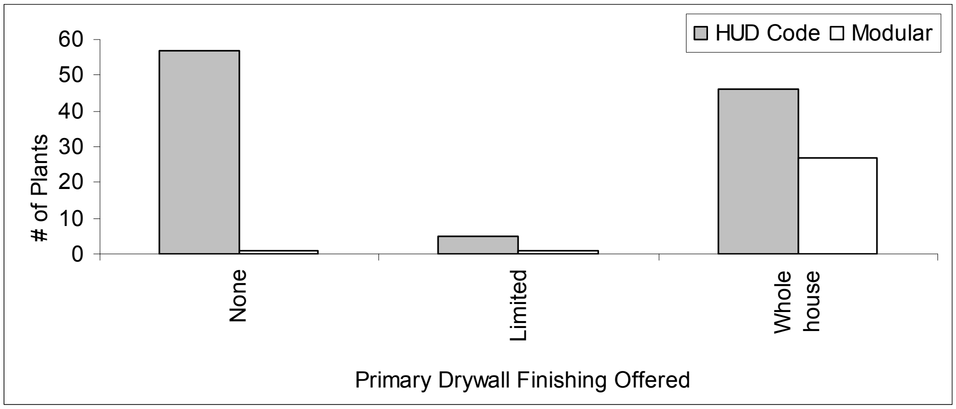

Figure 14- Product Premium distribution

Participating plants were asked to describe their product based on the number of modules per home (e.g., one, two, three, four or more than four modules). In this study, the number of modules used per home is considered a design characteristic of the home. More modules imply more complex design. The distribution of the primary number of modules per home for each plant is shown in Figure 15. 12 (11%) HUD-code plants primarily produce one module per home, 97 (86%) two, 3 (3%) four and 1 (1%) more than four modules per home. 1 (3%) modular plant primarily produces one module per home, 24 (83%) two, 3 (10%) four and 1 (3%) more than four modules per home. Two (1%) plants were not included, because of a tie for the primary number of modules per home. Note that this distribution may not be a good representation of the overall percentage of sections/module in the industry. Perhaps, larger modular plants are not well represented in the sample.

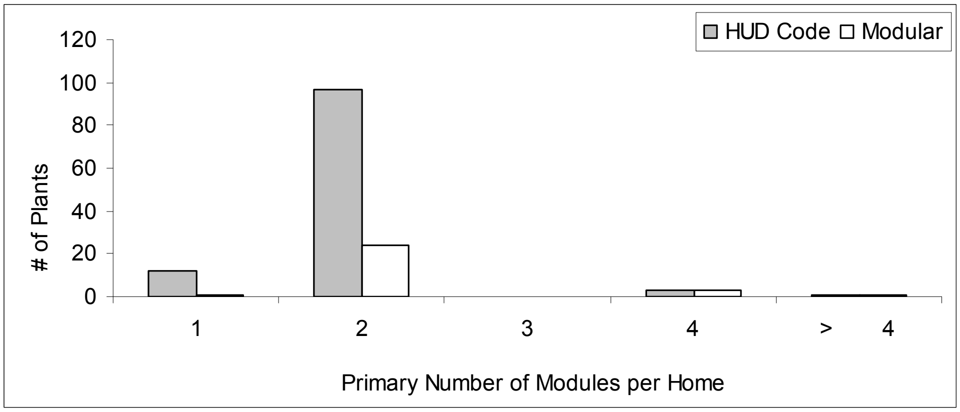

Figure 15-Product Design distribution

Plant Characteristics:

A summary of participating plant operating characteristics is shown in Table 4. The production rate of HUD-code plants is almost twice that of modular plants. HUD Code plants are 20% larger with six more production stations than a modular plant.

Table 4. Summary of Average Operating Characteristics

Plant Characteristics	HUD Code plants	Modular plants
Plant size (sqft)	146,709	117,795
Number of main-line workstations	27	21
Plant capacity (modules/week)	49	26
Modules produced per year	1,493	806
Homes produced per year	836	338
Annual sales($M)	$31.4	$21
Total annual labor cost ($M)	$4.5	$3.5
Number of modules in backlog	104	112
Annual number of accidents	27	24
Annual Labor turnover (%)	64%	50%
Annual service cost ($M)	$1.2	$0.7

Operational Performance:

A summary of participating plant performance on 13 basic operational performance measures is provided in Table 5.

Table 5. Summary of Average Operational Performance

Operational Performance Metrics	HUD Code plants	Modular plants
Plant size/current production (sqft/mod/week)	4,426	7,067
# production stations/ current production (stations/mod/week)	0.8	1.3
Material inventory turns/year	22	13
Sales $/module	$20,720	$26,054
Labor cost (% of sales)	14%	17%
Labor cost/module	$3,022	$4,340
Current production (modules/week)	33	17
Capacity utilization	70%	66%
Backlog (% of annual production)	7%	14%
Accidents/module	0.02	0.03
Customer Satisfaction	89%	90%
Service cost/module	$815	$823

Impact of Product Choice on Production Efficiencies

Analysis of Product Choice vs. Operational Efficiency

This section summarizes an analysis of operational performance versus product customization. The purpose of this analysis is to identify statistical significance between operational performance metrics and the product choice offered to the customer. The alternate hypotheses are stated as follows:

- H1: Operational performance differs with the number of standard models produced.
- H2: Operational performance differs with the level of customization offered.

Before testing the hypotheses, a normality test was conducted to check the distribution of the data. Since the data was not normally distributed, nonparametric statistical techniques were used. The Kruskal-Wallis Test was used, which is similar to an ANOVA for nonparametric data. This analysis helps to identify differences between groups (level of customization offered- none, minor changes, extensive changes and totally custom) across the operational performance metrics, by testing the null hypothesis that there is not difference among the groups. If results were significant (p-value < 0.05), a Dunn post hoc test was conducted to identify the specific groups that were statistically different. A box plot was also generated to visualize the differences among groups of standard models produced and the level of customization separately.

H1: Operational Performance Differs with the Number of Standard Models Produced.

The overall number of standard models produced by participating plants varied widely. In order to perform the hypothesis test, this product choice metric was categorized into three groups. Plants that produced less than or equal to 20 standard models, between 21 and 39 standard models and more than or equal to 40 standard models. The cut off number for the clustering was set based on the 33.33 percentile which was made up by those plants that offered 20 models or less.

HUD-Code Plants

Results from the Kruskal-Wallis analysis (Table 6) shows that at least one of the three groups of number of models produced differ with respect to some of their operational performance metrics: material inventory turns/year (p=0.001), labor cost (% of sales) (p=0.029) and labor cost per module (p=0.016). Thus, the alternative hypothesis (H1) is accepted for those metrics.

Table 6- Results of Kruskal Wallis Test For HUD-Code Plants and Models Produced

Test Statistics[a,b]

	Material inventory turns/year	Labor cost (% of sales)	Labor cost/module
Chi-Square	13.321	7.114	8.294
df	2	2	2
Asymp. Sig.	.001	.029	.016

a. Kruskal Wallis Test

b. Grouping Variable: Models Produced

To identify the specific group that is different, the Dunn post hoc test was performed. A box plot was then generated to visualize the differences among groups. Results revealed the following:

Material Inventory Turns per Year

This metric shows inventory carried relative to annual usage. Low inventory turns suggest inventory beyond that required to support production. High inventory turns reflects a more efficient operation. Results from the Dunn post hoc test (Table 7) reveal that material inventory turns/year differ significantly between plants that offer 20 or less and 40 or more standard models. Also the mid range group (21 to 39 standard models) differ from the plants offering 40 or more standard models.

Table 7- Dunn's Test for Material Inventory Turns of HUD-Code Plants

Comparison	**p-value**
<= 20 vs. 21 to 39	p>0.05
<= 20 vs. >= 40	p<0.05 *
21 to 39 vs. >= 40	p<0.05 *

Results from the box plot show that companies offering more standard models have lower material inventory turns than those companies offering less standard models (Figure 16). This suggests that plants offering more standard models carry more inventory - perhaps, they need to keep a larger variety of components to produce more models. This does indicate less efficient inventory levels associated with more choice.

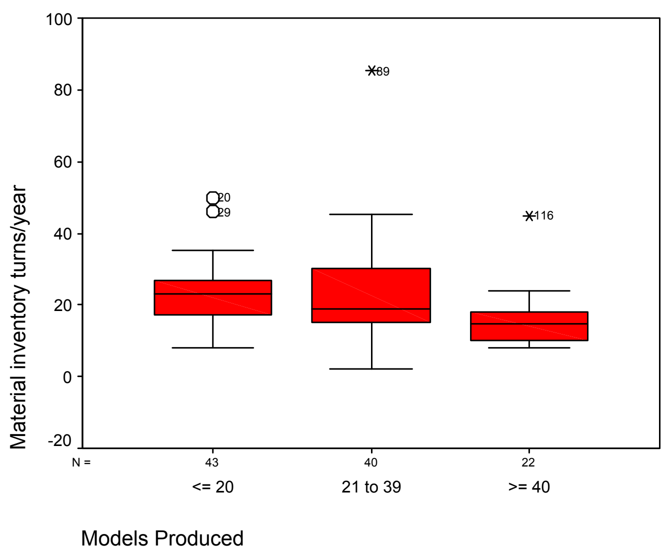

Figure 16- Box Plot for Material Inventory Turns Of HUD-Code Plants

Labor Cost (% of Sales)

This metric expresses total factory labor cost per sales dollar. It is a key measure of labor resource productivity. A high value implies labor inefficiency. Results from the Dunn post hoc test (Table 8) reveal that labor cost as a percentage of sales differs significantly between plants that offer 20 or less and 40 or more standard models.

Table 8- Dunn's Test for Labor Cost (% Of Sales) of HUD-Code Plants

Comparison	p-value
<= 20 vs. 21 to 39	p>0.05
<= 20 vs. >= 40	p<0.05 *
21 to 39 vs. >= 40	p>0.05

Results from the box plot show that companies offering more standard models have higher labor cost as a percentage of sales than those companies offering fewer standard models (Figure 17). This suggests that plants that offer more standard models might also incur lower labor productivity.

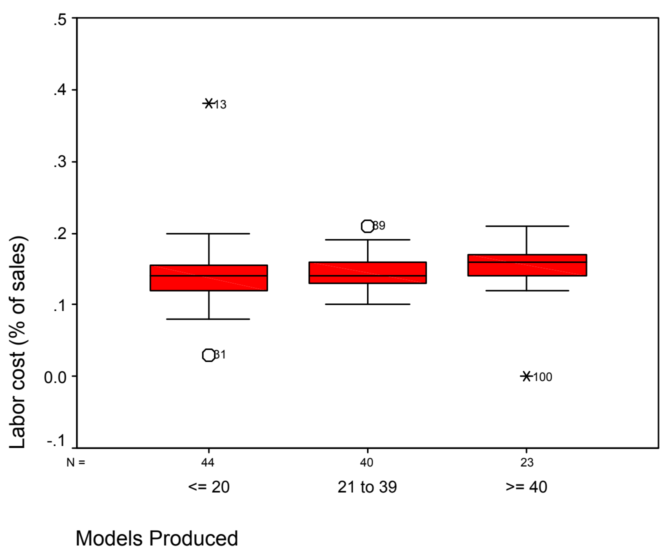

Figure 17- Box Plot for Labor Cost (% of Sales) of HUD-Code Plants

Labor Cost per Module Metric

This metric indicates the total factory labor cost per module. It is a key measure of labor resource productivity. Results from the Dunn post hoc test (Table 9) reveal that labor cost per module differs significantly between plants that offer 20 or less and 40 or more standard models.

Table 9- Dunn's Test for Labor Cost per Module of HUD-Code Plants

Comparison	p-value
<= 20 vs. 21 to 39	p>0.05
<= 20 vs. >= 40	p<0.05 *
21 to 39 vs. >= 40	p>0.05

Results from the box plot show that companies that offer more standard models have higher labor cost per module than those companies offering fewer standard models (Figure 18). As discussed in the previous section, this suggests that plants that offer more standard models might also incur lower labor productivity.

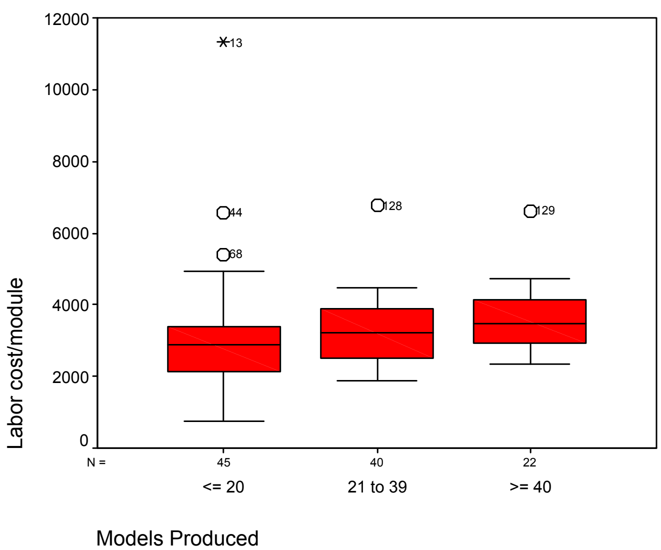

Figure 18- Box Plot for Labor Cost Per Module of HUD-Code Plants

Modular Plants

Results from the Kruskal-Wallis analysis (Table 10) shows that at least one of the three groups of number of models produced differ with respect to some of their operational performance metrics: material inventory turns/year (p=0.026). Thus, the alternative hypothesis (H1) is accepted for this metric.

Table 10- Kruskal-Wallis Results for Modular Plants

Test Statistics[a,b]

	Material inventory turns/year
Chi-Square	7.267
df	2
Asymp. Sig.	.026

a. Kruskal Wallis Test

b. Grouping Variable: Models Produced

Results from the Dunn post hoc test (Table 11) reveal that material inventory turns per year differs significantly between plants that offer 20 or less and 40 or more standard models.

Table 11- Dunn's Test for Material Inventory Turns per Year of Modular Plants

Comparison	p-value
<= 20 vs. 21 to 39	p>0.05
<= 20 vs. >= 40	p<0.05 *
21 to 39 vs. >= 40	p>0.05

Results from the box plot show that companies offering more standard models have lower material inventory turns than those companies offering less standard models (Figure 19). This suggests that plants offering more standard models carry excess inventory.

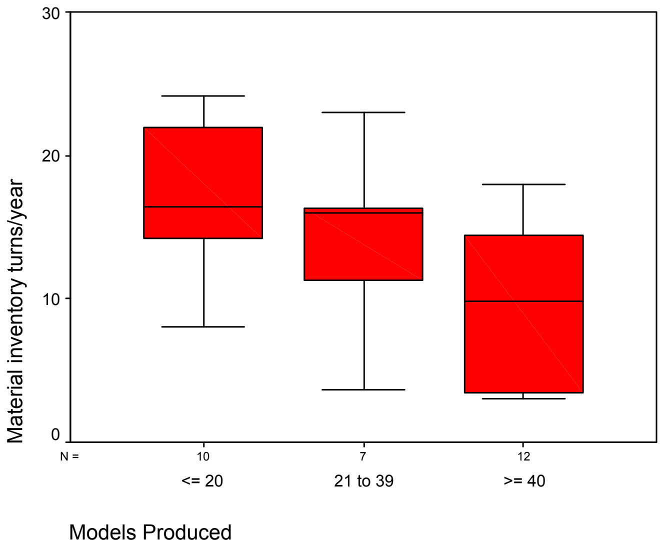

Figure 19- Box Plot for Material Inventory Turns per Year of Modular Plants

H2: Operational Performance Differs with the Level of Customization Offered

The level of customization offered by plants varies from none to totally custom. Plants reported the percentage of homes produced in each of the following customization levels: no customization, minor floor plan changes, extensive floor plan change and totally custom/new sheet of paper (the sum totaled 100%). Then, for this analysis the plants were categorized based on their primary level of customization provided- the level of customization with the highest percentage.

HUD-Code Plants

Results from the Kruskal-Wallis analysis (Table 12) shows that at least one of the four customization levels differ with respect to some of their operational performance metrics: sales per module (p=0.017), labor cost per module (p=0.016) and service cost per module (p=0.0004). Thus, the alternative hypothesis (H2) is accepted for those metrics.

Table 12- Results of Kruskal Wallis Test for HUD-Code Plants and Degree of Customization

Test Statistics[a,b]

	Sales $/module	Labor cost/module	Service cost/module
Chi-Square	10.204	10.350	18.199
df	3	3	3
Asymp. Sig.	**.017**	**.016**	**.000**

a. Kruskal Wallis Test

b. Grouping Variable: Degree of Customization

To identify the specific group that is different, the Dunn post hoc test was performed. A box plot was then generated to visualize the differences among groups. Results revealed the following:

Sales per Module Metric

This metric reflects the overall revenue generated per module. It also provides an important measure of productivity. Sales per module also suggests the overall value of the module, including labor, materials and profit. Results from the Dunn post hoc test (Table 13) reveal that sales/module differ significantly between plants that offer no customization and those that provide extensive changes. Plants that offer minor changes or totally custom homes do not differ from the others.

Table 13- Dunn's Test for Sales$/Module of HUD-Code Plants

Comparison	p-value
No custom vs. Minor changes	p>0.05
No custom vs. Extensive changes	p<0.05 *
No custom vs. Totally custom	p>0.05
Minor changes vs. Extensive changes	p>0.05
Minor changes vs. Totally custom	p>0.05
Extensive changes vs. Totally custom	p>0.05

Results from the box plot show that companies offering a higher degree of customization have higher sales per module than those companies offering a lower degree of customization (Figure 20). In general, a customized home is more expensive to build and a customer is willing to pay more.

