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Process flow improvement proposal using lean manufacturing philosophy and simulation techniques on a modular home manufacturer[1]

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Abstract

The United States housing market has significantly declined in the last few years. Moreover, moody's economy.com chief economist, Mark Zandi (Nov. 2009) thinks the housing crisis is not over and expects to see another leg down. This crisis in the housing market has caused a reduction in the demand for new houses nationwide, thus, significantly impacting housing manufacturers. Improvements in the housing manufacturing systems are therefore needed in order to become more competitive and sustainable.

This research is intended to develop a simulation model to improve the flow of modular housing manufacturing operations based on a time and processes study of a North Carolina modular homes manufacturer. Due to the housing market crisis this paper represents an alternative for those manufactures that require an upgrade in their production system to gain a competitive advantage. This research also studies the impact of lean manufacturing tools implementation with the use of a simulation model.

Several alternatives were analyzed and simulated in order to identify the best option for the company.

Results showed that several alternatives can be implemented in order to increase the production level by almost 40 percent; and labor cost per module can be considerably reduced. Moreover, operational cost can also be significantly reduced by the implementation of lean manufacturing tools and manufacturers can obtain competitive advantages by incorporating these changes to their manufacturing systems.

Keywords: housing, modular homes, flow, lean, simulation

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Introduction

Housing Market

The housing market is and will continue to be a growing market as long as population increases. The need for a place to live cannot be substituted; it can be considered as one of people's basic needs. The United States housing market has been growing for the last decade, but since 2006 the trend has changed to a downward trend (US Census Bureau, 2007) (Figure 1).

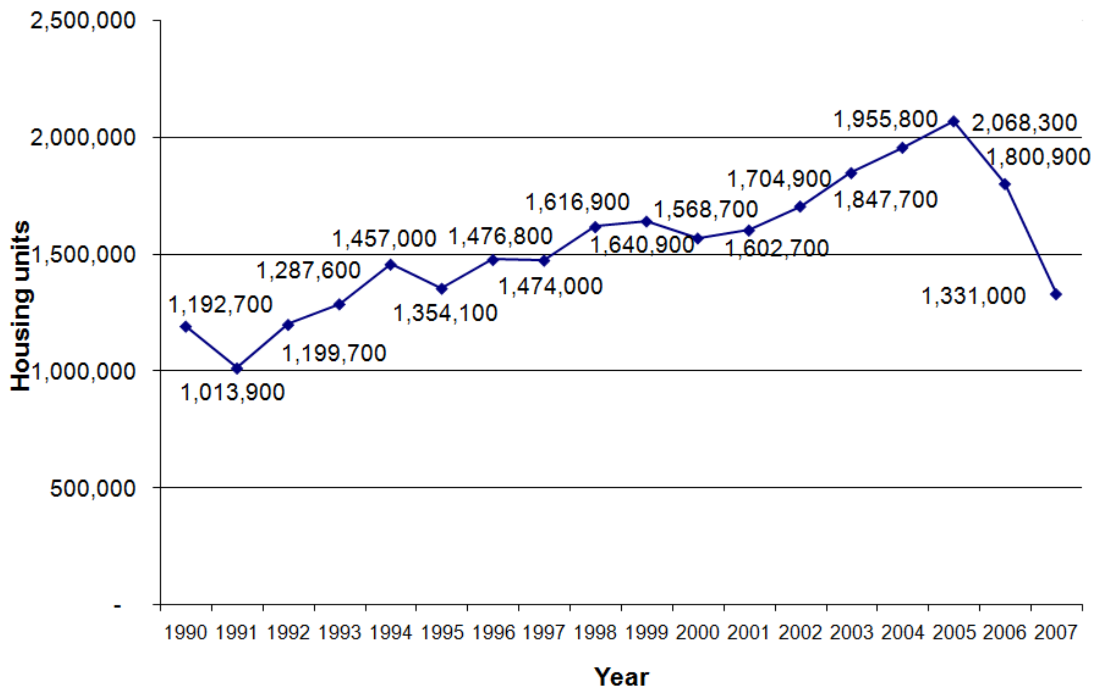

Figure1: US housing starts trends (source: US Census Bureau)

The US housing industry can be divided in many different ways by the number of rooms, materials used, type of foundation, type of structure, construction method and so on. The type of classification used will give a trend to that subdivision different than the whole market trend. In terms of construction method the US Census Bureau classifies them in site-built, modular, and others.

Modular homes refers to houses that are composed of several modules or sections that are manufactured in a controlled environment production facility and transported to the home site on flat bed trucks. Individual modules can be shipped being up to 90% completed (NAHB, 2008). Finished modular homes can look like any house built on site, top class designs are not a limitation for this construction system. Among the benefits of modular homes we can mention the following: improved working conditions, higher productivity, efficient building processes, better control systems, increased quality, reduced production time, improved material usage, and highly engineered homes (Pasquire and Connolly, 2002). The maximum size of the modules is restricted by roadways regulations; the dimensions cannot exceed 11 feet wide by 60 feet long (NAHB, 2007). On average, the homes manufactured by the facility subjected to this study contain 3 modules.

