Manufactured Housing Research Alliance

Getting Lean: Assessing the Benefits of Lean Production in Factory Built Housing

U.S. Department of Housing and Urban Development

PD&R

PATH
Partnership for Advancing Technology in Housing

Getting Lean: Assessing the Benefits of Lean Production in Factory Built Housing

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PREFACE

This document, *Getting Lean: Assessing the Benefits of Lean Production in Factory Built Housing*, is the final report of the first phase of a planned multi-year research effort to develop and implement lean production techniques for the factory built housing industry.

The Partnership for Advancing Technology in Housing (PATH), administered by the U.S. Department of Housing and Urban Development, is focused on improving the affordability and value of new and existing homes. Through public and private efforts, PATH is working to improve affordability, energy efficiency, environmental impact, quality, durability and maintenance, hazard mitigation and labor safety. Lean production is a series of techniques, the successful implementation of which will result in significant progress towards achieving many of these goals.

This research effort consisted of two parts. First, a benchmarking survey was conducted of home manufacturers across the country. Benchmarking current performance is a necessary first step in implementing lean production improvements as it provides a series of metrics to gauge future progress. The results of the benchmarking study also help guide future implementation efforts.

Second, an in-depth assessment was conducted at one case study plant. This case study was used to test the process of developing lean techniques for a homebuilding plant.

Lean production has been successful in transforming other industries, notably automotive manufacturing. With a focused research program and the commitment of leading manufacturers, similar results may be achievable in the factory homebuilding industry. The successful transformation of factory homebuilding into a lean industry will provide substantial benefits to consumers of affordable housing, as well as improve the health of the industry for years to come.

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EXECUTIVE SUMMARY

A survey was conducted of factory homebuilding plants comparing and contrasting indicators of production efficiency and product quality. The goal of this benchmarking project was to identify areas for potential production efficiency improvements through the application of lean production. Of the 275 plants producing factory built homes (HUD-code and modular), 141 provided data, yielding a 51% response rate. To compare plants within similar markets, the survey population was divided into seven groups based on product type and geographical region.

The survey revealed a substantial variation of plant performance within the factory homebuilding industry. Likely causes of variation include: geographic location, specific market dynamics and product line differences, as well as differences in operational performance. The extent of the variation suggests that operational performance differences between plants are significant and that there is ample opportunity for improvement in the industry.

One plant was selected as a case study for the development of lean production techniques. Production efficiency metrics for the case study plant were compared to the industry benchmarks developed in the survey. A concurrent engineering process was employed to identify production, energy efficiency and structural engineering improvements to the plant and its products. As a result of the analysis, it was determined that there was an opportunity to substantially improve production labor efficiency; dramatically increase capacity without additional plant or equipment; and reduce rework and service costs. To achieve these goals would require little capital investment but would demand time and dedication from management and a substantial cultural and operating change.

1

INTRODUCTION

1.1 OBJECTIVE

The objective of the research program, of which this project is the initial phase, is to develop lean production techniques that will shape the homebuilding factory of the future. Goals of the project include the following:

1. Increase design and production flexibility, expanding the range and type of building solutions offered by HUD-code and modular home producers while cost-effectively increasing production efficiency;
2. Produce and install homes with zero defects; and,
3. Eliminate waste in all forms, including cycle times, building materials and excess labor.

As the first step in reaching these goals, a comprehensive benchmarking effort was undertaken to gain an understanding of key production metrics that characterize the industry, and lean techniques were tested through implementation in a single homebuilding plant.

1.2 BACKGROUND

The construction techniques utilized today in the HUD-code and modular housing industry have changed very little in the past 50 years and differ little from those employed in traditional site built housing. The facilities have gotten bigger to accommodate the larger homes the industry builds today, and materials and methods of manufacture have evolved incrementally, but little has changed in the production processes, management of these processes, materials storage and transport methods or the actual materials used in the construction of the homes. While lean techniques have helped to catapult production efficiencies in other industrial sectors (notably automotive manufacture), examples of the application of these techniques to factory homebuilding are only beginning to emerge through this and other recent efforts. This research will help to develop these lean techniques and demonstrate their value to the HUD-code and modular housing industry.

Lean production is an approach to improving manufacturing efficiency. The goal of lean production is to satisfy the customer by delivering the highest quality at the lowest cost in the shortest time, using less of everything. This is accomplished by continuously eliminating waste in all forms: defects, overproduction, transportation, waiting, inventory, motion and processing. Originating with the Toyota Production System, lean production is the result of decades of development by automobile manufacturers, who have reduced average labor hours per vehicle by more than half with one-third the defects. Other industries have followed the automobile industry's lead, achieving similar results. Early studies have suggested similar opportunities for housing manufacturers.[1]

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[1] *Mullens, M. and M. Kelley, "Lean Homebuilding Using Modular Technology," Housing and Society, 31(1) 41-54, 2004; and Mullens, M. "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.*

Lean production methods focus on the value stream. A value stream is a process in which value, as defined by the end customer, is continually added to a product or service. Lean production philosophy is applied to two types of value streams: product flow and production flow. Product flow is the design flow from concept to launch of a new product. Production flow is the flow of the product from raw materials to the customer. Lean production encourages the mapping of the material and information flow within these two value streams to identify the value-added and non-value-added steps or processes. After identifying the non-value-added steps in a value stream, considered waste in the parlance of lean production, management can then focus efforts to eliminate that waste and improve safety, quality and productivity while reducing cost.

Lean production is a culture that becomes ingrained in the workforce of a company. It focuses on processes. It is not merely a management technique based solely on results. The guiding principles of lean production are:

- Elimination of waste in all forms
- Continuous, customer-driven workflow
- Continuous improvement
- Employee empowerment

Lean methods are applicable to manufacturing and service industries. For manufacturers, lean methods are applicable to production operations and office functions.

Typical benefits of converting from traditional mass production (sometimes termed “batch and queue”) to fully lean production can be dramatic and have been documented in a variety of industries.

Characteristics of a lean operation include:

- An orderly, clean work place
- Utilization of standardized “best practice” methods
- Plant layout designed to facilitate continuous product flow
- Just-in-time processing driven by customer demand or “pull“
- Single piece or small batch continuous workflow
- Quick changeovers of machines
- Minimal inventories
- Short order-to-ship cycles times
- Total quality control
- Defect prevention built into processes
- Rigorous application of preventative maintenance
- Team-based continuous improvement
- Partnership-oriented relations with suppliers and distributors

1.3 RESEARCH APPROACH

The research approach combined a national factory homebuilding benchmarking survey with the identification and evaluation of lean production techniques at a single plant. The results of the benchmarking and initial application of lean methods are discussed in this report along with a strategy for the ongoing development and dissemination of lean techniques. Each of these steps is described below:

1.3.1 Benchmark current production practices

Benchmarking current production practices provides a baseline for measuring the benefits associated with applying lean production strategies, for comparing alternative manufacturing practices and for pinpointing plant specific production weaknesses to be improved in subsequent phases of the work.

Benchmarking establishes a reference point for gauging the current level of plant efficiency and the range across many plants, as well as a basis for measuring the impact of the research. Plants can be benchmarked in a variety of ways, and no single benchmark portrays the overall degree of operating efficiency. Further, measures of performance must be referenced to corporate goals, markets and other factors. For example, a plant serving customers seeking higher-priced homes with wide design variations cannot be easily compared with a high volume, low price point producer.

Benchmark information was collected from a large group of plants through a survey. Information collected included several types of metrics, as shown in the survey form in Appendix A.

The benchmarking data was structured for most measures by industry segment based on defining characteristics, such as geographical location and product type. One full year of data was collected.

1.3.2 Develop and test lean production techniques at a selected plant

Initial efforts to test lean production methods were initiated in one manufacturing plant. The plant provided various opportunities for applying lean thinking. Working with industrial engineering researchers, specific recommendations were developed along with an implementation plan. This work began to evolve effective approaches for the industrial engineering community to work with housing manufacturers and provided a case study suggesting the benefits of applying lean thinking to home manufacturing.

A comprehensive approach was taken that involved conducting a thorough and iterative concurrent engineering process facilitated by a team of industrial engineers, a structural engineer and energy specialists. This team, along with plant staff, developed and ranked alternatives for improving production efficiency as well as product design improvements. The three disciplines worked in parallel, frequently sharing ideas and looking for synergies among potential recommendations.

The industrial engineers undertook a detailed investigation with the aim of uncovering the most promising opportunities for improving plant performance. These were grouped into a portfolio of techniques, some solving immediate performance problems and others that require looking to advanced technologies that result in more dramatic improvements in performance.

The structural engineer developed solutions to optimize performance and minimize material usage. Consideration was given to reducing home cost and weight and minimizing plant fabrication time. Among the major areas considered for improvement were connection methods and details and structural products, including appropriate proprietary and non-proprietary technologies currently available in developing alternative structural solutions.

Energy analysts reviewed the home designs, identifying changes that could improve the energy efficiency of the homes without significantly raising costs. Areas investigated included envelope systems and HVAC systems.