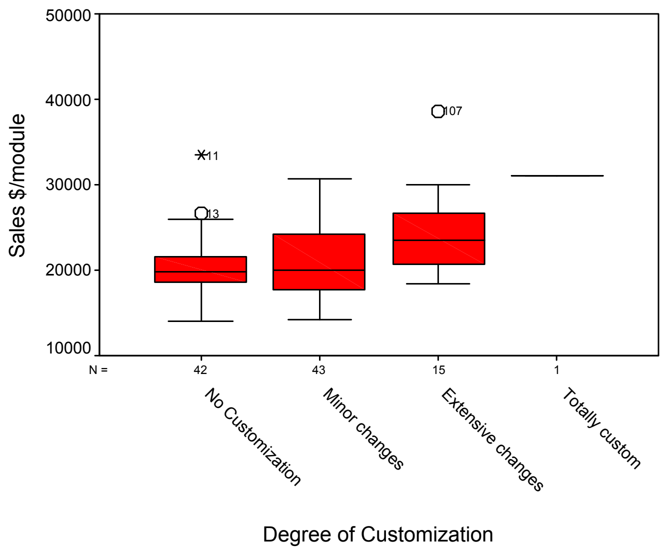

Figure 20- Box Plot for Sales$/Module of HUD-Code Plants

Labor Cost per Module Metric

Results from the Dunn post hoc test (Table 14) reveal that labor cost per module differs significantly between plants that provide no customization and those that provide extensive changes. Plants that offer minor changes or totally custom homes do not differ from the others.

Table 14- Dunn's Test for Labor$/Module of HUD-Code Plants

Comparison	p-value
No custom vs. Minor changes	$p>0.05$
No custom vs. Extensive changes	$p<0.05$ *
No custom vs. Totally custom	$p>0.05$
Minor changes vs. Extensive changes	$p>0.05$
Minor changes vs. Totally custom	$p>0.05$
Extensive changes vs. Totally custom	$p>0.05$

Results from the box plot show that companies that offer higher degree of customization have higher labor cost per module than those companies offering lower degree of customization (Figure 21). This result illustrates the additional labor required to customize a home. In general, standard models require less labor, since workers overcome the learning curve and increase productivity.

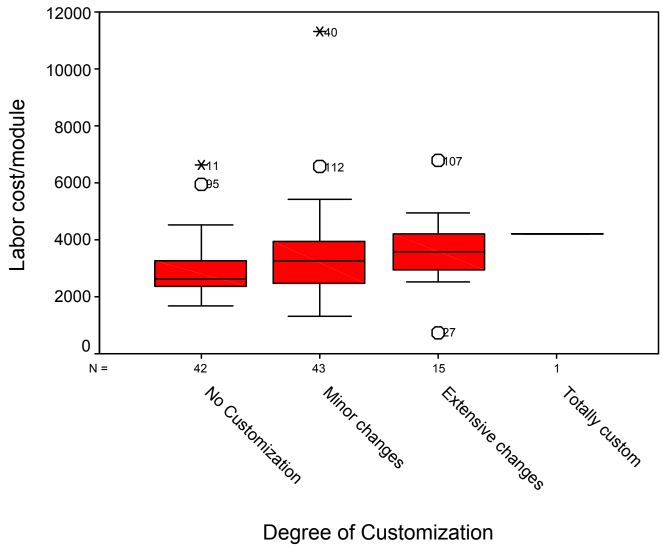

Figure 21- Box Plot for Labor$/Module of HUD-Code Plants

Service Cost per Module Metric

This metric indicates how much participating plants spend to resolve discrepancies identified after the home has been delivered to the customer. It is a key measure of quality. Results from the Dunn post hoc test (Table 15) reveal that service cost per module differ significantly between plants that provide no customization and those that provide either minor or extensive changes. Plants that offer totally custom choice do not differ from the others.

Table 15- Dunn's Test for Service$/Module of HUD-Code Plants

Comparison	**p-value**
No custom vs. Minor changes	P<0.05 *
No custom vs. Extensive changes	P<0.05 *
No custom vs. Totally custom	p>0.05
Minor changes vs. Extensive changes	p>0.05
Minor changes vs. Totally custom	p>0.05
Extensive changes vs. Totally custom	p>0.05

Results from the box plot (Figure 22) show that companies that offer higher degree of customization have higher service cost per module than those companies offering lower degree of customization. In plants offering higher degree of customization, customer orders vary in quantity and complexity in a short period of time. This situation affects labor productivity resulting in poor quality.

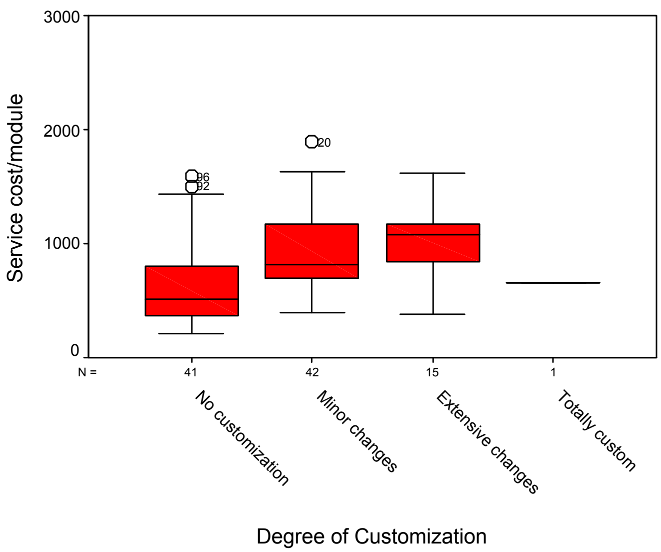

Figure 22- Box Plot for Service Cost per Module of HUD-Code Plants

Modular Plants

Results from the Kruskal-Wallis analysis showed no evidence that the groups differ. This outcome is due to the small sample size. The Kruskal-Wallis test has little power for small sample sizes, less than 5 on each sample. The sample of 29 modular plants was small. Of those 29 plants, 2 plants offered no customization, 13 offered minor changes, 11 offered extensive changes and 3 offered totally custom homes. Both the no customization and totally custom group of plants have less than five plants. The remaining two groups, minor changes and extensive changes, have more than five plants. To compare these two groups a Mann-Whitney test was performed. The Mann-Whitney test is equivalent to the Kruskal-Wallis test for two groups (t-test). Results from the Mann-Whitney analysis (Table 16) show that plant size per current production differ for the two levels of customization.

Table 16- Mann-Whitney Results for Modular Plants

Test Statistics[b]

	Plant size/current production (sqft/mod/week)
Mann-Whitney U	28.000
Wilcoxon W	106.000
Z	-2.339
Asymp. Sig. (2-tailed)	.019
Exact Sig. [2*(1-tailed Sig.)]	.019[a]

a. Not corrected for ties.

b. Grouping Variable: Degree of Customization

Plant Size per Current Production

This metric shows the space efficiency of a plant. Results from the box plot show that companies that offer extensive changes have higher plant size per current production than those companies offering minor changes (Figure 23). The production rate of plants that produce custom houses is typically lower than that of factories producing standard homes. Thus, the square footage of a plant producing more custom homes is amortized over fewer homes, resulting in lower space efficiency. To reach higher production rates, a custom plant may require more plant space for warehousing/staging custom materials and a special customization station to install them, again resulting in lower space efficiency.

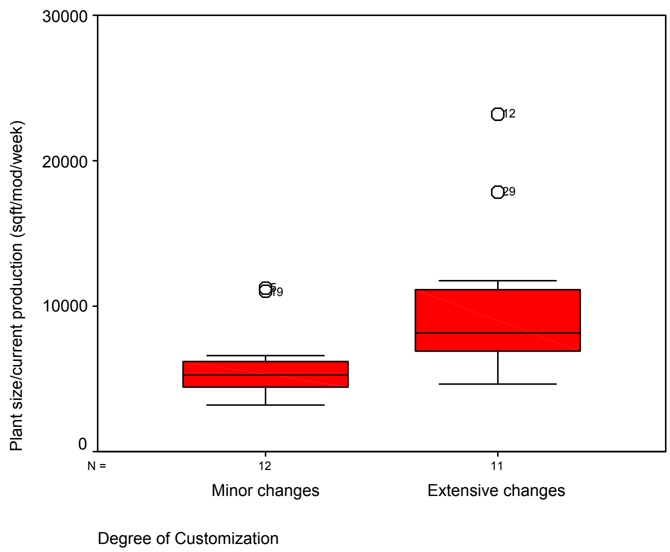

Figure 23- Box Plot for Plant Size/Current Production of Modular Plants

Relationship Analysis: Product and Operational Performance Metrics

A Spearman's correlation analysis was performed among the product variables and the operational performance metrics. The main purpose of this analysis was to identify the magnitude and orientation of the relationship among variables and the operational performance metrics. Results from the Spearman test are shown in Table 17 for HUD-code and Table 20 for modular.

HUD-Code Plants

Table 17- Spearman's Correlation for HUD-Code

Correlations

			Models Produced	Degree of Customization
Spearman's rho	Material inventory turns/year	Correlation Coefficient	-.291**	.141
		Sig. (2-tailed)	.003	.163
		N	105	99
	Sales $/module	Correlation Coefficient	.230*	.266**
		Sig. (2-tailed)	.017	.007
		N	107	101
	Labor cost (% of sales)	Correlation Coefficient	.267**	.252*
		Sig. (2-tailed)	.005	.011
		N	107	101
	Labor cost/module	Correlation Coefficient	.281**	.316**
		Sig. (2-tailed)	.003	.001
		N	107	101
	Customer Satisfaction	Correlation Coefficient	.037	-.240*
		Sig. (2-tailed)	.745	.036
		N	79	77
	Service cost/module	Correlation Coefficient	.042	.410**
		Sig. (2-tailed)	.669	.000
		N	105	99

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Models Produced

Results from the Spearman correlation test reveals that the number of models produced is significantly correlated with the following operational performance measures: Material Inventory Turns per Year (r= -0.291, p=0.003), Labor Cost (% of sales) (r=0.267, p=0.005), Labor Cost per Module (r=0.281, p=0.003) and Sales per module (r=0.230, p=0.017). These relationships are positive, with the exception of material inventory turns per year.

Degree of Customization

Results from the Spearman correlation test reveals that the degree of customization is significantly correlated with the following operational performance measures: Sales per Module (r=0.266, p=0.007), Labor Cost per Module (r=0.316, p=0.001), Service Cost per Module (r=0.410, p=0.000), Labor Cost (% of sales) (r=0.252, p=0.011) and Customer Satisfaction (r= -0.240, p=0.036). These relationships are positive, with the exception of customer satisfaction.

Modular plants

Table 18- Spearman's Correlation for Modular Plants

Correlations

			Models Produced	Degree of Customization
Spearman's rho	Plant size/current production (sqft/mod/week)	Correlation Coefficient	-.166	.375*
		Sig. (2-tailed)	.397	.050
		N	28	28
	Material inventory turns/year	Correlation Coefficient	-.512**	.183
		Sig. (2-tailed)	.005	.341
		N	29	29

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Models Produced

Results from the Spearman correlation test reveals that Material Inventory Turns per Year (r= -0.512, p=0.005) has a significantly negative correlation with the number of models produced.

Degree of Customization

Results from the Spearman correlation test reveals that plant size per current production (r=0.375, p=0.050) has a significantly positive correlation with the degree of customization offered of customization. In other words, plants that build more customized homes are less efficient in the use of their facilities.

Results Summary

The following table summarizes finding from the analysis of the impact of product choice on a plant's production efficiencies.

Standard Models Produced:

Table 19- Summary Table for Standard Models Produced

		Between-Groups Differences (Kruskal-Wallis Test)			
		≤ 20 vs. 21-39	≤ 20 vs. ≥ 40	21-39 vs. ≥ 40	Relationship (Spearman's Correlation)
HUD- code	Material Inventory turn per year		X		r = -0.291, p=0.003
	Labor cost (% of sales)		X		r=0.267, p=0.005
	Labor cost per module		X		r=0.281, p=0.003
	Sales per module				r=0.230, p=0.017
Modular	Material Inventory turn per year		X		r= -0.512, p=0.005

Degree of Customization:

Table 20- Summary Table for Degree of Customization

		Between-Group Differences (Kruskal-Wallis Test)						
		No custom vs. Minor changes	No custom vs. Extensive changes	No custom vs. Totally custom	Minor changes vs. Extensive changes	Minor changes vs. Totally custom	Extensive changes vs. Totally custom	Relationship (Spearman's Correlation)
HUD-code	Sales per module		X					r=0.266, p=0.007
	Labor cost per module		X					r=0.316, p=0.001
	Service cost per module	X	X					r=0.410, p=0.000
	Labor cost (% of sales)							r=0.252, p=0.011
	Customer Satisfaction							r= -0.240, p=0.036
Modular	Plant size per current production				X			r=0.375, p=0.050

HUD-code plants have a positive relationship between *standard models* produced and some of their operational performance metrics: *labor cost (% of sales)*, *labor cost per module* and *sales per modules*. This indicates that as the number of models produced increases, the operational performance metrics also increase. On the other hand these plants have a negative relationship between standard models produced and *material inventory turns*. In all cases, the operational performance deteriorates with an increase in choice. Although the difference between the groups is not significant, *sales per module* do tend to increase with the number of models produced. In modular plants, *material inventory turns* also has a negative relationship with the number of standard models produced, again suggesting a deterioration in operational performance as choice increases.

HUD-code plants have a positive relationship between degree of customization and some of their operational performance metrics: sales per module, labor cost per module, service cost per module and labor cost as a percentage of sales. This indicates that as the level of customization offered increases, these operational performance metrics also increase. On the other hand these plants have a negative relationship between degree of customization and material inventory turns. In all cases, the operational performance deteriorates with an increase in choice. Although the difference between the groups is not significant, customer satisfaction does decrease with the number of models produced. Modular plants have a positive relationship between degree of customization and two operational performance metrics: plant size per current production and accidents per module.

In general, operational performance deteriorates with an increase in choice. Therefore, industrialized housing manufacturers (and their customers) do pay a price for offering more choices to the customer and as observed from the analysis they have not yet reached the ideal of what mass customization promises. Furthermore HUD-code plants were observed to be less successful than modular plants in offering increased choice without deterioration in operational performance. The following section explores how increased product choice impacts the metrics found to be significantly related: labor cost per module, labor cost as a percentage of sales, service cost per module, inventory turns, and sales per module. Although the difference between the groups of choice was not found to be significant, this section also examines how customer satisfaction, plant size per current production and accidents per module might be impacted by increased product choice. Results are summarized in a cause and effect diagram in Figure 24.

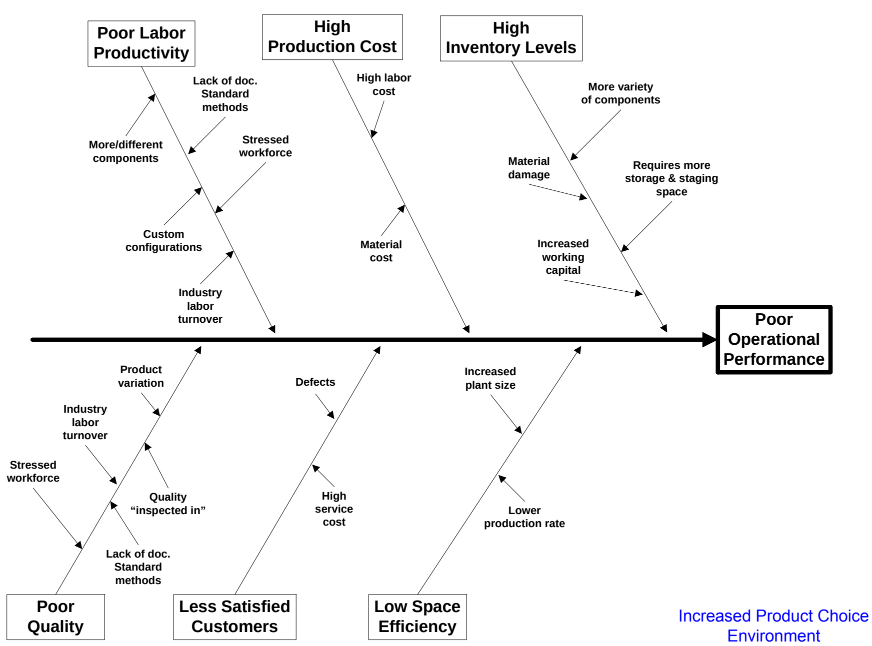

Figure 24- Cause and Effect Diagram

Product variation manifests itself in several ways on the manufacturing floor. More/different components are used to perform the same function. The different components are often fabricated and installed using different tools and methods. Custom configuration, even of common components, can increase complexity. This increase in components, with their unique tools and methods, coupled with custom configuration, with its increase in complexity, stress the workforce. Extra time is required to think through the process and then perform the actual work. The reduction in repetition makes it harder to improve on the learning curve. If errors are made, productivity is further reduced by rework. These factors are exacerbated by the lack of documentation of standard methods and high labor turnover within the industry (averaging 60% annually – MHRA, 2005). These factors obviously drive labor productivity metrics such as *labor cost per module* and *labor cost as a percentage of sales*. In turn, these metrics drive *sales per module*.

Quality can also be a victim of these workforce stress factors caused by product variation. Given the line-flow configuration of most HUD-code and modular plants and management's preference for synchronous flow/fixed cycle times, product variation often leads to performing more work in the same amount of time. Workers may not only hurry up when performing the actual task, but may rush drawing review and planning before the task begins. The result is a higher likelihood of discrepancies. Again, this is exacerbated by the lack of documentation of standard methods and worker inexperience associated with high labor turnover. If the company is fortunate and quality control systems are working well, discrepancies are identified in the factory and rework is the only consequence. However, quality specialists have long known that quality cannot be "inspected in", and this appears to be the case for these industrialized housing plants. S*ervice cost per module* is significantly, positively related to product choice. This may also explain increased homebuyer dissatisfaction with companies offering more custom homes.

Companies that offer more choice often keep a greater variety of components in inventory, leading to higher inventory levels. They do this to obtain quantity discounts, minimize re-order costs and shorten lead times. The natural consequence is an increase in *material inventory turns.* The result is increased working capital, storage and staging space, damage, and obsolescence.

The need to warehouse and stage a greater variety of components may also increase plant size. Plant size per current production rate may also be impacted by the longer line cycle time (lower production rate) typically associated with highly customized homebuilding. Since some elements of the plant (e.g., floor, wall and roof jigs) require a minimum footprint, this larger square footage is amortized over fewer homes.