The modular home industry, as shown in Figure 2, reached a peak in 2004 with over 42,000 homes and with a market share of 2.18%; in 2005 the units sold slightly dropped to over 41,000 with a market share of 2.00%; in 2006 the selling units dropped down to 38,000 with a market share of 2.13% and in 2007 the number went to 31,000 but with a continuous increase in the market share to 2.35% (National Modular Housing Council, 2007). Therefore, modular home sales are decreasing at a slower pace than the market due to its advantages and the consumer's acceptance of a higher and distinguish product (2008 information is not currently available).

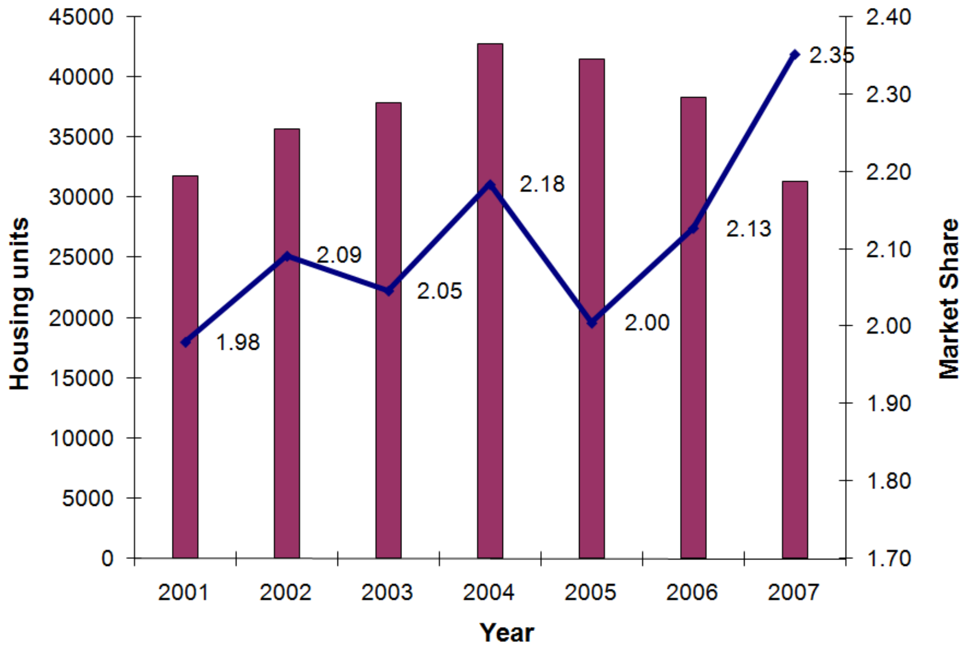

Figure 2: US Modular housing market levels

In relation to the housing crisis, Steve Like, 2007 Chairman of the National Modular Housing Council, states that this industry undoubtedly offers a number of advantages and value to the customer, including increased quality control, shortened time to completion and product engineering, all of which are getting more difficult to obtain using traditional building methods (NMHC summer 2007 news). A proposed solution is to market and offer those attributes and sell them properly to builders and homebuyers.

Lean Manufacturing and Simulation

The modular homes industry must prepare for a new business world where variety and customization of products and services become the norm. An important philosophy that fits these goals is lean manufacturing. It is called "lean manufacturing" because it requires far fewer resources: labor, capital, machinery, time and manufacturing space to make a given amount of products and services and to make them with fewer defects to precise customer specifications, compared with traditional manufacturing operations (LEI, 2005).

In addition, James Womack, who launched the Lean manufacturing Enterprise Institute (LEI) in 1997, stated in the LEI report (2007) that the biggest benefit of lean manufacturing is that it frees resources by using less human effort, less space, less capital, and less time. By freeing resources, lean manufacturing management turns waste into available capacity. Thus, the biggest benefits come when management uses this capacity to grow the business, whether it is a service or manufacturing enterprise.

Koskela (1992) presented a production management paradigm where production was conceptualized in three complementary ways, namely, as transformation, as flow, and as value generation – also termed the TFV theory of production. This tripartite view of production has lead to the birth of Lean Construction as a discipline that subsumes the transformation-dominated contemporary construction management (Koskela and Howell 2002, Berteslen and Koskela 2002).

Testa (2003) stated that while lean manufacturing definitely cost money to implement, the savings usually outweigh the costs many times over. Totev, cited in this report (Testa, 2003), mentioned the improvements and savings generated by the typical ongoing lean manufacturing program, such as reductions in downtime for both production and maintenance, reductions in changeover times by as much as 70 %, increases in productivity and throughput of as much as 50 % and savings of five to twenty times the cost of a one-time lean manufacturing project.

Despite the potential savings that lean manufacturing can provide, some industries are more reluctant than other to its implementation. Yet, Lean Manufacturing has proven to be a very flexible and adaptable philosophy, for instance, Hunter et al. (2004) showed a systematic case study in the wood furniture industry that “proves the flexibility of lean manufacturing due to is adaptive and cost effective, improves quality, and is ergonomically correct for workers”.