1.3.3 Communicate progress to all factory home builders

Customized reports were provided to each plant that participated in the benchmarking survey. In order to gauge their performance compared to other similar operations, plants were grouped into seven categories based on product and geographic region. The results of these efforts were publicized though industry media and presentations at industry meetings.

1.3.4 Establish a strategy for future research and development

Based on the experience of the benchmarking survey and the application of lean thinking to one case study plant, a strategy for the future development and application of lean techniques to factory homebuilding was developed. The strategy consists of expanding the pilot application of lean production techniques from a single plant to between eight and ten additional plants. Experiences gained by working with this larger cross section of plants can then be generalized to the industry at large.

The research team will work with selected manufacturers in areas that are likely to hold great strategic value in improving overall factory performance, with special consideration given to areas known for poor quality, low productivity, capacity bottlenecks and constraints to customization. These areas will be selected with the assistance of participating manufacturers based on the benchmarking results and plant-specific value stream mapping.

Of critical importance to this strategy is gaining the manufacturers' commitment to and ownership of the lean production process. This will be accomplished by requiring that participating companies invest time and resources in the project and assign a senior staff member as the lean advocate for the plant. The lean advocates will be central members of the project team and ultimately responsible for transferring the knowledge gained through the project to the plant and to the company as a whole.

2

BENCHMARKING

2.1 THE SURVEY PROCESS

2.1.1 The Purpose of benchmarking

Benchmarks are measures of current performance. The benchmarks established in this study are selected as measures of production efficiency. Once current performance is understood, goals can be set for performance targets, which are comparable measures based on best practices in the industry.

Benchmarks permit a subject plant to measure progress towards achieving these performance targets. Benchmarks also serve as a measure by which a plant can be compared to other home manufacturing operations.

2.1.2 Survey Development

An industry committee, consisting of representatives of large and small factory homebuilders, was convened to oversee and advise the project. One of the first tasks of the committee was to discuss and identify the most meaningful data to gather. Based on committee input, a draft survey instrument was developed. The draft survey questions were reviewed and critiqued by the committee, then modified and reviewed again in an iterative process. Once the questions were finalized, the survey form was developed in an electronic format that included built-in error-checking capability.

A beta test of the survey was conducted with seven manufacturers. Each of the seven manufacturers completed the survey for a single plant and then provided feedback to refine the survey questions' wording and terminology, and the look and function of the survey form. After suggested changes were made, the survey was distributed to all home manufacturers in the nation. The survey form is provided in Appendix A.

2.1.3 Conducting the survey

In parallel with the development of the survey, researchers identified and gathered contact information for factory home building companies across the U.S. Approximately 150 companies were identified, which among them operate 275 plants, both HUD-code and modular. Contact information was gathered for the key decision maker at each company (usually the president or CEO).

When the survey was ready for distribution and posted on the MHRA website, an email with a link to the survey was sent to the contacts inviting them to participate. Information about the survey and the MHRA lean production research efforts was also distributed through a variety of industry publications, industry meetings and follow-up emails. All factory homebuilders in the U.S. were eligible to participate. The survey was open for a four-month period from January through April 2005.

All information from participating manufacturers, including the identity of the companies themselves, was kept strictly confidential. To protect the privacy of the data, contractors involved in the data collection and data analysis were required to sign non-disclosure agreements.

2.2 SURVEY RESULTS AND ANALYSIS

2.2.1 Survey response

Completed surveys were received from 141 factory home building plants, representing 51% of the approximately 275 operating plants. Of this number, 29 plants produced primarily modular homes, representing about 25% of the modular plants in the U.S., and 112 plants produced primarily HUD-code homes, representing approximately two-thirds of all operating HUD-code plants.[2] The plants were widely distributed geographically, representing 27 states and Canadian provinces.

2.2.2 Survey data and analysis

The graphs shown in Figures 1 through 8 describe the performance of all 141 plants relative to some of the key benchmarking metrics.

Figure 1 shows the percent of labor resources in participating plants that are not available to produce product. It expresses the fraction of productive capacity that is lost, or the level of redundant labor resources necessary to maintain production capacity. Lost labor resources do not translate directly into financial loss if wages are not paid. However, some costly benefits (e.g., medical) are still paid regardless of absenteeism. Absenteeism also creates daily disruption on the plant floor, resulting in lost productivity and reduced quality. Together with labor turnover (see below), absenteeism is an important measure of worker satisfaction. A high value suggests workforce challenges. **Sample average: 6.03%**

Figure 1 Average absenteeism

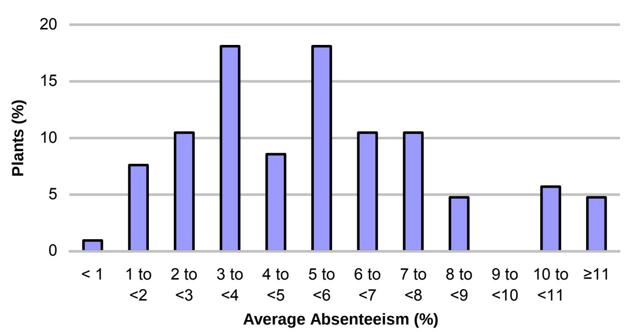


Figure 2 describes the stability of the workforce in participating plants (expressed in terms of annual labor turnover). Together with absenteeism, it is an important measure of worker satisfaction. A high value implies worker dissatisfaction. **Sample average: 61%**

[2] Plants were classified as either HUD-code or modular based on the majority of homes produced in the plant in the previous 12 months.

Figure 2 Average labor turnover

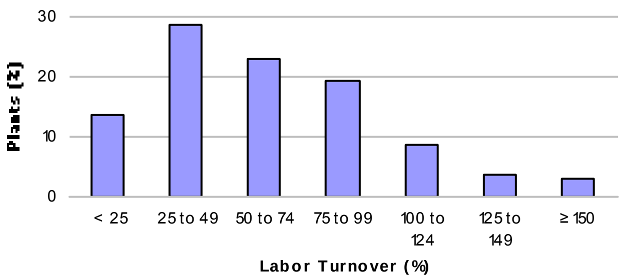


Figure 3 shows the total factory labor cost per floor produced. This is a key measure of labor resource productivity. Plants on the upper end of the scale should seek to reduce the metric by eliminating non-value-added activities and other forms of labor waste, and/or eliminating bottlenecks and smoothing flow. **Sample average: $3,187**.

Figure 3 Total labor cost per floor produced

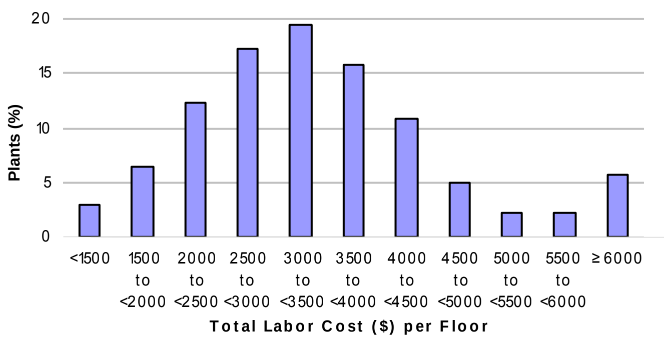
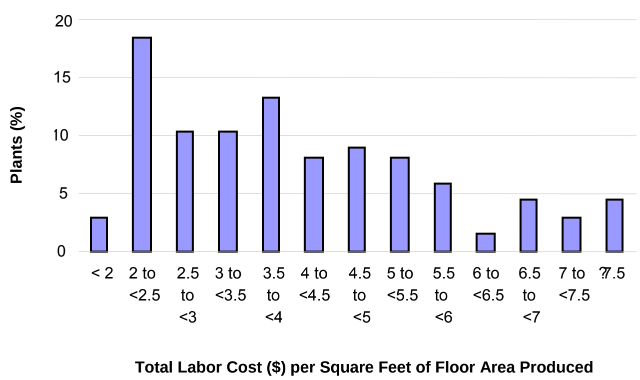


Figure 4 shows the total factory labor cost per square foot of floor area produced. This measure of labor resource productivity is similar to Figure 3 but accounts for varying floor sizes. There is a wide range of values reflecting the fact that there is a wide variety of home price points and customization levels included in the database. **Sample average: $3.69 per square foot.**

Figure 4 Total labor cost per square foot of floor area produced



Service costs are defined as the per-home cost of resources (labor and materials) wasted resolving discrepancies identified after the home is delivered to the customer. This key measure of quality is displayed in Figure 5. A high value suggests quality challenges. Plants on the upper end of the scale should seek to reduce service costs by identifying critical quality problems, pinpointing their root causes and developing and implementing solutions. **Sample average: $0.94 per square foot.**