CHAPTER 5: CASE STUDIES

Introduction

The target population for these case studies was a group of nine industrialized housing plants that initiated lean production efforts in 2006. These lean efforts were supported by MHRA and lean/industry experts from Senco Products and the University of Central Florida. Plant staff participated in a one week lean training session in April 2006, before implementation. The training covered basic lean concepts and techniques. The training was tailored to the industrialized housing industry and addressed the challenges of implementing lean in the industry. Participating plants began lean implementation in Summer 2006. Since the plants were new to lean production, the early implementation efforts took the form of Rapid Productivity Improvement (RPI) events in specific areas or departments. Two of these nine plants were selected for case studies, based on their accessibility and the researcher's personal participation in the lean implementation efforts, which facilitated potential learning opportunities.

For the case studies, two primary sources of information were used: on-site observation and interviews. In order to document the mass customization principles used at each participating plant, an interview with each plant was conducted, following a pre-determined set of questions (Appendix B). This set of question is aligned with the mass customization principles identified earlier. The main purpose of this interview was to capture the level of choice offered and mechanism to accomplish that level of choice offered by each company. Lean principles applied by each participating plant during the RPI events were documented using the RPI event form (Appendix C). The information was gathered mainly through interview and on-site observation.

Each case study is structured in two levels. At the plant level, the company background, product, and level of choice are described (from the mass customization principles interview, Appendix B). A general overview of how this level of choice is accommodated is also included. At the department level, product choice and lean principles are described, including a description and results of lean implementation (from the RPI event form, Appendix C).

The following section includes a case study of Company A, Company B and a common trend analysis to identify lean tools and techniques that allowed plants to offer product choice efficiently.

Company A

Plant Level: Company and Product Choice

Company A manufactures HUD-code and modular homes for a moderate to high-end market segment. The proportion of HUD-code and modular homes produced depends on customer orders, and has varied from 100% HUD-code to 80% modular/20% HUD-code. The company builds single family homes and multi-family condominiums and apartments. Although they can build one-of-a-kind, custom homes, they offer 101 different standard models from which customers can customize their own home. Standard models range from 510 to 3,397 square feet, 1 to 4 bedrooms, and 1 to 3 1/2 baths. The company offers high quality options and several standard choices in every standard model. For instance, textured drywall, 9 and 10 foot ceilings, solid surface countertops, and high-end cabinetry are some of the options available to homebuyers. For an extra level of customization, this company uses their own engineers to assist with any floor layout modifications that homebuyers request.

Production rate varies with orders from two to eight modules per day. The current production rate is four modules per day. During periods of slow demand, management responds by sending workers home early or shutting down production for the entire day. The erratic demand and poor work environment has increased employee dissatisfaction and turnover.

The company allows a high degree of customization by homebuyers. Customers are involved early in the design process, when unique designs can be realized or major revisions made to standard models. These major revisions can involve structural changes that require an engineering stamp. Figure 25 exhibits a high level value stream map of the product realization cycle, from the homebuyer's concept to the finished house. First, the sales department captures customer needs and generates an order (e.g. concept). This order is then processed by the engineering department, who review and approve the concept. Although structural changes can be made to accommodate any customization, that usually adds two months to the process because drawings must be reviewed and approved by a third party. Once the concept has been approved, the design is reviewed with the customer, manufacturing prints are generated and the production of this house is scheduled. The manufacturing department takes about two weeks to build the house. The production line accommodates a build-to-order, just-in-time production strategy. It is set up in side-saddle configuration (width-wise module movement) with floors, ceilings, and walls feeding the main line from off-line sub-assembly stations. An L-shape change in direction at the end of the line facilitates off-loading from the line. Upon completion in the factory, modules are delivered and set on the homebuyer's land. While the house is being built at the plant, the field service department does the needed site work and prepares a foundation, if required. The field service department takes about three months to lay the foundation, set and trim out a house.

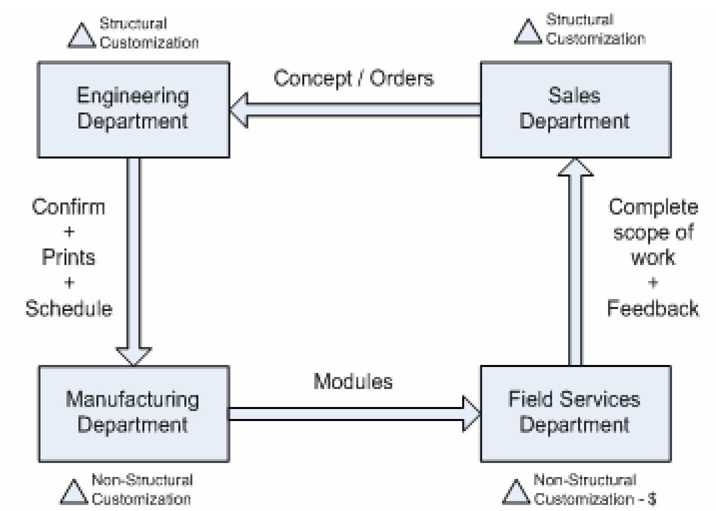

Figure 25- Product Realization Cycle and Customization

The company is currently experiencing insufficient manpower, poor logistical support, high levels of factory defects and other delays that lengthen the time to complete a house. Current production challenges include a lack of standard work procedures, a poor work environment and an unstructured improvement process. These challenges encourage instability and unpredictability.

The company supports the use of lean principles and other continuous improvement tools. Manufacturing has a dedicated lean advocate who oversees all lean training and implementation. The plant manager has overall responsibility for lean implementations and oversees all RPIs in the plant. The company believes that with time, using lean principles and tools will help overcome the inherited mass production layout and achieve flexibility in their process to accommodate product variety.

Plant Level: Mass Customization Principles

Customization postponement (mass customization principle #1) refers to delaying customization by mass producing common components and then assembling and/or customizing them based on specific customer orders. The mass production of common components can take place even before orders are received. This company allows structural changes to its standard models as well as completely new designs. These changes often affect the structure of core building elements such as floors, walls, and roofs. Therefore, once Engineering reviews and approves the design concept, customer can not make additional modifications (Figure 27). Customization can not be postponed because these core building elements can not be built-to-stock and then customized-to-order.

Like all homebuilders, this plant does enjoy the benefits of many modular/standardized smaller components (mass customization principle #2). Many of these components are finish components (i.e., cabinets, windows/doors, lighting/plumbing fixtures, siding, shingles) with variants that are directly and easily substitutable and are offered in many home designs. The benefits are discussed in greater detail in the discussion of labor flexibility below. While significant, these benefits do not extend on a larger scale to the critical core components of the home: floors, walls and roofs. The product architecture and basic building system does not facilitate the use of the modularity/commonality principle when larger scale product choice is allowed.

As indicated in the previous discussion, the company did not practice either customization postponement or product modularity. Although lean efforts accommodated product choice offered, there was no effort to change product design.

At the plant level, the company did accommodate product choice by providing some flexibility in the production system (mass customization principle #3). This flexibility included:

- Labor flexibility - Labor flexibility is a key strategy used to accommodate choice. There are several levels of labor flexibility. At the lower end, some options with common architectures are directly substitutable, requiring exactly the same procedures and skills. A good example is installing different colors of vinyl siding. Some options are substitutable, but require very different procedures and skills. For example, fiber cement siding is an optional upgrade from vinyl siding. Other options are extras, again requiring different procedures and skills. For example, the installation of tile on the shower surrounds and kitchen countertops requires a skilled craftsman who calculates the spacing and pattern for optimal efficiency. In many of the stations, the basic materials, skills and procedures are common; however, the configuration of each order is unique. Thus, basic skills are the same, but higher order skills are needed to accommodate the variation of unique configurations. Good examples include floor, wall and roof framing.

  All levels of choice, except the simplest of substitutions, are also likely to cause work content and labor hours to vary. Labor hours vary with procedural changes associated with different materials/components as well as with varying dimensions and complexity of each configuration. Work teams handle most of this time variation naturally, moving upstream on the line when they finish early and downstream when more time is needed (when they are not constrained to a specific workstation). This natural absorption of variation is greatly simplified when the line is properly balanced and when customer orders are sequenced to level the workload over time. When this approach fails to accommodate variation and bottlenecks occur, more real time and costly interventions are required. Utility workers are cross-trained so that they can be moved to temporary bottleneck locations caused by absenteeism or poor product mix. If utility workers are not available or the bottleneck is discovered too late to react, then overtime may be authorized for bottlenecked activities. If these tactics cannot resolve the problem, the bottlenecked work (and all subsequent work dependent on the bottlenecked work) may be completed in the yard after the module leaves the line. This is the least desirable of all options because of labor inefficiency and the likelihood of damage and rework.

  This plant requires new manufacturing associates to complete safety training and to learn a wide range of job skill sets needed for their role in the manufacturing process. Training is hindered by the lack of standardization. No standard work procedures documenting materials, tools/equipment, and methods were posted, causing variations in production methods, inefficiencies and rework. Once initial training is complete, associate empowerment is limited. Although the company encourages further associate development through leadership training, there is not a formal structure to support continuous improvement of associates. Therefore, if associates do not have knowledge of other trades or skills when they are hired, they are limited to their original assignment. This is a critical issue, since cross-trained utility workers are important when offering high levels of customer choice. It is also likely that the lack of standard work procedures exacerbates the cross-training issue.

- Layout flexibility - The current plant layout is not highly flexible. The main line is a legacy of the company's mass production heritage. Although it provides some flexibility for a work team to move to upstream or downstream workstations, this movement is constrained by fixed workstations where certain activities must occur (e.g., wall set and roof set are limited by crane access, roofing and wrap is limited by mezzanine access). The main line lacks space for queuing modules, large subassemblies (e.g., floors, walls, roofs) and larger quantities of raw materials and components. It provides neither an on-line or off-line 'customization' station for custom work inside the plant. As a result, custom finishing work is often finished in the yard after the module leaves the line.

  Inventory is a key tool in providing choice to the customer. Inventory consists of common raw materials (e.g., different length studs) and finish components (e.g., solid surface countertops and high-end cabinetry) used for pre-set options. Some of this inventory, primarily higher value/low inventory items, are kept in the factory near the line. Most inventory is kept in a warehouse near the plant. It is delivered to the plant in a just-in-time fashion as required by orders on the line. Inventory is not always well managed and sometimes is damaged or becomes obsolete.

- Equipment Flexibility - Much of product choice consists of substitutable components that utilize the same tools for sub-assembly and installation. The simplest example might be purchased components such as different color siding that uses exactly the same tools. Activities such as wall build use the same tools, but the framing table must be flexible enough to accommodate variations in length and height.

Department Level: Mass Customization and Lean Principles Used

The company conducted an RPI event to improve the painting of interior doors. Details of these efforts, focusing on the lean principles used, production flexibility resulting from lean principles implemented and the effects of product choice on lean principles are described in the following section.

Interior Door Area

Interior doors are prepped in the window and door department. The plant purchases primed interior doors and they must be painted with a finish coat. Previously, doors were hung in the module and then painted by workers using rollers. A process flow chart of this old procedure is shown in Figure 26. Several forms of waste were observed. Non-value added process steps included: 1) the movement of painters and their supplies between modules; 2) the masking of surrounding areas to prevent paint damage; and 3) rework due to poor paint finish, paint smudges, and damage by other workers. The plant manager and workers from the area conducted an RPI event to improve the painting procedure. They centralized the painting operation in an area near the line where doors are installed. The new paint area was designed as an enclosed paint booth, accommodating 28 doors in two lines of 14 doors each. Quick connect clamps are used to speed setup. The bottom plate that supports the door swivels so both sides can be painted with minimal effort. Paint rollers and brushes were replaced by a paint sprayer.

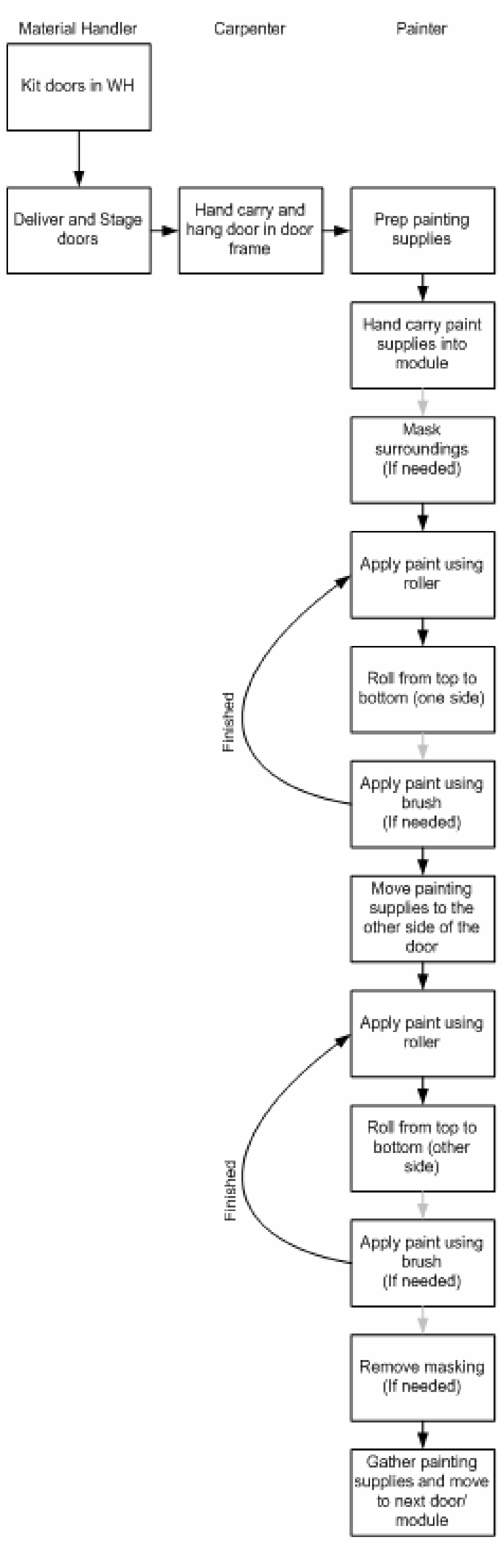

Figure 26- Process Flow Chart of the Old Painting Process

Doors for the house are kitted in the warehouse and then delivered and staged near the paint booth by a material handler (doors are pulled based on usage- empty staging area). When space becomes available in the booth and when the associated house is two to three line moves upstream (providing a drying time offset), workers hand carry each door from the staging area into the paint booth and set them up in the clamp system. The doors are placed on a swivel base plate and attached at the top by a plunger-type device that secures the top of the door (Figure 27). Doors are then sprayed on one side, swiveled, and sprayed on the other side. Once the doors are dry, they are removed from the clamp system and hand carried directly to the module for installation. The station where the doors are installed is adjacent to a raised bay which facilitates access in and out of the module. Figure 28 shows the process flow of the improved painting process.

Figure 27- Door Clamp System

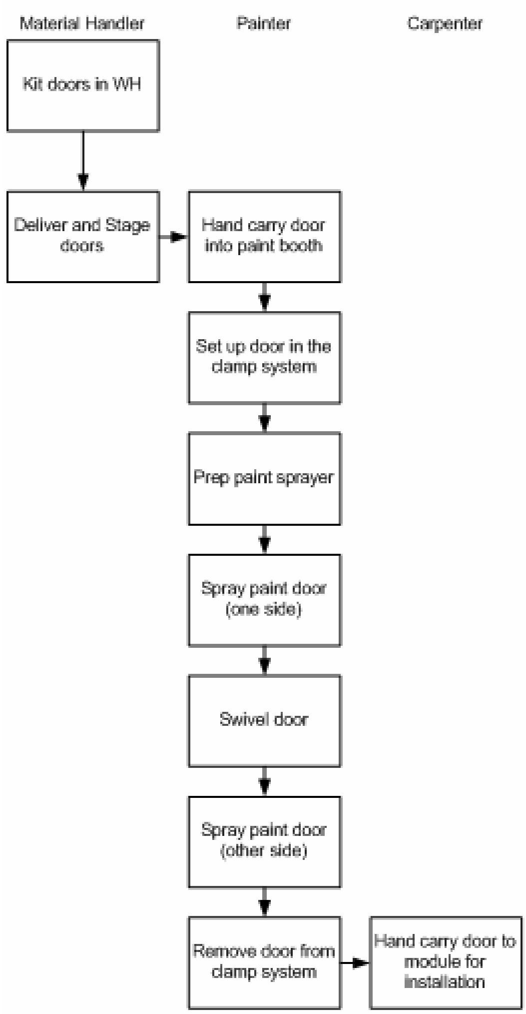

Figure 28- Process Flow Chart of the Improved Painting Process

The benefits of the new paint booth are notable. Spray application is faster and more uniform than the roller. Painters no longer travel to each module. No masking is required in the module. Standardized procedures in the paint booth are easily reinforced. The paint booth also prevents movement of paint and fumes to other areas of the plant. The plant spent $2,000 in material and manpower to build the paint booth. Total labor savings is estimated at $31,500 per year. Defects were reduced from 25% to 5% of doors.

Impact of Product Choice on Lean Principles

There are several dimensions of product choice related to interior doors: quantity, size, profile and color. Interior doors per home range from 2 to 14. There are a variety of door sizes (heights and widths) depending on location and use. Doors may be flat or have a raised profile with varying numbers of panels. Usually the homebuyer selects the door profile and door size is determined by company engineers. The company also allows the use of any custom door requested by the customer. Although all doors are now painted white with a glossy finish, color is potentially an option and will be considered. The following section describes how each lean principle was represented in this RPI and how each dimension of choice was accommodated for each principle:

Lean Principle #1- Create Continuous Process Flow to Bring Problems to the Surface

In an ideal continuous flow production system, value is added to the product no earlier than necessary to meet customer needs. Once started, value is added continuously until the product is completed and shipped to the customer. Large batch sizes and large work in process inventories are discouraged because they disrupt this continuous flow of adding value. The ideal batch size is one piece. Other wasteful delays that disrupt continuous flow are also eliminated. At a high level, the plant is an excellent example of continuous flow. Individual modules move continuously along a production line, with no significant queuing. Major components flow into the line synchronously. The new paint process does batch doors into and out of the paint booth, but does so in a highly controlled, synchronous manner, tied directly to the line. The new process creates continuous flow for the painter as he/she moves between doors in the booth. Waste that disrupts continuous flow (e.g., moving between modules and masking surroundings) is eliminated. Although an additional set-up is required to position doors in the paint booth, an innovative clamping system is utilized that allows workers to rapidly position doors and rotate doors for painting. The clamping system is an example of the Single Minute Exchange of Die (SMED) lean principle to minimize set-up time. Although an additional move is required to transport doors to the line, this move is minimized by locating the booth close to the point of door installation on the line. A second potential move was also eliminated by moving doors directly from the booth to the line, instead of into staging.