The manufactured housing research alliance also did its part in 2006 with the manufactured home industry (PATH 2006). The industry seized the value of lean manufacturing from the training course they held for representatives from nine manufacturing plants. They stated “the industry was just dying to have it brought to bear”, “lean processes have the potential to significantly increase production as bottlenecks and inefficient processes are streamlined and eliminated”, and “for the retailers it means better quality and quicker deliveries”.

Additionally, a lean philosophy was developed for the construction industry. According to the Lean Construction Institute, lean construction is a production management-based philosophy emphasizing the need to simultaneously design a facility and its production process while minimizing waste and maximizing value to owners throughout the project phases (including the post-construction phase) by improving performance at the total project level, using a conformance-based versus a deviation based performance control strategy, and improving the reliability of work flow among project participants (Howell 1999).

Tommelein (1998) indicated that the reason for the development of lean construction principles is that current industry project management tools are unable to describe adequately the construction process at a level on which lean production can be studied. Additionally, Abdelhamid (2004) combined lean thinking with the housing industry to promote the application of lean manufacturing to help the housing industry.

A major obstacle for accurate and reliable prediction of workflow progress is that the existing theoretical foundation for construction project management and the practical tools based on it, does not consider varying production rates within activities, splitting, interdependence, and interactions between activities, movement of resources between activities and do not account for uncertainty (Brodetskaia and Sacks, 2007). These obstacles led this research to a different tool that overcomes those limitations.

Simulation is, as stated by Abu Hammad (2002), the imitation of the operation of a real world process or system over time. It is used to investigate a wide variety of what-if questions about the real world system. Furthermore, among its applications we find that it can be used to evaluate suggested improvements to existing systems. This approach will help the industry to understand the value of lean manufacturing and what levels of improvements can be achieved. Additionally, an Analytic Hierarchy Process was used by Barshani et. al. (2004) to guide manufactured housing manufacturers. The process was designed to determine construction value adding features to help them maximize the delivery of value to the homeowners.

While "physical" simulation of a reengineered construction process for a mega project does not seem realistic, a computer enabled "virtual" simulation has been proven to be an efficient and cost-effective way to examine the potential performance of a proposed process. Computer simulation can be used to create an environment to validate and quantify the efficiency of a construction process that is reengineered through lean principles prior to its field implementation (Mao and Zhang, 2008).

Senghore et. al. (2004) used a simulation model to study the impact of different alternatives when modifying the production processes of a manufactured housing factory. Additionally, Farrar et. al. (2004) combined simulation techniques and lean concepts by using a simulation model to test some lean production concepts on road construction processes.

Objective

The modular home industry needs to increase their market share and differentiate from their competitors. Moreover, due to the market crisis the differences are required not only to increase market share but also to stay in business. Consumers constantly demand better, faster, cheaper and customized goods and this also applies to the housing industry, all of which are offered by the modular home industry. Therefore this research intends to show a solution to improve the manufacturing processes of a modular home facility with the use of lean manufacturing tools and simulation techniques.

Limitations

This research included all the processing operations performed within the boundaries of a modular home manufacturing facility. The improvement alternatives only considered the implementation of lean manufacturing tools. In addition, the computer simulation models focused on current and future state systems (alternatives).

System Description

A volumetric modular home manufacturing plant was the focus of research for this study. The facility has 124,000 sq feet with a floor space subdivision for 27 modules. The manufacturing processes are divided in 8 departments with a total of 153 employees that work in a temperature controlled environment. The current production rate is 14.53 modules per week and the desired stage is 20 modules per week. Each module contains a module base, walls and a module top; depending on the section of the house it also contains plumbing and wiring, electric features, bathrooms or kitchen cabinets (Figure 3).

Figure 3: Interior view of a module

The analysis of the manufacturing processes of the modular homes facility started by determining and specifying every production, administrative, and information process that is involved in the manufacturing of the modules. With this information and by interviewing supervisory personnel and doing continuous process observation of the production line we described every productive procedure starting from the sub-processes to the individual tasks. The description process is summarized in a general process flow diagram that contains 10 different processes (Figure 4).

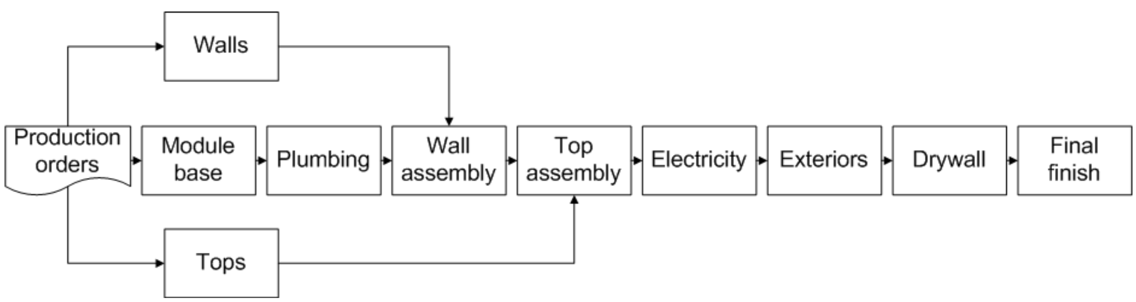

Figure 4: Modular homes manufacturing facility's flow diagram

The manufacturing processes of every module begin with the production of the base (foundation), the walls, and the tops simultaneously. By doing this the company assures that the walls and tops will be ready to assemble when the process needs to take place. The plumbing operations starts with the module base and after the walls and tops are assembled; part of the plumbing is finished. The electrical part of the process begins after the walls are in place and ends after the top assembly is finished. After all the plumbing and electrical operations are finished, the exterior work begins. The interior drywall operations then take place including all the waiting times due to several steps in drying and sanding. Final quality control is performed at the very end of the final finishing step.