Figure 5 Service costs per square foot of floor area produced

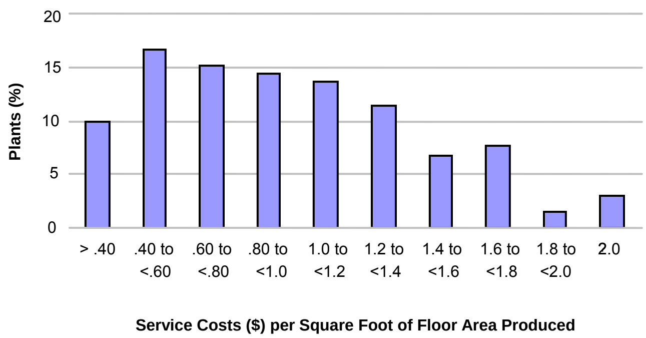
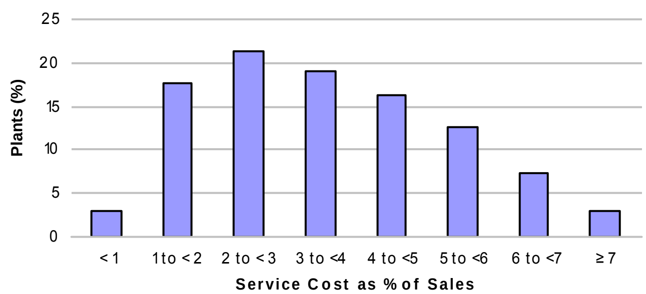


Figure 6 indicates the percent of each sales dollar spent on service costs. As above, the goal should be to significantly reduce such costs. **Sample average: 3.8%.**

Figure 6 Service costs as a percent of sales dollars



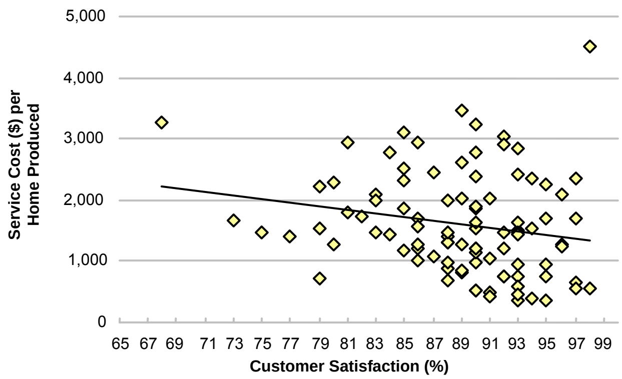
The graphs shown in Figure 7 and Figure 8 describe the relationship between key benchmarking metrics. The straight line shown on the graphs represents the linear relationship that "best fits" the data. This line is provided to show the general trend suggested by the data. It does not imply that there is a statistically significant or causal relationship between metrics.

Figure 7 plots quality (expressed as service costs per square foot of production) versus annual labor turnover for each plant (represented by a point on the chart). The trend line suggests a very loose correlation between higher labor turnover and lower quality (higher service costs). The wide variation in plant type (product price point, complexity and market region) may explain the lack of a stronger correlation between these two variables.

Figure 7 Labor turnover versus quality

The trend line in Figure 8 suggests that customer satisfaction and service costs are inversely correlated. The fit of the line to points is loose, but the overall trend direction is clear.

Figure 8 Customer satisfaction versus quality



A synopsis of some of the key benchmarking results is shown in Table 1. The national average as well as highs and lows are provided for 11 basic plant metrics and 11 productivity and quality measures.

Table 1 Benchmarking summary

Description	**Average**	**High**	**Low**
Basic Plant Metrics			
1. Number of models produced representing 90% of sales	30	109	1
2. Annual floors produced	1,388	6,039	172
3. Annual sales	$30,091,269	$119,288,811	$5,000,000
4. Order backlog	105	890	24
5. Annual direct labor cost	$3,745,609	$17,075,859	$139,000
6. Annual total labor cost	$4,441,914	$19,995,877	$214,000
7. Material inventory turns	20	85	2
8. Annual service cost	$1,133,005	$7,257,214	$50,000
9. Average absenteeism	4.95%	16%	0.5%
10. Labor turnover	62%	178%	5%
11. Capacity utilization	66%	120%	15%
Productivity and Quality Measures			
12. Productivity (direct labor dollars per floor produced)	$3,014	$10,465	$486
13. Productivity (total labor dollars per floor produced)	$3,548	$11,311	$748
14. Productivity (direct labor dollars per sq ft of floor area produced)	$3.55	$12.00	$0.65
15. Productivity (total labor dollars per sq ft of floor area produced)	$4.24	$17.10	$1.00
16. Productivity (direct labor cost as a percentage of sales dollars)	13%	40%	1.74%
17. Productivity (total labor cost as a percentage of sales dollars)	15.23%	40%	2.68%
18. Value generated (sales dollars per sq ft of floor area produced)	$27.21	$55.43	$12.83
19. Quality (service costs per home produced)	$1,603	$4,509	$347
20. Quality (service costs per sq ft of floor area produced)	$0.96	$2.25	$0.20
21. Quality (service cost as a percent of sales dollars)	3.6%	7.9%	0.6%
22. Customer satisfaction	89%	98%	68%

2.2.3 Survey conclusions

Because the product of the factory built housing industry is so different from that of other industries, it difficult to draw objective, industry-wide conclusions from the benchmarking survey results. Some metrics, however, permit comparison to other industries. For example:

- Total inventory turns within the modular and HUD-code housing industry (an average of 20 turns per year, calculated as annual materials cost divided by average inventory value) is far better than that reported for other industries (six in aerospace; twelve in automotive; six in construction; and eight in durable consumer products).[3] Note that metrics for the other industries are medians calculated using Cost of Goods Sold instead of Cost of Materials—this results in an overestimate compared to true inventory turns.
- Employee absenteeism within the factory built housing industry (6%) is much greater than in the industrialized sector of the economy overall (3%), but less than in some successful industry sectors such as automotive (10%).[4]
- Employee turnover within the factory built housing industry (61%) is far greater than in other industries (28% in construction, 17% in manufacturing).[5]
- Plant capacity within the factory built housing industry is far underutilized (average 31%) when compared with capacity in other industries (70-75%).[6]
- Customer satisfaction with the factory built housing industry (89%) is much better than that of some other industries (79% manufacturing/durable goods, 80% automotive).[7] However, this information is self-reported as compared with some industries that use independent consumer surveys (e.g., J. D. Power).

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[3] Drickhamer, D. (2004). “Tick Tock”, *Industry Week*, January 1, 2004. (Also see http://www.industryweek.com/ReadArticle.aspx?ArticleID=1365&SectionID=10)

[4] Mayne, E. and Clanton, B. (2004). “Ford: Show up for Work,” *The Detroit News*, September 9, 2004. (Also see http://www.detnews.com/2004/autosinsider/0409/10/a01-268458.htm)

[5] Potter, E. (2004). “Employee Turnover is Expensive”, *Employment Policy Foundation Fact Sheet*, October 22, 2004. (Also see http://www.epf.org/pubs/factsheets/2004/fs20041022.pdf)

[6] Taninecz, G. (2004). “All Systems Grow”, *Industry Week*, September 1, 2004. (Also see http://www.industryweek.com/ReadArticle.aspx?ArticleID=1494&SectionID=10)

[7] American Customer Satisfaction Index (2005). “Second Quarter Scores: Manufacturing/Durable Goods & E-Business”, from American Customer Satisfaction Index website, August 16, 2005. (Also see http://www.theacsi.org/second_quarter.htm)

Focusing on the factory homebuilding industry alone, the variation of performance within the industry is striking. Likely causes of variation include: geographic location, specific market dynamics and product line differences, as well as differences in operational performance. The extent of the variation suggests that operational performance differences between plants are significant and that there is ample opportunity for improvement in the industry.

3

APPLYING LEAN TECHNIQUES: A CASE STUDY

The Capsys Corporation modular housing plant was selected to use as a case study for applying lean production techniques to a factory home building facility. The goal was to develop and recommend changes to the plant's production system and product design, thereby improving production efficiency and products, including energy efficiency.

The case study team consisted of industrial engineers, a structural engineer, an energy efficiency specialist and the plant management. The team worked together in a collaborative process to identify opportunities to improve the efficiency and productivity of the product design and manufacturing operations.

Building upon the earlier benchmarking work described in Chapter 2, benchmarks and performance targets were established for the manufacturing operations. The product design, including structural design and energy efficiency, and production processes were analyzed to identify inefficiencies and suggest alternatives.