Product choice impacted implementation of this lean principle as follows:

- *Quantity of doors* – The old painting process was somewhat flexible in accommodating the workload variation (largely proportional) resulting from differing quantities of doors. Doors were installed and painted earlier and later on the line. When doors were painted later on the line, this caused later finishing operations to be pushed back even further, sometimes into the yard. This resulted in quality issues and overtime. The improved painting process better accommodates this variation. In fact, the new process addresses the root causes of this variation itself. This is discussed below under Lean Principle #3.

- *Door size*- The old painting process was very flexible with respect to door size. Since doors were kitted into area, no staging was needed for each door size. Once doors were installed in their rough openings, door size did not impact painting. The new system is equally versatile. Doors are still kitted into the area, requiring no staging for each door size. Doors are positioned inside the paint booth before painting. This extra set-up step was made highly efficient by using a clamping system that readily accommodates a range of door sizes, allowing quick positioning, turnaround and removal. Spray painting easily accommodates a range of door sizes. Painted doors are transported from the booth directly into the module. Therefore, no post-paint staging is needed for each door size.

- *Door profile*- The old painting process was somewhat flexible with respect to door profile. Since doors were kitted into area, no staging was needed for each door profile. Door profile did dictate the painting method: flat doors were painted with rollers while paneled doors also required brushes. The use of two different painting methods added complexity and extra process steps, interrupting process flow and increasing the overall cycle time as well as cycle time variability. The new process is more accommodating to door profile variation. Doors are still kitted into the area, requiring no staging for each door profile. Door positioning using the clamping system is not affected by door profile. Spray painting more easily accommodates a range of door profiles, eliminating multiple methods and smoothing process time variability. Painted doors are transported from the booth directly into the module. Therefore, no post-paint staging is needed for each door profile.

- *Door color*- Since all doors are currently painted white with a glossy finish, color choice is not an issue. However, it is instructive to consider the flexibility of each paint process in accommodating different colors. The old painting process would be somewhat flexible with respect to door color. Door color would not impact the process until the painting step. A color change would necessitate several extra steps including: return to the paint supply crib; change-out/clean-up paint, brushes and rollers; and return to the module. These extra steps would interrupt process flow and increase the overall cycle time. The new process would be more accommodating to door color variation. Door positioning using the clamping system would not be affected by door color. Spray painting would more easily accommodate a range of door colors. Once doors are positioned and secured in the painting booth, the worker would be able to change paint color by changing the sprayer's hose or using a multi-color trigger sprayer. The use of the paint sprayer would facilitate and reduce the cycle time of paint preparation and cleanup and eliminate travel time between the module and the paint supply crib. Painted doors are transported from the booth directly into the module. Therefore, no post-paint staging would be needed for each door color.

Lean Principle #2- Use Pull Systems to Avoid Overproduction

A pull system is a method of controlling the flow of resources, both material and process, by replacing only what has been consumed. Production should be pulled from the customer end, including both internal and external customers, to avoid overproduction and facilitate continuous flow. At a high level, this plant follows a pull approach by only producing homes that are ordered by homebuyers. The main production line dictates the need for interior doors and the painting operation responds to the actual demand of the line. The old process pulled a kit of doors from the warehouse for each home on the line and transported the kit into a staging area serving the line. When the house reached the appropriate workstation on the line, the doors in the kit were carried into the module and installed. A painter then painted each door in the module. The new process also uses the pull system concept, pulling primed doors from the warehouse to the staging area and then into the paint booth as needed by the main production line. Interior door are batched per module and painted following a first-in, first-out (FIFO) sequence. Painted doors are allowed to dry in the booth until they are needed on the line. Painted doors are then transported from the booth directly into the module. This approach avoids excess work-in-process and overproduction of painted doors. The painting process becomes more efficient and lead times, storage space required and expenses are reduced.

The choice of door quantity, size, profile and color does not impact implementation of the pull principle. Doors are pulled through the process as a kit, one kit for each home – not by unique door configuration.

Lean Principle #3- Level Out the Workload

Producing orders 'just-in-time' to customer demand can result in uneven production levels, periodically over/under loading people and equipment. This principle seeks to level production over some period by spreading high volume and difficult product mixes uniformly over the period. In this plant, customer orders vary in quantity and complexity from week to week. One week the plant may build many, complex homes stressing workers and equipment and paying overtime. The next week order volume and complexity may plummet, sending workers home. This situation results in poor quality and dissatisfied workers. The plant does its best to level load production, producing earlier than necessary when needed to level production and spreading complex/labor-intensive orders over time.

Because door installation and painting is not critical to overall line flow, door-related activity is not used as a criterion to level load the line. Therefore, it is important that the door painting operation be flexible enough to absorb workload variation caused by the four dimensions of customer choice: door quantity, size, profile and color. This variation is addressed above in Lean Principle #1. The old process flexed by installing and painting doors earlier and later on the line. When doors were painted later on the line, this caused later finishing operations to be pushed back even further, sometimes into the yard. This resulted in quality issues and overtime. The improved painting process better accommodates this variation in quantity and complexity. Centralizing door painting in the new, offline booth removes door painting from the critical path. This allows subsequent finish activities to begin earlier, leveling the work and effectively reducing the overall production cycle time. It also allows more flexibility for these activities to react to rework and other delays. Even if door painting is significantly delayed, since doors are painted before installation, they can be flexibly installed later in the process.

A related advantage of the new process results from the use of the spray paint system. Spray painting actually reduces the complexity, skill level, cycle time and cycle time variability of the paint task. Therefore, even though we only have one booth to paint in (instead of multiple workstations on the line), the need for flexibility is much less. The company has effectively addressed the root cause of workload variability. As stated previously, if we are running behind in painting, we can still paint in the booth and install doors downstream on the line. Finally, it is easier to train staff in this area and cross-train staff from other areas.

Lean Principle #4- Build a Culture of Stopping to Fix Problems, to Get Quality Right the First Time

This principle refers to employee empowerment and their role in quality. The bases of this principle are to build in support systems to quickly solve problems. All employees are allowed to stop production to signal and fix a quality problem. The goal is to achieve and deliver perfect first time quality. Lean tools such as Poke Yoke and Jidoka are used to facilitate the implementation of this principle.

The old process was observed and the root causes of poor quality were identified. Based on these findings, the improved painting process was designed to ensure first time quality. The new process uses lean techniques such as Poka Yoke (e.g. swivel bottom plate). The paint booth was designed and located in an enclosed area to avoid traffic, preventing damage by other workers. The booth also allowed paint to be sprayed, providing a more uniform finish and minimizing variation from different batches of paint. It also eliminated the need to mask surroundings in the module, eliminating collateral damage. The swivel bottom plate allowed both sides to be painted without touching the wet doors. Taking the painting operation off the main production line also provided more time for possible rework, without delaying other activities.

Product choice impacted implementation of this lean principle as follows:

- *Quantity of doors* – The old process was highly susceptible to quality problems caused by increases in workload. As workers moved faster trying to complete production within the line cycle time, at some point they sacrificed painting quality. This resulted in rework, customer dissatisfaction and service calls. As the worker moved farther down the line from the ideal paint workstation, the chance for collateral damage to surrounding finished surfaces increased. If/when this work slipped into the yard, the risk of collateral damage increased even further. As described in Lean Principle #3 above, the improved painting process better accommodates this variation in quantity and complexity. The use of a paint sprayer actually addresses the root cause of greatly increased cycle time caused by increasing workload, greatly reducing paint cycle time.

- *Door size*- In the old system, the dimension of door size did not impact the quality culture or quality of the door finish. The improved system was redesigned using lean techniques to ensure first time quality. The clamping system used to position doors for a high quality painting process was designed to accommodate a range of door sizes.

- *Door profile*- The old system used both roller and brush to accommodate different door profiles. The finish quality depended on each worker’s skill and experience. No lean techniques such as Poka Yoke were able to be used to set limits on how the painting operation should be performed to obtain acceptable quality standards. In the improved process, spray painting can easily accommodate a range of door profiles and provides a uniform coat and better finish quality than the old system.

- *Door color*- In the old and improved processes, door color did not impact the quality culture and/or quality of the door finish.

Lean Principle #5- Standardized Tasks Are the Foundation for Continuous Improvement and Employee Empowerment

Task and process standardization are the foundation for continuous improvement and employee empowerment. This principle identifies the use of standards to capture and share individual and team innovation throughout the company. It also reinforces employee empowerment by allowing employee creativity to improve upon the standard. Employees should participate in the writing of standard procedures. This will empower employees to participate in the improvement and growth of the company.

The painting operation was redesigned during an RPI event by the plant manager and workers from the area. The paint booth in the improved system defined the environment for the task and dictated the standard painting process. Workers use the same standard painting process for different types of doors.

Product choice impacted implementation of this lean principle as follows:

- *Quantity of doors* - In the old and improved processes, quantity did not impact standardization of the task.

- *Door size*- In the old and improved processes, door size did not impact standardization of the task.

- *Door profile*- In the old process, the standard task of painting is affected by the door profile. Raised panel doors required two painting methods, roller and brush. The improved process can accommodate any door profile without affecting the standard procedure. The two manual painting methods also detracted from standardization, since both require "free hand" work, making finish quality more dependent on worker skill and experience.

- *Door color*- In the old process, door color did affect the standardized task by adding extra steps when changing paint color (e.g. roller/brush cleanup and get new paint). The dimension of door color could affect standard procedures in the new system by adding a step to change the paint hose to a different color or use a multicolor trigger sprayer. The paint changeover required for the improved process is significantly shorter compared to the old process.

Lean Principle #6- Use Visual Control So No Problems Are Hidden

This principle includes the use of 5Ss (Sort, Straighten, Shine, Standardize and Sustain) to make the work place more organized and productive. Visual controls help workers determine if they are within standard condition and should be integrated to the value added work to improve flow. In the old process, the painting operation was hidden in each module. Other workers and supervision could not readily assess the status of door painting. In the improved system, visual control was integrated into the area. Other workers and supervision can easily observe doors in the paint booth and quickly assess the status of the area: how many doors are ready to be painted, the quality of the painting operation, and the number of doors ready for assembly.

The choice of door quantity, size, profile and color does not impact implementation of visual control.

Lean Principle #7- Use Only Reliable, Thoroughly Tested Technology That Serves Your People and Processes

Before implementing automation, the process must be streamlined by reducing or eliminating non-value added activities. Automated systems are more costly and difficult to implement and change. Technology should be use to support people, process and values. The technology used must be flexible to accommodate process improvement as business changes as well as increasing customer choice. In some cases, implementing simple and inexpensive solutions is a better approach. For instance, the mechanized (not automated) spray paint system implemented in the improved painting operation provided greater productivity with better finish quality and better production performance as customer choice is increased. The positive impacts of the spray paint system on all dimensions of product choice are described in Lean Principles #1, 3, 4, and 5 above.

Company B

Plant Level: Company and Product Choice

Company B manufactures only HUD-code homes for a moderate market segment. Production rate varies with orders from five to six modules per day. This company offers their customers 47 different models in configurations of single, double or triple wides. Floor plans range from 737 to 2,458 square feet, 2 to 6 bedrooms and 1 to 3 bathrooms. This company achieves customization only by allowing customers to choose from a pre-determined set of options or features: six wallpaper styles, three Formica countertop colors, three shingle colors, three carpet colors, four exterior vinyl siding colors, two vinyl trim colors and six shutter colors. In addition, this company offers several special features such as three insulation packages for floor, walls and ceiling, two wall thicknesses (e.g. 2"x4" or 2"x6" exterior walls), three water heaters, and two bath tubs. Upgrade features include stainless steel appliances, extra ceiling fans, overhead ducts, plywood exterior sheathing, thermopane patio doors, crown & baseboard molding, crane board siding, ice block window over tub, plywood sub-flooring and a recessed frame for a permanent foundation. Most of the options offered are based on raw material/component substitution or addition.

All of the homes produced by this plant are ‘package homes’, homes that include a set of features at one low price - for which other manufacturers would charge a premium. The included features are: thermopane windows, oak cabinets, plush carpet, vaulted throughout, 48" shower, 21' dormer, vinyl lap siding, fireplace, dishwasher, CD player, chandelier, ceiling fans, porcelain lavatories, deep white sink with goose neck, microwave, fluorescent lights, and 2" blinds. Since all of the 47 different models built at this plant include these common features, the plant benefits from a closer buyer/seller relationship with fewer suppliers (e.g. exclusive vendors) and gains operational efficiency as workers develop proficiency installing common components. This company limits any layout customization by the homebuyer. Figure 29 exhibits a high level value stream map of the product realization cycle. Typically, prospective homebuyers visit a dealer to select a specific model and choose from a pre-determined set of options (e.g. countertop color). The sales department at the dealer sends the order to the plant including the model and the homebuyer’s selection of options. This order is then processed by the plant, which sends specifications to the manufacturing department where the home is built. The manufacturing department takes about 3 days to build the house. The production line is set up in a side-saddle configuration (width-wise module movement) with floors, walls, ceiling and cabinet (mill shop) feeding the main line from off-line sub-assembly stations. At the end of the line, an L-shape change in direction facilitates off-loading from the main line. Upon completion in the factory, modules are delivered and set on the homebuyer’s land.

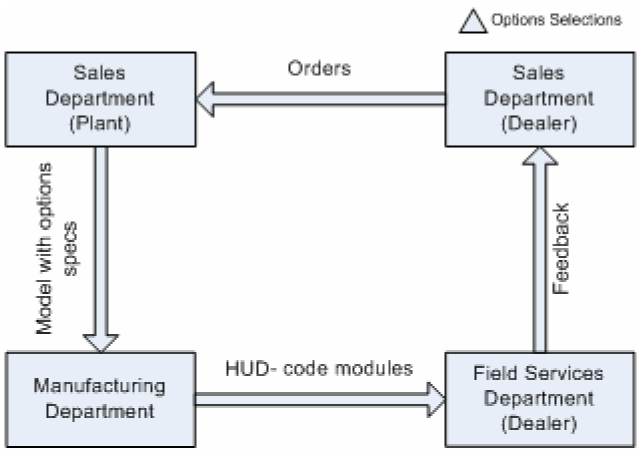

Figure 29- Product Realization Cycle and Customization

This company had sufficient customer orders to work at full capacity at the time of this study. The company is currently experiencing some operational inefficiency on offline stations including wall build and the mill shop. These inefficiencies affect flow on the main production line. The takt time of the main production line is 46 minutes, while the cycle times of the wall build area is 65 minutes and the cabinet area is 78 minutes, during peak production. The variability of cycle times in these offline stations creates bottlenecks on the main production line. If the bottleneck is in an equipment-constrained station (e.g., wall set that is linked to wall build by crane), the module cannot leave the station until the activity is complete (e.g., all walls are set). Upstream modules cannot cycle forward, and downstream work is delayed as holes are created in the main production line. If the bottleneck occurs in a station that is not equipment-constrained (e.g. cabinet installation), the main production line can continue to cycle forward and upstream work is not affected. However, downstream activities that are dependent on the delayed work are also delayed and moved away from their ideal stations close to staged material and supporting offline shops/stations. This introduces additional inefficiencies into the process that can also result in incomplete modules exiting the plant to the yard where work is finalized. Yard work is notoriously inefficient due to the logistical problems of accessing people, materials, and equipment and lack of supervision. These inefficiencies and delays lengthen the time to complete a house.

The company supports the use of lean principles to improve their current operations. The company has strong senior management involvement in the lean effort. The plant manager served as the initial lean advocate for the plant, but a production worker has now been assigned this full-time role. Support was also evident in the number of production workers involved in lean events and investments in lean changes.

Plant Level: Mass Customization Principles

This company allows customers to select from among the 47 standard models and customize from a pre-determined set of options (mostly raw material or component substitution). Customers are not involved in the actual design of the home. Once the order is generated, customers can not further customize their homes (Figure 31). There are few common core building elements (floors, walls and roofs) among the various models. Although these common building elements (and indeed all core elements for each model) could be pre-built-to-stock in large batches and inventoried, this is severely limited by plant size and the size and cost of these elements – and it certainly is not lean. Therefore, delaying customization (mass customization principle #1) is not practiced by this company.

This company provides a basic package of features in all of their home models. Therefore, product commonality (mass customization principle #2) takes place at some level. However, the commonality does not extend up the architecture to the core components (floors, walls, and roofs). Therefore, like company A, the product architecture and basic building system do not facilitate the use of the modularity/commonality principle, even when product choice is significantly reduced.

Although this plant does not offer a high level of customization, it accommodates the production of several models and pre-determined set of options by providing some flexibility in the production system, as defined by mass customization principle #3:

- Labor flexibility- since this plant only offers a set of pre-determined options and product customization is limited (e.g. layout customization is not allowed), the labor flexibility required is low. The pre-determined options have common architectures and are directly substitutable, requiring exactly the same procedures and skills (e.g., installing different colors of shingles).

- Layout flexibility- the current plant layout is not very flexible, but is flexible enough to handle the current product mix and volume. For the product choice activities that take place at the offline stations, the critical factor of layout flexibility is having the different materials staged, organized and positioned to encourage flow (e.g. flow oriented design). Offline stations that lack a flow oriented layout incur additional operational inefficiencies. For the product choice activities that take place on the main production line and are not equipment-constrained (e.g. shutters installation), flexibility is achieved by allowing workers to move upstream or downstream on the line. This flexibility may be at the cost of production efficiency, since installation occurs further from staged material and supporting offline shops/stations. On the other hand, equipment-constrained activities (e.g. wall set that is linked to wall build by crane) are not flexible. If product choice activities have to take place in a specific station that is equipment-constrained, then the module can not be started until the module arrives in the workstation and cannot be moved until the activity is completed. This prevents upstream work that may be bottlenecked by the workstation and downstream work that might be delayed.