For detailed information we described each and every one of the activities involved in the manufacturing process gathering information from different sources (management interviews, supervisory level interviews, and a time study). A complete time study was done with a follow up of different modules throughout the entire facility. Also, additional system performance information was obtained from historical production information from the company data. Figure 5 represents the current value stream map of the operations.

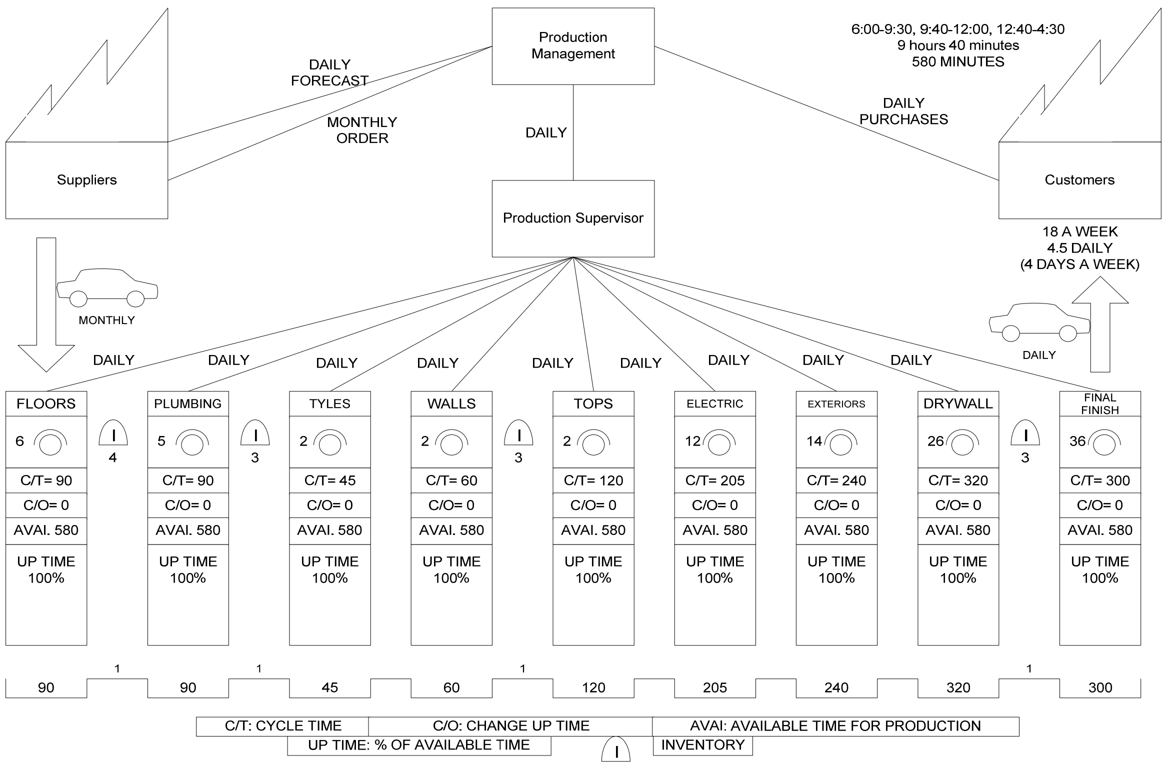

Figure 5: Current value stream map of the manufacturing facility

These activities are performed by over 150 employees distributed in different proportions in each step of the process. Floor space is also a constraint of the system; the floor has enough capacity for 27 modules at a time. On a regular basis, work is not performed on all 27 modules places, but the space is still required to balance the system due to fluctuations on processing time.

This study is focused on the manufacturing activities and processes of a modular homes manufacturing facility. It does not consider any previous or further steps in the supply chain as well as the final assembly of the modular homes. Therefore, this project is not considered lean construction since it does not contemplate the final assembly of the modules on the construction site; the incorporation of the post manufacturing operations is suggested as future work of this research. The improvement of the depth of the analysis or the addition of the supply chain analysis is suggested for future research.

Simulations

Even though lean manufacturing has the reputation of paying for itself, this current research used computer simulation as a tool to test different lean manufacturing tool implementation alternatives without affecting any current house construction, with minimal economic impact, and minimal employees and customer impact.