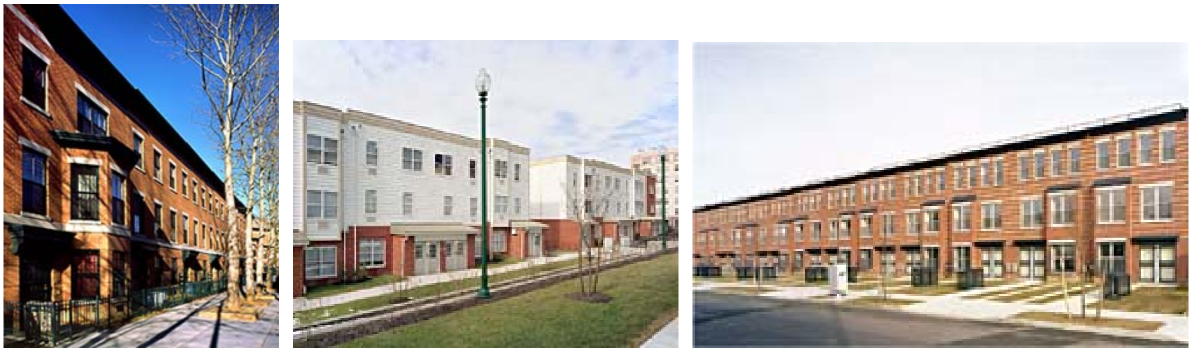
3.1 INTRODUCTION TO THE CASE STUDY PLANT

Capsys Corporation is a manufacturer of modular residential buildings located in Brooklyn, NY (see Figure 9). Capsys is unique among residential modular producers in that it serves primarily an urban market and uses a steel-based building system. All of Capsys' work is project-based for developers or general contractors as opposed to individual home sales. Projects typically contain from seventy to several hundred homes and last from several months to more than a year in production. The plant works on a single project at a time and re-tools each time they start a new job.

Figure 9 Capsys plant, interior and exterior

Most of Capsys' projects consist of attached townhomes with flat roofs. They also have built a number of multi-family residential structures and some commercial buildings. Their townhomes are typically built as affordable housing for first time homebuyers (see Figure 10).

Figure 10 Typical Capsys residential projects



The Capsys building system utilizes a welded structural steel frame with cold-formed steel framed infill walls. Most Capsys townhome designs use a plywood subfloor over cold-formed steel joists. However, they also use a concrete floor deck on some projects.

Capsys does all their own transportation and installation of the units. They transport on local roads rather than interstate highways and so can build and transport units up to 20 feet wide, enabling each townhome floor to be contained within a single module.

Capsys operates a single manufacturing facility which is described in greater detail in Section 3.3 below.

Figure 11 Capsys modules being set on three typical residential projects

3.2 CASE STUDY METHODOLOGY

The case study methodology utilized a concurrent engineering process. Concurrent engineering is a design approach that integrates the work of several disciplines simultaneously to develop solutions for a multifaceted problem. Concurrent engineering and lean manufacturing techniques have been demonstrated to improve production efficiencies in several industries, including the automotive industry. For the case study, the research team took a concurrent engineering approach using the disciplines of industrial engineering, energy efficiency design and structural engineering.

The process was iterative and was used to develop and rank opportunities that have the potential to achieve the performance targets identified in the benchmarking task.

The case study methodology included collecting a wide variety of data on previous home designs and past performance of plant operations. This data enabled team members to understand the Capsys production system and end products. It was used both in the benchmarking process and in the concurrent engineering process.

3.2.1 Observation in the plant and value stream analysis

Industrial engineers spent three days in the Capsys plant observing all activities at each station on the production line. They collected information that describes Capsys' plant and operations, enabling them to accomplish the following:

- Develop a value map of Capsys' production process.
- Identify the activities involved in each process for every stage of production.
- Classify each activity as either value-added or non-value-added.
- Determine flows between production line activities.
- Estimate the resources used to support non-value-added activities and explore options for eliminating or reducing them.

Industrial engineers used the data collected during plant observation to develop a high-level value stream map (see Section 3.3) and to do detailed analysis of specific plant activities.

3.2.2 Energy analysis

The energy efficiency specialists collected information on the range of designs offered by Capsys enabling them to do the following:

- Describe the features of the home that impact energy performance.
- Identify alternative design strategies that minimize energy usage without increasing costs.
- Estimate annual energy usage via a computer simulation program (see Appendix C).
- Conduct an energy audit of a typical building unit (including blower door and duct blaster testing).

3.2.3 Structural analysis

The structural engineer collected information in order to:

- Document the steel member sizes to determine if additional efficiencies can be gained by reducing member sizes.
- Document the structural system design to suggest alternative structural schemes.
- Document the types of fastening systems Capsys uses for typical building units and determine if other systems might be more cost-effective and desirable from a design and production standpoint.

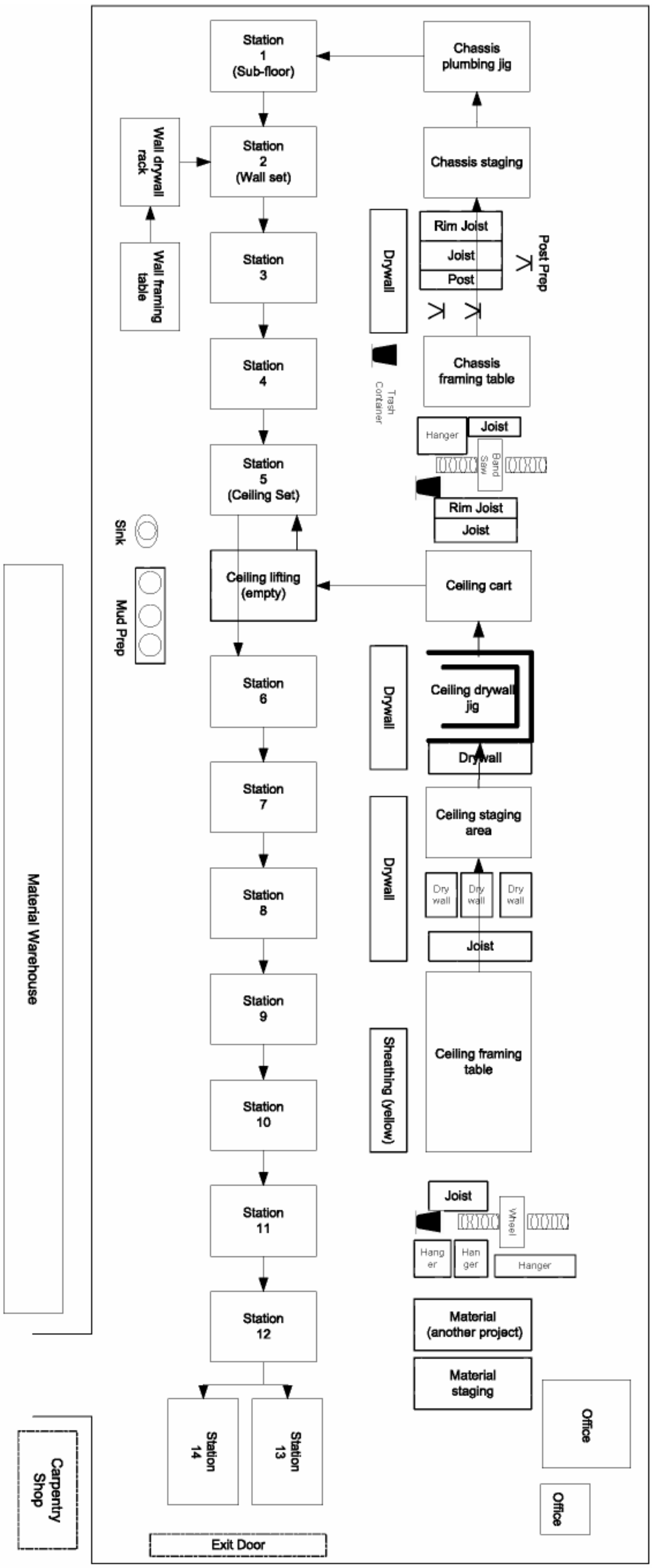
3.3 OVERVIEW OF THE CASE STUDY PLANT

Capsys has been in the present plant since opening in 1996. They have produced over two million square feet of residential and commercial structures in that time. During normal operations, the plant workforce consists of approximately 60 factory workers plus 15 management, engineering and clerical staff. The plant production staff is unionized with an average labor rate of roughly $25 per hour.

The plant is located in a 65,000-square-foot former shipbuilding facility. The main line runs down a 60-foot-wide, very high center bay serviced by a bridge crane. Two narrower outboard bays flank the main bay. The north outboard bay, which contains the ceiling and floor subassembly areas, is also serviced by crane. The outboard bays are limited in height and width, fixing the module length to approximately 40 feet maximum. The southern outboard bay contains the wall panel assembly area, carpentry, plumbing and mechanical workshops, and material storage.