  Inventory is a key tool in providing the level of choice offered by this plant. Inventory consists of common raw materials and components (e.g. wallboards) used for pre-determined options. Some of this inventory is staged at their corresponding offline stations or close to the station on the main production line where it's used. Most of the inventory is kept outside the plant in a covered area and is delivered to the plant based on consumption.

- Equipment flexibility- since product choice is achieved by a set of pre-determined and substitutable options, workers use the same tools to accommodate variation. The orientation of the crane limits some activities such as roof and wall setting.

Department Level: Mass Customization and Lean Principles Used

The company conducted an RPI event in the interior wall build area. Details of these efforts, focusing on the lean principles used, production flexibility resulting from lean principles implemented and effects of product choice on lean principles, are described in the following section.

Interior Wall Build Area

The interior wall build area is where the partition (interior) and end walls are assembled. The assembly takes place on 4 framing tables (3 for partition walls and one for end walls) and entails building the frame and installing the wallboard on one side of the frame (Figure 30). All materials used in wall assembly (e.g., top and bottom plates, studs, rough opening framing components and wallboard) were pre-cut to size in supporting workstations in the area. The old layout, including equipment location, material staging, and material flows, is shown in Figure 31.

Workers in the wall build area received the production order specifying the panels required for the next module on the line. Working one panel at a time, workers retrieved lumber from bundles of 2x4s staged on the stud roller bed conveyor. They carried the lumber to one of 3 chop saws located along the upper wall, where they measured, marked, cut each component to size, and labeled each component by hand. Cut studs were kitted by panel and placed on a staging cart located near the two central framing tables. The 3 partition framing tables used this staging cart. The end wall framing table used a 2x6 stud. These studs were staged close to the upper entrance and were cut to size on the framing table. Other workers in the area retrieved wallboard from bundles staged on the S/R (sheetrock) roller conveyor or on the floor nearby.

They carried the wallboard to one of two saws or to a slitter. The jig table of the saw/slitter was set at the specified size and wallboard was cut to size, labeled by hand, and placed in an adjacent staging cart.

Workers on the framing tables selected a panel to build, obtained the drawing and retrieved framing components from the staging cart. They then positioned the components as specified by the drawing and attached them using a nail gun. Templates were used on the framing tables to guide framing of door openings. They then retrieved the pre-cut wallboard from the staging cart, positioned it on the frame and attached it to the frame using an adhesive gun and staples. The completed panels were then staged upright adjacent to the tables awaiting transport to the line. Panels were moved to the line by two methods, depending on location of the framing table. Panels staged next to the lower tables were transported by bridge crane, while panels staged next to the central tables were dragged along the floor by hand.

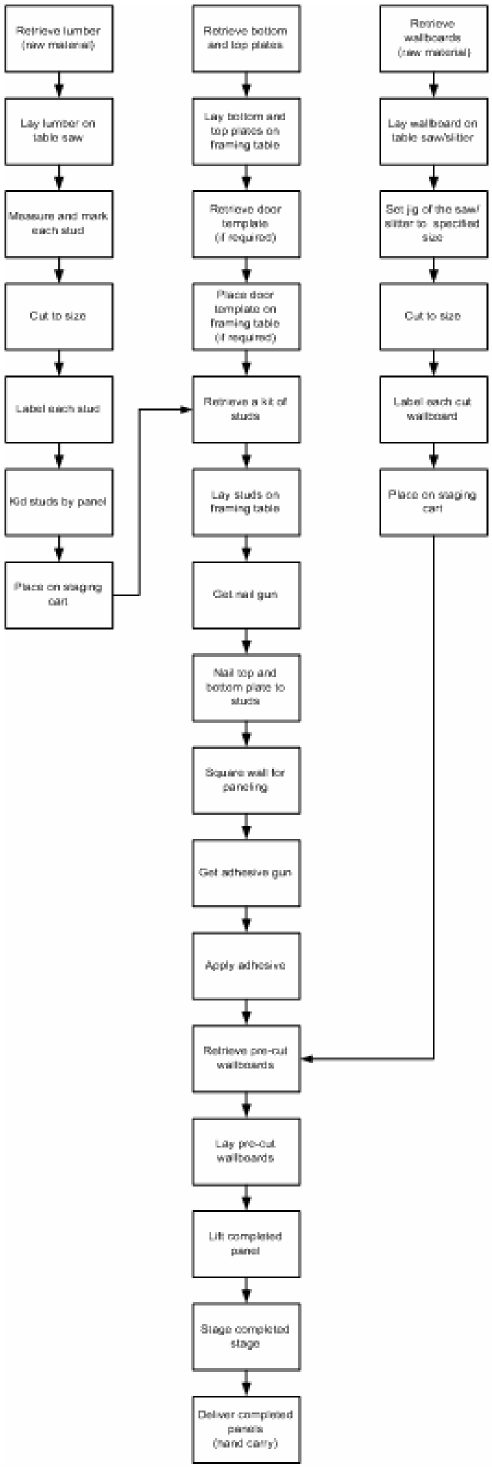

Figure 30- Process Flow Chart of Old Process

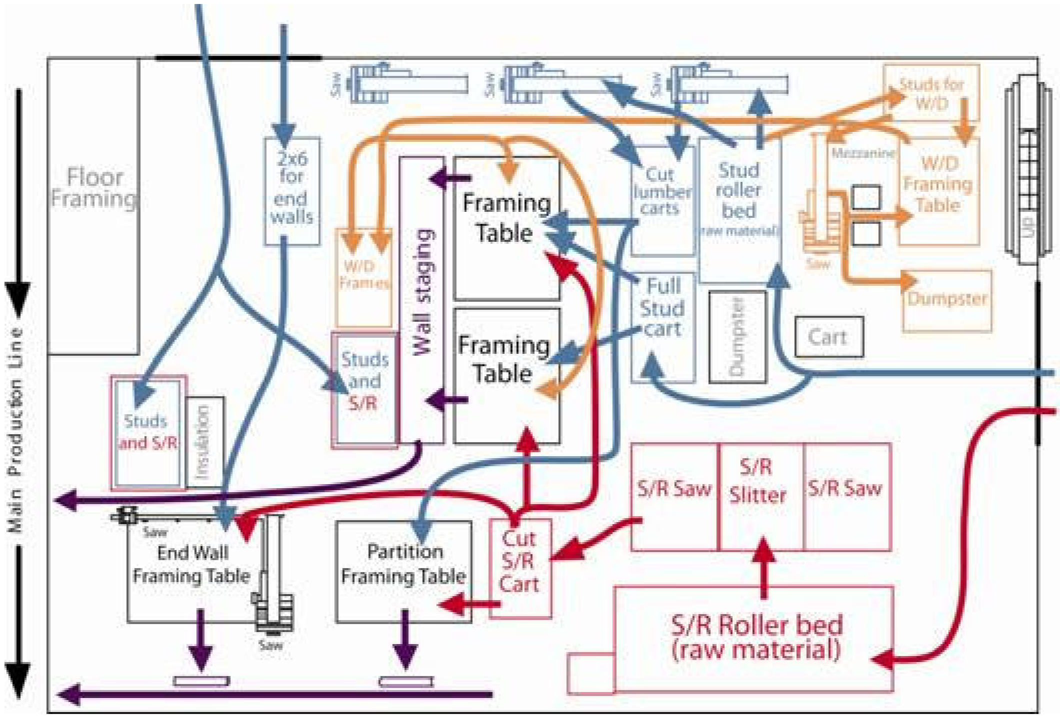

Figure 31- Material Flow at Interior Wall Build Area before RPI

The over-riding issue in the wall build area was that it was not able to consistently keep up with the main production line, creating a bottleneck to line flow and restricting capacity. The TAKT time on the main line was 48 minutes, while the cycle time of the wall build area was 65 minutes during peak production periods. The company believed that the longer cycle time in wall build was the result of inefficiencies in the area. Various forms of waste were evident in the process. As evidenced by the spaghetti diagram shown in Figure 7, flows went in every direction, many were lengthy, and they often crossed other flows, creating congestion. Layout was a key issue. One chop saw was located near the raw material staging area (stud roller bed) and the cut lumber staging cart, while the other two saws required longer moves. The cut lumber staging cart served one framing table well, but not the other two tables. Although there was a designated area to stage raw wallboard (e.g., S/R roller bed), it was not fully used because of limited accessibility. Instead, material handlers often staged bundles of wallboard on the floor in any open space. This further congested the area. The staging area for the pre-cut wallboard (cut S/R cart) was close to two framing tables, but further from the other two and framers had to travel longer distances to retrieve materials.

The L-shaped orientation of the framing tables limited use of the crane to only those tables on the lower side and forced framers on the central tables to drag finished walls through the middle of the wall build area to the main line. This caused further congestion in the area. Since the framing tables were viewed as the immediate bottleneck, framer movement of materials to the tables and finished panels to the line were considered critically important. Framers also had to find and sort the components in their kits as they positioned them on the tables.

Basic supporting activities were not efficient. For example, process instructions for the sawyers were not straight forward and no jigs were provided to aid in cutting. Sawyers were not always able to keep up with the framing tables, causing critical downtime on the already bottlenecked tables. Another issue that was discovered was an imbalance in panel assignments to the framing tables. This became painfully apparent when one table completed its assigned panels for one module and started building panels for the next module while the other tables struggled to complete panels for the previous module. This situation suggested poor information flow between the supervisor and the workers and an overall lack of coordination. Workers relied heavily on the area supervisor because the process was not standardized.

An RPI event was conducted to improve the activities and flows in the interior wall build area. Participants included the plant manager, selected workers from the area and related areas, and maintenance. The focus of the effort was to rearrange the layout to improve process flow. The improved layout (Figure 32) also promotes visual management because it is clutter free and well organized. Some of the changes accomplished in the RPI, included:

- The two central framing tables were moved and aligned with the lower two tables. This allowed finished walls to be staged so that they were accessible by the bridge crane, which could be used to deliver all finished walls to the main production line. The use of the crane relieves physical strain on framers, reduces transport time and relieves congestion in the area.
- Half of the existing mezzanine, used for insulation storage, was moved to open up floor space for the improved layout.
- Wallboard cutting was rearranged to smooth flow. Raw material was staged in a new rack that held six different colors of wallboard, two different sizes per color. The new rack is easy to replenish from the front and puts less strain on cutters as they pull material and transport it to the cutting tables (e.g. pulling over their heads). The saws/slitter was relocated away from the traffic path, facilitating wallboard handling. A dumpster was placed right immediately behind the saws/slitter for scrap. Next to the saws/slitter a staging area for the cut wallboards was designated. The new layout encourages continuous flow by allowing workers to pull raw material from the racks, then turn to the saw/slitter, cut the wallboard to size, place the pre-cut wallboard in the staging cart and throw the scrap in the dumpster. The new layout keeps the workers in the area.
- The stud cutting activity was rearranged, including new raw material storage racks, two saws, and new pre-cut component staging bins. The improved layout aligned these elements to achieve a straight-line flow. The lumber storage rack was relocated on the upper wall to provide in-line flow for the material handler during delivery. Two chop saws were turned 90 degrees and relocated directly below the storage racks. New pre-cut component staging bins were located directly adjacent to the framing tables (each bin can hold studs for up to ten panels). Sawyers place cut components directly in the bins, eliminating the need for framers to leave their tables to obtain components. A new procedure and labeling system was developed to organize pre-cut materials in the bins. The procedure directs the framers activities, eliminates the framers task of finding and sorting components and allows everyone in the area to visually monitor production performance at each table.
- Process documentation was improved for cutting wood components and jigs were provided to simplify cutting and improve quality.
- Area supervision was trained to monitor the status of each table and the main production line and manage activities in the area to minimize disruptions to main line flow.

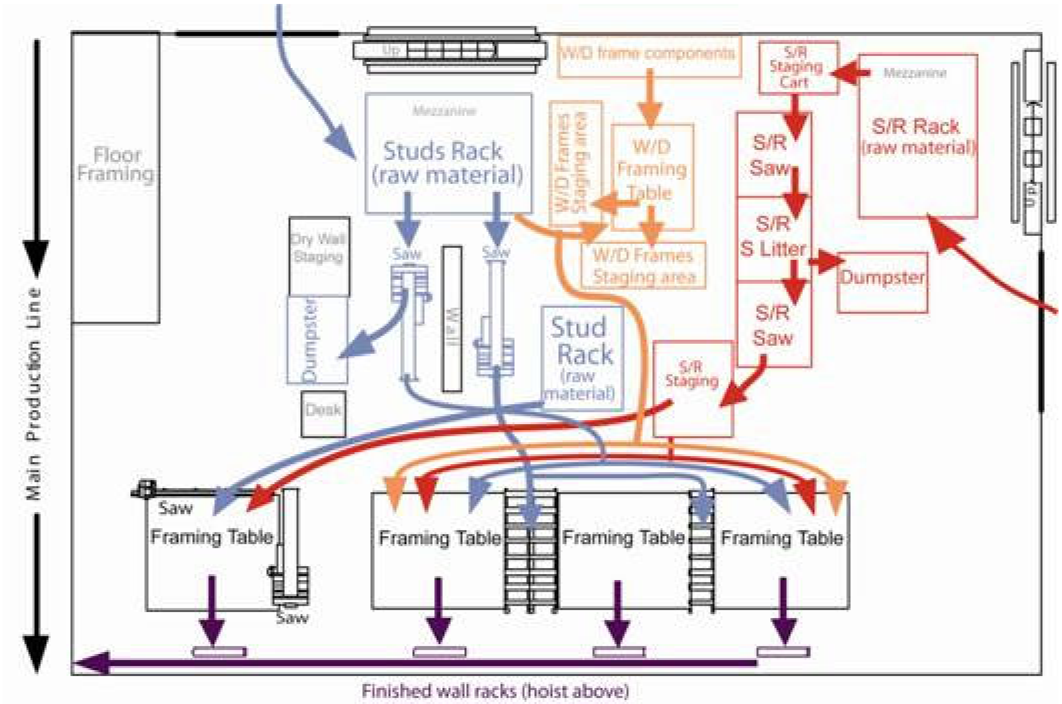

Figure 32-Material Flow at Interior Wall Build Area after RPI

This plant spent $25,786 to improve the wall build area. Productivity was improved and the wall build area is now synchronized with the main production line. The number of framers require at the wall build table was reduced from nine to seven. The two framers were reassigned to other departments. Space was reduced by 12% and overall quality was improved (e.g. wallboard damage was reduced by 10%). This RPI resulted in a total labor savings of $73,200 per year.

Impact of Product Choice on Lean Principles

There are several dimensions of product choice related to interior walls: quantity, size, wallpaper color, and number of openings. The number of walls ranges from 14 to 27 per house, with a house consisting of 2 modules. There are a variety of interior wall sizes (heights and widths) depending on the house model. The wall height varies with respect to the location within the house. Interior walls that are parallel to the end walls are sloped at the top to match the roof slope (e.g., wall studs are progressively shorter in length). The company offers six different wallpaper colors for interior walls. Usually the homebuyer selects the wallpaper color and the house model. The quantity, size and the number of openings are dictated by the house model. The following section describes how each lean principle was represented in this RPI and how each dimension of choice was accommodated for each principle:

Lean Principle #1- Create Continuous Process Flow to Bring Problems to the Surface

The improved layout was designed to smooth process flow. It was achieved by: 1) removing clutter and defining traffic paths; 2) moving equipment and materials closer together and away from the traffic paths; and 3) locating the four framing tables adjacent to the main production line. Identifying the traffic paths helped to define the overall flow in the area. The wallboard equipment is organized to follow the flow of material as it is cut to size and staged for the framing activity. It is organized in an L shape, which encourages efficient movement of people and materials. A new rack was built to stage the different colors and sizes of wallboard and has easy access for replenishment. The improved system forces the material handler to stack bundles of wallboard in the rack, since there is no unused space - all space is assigned to other activities or designated as traffic paths. Excessive walking to get materials and time sorting for studs was eliminated by consolidating the stud operation. The lumber storage rack and the two saws are aligned across the framing tables to encourage a straight flow. The new location of the lumber storage rack provides an in-line flow for material replenishment. A jig is used to simultaneously cut all of the different sizes of studs for a specific wall, creating a one-piece flow and eliminating the need to individually measure and mark each stud length. This jig reinforces standard procedures and helps to stabilize flow by reducing variation in cycle times. The process of staging pre-cut studs for the wall frame was improved with the use of the labeled racks. A controlled inventory of pre-cut studs corresponding to about five panels is kept in each bin to smooth the flow. The labeling system directs framers to produce all of the walls required for a module before moving to walls for the next module. The new arrangement of framing tables allows a better flow of material from supporting activities and the use of the crane to transport finished walls. Waste that disrupts continuous flow (e.g., walking long distances and searching for components, poor communication, etc) is eliminated. The improved layout links supporting activities, making greater use of the floor space. This eliminates the need to build more capacity which is particular important to this small plant. The improved layout allows the on time delivery of the right walls to the main production line. In turn the interior wall assembly is synchronized with the main production line.

The product choice dimensions impacted the implementation of this lean principle as follow:

- *Wall Quantity* – the old process made the main production line increasingly susceptible to bottlenecking and disruption with an increase in workload. The unnecessary load on the framing tables and the framers caused by congestion, long travel times, manual transport, poor process instructions, no jigging, and lengthy parts sorting was increased with an increase in panel quantities. Creating continuous flow reduced the impact of increased workload. Supporting activities were more flexible, because of their shorter cycle times (compared to wall build) and a buffer of WIP pre-cut material (e.g., five panels per framing table) helped mitigate quantity variation. Similarly, an inventory of completed panels is kept after framing and is affected by the quantity variation. This inventory is replenished based on the line needs. The number of panels staged varies depending on wall quantity and must be managed carefully to prevent double handling of completed panels (e.g., stacking sequence should follow the delivery sequence). Further, the number of completed panels is limited by the size of the staging area. The new labeling system on the pre-cut stud bins allowed supervision to better coordinate all framing tables, also improving the ability to handle variability in quantity. This is discussed below under Lean Principle #3 and 7.