Computer simulations of the production system were performed to test and predict the output of different alternatives. The procedure to develop a simulation model begins by gathering information about the system functions in terms of entities, resources, processing time, transferring time, queuing time and system constrains. All the information needs to be transformed into specific parameters to be able to replicate the real operations in a simulation. In any computer simulations it is important to assure that the model is a good representation of the real system (validate the model).

All the simulations of the production area were developed using Arena 5.0 from Rockwell Software Automation®.

Developing the Simulation

Basic Model

The first model developed was used to determine the accuracy of the information provided by the production supervisors. The simulation involves only 37 different activities with time durations based on the time provided by the supervisors (the level of details in this simulation is poor because it only considers big sub-processes) and simulated as two statistical distributions (based on the information provided the best distributions to use were uniform and triangular). The model includes the assigned working activities for all the employees and the time those activities takes to be completed. The duration time of the activities are simulated as statistical distributions to simulate the variability of the operations and times between one module produced and the next. In this case, the decision between using a uniform distribution or a triangular was based on the information gathered in the interviews. The model incorporates differences between one module and the others only in terms of their processing time in each station. The system variations are only simulated as differences in processing times. The time elapsed between the processing of one module and another was included with moving time of parts and materials as well as transporting the modules from one station to the next. More details of the model are not included due to page limitations and confidentiality agreements.

To validate the simulation we used weekly output data from the historical production information; the base unit used is modules per week. The information for the weekly output contains the last 134 production weeks and the simulation also replicates weekly performance 134 times. The first validation process was a graphical comparison having the lower and upper limits set at a value of average plus/minus one standard deviation; all the weekly output was contained inside the boundaries (Figure 6).

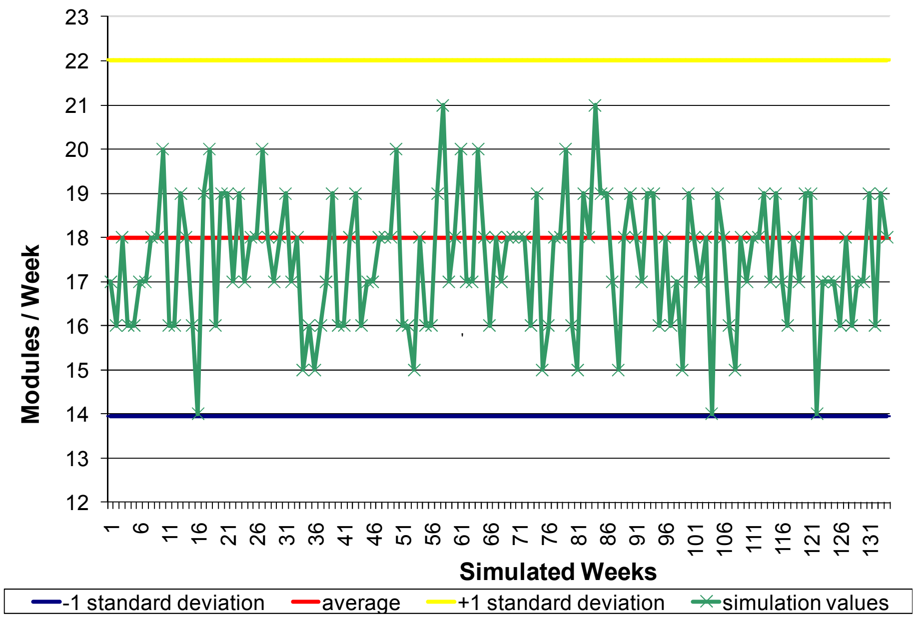

Figure 6: Basic model graphic validation

Figure 6 indicates that the simulation had variability in its output just any real system has but at the same time those variations are within the maximum and minimum levels that were established to assure that the simulation variability does not exceed the real system variability.

The second validation is a statistical mean comparison where the result was the average of the simulation output and the historical output are the same with a 95% confidence and a p-value of 0.158. All the statistical validations were performed using the statistical software SPSS® 16.0.

Detailed Model

Having validated the sub-processes in the previous model and the times provided by the supervisors, those values were compared with the arrangement of activities gathered with the detailed time study. This second model was developed with higher detail than the previous one. This system has 114 different activities with 53 different groups of personnel for the different activities (activities and groups numbers were based on the time study). The purpose of this model is to have detailed information in order to perform better system analysis. The detail model includes the same variables as the previous model with a higher level of detail. In this model the decision of the type of variable used to simulate processing time were based on the results from the process and time study.

For this model an initial validation was made by comparing the information validated in the previous model with the throughput of the different groups of simulated activities (same procedure used to validate graphically the first model). Doing this step by step comparison helps to represent accurately the real process as a holistic system and also as sub-processes. The results of all the comparisons are that the time study represents the system.

For a higher confidence level of the detailed simulation we used an additional comparison, the output of the system. The simulation output was compared to the current year information data. We choose current year data instead of all the historical information to reduce the variability of production levels throughout the years. The boundaries for the graphical comparison were the minimum and maximum values of the system's output for the year 2007. The final result in Figure 7 is the validation of the model.