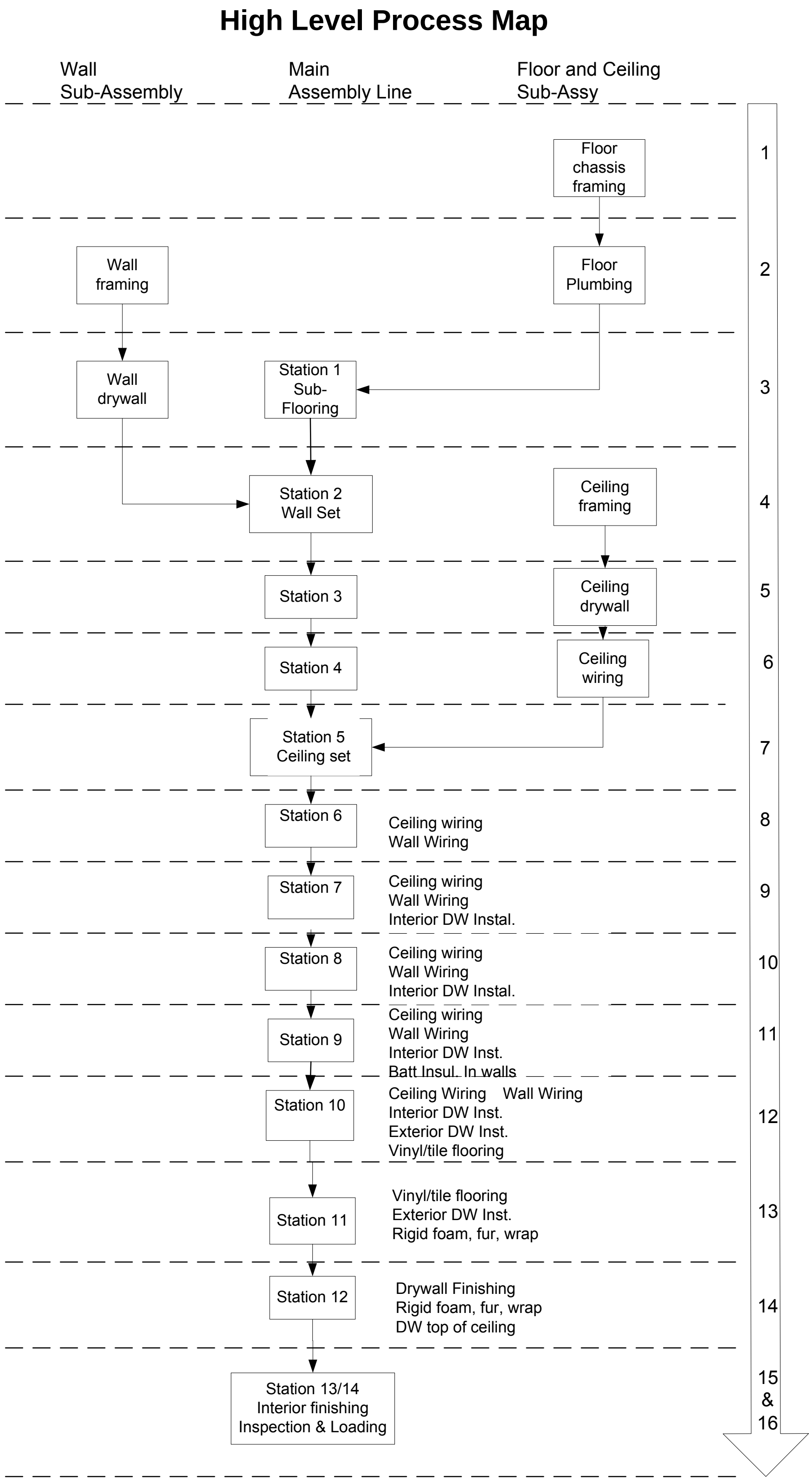
Capsys' typical production line as shown in Figure 12 is set up in sidesaddle configuration with floors, ceilings and walls feeding the line from the outboard bays and two side-by-side finish stations at the end of the line. The production line typically runs on a 4-, 6- or 8-hour cycle time, depending on module complexity and production needs.

Figure 12 Schematic of the Capsys production line



A high-level process map of the Capsys plant is shown in Figure 13. The map includes each high-level activity; the physical location(s) within the plant where the activity typically takes place; and a time line indicating the production cycle during which the activity occurred. This map was generated based on observation of the production of the Edgemere project in February 2005. During the visit, the plant operated at a rate of four modules per week, with an equivalent cycle or TAKT time of 10 hours per line move. This production rate is 40% of the full production rate of the factory and was driven by anticipated need for the modules at the site rather than limitations in factory output.

Figure 13 High level process map of the Capsys plant



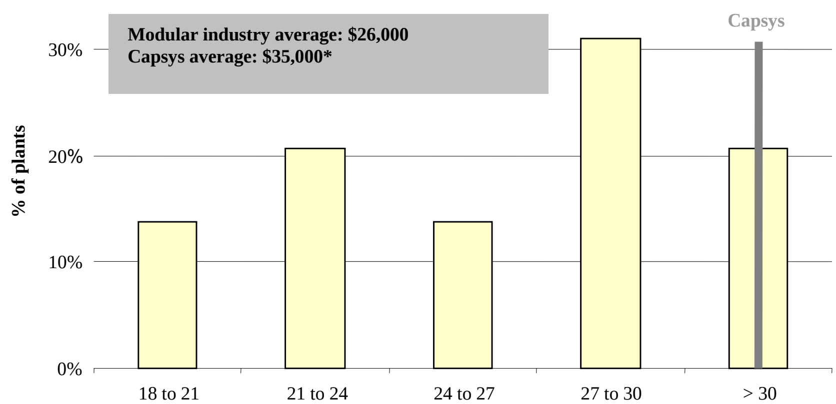
3.4 BENCHMARKING THE CASE STUDY PLANT

Selected data collected from Capsys was compared to the modular home segment of the database developed from the benchmarking survey.

While Capsys is a different type of company with a different business model and producing a different product type than most other modular home manufacturers, there are several comparisons that are relevant.

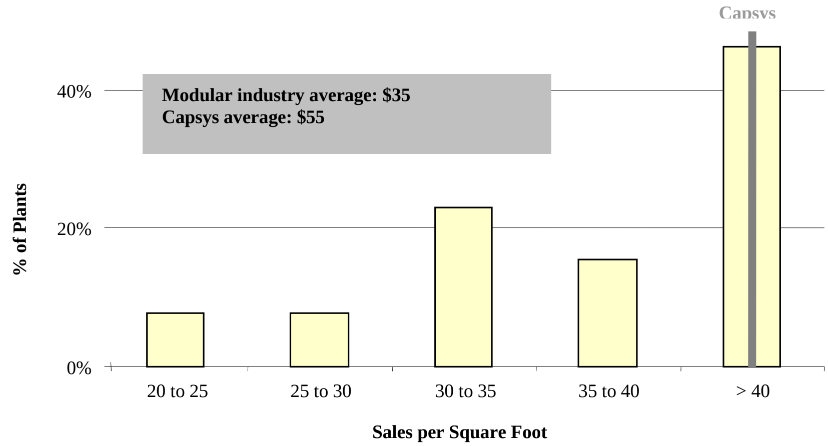
For example, Capsys' average sales per floor (Figure 14) and sales per square foot of home produced (Figure 15) are substantially higher than the average modular plant. The higher costs are due to the fact that, despite producing entry level products, Capsys uses a high-cost building system (structural steel frame) and delivers homes in a high-cost market (New York City). Unlike most modular producers, Capsys transports and installs its units, the costs of which further inflate these sales figures.

Figure 14 Sales per floor



*Average of Nehemiah, Atlantic Center and Bayview projects

Figure 15 Sales per square foot of home produced



Capsys' average production rate (in floors per week) (see Figure 16) for the projects studied was less than half that of the typical modular plant, while their capacity utilization (see Figure 17) was similar to the modular industry average for the period studied.

Figure 16 Production levels

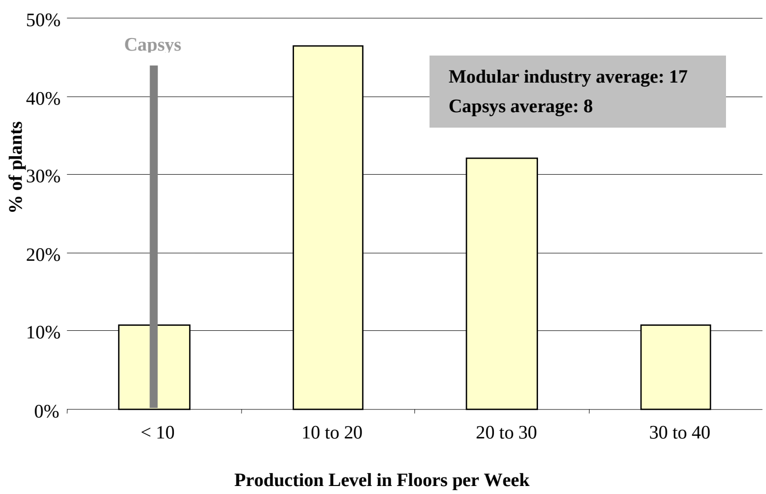
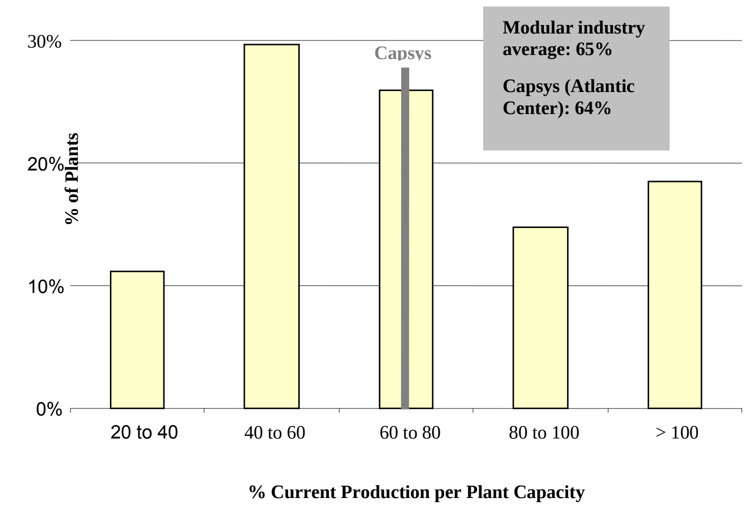


Figure 17 Capacity utilization



As would be expected in a high-cost labor market, the ratio of labor costs as a fraction of sales (see Figure 18) and per square foot of homes produced (see Figure 19) was much higher for Capsys then for the industry at large.