- *Wall Size*- The old framing tables were flexible enough to handle wall size variation. However, the flow of finished walls from the two central framing tables was inefficient and worsened with larger walls because of the serpentine travel path. Panel movement also blocked much of the other traffic in the area. The stud component cutting activity was very sensitive to size variation, especially sloped walls, since all studs were individually measured, marked and cut to size. The wallboard activity was also affected by wall size, since cutters often had to search for the correct size wallboard. The new system is more forgiving with wall size. Transportation of different size panels is easily accommodated by the crane. Jigs on the chop saws allow studs for any size wall to be easily cut without individual marking. Three jigs were made to accommodate the most popular home models. The S/R rack for raw wallboard provides easy access to the two different sizes of wallboard. This is discussed below under Lean Principle #7.

- *Wallpaper Color*- Wallpaper color affected process flow in the old system. Due to the lack of accessibility of the roller bed, material handlers often staged bundles of wallboard on the floor blocking traffic path. Since each color needed to be accessible, each different color meant another bundle staged on the floor and greater confusion and congestion in the area. In the improved process, the use of a rack with an assigned location for each wallboard color facilitates the process flow and standardizes the process. Although the rack was replenished with raw material based on usage (e.g., customer orders), the amount replenished was not. Material handlers delivered a bundle of the color of wallpaper consumed. From a lean perspective, this inventory may be seen as waste, but it is necessary to maintain a continuous flow and reduce the handling of the raw wallboards. Further, this inventory helped ensure adequate levels of product choice (e.g., all of the pre-determined colors of wallpaper).

- *Openings*- The old process used templates to facilitate the framing of common openings on the framing tables. These same templates are used in the new process. This is discussed below under Lean Principle #7.

Lean Principle #2- Use Pull Systems to Avoid Overproduction

The old process pulled raw material from the warehouse based on usage. A small controlled inventory of pre-cut studs and wallboards was kept to smooth flow between the pre-cutting and the framing tables. This inventory was replenished (pushed) based on customer orders. Framing tables pulled from this inventory. An inventory of completed panels was staged after framing. This inventory was replenished (pushed) based on customer orders. When the module reached the appropriate workstation on the line, the walls were carried into the module and set. Lack of coordination in the area sometimes resulted in a shortage of panels for a module in the wall set station on the main line, at the same time that one or more framing tables were framing panels for a future module. Fortunately, push replenishment in the old process could not result in too much overproduction, since inventory was limited by staging area size. The new process more effectively pulls wood framing components into the component staging racks. The new control procedure on the component bins also coordinates panel production on the framing tables with main line needs. This is discussed below under Lean Principle #7.

The choice of wall quantity, size, and openings does not impact implementation of the pull principle, since walls are produced to order (one set of walls per module and one set of component per wall) and not by unique wall configuration. Wallpaper colors did impact implementation, since it required a separate staging location for a bundle of each color.

Lean Principle #3- Level Out the Workload

In the old system, workload varied greatly with the number and size of panels required for a given home. To balance this workload among the framing tables, the assignment of wall panels to framing tables was done in advance, based on the supervisor's experience, knowledge of framer capabilities and knowledge of the production schedule. In practice, this process resulted in a workload imbalance, overworked framers and delays on the main production line as they waited on wall panels. The improvements to enhance continuous flow (addressed above in Lean Principle #1) greatly reduced the impact of potential imbalances. The most effective element of the new process in reducing imbalances was the use of the component staging bins adjacent to the framing tables. The sawyers cut components for each panel and loaded them into available rack openings. Components are cut in the same sequence as panels are needed on the line. The system effectively pulls wood framing components into the component staging racks and synchronizes wall panel framing with main line needs.

Lean Principle #4- Build a Culture of Stopping to Fix Problems, to Get Quality Right the First Time

The old process was observed and the root causes of poor quality were identified. Some of the causes of poor quality included: the lack of appropriate material storage, dragging completed panels through the congested area, and lack of standardized procedures. Wallboards were staged on the floor exposed to traffic and potential damage. Finished walls were exposed to potential damage when hand carried to the main line through a cluttered and undefined traffic path. In the improved process, the wallboard defect rate was reduced by enforcing the use of racks to stage the boards and the use of the crane to convey finished walls. The improved system was designed to ensure first time quality by using lean techniques such as Poka Yoke (e.g. jigs). The implementation of jigs for the stud cutting operation supports process standardization and maintains acceptable quality standards, improving the overall quality of the walls. Standardized work is a countermeasure to quality problems.

The product choice dimensions impacted the implementation of this lean principle as follow:

- *Quantity of Walls* – In the old and improved processes, the number of walls did not impact the quality culture and/or quality of walls.
- *Wall Size* - In the old process, stud cutting was prone to quality problems caused by size variation. Sloped walls were a critical problem, requiring much manual measuring and marking. The process of cutting studs progressively larger for sloped walls was not standardized. This is discussed under Lean Principle #1 and 5. In the improved process,

the use of jigs to cut studs supports work standards, encourages product consistency and maintains proper quality standards.

- *Wallpaper Color* - In the old and improved processes, wallpaper color did not impact the quality culture and/or quality of walls.

- *Openings* - In the old and improved process the dimension of door size did not impact the quality culture or quality of the door finish. Variation is handled up to quality standards with the use of templates as described in Lean Principle #7

Lean Principle #5- Standardized Tasks Are the Foundation for Continuous Improvement and Employee Empowerment

The new flow layout gave structure to the area, enforcing the location of activities, staging areas and traffic paths. Jigs on the component cutting area allowed a simplified and more uniform standard process for the wide range of wall configurations. The component bin at the framing tables and the standardized procedures for its use resulted in a standardized process, regardless of the quantity or size of walls. The processes are described in the above Lean Principle #1.

Lean Principle #6- Use Visual Control So No Problems Are Hidden

Visual control was integrated into the wall build area. By removing the clutter in the area and creating designated areas for material and WIP, the plant manager or area supervisor can quickly assess the status of the area: how many walls are ready to be set, pre-cut sheetrock, pre-cut studs, etc. As described in Lean Principle #1, the improved process uses a new shelf to organize the different colors of wallboards and a labeled rack for pre-cut studs, facilitating visual management.

The choice of wall quantity, size and number of openings does not impact implementation of visual control. Wallpaper color did impact implementation, since it required defining a location for a bundle of each color. Further, it required space and equipment to stage each of color and size of wallboard offered.

Lean Principle #7- Use Only Reliable, Thoroughly Tested Technology That Serves Your People and Processes

The old system is a good example that a process must be streamlined before implementing automation. The old layout did not allow framers to deliver finished walls using the crane due to the location of the two central framing tables. The implementation of jigs for cutting studs to size facilitates the operation and improves quality. The use of templates for the door opening in the framing operation speed production. Using the crane to deliver the wall to the main production line relieves strain on workers and speeds production. All of these tools implemented improve quality and productivity of the wall build area while accommodating a variety of customer choices. The positive impact on all dimensions of product choice of the jigs/templates is described above in Lean Principles #1, and 4.

Common Trend Analysis

In the previous section the two case studies described how each company accommodated different levels of product choice and how it impacted each lean principle. The common trend analysis seeks to identify common and conflicting findings from these case studies. A set of negative propositions based on the lean principles are used to structure this analysis. The lean tools and techniques that allowed case study plants to offer product choice efficiently were identified. Then, based on the lean implementation outcome of each case study, the propositions were either supported or refused. This analysis results in guidelines which will enable homebuilders to better meet homebuyer needs without sacrificing production efficiencies.

Sample Characteristics and Impacts

At the plant level, company A allows more customization than company B. Yet, the wall build area in company B is more affected by choice than the paint booth in company A. The wall build activity is more complex than the door painting activity. Walls are built from many components, requiring supporting activities for component prepping. This makes the wall build activity more susceptible to the effects of product choice than the paint booth. While there are several dimensions of product choice related to interior doors (e.g., quantity, size, profile and color) and interior walls (e.g., quantity, size, wallpaper color, and number of openings), each dimension affects the lean implementation differently, since some choices are process disruptive and some are not.

Proposition Evaluation

P1: Product Choice Makes Continuous Process Flow More Difficult

Typically, product choice causes work content and labor hours to vary. Labor hours vary with procedural changes associated with different choices (e.g. materials/components, varying dimensions and/or complexity of each configuration). This variation in cycle time makes it difficult to establish continuous flow as it limits the possibility of smooth hand-offs at the different stages of the production process. Together with an increase in complexity, cycle time variation also increases the likelihood of quality problems, as workers hurry up, then wait. Product choice is also likely to require different production equipment and tools. This can make layouts more complex, resulting in inefficient space utilization and flow. Product choice may also increase staging requirements for raw materials and sub-assemblies, having similar negative impacts on space and flows.

While the level of product choice offered in the two case study areas (walls and doors) is different, they both benefited from the development of more continuous process flow. Nonetheless, the range of product choice and the complexity of activities required to achieve this choice did impact the lean implementations. Creating continuous flow in door painting was less challenging than in wall build, since product choice was more limited (e.g., there is a finite configuration of doors dimensions, whereas there is an unlimited number of wall dimensions) and since there were no supporting activities (compared to wall framing with two supporting activities). Furthermore, each of these wall build supporting activities also required flexibility to handle choice and had to be well coordinated, making it even more challenging.

Several important continuous flow concepts were critical in both cases: off-line parallel production, process optimization, and layout optimization. Each is discussed in the following analysis. From a lean perspective, the movement of activities off the main line, while still providing continuous, but parallel flow, reduced main line, critical path cycle time. From a mass customization standpoint, it effectively disconnected the main line from any cycle time variability resulting from product choice. These advantages were obtained at the cost of dedicating floor space for the off-line activities.

Process optimization not only improved productivity and quality, but also smoothed variability associated with product choice. The new lean paint booth provided fast, high quality painting in an environmentally controlled environment. The quick clamping system in the paint booth minimized set-up/tear-down time. From a mass customization standpoint, the spray paint process and the innovative clamp system virtually eliminated cycle time variability associated with product choice. In the wall build area, the use of jigs for cutting wall-specific kits of studs and the use of templates for assembling door openings greatly improved productivity, increased quality, and helped to accommodate product choice without increasing any effort and without affecting the flow. From a mass customization standpoint, these jigs and templates virtually eliminated cycle time variability associated with product choice. A challenge for the lean improvement team was building cost-efficient wall jigs for the large number of unique wall configurations. As a first step, the lean team agreed to build jigs for the most frequently used walls.

Layout optimization facilitated continuous flow by reducing travel times, congestion and delays and reducing variability associated with product choice. The paint booth consolidated door painting, allowing painters to move between doors with little effort and no disruption. The paint booth also served as a staging area to support continuous flow of painted doors to the main line and limiting WIP inventory of painted doors. From a mass customization standpoint, the booth reduced the variability in cycle time associated with traveling to more/fewer doors in the house. The new layout in the wall build area moved equipment and materials closer together, shortening process flow. A critical part of this rearrangement was moving the two central framing tables under the crane, minimizing congestion. Providing controlled staging for pre-cut components and finished walls also facilitated continuous flow and limited the production of WIP inventory. From a mass customization standpoint, moving wall build activities closer together also reduced the variability associated with handling different quantities and configurations of walls. Moving the two central framing tables under the crane made it very easy to move larger numbers of larger panels to the line without disrupting other activities in the department. A challenge for the lean team was providing easily accessible staging locations for each color wallboard. Although it was difficult, it was accomplished by using multi-level racking.

In general, these results suggest that good concepts for lean, efficient continuous flow were also good concepts for (or easily accommodated) handling a range of product choice. Results showed that the creation of continuous process flow is feasible for different levels of product choice, but that the success may depend on redesigning the process and layout to eliminate all forms of waste and reduce the impact of product choice on cycle times and quality (e.g., reducing the variability caused by product choice). Thus, Proposition 1 is rejected.

P2: Product Choice Makes Pull Systems More Difficult

A pull system is a lean concept of production control that assures that production matches customer requirements – no more and no less. The ideal form of pull is a continuous flow production line that produces the same product at the exact rate (TAKT time) as demand. Pull systems based on kanban-controlled replenishments seek to provide a high level of control when the ideal cannot be met, due to complexity of production mix and/or production process. As the number of unique raw materials and sub-assemblies increase, the number of kanbans can increase, making the system more complex and less efficient. Thus, increasing product choice can make lean systems less attractive. However, pull system concepts can greatly simplify and add tractability to production processes with high product choice.

Both lean implementation efforts used a build-to-order production control concept that incorporated component kitting by order. For wall build, individual walls are sequenced for production based on main line requirements. Walls are pulled to the line from the wall staging areas in the assembly sequence needed by the current module in the wall set workstation. Individual walls are built on framing tables when space opens up in the limited staging area adjacent to each table. Wall framers pull the next kit of components (representing the next wall needed on the line) from the component bin located next to each table. Space in each bin is limited to control production. Component cutters cut wood and wallboard components for the next wall needed on the line when space opens up in the respective component bins. They pull raw materials from stud and wallboard staging racks that provide one opening for each raw material. When material is near empty, material handlers replenish material from outside storage.

This pull process assures that the right material will be available for each step of the process when it is needed, without oversupply.

Using this process, each raw material has a unique staging location. As product choice increases (e.g., wallboard colors) this scheme becomes more complex and less efficient. Note, however, that the lean team accommodated these choices by using multi-level racking. Note that stud components for all wall configurations were cut from the same stud material and, thus, did not add complexity. For pre-cut components and sub-assemblies, workers pull built-to-order kits, instead of unique part numbers. Pulling built-to-order kits provides a pull system without having to inventory and control every unique component and sub-assembly used in the process.

The door painting activity also followed a pull approach. Doors are pulled from the paint booth when the module is ready on the main line. Doors for a house are pulled as a kit from the door staging area when space is available in the booth. Doors are kitted and pulled from the warehouse to the staging area when empty space in the staging area signals that more doors are needed. This built-to-order kitting scheme assures that the right material will be available for each step of the process when it is needed, without oversupply and eliminates the impact of product choice on the pull process.

In both cases, continuous flow pull systems were developed to assure that the right material was available when needed, without oversupply. Built-to-order kits were used to make the pull process tractable, given the many product configurations and component sizes. Staging and controlling unique raw materials was the greatest challenge, but successful solutions were developed by the lean implementation team. Thus, Proposition 2 was rejected.

P3: Product Choice Makes Leveling Out the Workload More Difficult

The goal of leveling out workload is to mitigate the effects of variation caused by product choice. However, leveling the workload is likely to be more difficult as the dimensions of product choice increase, since we are increasing the number of objectives in a multi-objective optimization problem.

In neither case study plant did management schedule the main line to accommodate interior wall or door variation. However, workload balancing was greatly improved as a result of process changes in each area. Only one painter was required in the door spray paint booth - there was no need to balance workload. In the wall build area, jigs eliminated much of the variability associated with choice in the wood component cutting process and templates took some of this variability off the framing tables. Framing table loading was leveled with the use of component staging bins. These bins were replenished with components by the sawyers, who filled bins as they became empty with parts for the next wall needed on the main line.

Workload leveling for the two choice factors (doors and interior walls) was not accomplished on the main line, where it would be most effective. Other more important factors (e.g., area, roof complexity) were used instead. However, workload leveling was improved in each of these two areas by local process improvements in the areas. These improvements helped to mitigate variation and facilitate the processing of product choice. Thus, Proposition 3 is rejected.

P4: Product Choice Makes the Development of a Quality Culture More Difficult

Product choice introduces variation which can result in reduced quality and more rework. This proposition is supported by the survey findings discussed in Chapter 4. However, building quality into the process helps prevent quality issues from occurring. Further, defects are quickly identified, contained in the area, the root cause is identified and corrective action is taken. As a result, only products satisfying the quality standards will be passed on to the next process on the production line and eventually to the customer. This is particularly important when building new configurations or offering choice, because of the deterioration of production efficiency due to rework. Further, there is no buffer inventory to fall back on in case of rework.

Both case study areas optimized processes to not only increase productivity, but to greatly enhance product quality over the range of product choice offered in the area. In the wall build area, jigs and templates were designed to improve productivity, better handle product choice variation, and at the same time serve as a method to build quality into the procedures. The use of jigs to cut studs supports the implementation of work standards, which encourage product consistency and maintain proper quality standards. The number of jigs required is dictated by the level of product choice offered (e.g. home models offered). Similarly, door templates provided a more standard method for building various rough openings on the framing tables. Product choice (the number of unique opening sizes) dictates the number of templates required. The jigs and templates encourage defect-free processes (Jidoka).

The new door spray paint booth was designed to ensure quality by providing a simpler, more uniform painting process, avoiding contamination/damage and minimizing variation from different batches of paint. This is another excellent example of Jidoka, built in quality in the process. Since the painting activity was removed from the main line, this made the activity more flexible and allowed more time for possible rework without affecting other activities.

In summary, process optimization mitigated much of the potential quality problems associated with product choice. Thus, Proposition 4 is rejected.

P5: Product Choice Makes the Development of Standardized Tasks More Difficult

Product choice introduces variation that can make the development of standardized tasks more difficult. However, standardized tasks can be used to mitigate the negative effects of increased product variety and variability.

Both case study areas adopted optimized processes that standardized production methods over the range of product choice offered in the area. The door spray paint booth used an innovative clamping system to position all door configurations for painting. The spray paint process in an enclosed booth eliminated almost all of the process variation associated with painting with a roller and brush in the house.

The use of jigs for pre-cutting wall components simplified and standardized the process for a wide range of wall configurations. The component bin at the framing tables and the procedures for its use resulted in a standardized process, regardless of the number and configuration of walls. In addition, this procedure also standardized the sequence of the walls to be built.

While increased product choice is likely to increase standard process documentation, this can be mitigated by proper process selection – developing and selecting processes that use standard tools and methods to produce the range of choice offered. Thus, Proposition 5 is rejected.