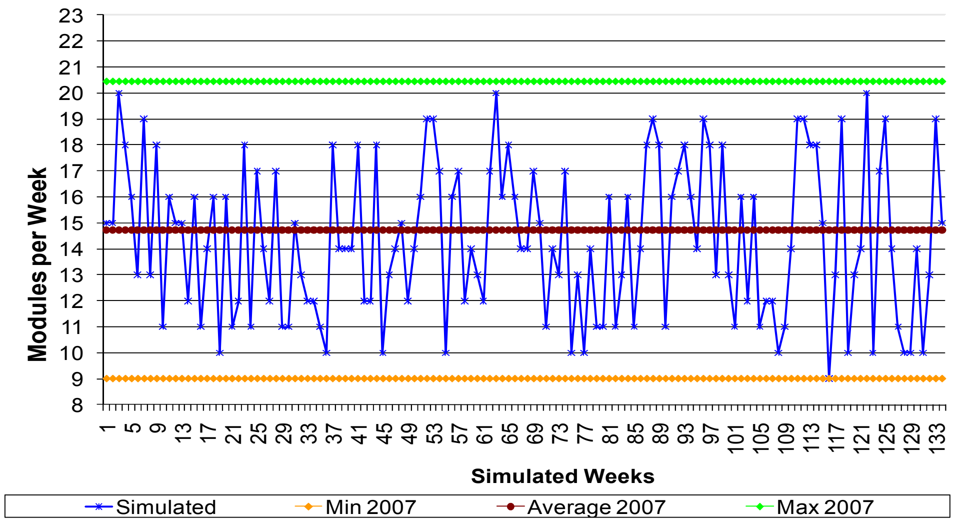

Figure 7: Detailed model graphic output validation

Improvement Alternatives

The different alternatives simulations were performed in detailed. This model allows the user to do small variations in the system to study changes in the output. All the proposed alternatives and the original simulation considered the physical restrictions of the real system.

The alternatives selected for the study were based on the current state of the manufacturing facility and the results obtained from the detailed simulation (processing time, queuing time, queuing size, and production throughput).In addition, some of the alternatives were requested by the company since they were in progress or part of an improvement plan. The comparison variable between the current system simulation and the proposed alternatives was weekly output.

Cross-training

From detailed study of the current system simulation several parameters led to this first proposed alternative. Resources utilization (workforce) and the number of modules in the processes queue indicated that there is an uneven distribution of the personnel throughout the facility. The objective of this alternative is to reduce workforce idle time while achieving a better continuous flow system. The key to good crew performance is to limit the variability in labor productivity by matching changes in workflow with flexible work assignments (Thomas et. al. 2003).

The proposed strategy is to train employees to be able to shift positions within the production line and perform different working tasks to acquire the ideal personnel distribution. The initial system consists of 53 working teams with specialized employees in every one of them; the proposed system (changes to the model to simulate the alternatives) has only 14 groups where every team member is trained to work in more activities than before. The system works with the same amount of employees. The difference between the current simulation output and the alternative is represented in Figure 8. The red line on figure 8 represents the simulated values of the current manufacturing conditions or the baseline for comparison and the blue line represents the improvement achieved with the proposed alternative.

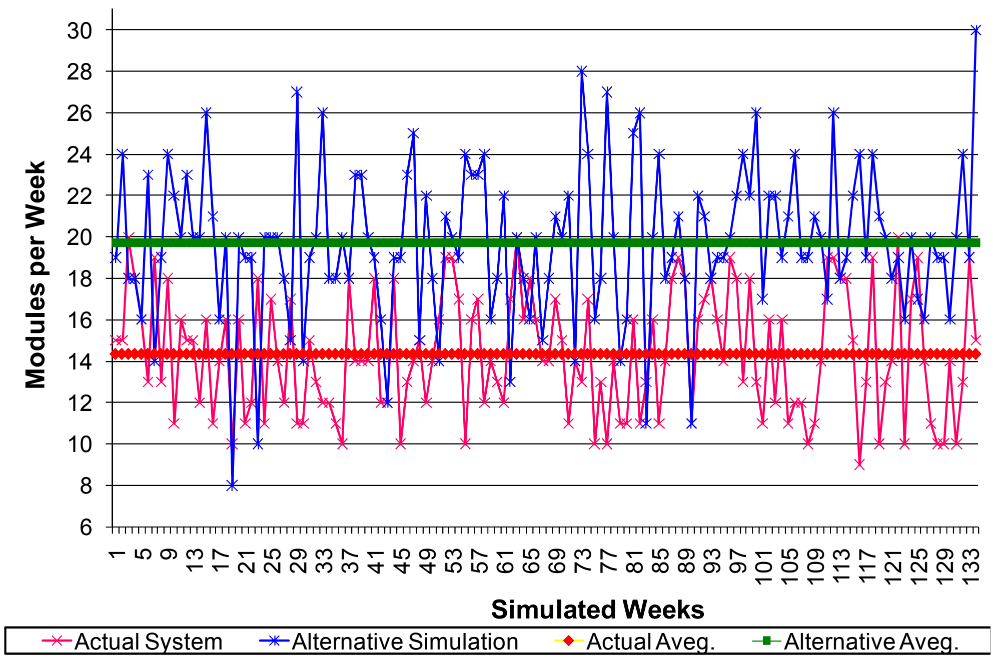

Figure 8: Cross-training alternative comparison with current system

The visual difference was analyzed with an average statistical differences test and the result was an improvement on the output of 37.44%.