Figure 18 Total labor cost as a percent of sales

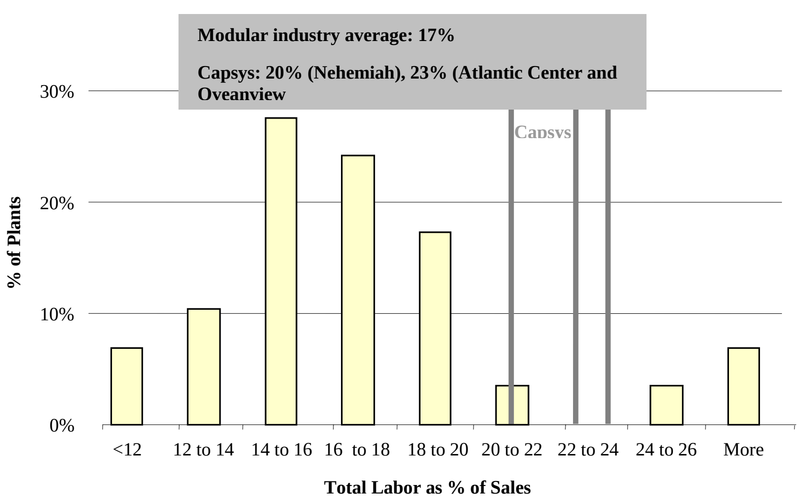
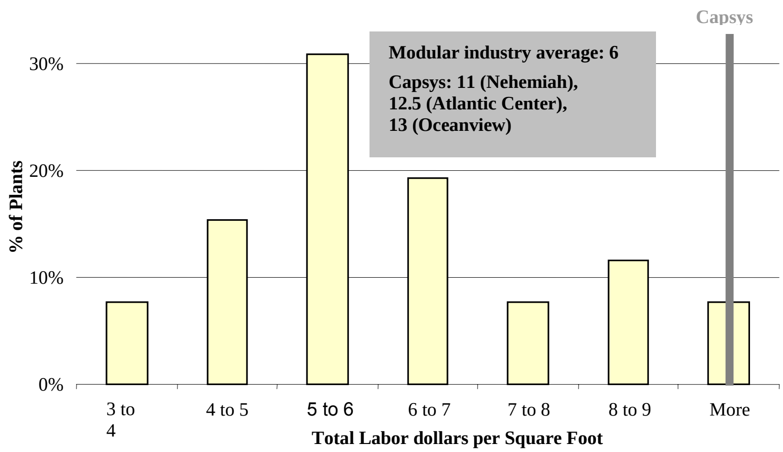
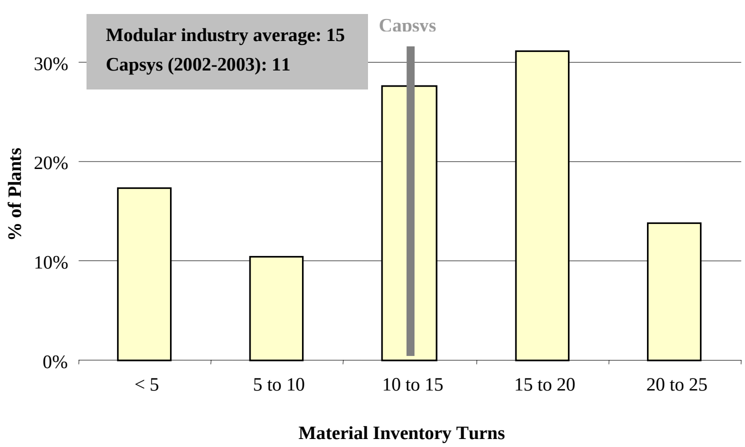


Figure 19 Total labor cost per square foot of home produced



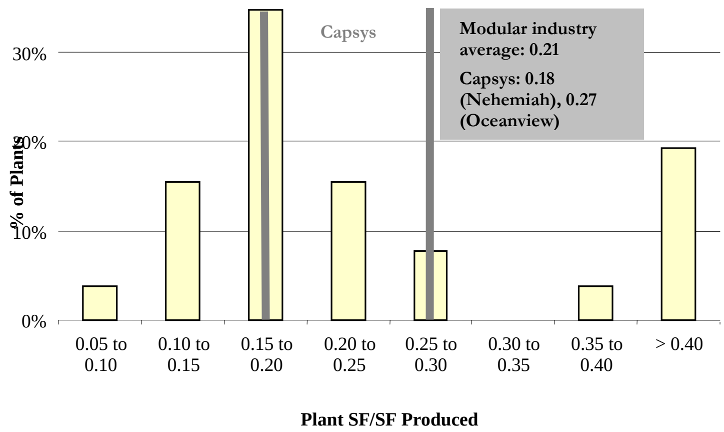
Capsys' inventory turn rate is lower than the modular industry average (see Figure 20). The company routinely orders and receives all materials before a project starts. Because project duration ranges from several months to over a year, this inventory management policy drives average inventory levels up and decreases inventory turns. Capsys adopted this policy due to poor supplier reliability and the high cost of project delay.

Figure 20 Material inventory turns



Capsys plant size per square foot produced is in line with the industry average (see Figure 21).

Figure 21 Plant size per annual square foot of home produced



3.5 OBSERVATIONS AND RECOMMENDATIONS

MHRA concurrent engineering team members, including industrial engineers from the University of Central Florida, structural engineers from ADTEK Engineering, Inc. and energy specialists from MHRA observed and reviewed the design and production of a number of Capsys Corp. products and projects. After an initial analysis of opportunities for improvements, a comprehensive list was compiled. The team then reviewed and prioritized the list during a series of meetings and identified the top items for consideration by Capsys.

Industrial engineering offers the most potential benefits, therefore structural and energy recommendations have been integrated into the industrial engineering recommendations to form the group of primary recommendations described in Section 3.5.1. Additional energy and structural ideas are included in Sections 3.5.2 and 3.5.3 respectively. These opportunities represent ideas for further investigation.

3.5.1 Primary recommendations

These top recommendations, all based on lean production principles, are believed to have the greatest potential to positively impact Capsys' production operations. The criteria for selecting the primary recommendations were

- High return
- Low cost
- No major capital investment
- Applicable to most Capsys products/designs
- Incremental change to current practice

Each recommendation is listed below in Table 2 along with a qualitative estimate of the relative cost to implement and the potential benefit (in terms of cost savings) to Capsys.

Table 2 Top ten recommendations for lean production improvements

Recommendation	Cost	Savings
1. Expedite electrical processes	Low	Medium-high
2. Spread line activity by moving work upstream	Low-medium	Medium-high
3. Rationalize material staging and replenishment	Low	Low-medium
4. Purchase right-sized materials	Low-medium	Medium
5. Use the right tool for the job	Low	Low
6. Create sub-assembly cells	Low-medium	Low-medium
7. Use positioning guides and jigs	Low-medium	Low
8. Reduce welding	Medium	High
9. Re-engineer roof slope	Medium	Medium
10. Order the workplace	Low	Medium

These primary recommendations are described in detail below. In many cases, each recommendation is actually a series of related recommendations affecting a common process in the plant. For each, the observation that illustrates the problem is discussed, followed by recommended corrective actions.

Figure 22 Working on top of a module

1. Expedite electrical processes

Electrical processes have been identified as one of the most problem prone areas in the plant. Changes to the manufacturing processes in both the ceiling and wall wiring areas have the potential to improve productivity and improve safety.

A. Ceiling wiring

i. Observation: Ceiling wiring activities were clearly disorganized. Wiring took place on the wiring cart at floor level and on the main line after the ceiling was set. It was clearly more difficult and less safe on the main line, with the electrician elevated and forced to walk on the ceiling joists instead of the gypsum board (see Figure 22 and Figure 23).