P6: Product Choice Makes Visual Control More Difficult

In general, product choice makes the use of visual control less effective, because choice affects the space and equipment needed for staging unique components. Further, it is harder to maintain and sustain the increased number of SKUs. However, implementing visual controls helps to make the work place more organized and productive. Visual controls also help communication by letting worker know at a glance how work should be done, where items belong and status of work. This level of organization facilitates product choice.

In both case studies, several factors mitigated most of the potential visual control problems associated with product choice: build-to-order kitting and layout optimization. Build-to-order kitting was effective in both areas in reducing the number of WIP components that needed to be staged and tracked. In the door spray paint booth, door kits were staged and tracked in the staging area and in the paint booth (both during and after painting), instead of each unique door configuration before, during and after painting. The same was true in the wall build area – kits of walls (lot size one) and wall components were staged and tracked, instead of unique wall components.

Layout optimization in both case study areas was highly successful in facilitating visual control. With the centralization of painting in the paint booth, workers could easily see and evaluate the status of activity, instead of having to go inside of each module to see all of the doors. The relayout of the wall build area organized materials and equipment around simple straight line flows. It also eliminated random clutter and congestion. The primary challenge for the lean team was staging for wallboards, which eventually required more space and equipment to stage varieties of colors and sizes.

Product choice did challenge the lean team in organizing the area and implementing visual control, primarily in staging unique raw materials. However, using lean concepts such as build-to-order kitting and layout optimization mitigated most of the potential visual control problems associated with product choice. Thus, Proposition 6 is rejected.

P7: Product Choice Makes the Use of Technology (That Serves People and Process) More Difficult

Product choice typically makes process technology (mechanization and automation) more expensive and less productive. However, the proper use of technology can serve people and processes, freeing workers from repetitive, strenuous and dangerous tasks, adding capacity and enhancing process quality.

Both case study areas used only simple process technologies. However, these technologies yielded substantial benefits: increasing productivity, improving quality, reducing variability associated with choice, and reducing strenuous tasks. These innovations, including the spray paint system, component cutting jigs and overhead crane, were discussed earlier in the section.

Clearly, the need to accommodate product choice limited the use of process technology. However, the use of the simple technologies adopted profoundly affected the productivity and quality in each area and better enabled the area to accommodate product choice offered. Thus, Proposition 7 is rejected.

In general, the case studies showed that product choice does not necessarily make the implementation of lean concepts more difficult. Some lean concepts, like workload balancing and standardizing tasks, clearly facilitated the handling of product choice. Other lean concepts, like creating a continuous process flow, can be made to work well, even with increased choice.

Industry Guidelines

Findings from the case study are summarized in the following set of guidelines for implementing the seven lean principles while maximizing product choice.

1. Move activities affected by customization off the main production line. Develop off-line parallel processes that are synchronized to main line flow, delivering sub-assemblies on a just-in-time basis. A similar approach is to designate an off-line 'customization' station for custom work. This strategy works from a lean perspective because it reduces the main line, critical path cycle time and from a mass customization perspective because it effectively disconnects the main line from any cycle time variability due to product choice. This strategy can be used in other activities such as building porches and dormers or preparing wiring harnesses.
2. Optimize and standardize activities that are affected by product choice. Develop common methods, equipment and tools that simultaneously are highly efficient, assure quality, and minimize process cycle time variation due to product choice. This strategy can be used in the trim department, by pre-cutting and pulling trim kits for windows and doors.
3. Move equipment and materials closer together. Utilize straight line, L or U-shaped flows. From a lean perspective, this reduces travel waste such as excessive travel time, congestion delay, and related damage. From a mass customization perspective, it reduces the variability of cycle time associated with the number of trips or movements to get material for different product configurations. This strategy can be used in all the departments across the plant.
4. Use continuous flow systems whenever reasonable. When production flow needs to be disconnected due to process variability, use limited queues with kanbans to drive production. When product choice or product architecture results in many components, consider pulling materials in built-to-order kits, instead of unique part numbers. This strategy can control inventories and insure sub-assembly availability, even as product choice increases. This strategy can be used in the floor department, by cutting and pulling floor joists as a kit. This strategy can be used in the trim department, by pre-cutting and pulling trim kits for windows and doors.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The main objective of this study was to develop guidelines to improve the effectiveness and efficiency of homebuilding through mass customization. This study focused on the homebuilding production system and lean as an approach to achieve mass customization. The study characterized the product choice that is currently being offered by U.S. homebuilders and the impact of customization on plant production efficiency. A case study of two plants implementing lean production principles provides more detailed insight into the relationships between mass customization and lean production principles. The chapter summarizes the results of this study and proposes conclusions and recommendations for future study.

The results of the industry survey revealed that both HUD-code and modular homebuilding plants offer many more models in their marketing literature than they actually produced. Typically, HUD-code plants offer more models than modular plants (an average of 92 models vs 82 models for modular), yet their customer satisfaction ratings are significantly lower. While offering fewer models, modular plants actually produce more models and provide more extensive customization. This likely illustrates the distinction between customized product and product variety made by Pine and Gilmore (1999). They stipulate that product variety does not necessarily equate to customization or fit with customer wants (i.e. a customer may not find the house that they want among so many models). While the match between customer wants and product offerings was not evaluated in this study, the large number of available models does suggest that further inquiry into this strategy is warranted. Perhaps, the HUD-code industry strategy of offering a large number of models and limiting the degree of customization may not be the best approach to mass customization.

Operational performance was found to deteriorate with an increase in choice. Therefore, industrialized housing manufacturers have not reached the ideal of mass customization and are paying a price for offering more choices to their customers. Furthermore, HUD-code plants were observed to be less successful than modular plants in offering increased choice without deterioration in operational performance. The metrics that were found to deteriorate significantly were *labor cost per module, labor cost as a percentage of sales, service cost per module, inventory turns,* and *sales per module.* Metrics that worsened with increased choice, but not significantly, were *customer satisfaction,* and *plant size per current production*. In all cases, the operational performances declined with an increase in choice. These results revealed that plants offering increased product choice are likely to suffer poorer labor productivity, greater inventory, higher production costs, more quality issues, less satisfied homebuyers, and lower space efficiency. These findings can help homebuilders pinpoint areas in which to focus improvement efforts and become more efficient in offering increased product choice.

One approach that is being used to address the industry challenges described above is implementing lean production. Results show that in some respects the industrialized housing industry is already somewhat lean (e.g. it works on the basis of customer pull and continuous process flow, maintains little inventory). However, on a broader level, the application of lean principles would require a major cultural change (e.g. improved quality culture and the use of technology that serves people and processes). Results also show that the application of lean principles can be applied effectively to plants offering different levels of product choice. For instance, the two case study plants were at opposite side of the customization spectrum - one producing highly custom homes and the other producing standard homes with pre-determined sets of options. However, both were able to effectively accommodate choice within their department/process where lean was implemented.

Plants that offer more choice tend to incur higher production costs. A custom home is more expensive to build than a standard home, increasing product cost as the product choice increases. Alford et al. (2000) found that increasing product variety to extend market coverage or to respond to customer demands results in escalating costs and complexity in the manufacturing system. This complexity also affects labor productivity. Similar to Qiao et al. (2004), this study found that extra labor is needed to compensate for product and order variations. In order to integrate a lean solution to this challenge, plants should consider evaluating the core skills and other labor characteristics that may be shared among different product choices. Labor flexibility is a key strategy used to accommodate product choice. It is important to maximize workforce skills by offering options that can be handled by similar skills. For example, offering several types of floor tiles (e.g. porcelain, slate, travertine, etc) allows the company to appeal to a broader market. Since the same skills and processes are required to install this range of flooring, cycle times are not likely to be affected. Yet, this strategy will mitigate issues of poor labor productivity and higher production costs.

Another lean approach to improve labor productivity is line balancing. One approach to better balance the line is to move activities that are affected by product choice off the main line. This not only reduces total line cycle time, but eliminates the associated cycle time variability from the main line. For example, removing the door painting operation from the main line and centralizing it in an offline paint booth reduced process cycle time, reduced cycle time variability and improved quality. More flexible process alternatives should be explored to absorb the workload variation caused by the various dimensions of customer choice. Another advantage of this off-line approach is that rework can be performed without affecting the flow of other activities.

Excess inventory is also a problem faced by plants that offer more choice. This is consistent with Qiao et al's. (2004) findings that indicated that extra inventory is needed to compensate for product and order variations. In the homebuilding industry this increase in inventory is due to the need for a greater variety of components to accommodate increased product choice. Excess inventory results in many forms of waste: opportunity cost, storage space, damage, obsolescence, longer lead time, multiple handling, etc. A lean approach observed in the case study plants to control inventory levels was to use continuous flow or to pull inventory from one work area to the next. This strategy was often enhanced by using a build-to-order strategy, in which kits and sub-assemblies are built-to-order and flowed/pulled through the production process. This strategy eliminates the need to stockpile and create kanbans for unique WIP items.

Product variation also leads to quality issues that cause production rework. If the problem is not identified and repaired in the factory, it may be found after the house is delivered to the homebuyer. Sievanen et al. (2000) highlighted the importance of quality controls for companies offering customization to prevent passing defects to the customer. The housing industry tends to inspect quality in, rather than using standardized procedures and Jidoka approaches to prevent quality issues. Plants should turn to more standardized procedures as a way to build quality in, while still providing product choice. For example, the use of jigs for cutting wood components and a sprayer for painting doors minimized process variability associated with a large variety of sizes and styles. The standardized process minimized the opportunity for quality problems, while also minimizing cycle time and cycle time variability. The use of simple technology and tools can effectively address issues such as poor labor productivity, high production costs, product quality problems and customer dissatisfaction.

Plants that offer more choice tend to be less efficient in their use of manufacturing space. This finding is due to the fact that production rate for those plants are typically lower than that of factories offering less product choice. Therefore, their square footage is amortized over fewer homes, resulting in lower space efficiency.

Relationship between Mass Customization and Lean in the Housing Industry

The industrialized housing industry is not well suited for two important mass customization principles: customization postponement (mass customization principle #1) and modularization (mass customization principle #2). The product architecture and the sequential production process does not permit early mass production of components and later assembly of these components and additional customization based on customer orders. The core product is affected by model type and any customer specified customization. Therefore, product choice starts to impact the product and the process from the very beginning of the line. Most component/sub-assemblies are customized for an order or come in many configurations (based on model). The sub-assemblies are very large. Together, these factors would result in large inventory quantities and large staging areas.

The two case studies plants were at opposite sides of the customization spectrum. One produces highly custom homes and the other standard homes. At the plant level, this industry accommodates different levels of product choice by using mass customization principle #3, providing flexibility in the production system. The production flexibility includes labor, layout and equipment flexibility. These flexibilities are supported by the lean principles. A description of the effects of product variety on each lean principle follows:

- Results from the lean case study plants showed that the creation of continuous process flow is feasible for different levels of product choice, but that success may depend on redesigning the process and layout to eliminate all forms of waste and reduce the impact of product choice on cycle times and quality (e.g., reducing the variability caused by product choice).
- In the lean case study plants, the pull system helped to assure that the right material was available when needed, without oversupply. Built-to-order kits were used to make the pull process tractable, given the many product configurations and component sizes. This facilitated the synchronization of offline operations with the main line and prevented the overproduction of components. Staging and controlling unique raw materials was the greatest challenge, but successful solutions were developed by the lean implementation team.
- Workload leveling for the choice factors (doors and interior walls) in the lean case study plants was not accomplished on the main line, where it would be most effective. Other more important factors (e.g., area, roof complexity) were used instead. Workload leveling was improved in each of these two areas by local process improvements in the areas. These improvements helped to mitigate variation and facilitate the processing of product choice. Similarly, Ballard and Tommelein's (1999) results demonstrated the importance of workload balance, by identifying variation and instability of the flow as the main cause of unbalanced activities between construction trades.
- Surveyed plants that offered increased product choices were susceptible to quality problems, perhaps caused by increased complexity associated with product choice. The lean case study plants used process optimization to mitigate much of the potential quality problems associated with product choice.
- Process standardization promoted continuous improvement and employee empowerment in the lean case study plants. While increased product choice is likely to increase standard process documentation, this can be mitigated by proper process selection – developing and selecting processes that use standard tools and methods to produce the range of choice offered.
- Product choice did challenge the lean teams in the case study plants. Organizing the area and implementing visual control, primarily in staging unique raw materials, was difficult. However, using lean concepts such as build-to-order kitting and layout optimization mitigated most of the potential visual control problems associated with product choice. Formoso and Santos (2002) studied some examples of visual controls in homebuilding, observing a positive correlation between visual controls and efficiency. In a similar way,

Heineck et al. (2002) reported productivity gains in construction sites, by implementing improvements on process transparency.

- The need to accommodate product choice in the case study plants limited the use of process technology. However, the use of the simple technologies adopted profoundly affected the productivity and quality in each area and better enabled the area to accommodate product choice offered.

The case studies showed that product choice does not necessarily make the implementation of lean concepts more difficult. Some lean concepts, like workload balancing and standardizing tasks, clearly facilitated the handling of product choice. Other lean concepts, like creating a continuous process flow, can be made to work well, even with increased choice. In general, the results suggested that good concepts for lean (e.g., efficient continuous flow, effective pull system, workload leveling, defect-free processes, standard tasks, good visual controls, and reliable technology) were also good concepts for (or easily accommodated) handling a range of product choice. Thus, lean concepts may be the method for homebuilders to achieve production efficiencies, while allowing product customization. Similarly, Tu et al. (2001) and Da Silveira et.al. (2001) concluded that lean production is an important factor that supports mass customization.

Industry Guidelines

Findings from this study are summarized in the following set of guidelines for implementing the seven lean principles while maximizing product choice:

1. Move activities affected by customization off the main production line by developing off-line parallel processes that are synchronized to main line flow and deliver sub-assemblies on a just-in-time basis. A similar approach is to designate an off-line ’customization’ station for custom work.

2. Optimize and standardize activities that are affected by product choice by developing common methods, equipment and tools that simultaneously are highly efficient, assure quality, and minimize process cycle time variation due to product choice.
3. Move equipment and materials closer together. Utilize straight line, L or U-shaped flows.
4. Use continuous flow systems whenever reasonable. When production flow needs to be disconnected due to process variability, use limited queues with kanbans to drive production. When product choice or product architecture results in many components, consider pulling materials in built-to-order kits, instead of unique part numbers.

In general, there are some benefits to be realized from the use of some lean principles in a mass customization environment. These results reflect the similarities of both mass customization and lean production as far as their goal to reach mass production efficiencies. Lean principles are not necessarily concerned with increasing product variety. Typically, product standardization is associated with efficiency, and customization with inefficiency and high costs. The literature reflects this dichotomy, often distinguishing between creativity and efficiency (e.g., Benner and Tushman, 2002). Certainly, the tradeoff between customer choice and productivity, between creativity and efficiency will be a critical element of business strategy for 21^{st} century manufacturers. This research demonstrates that the use of lean principles can support mass customization in reducing the impact of these tradeoffs.

Study Contribution

This study makes a significant contribution to the knowledge of Mass Customization and Lean. The contribution of this research is two fold. First, this study identified the challenges faced by plants offering increased product choice. This helps homebuilders pinpoint areas in which to focus improvement efforts and become more efficient in offering increased product choice. Second, this research identified lean principles that could facilitate mass customization for the industrialized housing industry. More specifically, findings from this research will contribute to a better understanding of the applicability of mass customization strategies in the housing industry and is expected to provide useful guidelines for builders interested in addressing specific customer needs, while managing the operational complexities resulting from product variety.

Study Limitations

Some limitations to the study results must be noted. The industry-wide survey included more plants that were primarily HUD-code than modular. It is likely that some modular manufacturers chose not to participate because they do not wish to be associated with the manufactured housing industry. Only two plants were selected for case studies. Additional plants were not included due to limited access, limited potential learning opportunities, and the time and effort required for analysis. The two case study plants implemented lean in two very different areas. This limited direct comparison. Finally, although both a custom plant and a standard plant were selected for the case study, the level of choice offered in their case study departments was not reflective of the plant wide level of choice.

Recommendation for Future Study

The findings that emerged from this study are enlightening, but limited. Several directions of future research might build on the findings of this study. First, a natural progression of this work is to replicate this analysis in other departments and plants, including an extension to other industries. Secondly, this research was limited to an exploration of the relationship between mass customization and lean within the manufacturing plant. Future study should expand this exploration up the supply chain to include the suppliers. Finally, this research focused on a single component of mass customization – production system design. Future study should focus on the remaining two components, product design and supply chain design.

APPENDIX A: MANUFACTURED HOUSING RESEARCH ALLIANCE INDUSTRY-WIDE SURVEY

Corporate

1. How many housing plants are operated by the parent company of your plant?

Product

2. What type of homes do you build? Please indicate the % of homes produced last year in the following categories:
    a. HUD Code
    b. Modular (residential)
    c. Commercial
    d. Other
    e. Total – 100%

3. How many models are offered in the current marketing literature that are actually produced by your plant?
4. What level of customization have you provided on these models? Please indicate the % of homes produced last year in the following categories:
    a. No customization – no departure from base model shown in marketing literature (for example, no floor plan or structural changes)
    b. Minor floor plan changes – for example, stretches or flips
    c. Extensive floor plan changes – for example, new kitchens or completely new floor plans
    d. Totally custom – new sheet of paper
    e. Total – 100%

5. How many homes featured finished drywall? Please indicate the % of homes produced last year in the following categories:
    a. No finished drywall
    b. Limited finished drywall -few rooms
    c. Whole house finished drywall (except possibly wet rooms)
    d. Total – 100%

6. How many homes featured other unique design elements? Please indicate the % of homes produced last year in the following categories:
    b. Multi-story – including 1 ½ story
    c. Hinged roofs
    d. Total – need not total 100%

7. How many floors were produced for each home? Please indicate the % of homes produced last year in the following categories:
    a. Single section
    b. 2 section multi-section
    c. section multi-section
    d. section – multi-section
    e. More than 4 sections
    f. Total – 100%

Plant

8. In what state is this plant located?
9. What is the annual production of this plant? Please answer as many as you can.
    a. Sales $
    b. Floors
    c. Homes
    d. Square feet

10. How many floors could this plant produce in a standard 40 hour work week (single shift) if orders were unlimited? Assume that the model mix is similar to that of the past 12 months.
11. What is the plant's annual production labor cost (total wages including bonuses without fringes/benefits) and the number of employees in each category?
    a. Direct – line workers
    b. Indirect – Material Handlers, QC, Supervision, etc.