5S Implementation

Even though the facility was reasonably tidy and clean while the time study was performed, the second study alternative is based on 5S. This tool, as all other Lean Manufacturing tools, is based on continuous improvement and therefore it is important to keep improving the manufacturing parameters to promote the philosophy. In this case we assumed a reduction of the processing time as the result of 5S implementation (changes to the model to simulate the alternatives); this assumption allowed us to simulate this alternative using the variables that the simulation models uses. Even though the improvement achieved by 5S can vary from one facility to another; in this alternative we studied low improvement levels (5% and 10% process time reduction) to evaluate the impact of manufacturing time reduction in the system output.

In this case, both alternatives (5% and 10% process time reduction) provided an improvement of the system's output. A graphical comparison between the improvement and the current system does not provide much information because the differences are very small. A statistical comparison test was performed and indicates that the improvement of the system was of 5% and 7.4% respectively.

Takt time alternative

The third proposal is based on the takt time. The ideal takt time set by the company is 20 modules a week or one module every two hours. To adjust the system to this pace we redistributed activities to balance each station to a length of approximately of two hours. The system was also transformed to a pure pull system; all the buffer stations represented in the current value stream map were eliminated; these are changes done to the simulation model.

This simulation proved to be unsuccessful, seeing that the variability of the operational time and the elimination of the buffer stations affected the system in a negative way causing a decrease in the system's output.

Further alternatives were studied to reach the desired 20 modules per week state. The proposed alternatives focus on reducing the processing time between the different workstations. The first additional change to the system is the usage of buffer stations; this new alternative presents less buffer stations than the current system due to the increment of work stations from the previous alternative and due to floor space limitations.

There is an improvement in the output compared to the first takt time proposal but the final result is still less modules per week than the current system. Further analysis regarding takt time approach is described next.

The variability of the systems needed to be reduced in order to analyze the takt time approach. Considering the floor space restriction was at a maximum, the variability was reduced by incorporating the cross-training alternative. In this case we combined the takt time with the buffers proposal and the cross-training. The proposed system worked with 14 groups as the first suggested redesign.

The achieved result of this simulation, as it can be seeing in Figure 9, is an improvement of 38.58% of the output; this improvement was statistically analyzed with a confidence level of 95%, the improvement is produced by changes in the system and not due to statistical variances. The level of improvement achieved was a result of all the different alternatives combined.

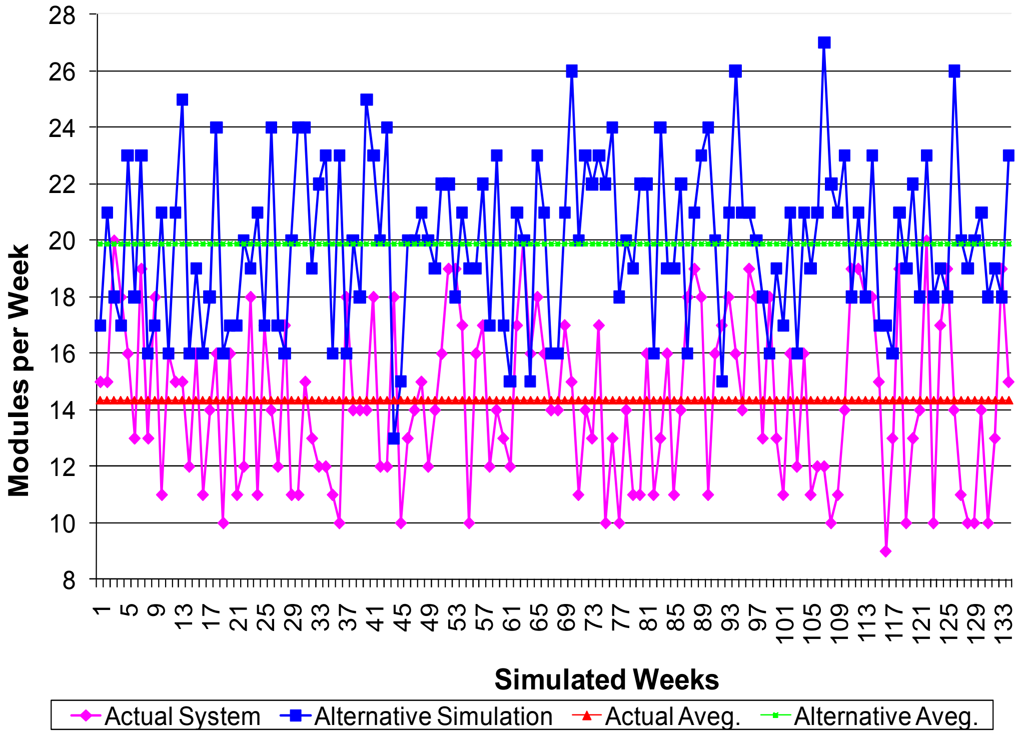

Figure 9: Final takt time alternative comparison with current system

Results and Analysis

To set an economic comparison between the proposed alternatives we started with the assumption that the system does not incorporate personnel to accomplish an increase in output. The financial improvements are going to be reflected as a cost reduction per module. The calculations are based on the distribution of the same labor cost over more modules produced since no salary changes. The associated cost of the improvements considers training expenses in every alternative and floor rearrangement for the last alternative. The costs associated with training were determined in conjunction with the company based on the skill of the employees at the time of study.