Recommendation: All ceiling wiring should be performed on the wiring cart. This is not only more efficient and safer, but also allows all subsequent activities to be started earlier. The data in Table 3, taken from time studies conducted in the plant, show that it is up to 25% more efficient to perform the wiring on the ceiling cart (see Figure 24) before the ceiling is set on the module.

Figure 23 Wiring on top of a module

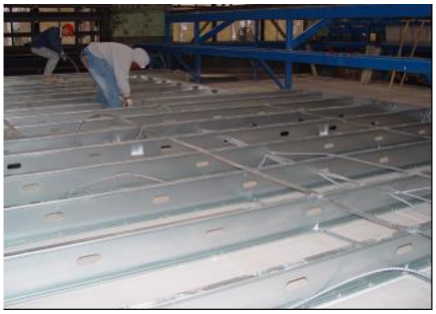
Table 3 Labor required for ceiling wiring

Module type	Ceiling cart (on floor)	Main line (after set)	Labor difference
1st floor	7.5 labor-hrs	9.3 labor-hrs	1.8 labor-hrs
2nd floor	2.5 labor-hrs	2.6 labor-hrs	0.1 labor-hrs

ii. Observation: Electricians seldom wired a ceiling without interruption. Instead, they were directed (or wandered) from module to module, interspersing ceiling with wall wiring activity.

Recommendation: Electricians responsible for ceiling wiring should complete each module (on the wiring cart) before moving to another module.

Figure 24 Wiring on the ceiling cart



iii. Observation: Pulling wiring in corrugated conduit through the punch outs in the metal ceiling joists was difficult. Often requiring two operators (one to feed and one to pull), it became even more difficult as more wiring was run through the same punch out.

Recommendation: Use plastic inserts in punch outs, run wiring over joists (in first floor ceiling), or use open web truss joists (e.g., JoistRite).

iv. Observation: Electricians appeared to have difficulty locating electrical boxes for ceiling fixtures.

Recommendation: The standard work plan (see also recommendation 10) should clearly specify where each box is placed for each floor plan. Electricians should be trained to read the work plan and install boxes according to the plan. Ideally, with the proper line balance, boxes might be installed earlier on the ceiling framing table. If this is possible, the table might be marked to indicate box location.

B. Wall wiring

i. Observation: In most cases, electricians installed electrical boxes in walls after the ceiling had been set (see Figure 25). This delayed completion of wiring installation. Electricians could install electrical boxes as soon as walls are set.

Recommendation: Given proper line balance, boxes could be installed even earlier, during wall framing.

Figure 25 Installing an electrical box

ii. Observation: In the few cases where framers installed boxes, they were often installed at the wrong location. Electricians also installed boxes in the wrong location. Corrective action to relocate the boxes was required by framers and electricians.

Recommendation: The precise location of electrical boxes should be included on the standard work plans of both wall framing and electricians.

iii. Observation: Wall outlets were typically wired through the ceiling rather than through walls. This required the ceiling to be set before wiring could begin.

Recommendation: Running outlet wiring horizontally through walls would minimize wiring in ceiling, reduce labor, reduce wiring length and allow wall wiring to begin before the ceiling is set.

iv. Observation: Instead of moving continuously from one module to the next module on the line, electricians responsible for wiring walls often appeared unsure of their next task. Once started, electricians seldom completed work in a module without interruption. Instead, they were directed (or wandered) from module to module, interspersing ceiling wiring with wall wiring. They seldom worked as a team on the same module. Instead they worked on as many as three modules at the same time. These factors disrupted any continuous workflow by the electricians and bottlenecked all downstream activities. For example, during the observation period, lack of electrician flow was suspected in being the cause behind the fact that in 2-½ days of observation, no interior gypsum board hanging was completed (start-to-finish) and only one module completed gypsum board taping and sanding (start-to-finish).

Recommendation: The wall wiring team should move in sequence, completing each module before starting the next module on the line.

v. Observation: Electricians spend a lot of time walking to get supplies from a distant cart.

Recommendation: Each electrician should have their own material supply cart and should keep the cart adjacent to the module they are working on, including a stock of pre-cut wall stud components for mounting panels (see Recommendation 3).

2. Spread line activity by moving work upstream

Observation: Too many activities have migrated to the end of line. Wall board finishing takes place at the next-to-last station, forcing all subsequent activities (sand, paint and all finish activities) to the two parallel stations at the end of the line (see Figure 26). This is far too much activity in too little space and time to guarantee quality. At the same time, upstream modules often sit idle.

Recommendation: To resolve this problem, work must be moved upstream: wall board finishing must be completed earlier, which means gypsum board installation must be completed earlier, which means electrical wiring must be completed earlier. To reiterate, electrical wiring is a critical bottleneck in the process, forcing all subsequent activities downstream. The previous section describes opportunities for expediting the electrical processes.

Figure 26 Finish operations at the end of the line

3. Rationalize material staging and replenishment

A. Materials staging

Materials were often staged far from their point of use. Materials should be located as close to their point of use as practical. Examples include:

Figure 27 Installing an electrical panel

i. Observation: Material staging locations in the floor framing workstation are not efficient.

   Recommendation: Stage rim joists, joists and galvanized blocking near the band saw (on the right side of the framing table). Stage joist hangers, nails, gypsum board and metal strips on the left side of the framing table.

ii. Observation: Electricians consistently left their workplace to obtain electrical supplies. Most supplies were kept on a supply cart. However, this cart was seldom located at the point of use. At best, the cart was located immediately outside the current module being wired, requiring the electrician to leave the module. The three or four electricians wiring the walls were seldom working on the same module, requiring at least some electricians to interrupt their wiring and walk longer distances for supplies. Occasionally the cart would be left near a module where no-one was working. When an electrician walked to the cart to get supplies, they typically carried only a handful back to the point of use.

   Recommendation: A supply cart should be provided for each team of electricians that typically work together on the same module. Each team should keep their cart located close to the point of use (see Figure 28).

Figure 28 An electrician's cart

iii. Observation: Electricians often needed metal wall studs to mount panels. When studs were needed, electricians would walk to the wall framing area.

   Recommendation: Pre-cut wall studs should be located near the panel mounting location on the line.

iv. Observation: Exterior gypsum board sheets were staged two stations upstream from their point of use on the line. To replenish their cart, operators had to walk to this staging area (see Figure 29).

   Recommendation: If gypsum board were staged closer to the point of use, carts could be eliminated, thus eliminating double handling.

Figure 29 Loading gypsum board on a cart

v. Observation: The mud mixing station is located six stations from the point of use on the main line. To replenish their buckets, operators had to walk to the mixing station.

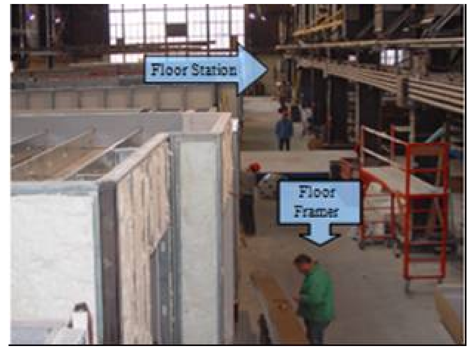
   Recommendation: Locate mud mixing station closer to the point of use.

B. Materials replenishment

Observation: When operators depleted materials at their workstation, they often interrupted their assigned activities and walked excessive distances to the warehouse or stockroom to replenish. Examples include:

- When the ceiling gypsum board installer ran out of screws, he walked to the warehouse to obtain more screws (see Figure 30).
- When the wall set crew ran out of materials, they walked to the warehouse.
- When an electrician ran out of electrical supplies on the supply cart, he walked to the electrical stockroom located in the back of the plant. The electrician did not return for at least 20 minutes.

Figure 30 Floor framer fetching gypsum board



- Gypsum board was installed on the inside of each rim joist prior to framing. This gypsum board was staged near the point of use; however, it was considered unusable by the operator who routinely walked to another stack of gypsum board serving the main line.

Recommendation: A kanban system should be used to replenish materials. A kanban is a visual signal indicating a need for more production or replenishment of material. For example, when the supply of screws in an area reaches a designated replenishment level (perhaps when one of two containers of screws is emptied), a kanban signal (perhaps the empty container) triggers replenishment from the warehouse. A utility/replenishment operator visually checks for kanban signals daily and performs the necessary replenishments. When materials are unusable, they should be replaced with usable materials.

4. Purchase right-sized materials

Observation: Improperly sized raw materials often lead to excessive processing, motion, and material waste. Examples include:

A. The rim joist on each long side of the ceiling frame was formed by welding four shorter components. One component requires cutting to size, also creating waste (see Figure 31).

Figure 31 Welded sections of ceiling rim joist

B. Upper and lower steel tracks forming the top and bottom plates of the wall frame were formed by welding shorter components. Follow-up investigation indicated that the wrong size tracks had been purchased from the vendor. One component requires cutting to size, also creating offal (see Figure 32).

Figure 32 Welded wall track

C. Unlike other types of exterior gypsum board, yellow faced gypsum board used on the exterior of demising walls (walls separating living units) was not purchased in 12’ lengths. The sheets were cut and then lifted onto scaffold for installation, one piece at a time (see Figure 33 and Figure 34).