12. What is the current size (square feet) under roof of the production facility and all supporting buildings (shops, warehouse, etc.)?
13. How many production stations do you have on the main assembly line, excluding off-line feeder stations? Please indicate the number of stations in each category:
    a. Under roof
    b. Outside/uncovered

14. What is the current production level – floors per week?
15. What is your current backlog - floors?
16. How many times did your material inventory turn in the last year (annual material cost/average inventory level)?
17. What are the primary and secondary production bottlenecks/problem areas that most need improvement?

Employee Satisfaction / Safety

18. How many OSHA Recordable Accidents have been reported in the last 12 months?
19. How many of these cases resulted in days away from work?
20. How many of these cases resulted in job transfer or restriction (light duty)?
21. How many total work days were lost in accident-related days away from work?
22. How many work days were affected by accident-related job transfers or restrictions (light duty)?
23. What was the average % absenteeism in the last week?
24. What was the % production labor turnover in the last year?
25. List any continuous improvement programs that were used in the last year. For example, quality councils, quality circles, continuous improvement teams, etc. For each, please list the number of employees involved.
26. Do you currently have an incentive pay program for production employees? If so, what general types of performance are rewarded? Please indicate all that apply and briefly describe specific measures used to determine rewards (for example, Labor Productivity/efficiency – weekly labor cost per sales $.
    a. Labor productivity/efficiency
    b. Safety
    c. Quality

Customer satisfaction / Quality

27. Based on the results from Customer Satisfaction Surveys during the last year, what % of your customers are satisfied?
28. What is your annual service cost?
29. During the last year, what were the top 5 discrepancies requiring service? Please rank highest to lowest and be specific, for example: floor squeaks, cabinet damage, wallboard cracks, difficulty opening/closing windows. Please do not give only general categories such as electrical, plumbing, etc.

APPENDIX B: INTERVIEW QUESTIONS FOR THE MASS CUSTOMIZATION PRINCIPLES

DOCUMENTING MASS CUSTOMIZATION PRINCIPLES AT PLANT LEVEL

The main purpose of this section is to capture the level of choice offered and the mechanisms to accomplish it.

1. How many standard models do you offer?
2. Do you allow a customer to make changes that require structural changes that will require an engineering stamp?
3. Do you allow a customer to make non-structural changes such as dimensional changes? (e.g. omit or add an interior non-load bearing wall).
4. Do you allow a customer to choose from a pre-determined set of options or features?
5. What kind of options or features do you offer? (types and quantities)
6. Can those options or features be used on any home design or only in specific models?
7. Are these features plug compatible or do they necessitate related changes in other parts of the home or in other production activities?
8. Which components that help you achieve variety on your models are built in-house and which are bought from a supplier? (e.g. cabinets).
9. Do you accept customer requirements that exceed your current production system capacity? (i.e., overcoming plant limitation by building off line)
10. What production system elements limit your ability to customize? What unique features of your production systems facilitate customization?

DOCUMENTING MASS CUSTOMIZATION PRINCIPLES AT DEPARTMENT LEVEL (RPI)

The main purpose of this section is to capture different variations of the elements/component/subassembly that allows for product choice and the mechanisms to accomplish it.

1. How many standard elements/component/subassembly are build/assembled at this station?
2. Do you allow a customer to choose from a pre-determined set of component or can customer choose a unique style (e.g. custom)?
3. What kind of options or features do you offer at this station? (types and quantities)
4. Can those options or features be used on any home design or only in specific models?
5. Are these features plug compatible or do they necessitate related changes in other parts of the home or in other production activities?

6. Which components that help you achieve variety on your subassembly are built in-house and which are bought from a supplier?.

7. Do you accept customer requirements that exceed your department/station current production system capacity? (i.e. special elements)

8. What production system elements limit your ability to customize? What unique features of your production systems facilitate customization?

Additional questions: Mass Customization vs. Lean implementations

- What's the effect of this level of customization on lean implementation?
- Does customization made it more difficult to do lean or made lean less effective?
- Does lean made it more difficult to offer product variety?

APPENDIX C: QUESTIONNAIRE FOR THE RPI EVENTS

DOCUMENTING THE RPI EVENT AT DEPARTMENT LEVEL

1. RPI Event date- including start and end day.
2. List of participants- including title/job function and role in the RPI.
3. Objectives of the RPI- including description of current problems.
4. Description of process targeted by the RPI event.
5. Description of current process (before RPI event)- describe the area of the plant including layout and material flow, describe activities, typical number of workers, and describe the effects of product customization at each process.
6. Description of improved process (after RPI event)- describe the area of the plant including layout and material flow, describe activities, typical number of workers, and describe the effects of product customization at each process.
7. Data (before and after) – e.g. cycle times, inventory level, space used, WIP level.
8. Accomplishments resulting from the RPI.
9. How each process benefited from the RPI event?
10. Was customization simplified after the RPI event?
11. How each lean principle (Table 2) was used in the RPI event?

LIST OF REFERENCES

Alford, D., Sackett, P., and Nelder, G. (2000). " Mass customization – an automotive perspective". International Journal of Production Economics, 65, pp. 99-110.

Andel, T. (2002). "From common to custom: The case for make-to-order". Material Handling Management, 57(12) pp. 24-31.

annual conference, Copenhagen, Denmark, August 3-5.

Barlow, J., Childerhouse, P., Gann, D., Hong-Minh, S., Naim, M., and Ozaki, R. (2003). "Choice and delivery in housebuilding: lessons from Japan for UK housebuilders". Building Research and Information. 31(2) pp. 134-145.

Bashford, H., Sawhney, A., Walsh, K., and Kot, K.,(2003). Implications of Even-Flow Production Methodology for the US Housing Industry, Journal of Construction

Bedworth, D.D., Henderson, M.R., and Wolfe, P.M. (1991). "Computer-Integrated Design And Manufacturing", McGraw-Hill, New York, NY.

Bernold, L. (2004). "Web-Based Synchronous Communication in Construction: Breaking Out of the Zero-Sum" Proceedings of the NSF Housing Research Agenda Workshop, Feb. 12-14, 2004, Orlando, FL. Eds. Syal, M., Hastak, M., and Mullens, M. Vol 2, Focus Group 1, 51-59.

Blecker, T., Friedrich, G., Kaluza, B., Abdelkafi, N., and Keutler, G. (2005). " Information and Management Systems for Product Customizaiton". Springer Science and Business Media, Inc.

Bowersox, D. J. and Morash, E. A. (1989). "The integration of marketing flows in channels of distribution". European Journal of Marketing, 23(2) pp. 58-67.

Chandra, C. and Grabis, J. (2004). "Mass Customization: A Supply Chain Approach". Kluwer Academic/ Plenum Publishers, New York. Chapter 3: Mass Customization: Framework and Methodologies, pp. 63-85.

Chandra, C. and Kamrani, A. (2004). "Mass Customization: A Supply Chain Approach". Kluwer Academic/ Plenum Publishers, New York.

construction. Espoo, VTT Building Technology. 296 p. VTT Publications; 408. WWW:http://www.inf.vtt.fi/pdf/publications/2000/P408.pdf.

Da Silveira, G., Borenstein, D & Fogliatto, F. (2001). Mass customization: Literature and research directions. International Journal Production Economics, 72, pp. 1-13

Daghestani, S. (1998) "Design and Reconfiguration of Manufacturing Systems in Agile Manufacturing Environments". Master Thesis, Virginia Polytechnic Institute and State University.

Davis, S.M. (1987), Future Perfect, Addison-Wesley Publishing, Reading, MA

Davis., S.M (1989). From future perfect: Mass customizing. Planning Review, 17(2) pp. 16-21.

Dennis, Pascal, Lean Production Simplified: A Plain Language Guide to the World's Most Powerful Production System, Productivity Press, New York, NY (2002).

Duguay, C. R., Landry, S., and Pasin, F. (1997). "From mass production to flexible/agile production". International Journal of Operations & Production Management, 17(12) pp. 1183-1195.

Duray, R. (2000). Mass customization. Swamidass (Ed.), Encyclopedia of production and management. New York: Kluwar Academic Publishing.

Duray, R. (2002). " Mass customization origins: mass or custom manufacturing? International Journal of Operation & Production Management, 22(3) pp. 314-328.

Duray, R. and Milligan, G., (1999). Improving Customer Satisfaction through Mass Customization, Quality Progress, August, pp. 60 – 66.

Duray, R., Ward, P., Milligan, G., and Berry, W. (2000). "Approaches to mass customization: configurations and empirical validation". Journal of Operations Management, 18, pp. 605-625.

Feitzinger, E., and Lee, H. L., (1997). "Mass customization at Hewlett-Packard: the power of postponement". Harvard Business Review, January–February, 75(1) pp. 116–121.

Fisher, M. (1997). "What is the right supply chain for your product?". Harvard Business Review, March/April, 105-116.

Formoso, C. T. and Santos, A. (2002) "An exploratory study of process transparency in construction sites" Journal of Construction Research, World Scientific Publishing Company,Vol. 3, No. 1, pp. 35/54.

Gilmore, J. and Pine, J. (1997). The four faces of mass customization. Harvard Business Review, 75(1) pp. 91-101.

Gooley, T.B. (1998). "Mass Customization: How Logistics Makes it Happen". Logistics Management and Distribution Report. 37(4) 49-52.

Guruswamy, R. (2004). Supporting Mass Customization: A Three Dimensional Concurrent Engineering (3-DCE) Perspective. IEMS MS thesis. Arizona State University. Advisors: Dr. J. Fowler, Dr. M. Rungtusanatham, Dr. G. Mackulak.

Habraken, N.J., (1976). "Variations, the Systematic Design of Supports". With J.T.Boekholt, A.P. Thyssen, P.J.M. Dinjens: MIT Laboratory for Architecture and Planning; distributed by the MIT Press, Cambridge, USA and London.

Hart, C. (1995). "Mass customization: conceptual underpinnings, opportunities and limit". International Journal of Service Industry Management, 6(2) pp. 36-45.

Heil, G., Parker, T. and Stephens, D. (1997). One size fits one: Building relationships one customers and one employee at a time. Van Nostran Reinhold: International Thomson Publishing Company.

Hines, J. A., Kokkinos, A., and Fedock, D.S.(2001). Benefits of SCR Design for Constructability. Presentation to Power-Gen International 2001, Las Vegas, Nevada.

Ho, T. and Tang, C. (1998). Product Variety Management: Research Advances. Kluwer Academic Publishers, Norwell, Massachusetts

Holweg, M. and Pil, F.K. (2004) The second century: reconnecting customer and value chain through build-to-order: moving beyond mass and lean production in the auto industry. Cambridge, Mass.: The MIT Press.

implementations." Proceedings of International group of lean construction, 12th

Jeong, Jae G. (2003). Supply Chain Analysis and Simulation Modeling for the Manufactured Housing Industry, Master's Thesis, Purdue University, West Lafayette, IN.

Kahn, B. (1998). Dynamic relationship with customers: High variety strategies. Journal of the Academy of Marketing Science, 26(1) pp. 45-53.

Kendall, S and Teicher, S (2000). Residential Open Building. London & New York: E & FN Spon

Kendall, S. (2004). "An Open Building Approach to Residential Construction: A Strategy for Balancing Efficiency and Variety in Construction Management and Production" Proceedings of the NSF Housing Research Agenda Workshop, Feb. 12-14, 2004, Orlando, FL. Eds. Syal, M., Mullens, M., and Hastak, M. Vol 2, pg. Focus Group 1.

Koskela, L. (1993). Lean production in construction. Proceedings of the 10th ISARC, Houston, Texas, May 24-26, 47-54.

Koskela, Lauri (2000). An exploration towards a production theory and its application to

Koste, L. and Malhotra, M. (1998) "A Theoretical Framework for Analyzing the Dimensions of Manufacturing Flexibility". Journal of Operations Management. (18) pp. 75-92.

Kotha, S. (1996). " From mass production to mass cutomization: The case oc the National Industry Bicycle Company of Japan". European Management Journal, 14(5) pp. 442-450.

Kotha, S., (1995). "Mass customization: implementing the emerging paradigm for competitive advantage". Strategic Management Journal, 16, Special Issue, pp. 21-42.

Lampel, J., Mintzberg, H. (1996). Customizing customization. Sloan Management Review. 38 pp. 91-101.

Lau, S. R. M. (1995). Mass customisation: The next industrial revolution. Industrial Management, 37(5): 18-19.

Liker, J (2004). The Toyota Way: 14 management principles from the world's greatest manufacturer. McGraw-Hill, New York, 350 pp.

Lu, R., and Gross, L. (2001): Simulation Modeling of a Pull and Push Assemble-to-order System, The European Operational Research Conference, 2001, Rotterdam, The Netherlands.

MacDuffie, J., Sethuraman, K., and Fisher, M. (1996). Product variety and manufacturing performance: Evidence from the International Automotive Assembly Plant Study. Management Science, 42(3) pp. 350-369.

Mikkola, J. (2001). Modularity assessment of product architecture: Implications for substitutability and interface management. Proceeding from DRUID's Nelson and Winter Conference, Aalborg, Denmark, June 12-15, 2001.

Mikkola, J. and Larsen, T. (2004). "Supply-chain integration: implications for mass customization, modularization and postponement strategies". Production planning and control. 15(4) 352-361.

Muffatto, M., (1999), "Introducing a platform strategy in product development". International Journal of Production Economics, 60-61, pp. 145-153.

Mullens, M. (2004). "Production flow and shop floor control: Structuring the modular factory for custom homebuilding" Proceedings of the NSF Housing Research Agenda Workshop, Feb. 12-14, 2004, Orlando, FL. Eds. Syal, M., Mullens, M. and Hastak, M. Vol 2.

Mullens, M. and M. Hastak (2004). "Defining a National Housing Research Agenda: Construction Management and Production" Proceedings of the NSF Housing Research Agenda Workshop, Feb. 12-14, 2004, Orlando, FL. Eds. Syal, M., Mullens, M. and Hastak, M. Vol 2.

Mullens, M. and Toleti, R. (1996). "A Four Day Study Helps Home building Move Indoors" Interfaces, 26(4)13-24, July.

Naim, M. and Barlow, J. (2003). "An innovative supply chain strategy for customized housing". Construction Management and Economics, 21 pp. 593–602.

National Association of Homebuilder (NAHB), (2004). "Mass Custom Builders: Redefining Customers Options" by NAHB Research Center Staff.

Ohno, T. (1988). "Toyota Production System", Productivity Press.

Picchi, F. and Granja, A. (2004) "Construction sites: using lean principles to seek broader

Pil, F. and Holweg, M. (2004). Linking Product Variety to Order-Fulfillment Strategies. Interfaces, 34(5) pp. 394-403.

Pine II, B. J. (1993). Mass customizing products and services, Planning Review 21 (4) pp. 6-13.

Pine II, B. J. and Gilmore, James. (1999). The Experience Economy, Boston, Massachusetts: Havard Business School Press 1993.

Pine II, B. J., (1993), Mass Customization: The New Frontier in Business Competition, Harvard Business School Press, Boston, MA.

Pine II, B. J., Victor, B., and Boynton A. C. (1993). "Making mass customization work". Harvard Business Review, pp. 108-119.

Qiao, G., Lu, R. F. and McLean, C. (2004) Process control and logistics management for Mass Customization Manufacturing. IIE Conference Proceeding 2004, Houston, Texas.

Qiao, G., Lu, R. F. and McLean, C. (2003) Flexible Manufacturing Systems for Mass Customization Manufacturing. National Technical Information Service (NTIS) (www.mel.nist.gov/msidlibrary/doc/flexms).

Rother, M., and J. Shook, 1999: Learning to See, The Lean Enterprise Institute, Brookline MA.

Salem, O. and Zimmer, E. (2005). Application of lean manufacturing principles to construction. Lean Construction Journal, Volume 2, Number 2.

Schilling, M. A., (2000). "Toward a general modular systems theory and its application to inter-firm product modularity". The Academy of Management Review. 25(2) pp. 312–334.

Sheridan, 1993 Sheridan, J.S., *Agile manufacturing: stepping beyond lean production*. Industry Week, 242(8) pp. 30-40.

Shewchuk, J.P. (1998) Agile manufacturing: one size does not fit all. *Proceedings of the IFIPWG 5.7 Conference on Strategic Management of the Manufacturing ValueChain* (Troon, Scotland), Kluwer Academic Publishers, , 143-150.

Sievanen R, Nikinmaa E, Nygren P, Ozier-Lafontaine H, Perttunen L, Hakula H. 2000. Components of functional-structural tree models. Annals of Forestry Science 57: 399–412.

Tseng, M., and Piller, F. (2003). The Customer Centric Enterprise. Springer Science and Business Media, Inc.

Tseng, M.M. and Jiao, J. (2001): Mass Customization, in G. Salvendy (Ed.) Handbook of Industrial Engineering, 3rd edition, New York: Wiley, pp. 684-709.

Tu, Q., Vonderembse, M. and Ragu-Nathan, T.S. (2001). The impact of time-based manufacturing practices on mass customization and value to customer. Journal of Operations Management, Volume 19, 201-217.

Ulrich, K. and Eppinger, S. (2004). " Product Design and Development". McGraw-Hill, Third Edition.

Voss, D., A new spring for manufacturing. Journal of Business Strategy, 1994, 15(1), pp. 54-56.

Whang, S. and Lee, H. (1998). "Value of Postponement". Product Variety Management Research Advances. Kluwer Academic Publishers, Boston, 65-84.

Womack, J. and Jones, D. (1996). "Lean Thinking : Banish Waste and Create Wealth in Your Corporation", Simon & Schuster, New York.