Every increase in weekly production levels implies also a reduction in labor cost per module (same total labor related cost divided by more production units). The comparison summary of all the alternatives is showed in Table 1.

Table 1: Improvement levels and economic comparison between the alternatives

Alternative	Production Improvement	Cost Reductions	Annual Savings	Associated Cost
Cross-training	37.4% from 14.35 to 19.72 modules per week	27.2% per module	$ 1,131,000.00	$ 5.420.00
5S Implementation 5%	5.0% from 14.35 to 15.07 modules per week	4.8% per module	$ 199,000.00	$12,050.00
5S Implementation 10%	7.4% from 14.35 to 15.41 modules per week	6.9% per module	$ 287,000.00	$ 35,000.00
Takt Time	No Improvement	No Improvement	No Improvement	-
Takt Time with Buffers	No Improvement	No Improvement	No Improvement	-
Takt Time with Buffers and Cross-training	38.5% from 14.35 to 19.89 modules per week	27.8% per module	$ 1,156,000.00	$ 62,420.00

As can be seen from Table 1, the first alternative shows a 37.44% throughput improvement going from an average weekly production of 14.35 modules to 19.72. That throughput increase also reduces the labor cost per module in 27.24%. These variations do not follow a linear trend. Despite the relative small cost reduction the total annual savings exceeds one million dollars.

The 5S alternatives show an improvement in throughput that increase as the processing time are reduced. This trend is also not linear; the 5% processing time reduction generated a throughput increase of 5.04% while the 10% processing time reduction generated a 7.43% increase in production. Despite presenting good improvements the associated cost of these alternatives are higher than the first alternative because the company believes their employees need more training to implement good and sustainable 5S practices than for the cross-training alternative.

The initial approach for the takt time alternatives did not show improvements to the system because the system's variability requires a method to improve the manufacturing flow. The incorporation of buffer stations was not enough in this scenario because of floor space limitations. The inclusion of cross-training incorporates an additional method to improve the flow of the system.

The proposed alternative which shows the greatest benefit is the takt time with buffers and cross training. Even though this is the best alternative it can also be stated that the biggest contribution to the improvement comes from the first cross training alternative and therefore this should be the first focus of change. This alternative provides yearly savings (based on previous assumptions) of over $1,000,000.00.

All cost information was provided by the company and it is specific to the company. Detailed information cannot be published here due to confidentiality agreement with the company. However, the percentages values and trends between cost and benefits could be applied to similar facilities to determine the levels of improvements that could be obtained.

Conclusions

The modular housing market must seek improvement alternatives as a part of their global strategy to stay in business, to remain competitive and to increase their market share in a tougher market. Positive differentiation is one of the keys in any market to earn top positions and to remain in consumers' minds.

The key to a good modeling system is to have appropriate data to use as an input to the system as well as an adequate process to characterize the data in terms of a function usable in the model. The limitations of the model will also be a factor that will determine the types of analyses that can be performed.

Models allow simulating the manufacturing process of a modular homes manufacturer and evaluating the impact of implementing some Lean Manufacturing tools in order to show a skeptical company the advantages of Lean Manufacturing.

The takt time alternative (the alternative where only takt time was considered) showed that Lean Manufacturing tools should be analyzed and adapted prior implementation to best suit each individual industry needs and constrains.

Lean Manufacturing tools, as the one studied in this research, proved to be good strategies for modular homes manufacturers to achieve improvements that significantly outweigh the cost of the implementation.

This research gives a set of alternatives to improve the output of a productive system without incurring in mayor investment. The best alternative is to target the current ideal takt time with buffers combined with the cross training staff alternative by distributing activities and personnel to obtain a better flow.

Improvement alternatives, with set goals like the results of a simulation model, can guide practitioners through the improvements paths to be successful in their implementation. A known successful alternative will help to engage the employees to reach a defined future state and avoid trial and error implementations that might be very costly.

Further efforts should also be considered as differentiating strategies. Some of those efforts that are not considered in this research but should be part of the manufacturers practices are: on time deliveries with short delivery times with a trend to a just in time system; high customizing options; energy star certifications as well as green construction certifications to provide an incentive for the customers to prefer one manufacturing over another.

In addition, for a complete improvement of any facility operations it is important to strengthen the relations throughout the entire supply chain, from all the suppliers to the customers. Accurate performance and on time information, in every level of the chain, will give the required smoothness to the system to deal with the current market situation; this approach of the supply chain is part of lean construction.

A further study that involves the post- manufacturing activities until the houses are finished on site could bring important insights on how to synchronize all the processes to maximize the value adding activities.

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