Recommendation: Specify and order materials in long or cut-to-size lengths to minimize cutting in the plant and waste.

5. Use the right tool for the job

Better tool selection will minimize wasted processing time. For example:

Figure 33 Installing yellow-faced gypsum board

Figure 34 Installing 12 foot long gypsum board on a demising wall

i. Observation: The band saws used to cut components in the ceiling framing and floor framing areas were not being used to its potential (e.g., bulk cutting). At most two blocks were cut at one time.

   Recommendation: If bulk cutting is not used, a chop saw with a diamond blade will be a better choice for smaller volume cuts.

ii. Observation: Wall framing requires many screw attachments. Each is time consuming (see Figure 35).

   Recommendation: Replace screws with other fasteners, such as nails or drive pins.

Figure 35 Installing furring strips with an electric drill

iii. Observation: Grinding wheel used in wall framing station is slow.

   Recommendation: Replace the grinding wheel used to cut metal wall framing components with a chop saw with diamond blade.

iv. Observation: A corded electric drill with manual feed of screws is the standard tool for assembling light gauge framing components and installing gypsum board.

   Recommendation: Replace the slow manual feed drills with auto-collating screwdrivers.

v. Observation: Inappropriate slow manual saw used to trim wall board (see Figure 36).

   Recommendation: Replace the slow manual gypsum board saw with a power router or correct hand saw.

Figure 36 Trimming gypsum board

6. Create sub-assembly cells

Observation: The three progressive assembly workstations (framing, gypsum board installation and wiring) in the ceiling assembly area are operated independently. However, their operations are not independent. For example, gypsum board installation is tightly linked to wiring, since the ceiling cart must be empty before a ceiling can be moved from the gypsum board installation jig. The ceiling staging area between framing and gypsum board installation partially disconnects gypsum board installation from framing, but at the cost of double handling frames and carrying excess work in process inventory.

The need to synchronize flow between workstations is complicated by the need to better utilize the three operators working in the area, who are less than fully utilized at the current production rate. These operators were routinely observed to be absent from their workstation, sometimes performing other activities to fill their idle time.

Recommendation: A potential solution to this situation is the lean production concept of cellular manufacturing, coupled with the concepts of balanced workloads, continuous flow and kanban-driven production. Treating the three workstations as part of the same manufacturing cell, total work (average labor hours) within the cell would be calculated for the production cycle. This work would then be used to determine the total manpower needed within the cell—likely two operators instead of the three currently assigned. Workload would then be balanced between the two operators. For example, one operator (the welder) might be principally assigned to welding and partially assigned to gypsum board installation. The other operator, an electrician, might be principally assigned to wiring and partially assigned to gypsum board installation. Together, their job is to move one completed ceiling out of the cell each production cycle. Within the cell, production can be kanban-driven. For example, instead of continuing to frame until the staging area is filled (resulting in double handling and excess work in process inventory), the staging area can be eliminated and an empty framing table used as the visual signal for the welder to start framing the next ceiling.

A pure cellular manufacturing solution ignores the issue of skilled trades, pay differential and union labor rules. For example, the welder builds frames (primary task) and also helps to install gypsum board (secondary task). If this pure cellular solution is not possible, then one might consider the concept of skill-focused virtual cells. Here, each virtual cell is defined by function rather than the part/product produced. For example, the welding activities in both floor and ceiling framing areas might be combined in a virtual "welding cell," where the welder(s) move between workstations and accomplishes both tasks during the same production cycle. Although this approach has the advantage of focusing and minimizing highly skilled (and high cost) labor, it may not result in the continuous flow provided when workers are assigned to a more limited area and focused product.

The cellular manufacturing concept can also be applied to the wall assembly (window/door opening framing, wall framing and gypsum board installation) and floor assembly (framing and plumbing) areas.

7. Use positioning guides and jigs

Observation: Operators spend substantial amounts of time examining plans, measuring dimensions and repeatedly marking locations for the same parts. Yet errors still occur and rework is required.

Recommendation: To improve productivity and reduce rework, construct or mark simple low cost jigs to guide repetitive assembly operations. Examples include:

i. Ceiling, floor and wall framing. Use scales or jigs to measure the distance between joist hangers/studs and to square components.

ii. Ceiling gypsum board installation. When two operators lifted a ceiling frame on top of the jig, they noticed that insufficient gypsum board had been pre-positioned on the jig (see Figure 37). They had to re-lift the frame and position additional gypsum board. A potential solution is

Figure 37 Placing ceiling hanger angle sections in the ceiling jig

to measure and mark the surface of the jig indicating the perimeter of gypsum board required.

iii. Ceiling gypsum board installation. Attaching gypsum board to the underside of the ceiling frame using screws is a difficult and tedious process. Each joist location behind the gypsum board has to be marked with a line and then screws fastened. A potential solution is to add lights (possibly lasers) to indicate joist positions. Capsys might also consider the use of a foam adhesive similar to that used in wood frame modular ceiling assembly.

iv. Ceiling wiring. The surface of the ceiling cart can be marked to provide a template for ceiling wiring runs and electrical boxes (see Figure 38). This would eliminate much of the time electricians spend measuring to locate electrical boxes for ceiling fixtures. A more sophisticated version might use fiber optic lighting mounted in the surface of the ceiling cart.

Figure 38 Wiring the ceiling on the ceiling cart

v. Wall framing. Update shop floor drawings to include all information needed for assembly (e.g., location of studs and electrical boxes). Framers often leave the workstation to discuss the location of electrical boxes time with electricians.

vi. Fix all wall dimensions. Standardize wall dimensions and provide clear shop drawings. Wall framers were often interrupted by other workers to help fix frame-related problems.

Figure 39 Welding a corner post

vii. Provide correct indications on frame. Several frames came with the incorrect information, causing gypsum board installation on wrong side of frame, electrical boxes improperly located, etc.

8. Reduce welding

Observation: Welding is used extensively in the Capsys framing process (see Figure 39 and Figure 40). Welding is a slow, labor-intensive process that over the long-term degrades the vision of welders. Welding light gauge material is particularly difficult and risks destroying the protective galvanization on the surface of light gauge members.

Figure 40 Welded chassis corner

Recommendation: There are several approaches for reducing welding. First, the need for welding smaller components together to form longer linear components can be eliminated simply by purchasing longer, right-sized materials (see sections 3.A. and 3.B. above). If steel framing tracks must be combined linearly, they can be spliced by screwing into scrap stud pieces, since the connection is not structural. Some connections cannot be eliminated. For example, connection of rim joists, joist hangers, transverse joists, blocking hangers, and blocking requires considerable stitch welding in ceiling and floor framing. Potential solutions include replacing stitch welding with other fasteners, such as spot welding, nailing/drive pins, or bolting.

At a minimum, welders should use the relatively inexpensive (~$200) auto darkness/ LCD helmets, which are safer and improve productivity by eliminating the need to flip the mask up and down.

9. Re-engineer roof slope

Observation: Upper level modules have pitched roofs (8” pitch over 40’) to provide drainage (see Figure 41 and Figure 42). The module side walls taper slightly from front to back. To provide this slope, wall studs are cut at progressively shorter lengths, creating many different work-in-process components. To increase efficiency, these studs are cut in batches and stored as excess work in process. This design approach results in stud-to-top track connections that are difficult and sometimes of poor quality. It also requires the production of triangular-shaped wall assemblies to square the side façade. Finally, it affects the look of the ceiling inside the module.

Figure 41 Wall framing station with rack of graduated studs in background

Figure 42 Sloped wall

Recommendation: Potential solutions include changing the approach to providing a roof slope by either using flat walls and pitching the joists in the ceiling frame; or, building flat walls and ceiling frames and creating the slope using built-up roof insulation as is typical in commercial roofing. See page 34 for a more detailed description of these recommendations.

10. Order the workplace

The 5Ss of lean production – sort, set in order, shine and inspect, standardize and sustain – are together the foundation principles of any lean operation. The goal in applying the 5Ss is to establish order and allow visual management in each workplace throughout the plant.

Sort—the first principle is to sort out and eliminate materials that are not needed.

Observation: The ceiling framing workstation had material from previous projects staged in the area. These materials impeded the routine flow of work and were obstacles to be avoided by workers. They were also potential hazards.

Recommendation: Each operator should thoroughly inspect their workplace, identifying with tags or other marks unneeded items. All tagged items should then be removed.

Set in order—along with removing unneeded materials from the workplace, the needed items can be organized in logical areas to improve efficiency.

Observation: Operators were observed searching for equipment: clamps at the ceiling framing and floor framing workstations, electric drill and deadman supports in the ceiling gypsum board workstation.

Recommendation: Material and equipment that supports production should be organized along three dimensions: what, how many and where. To fix the location of equipment and material, tape can be used to designate their home position on the floor and labels can be used for identification. A shadow box can be used to locate tools and jigs. Colored tape can be used as a visual reminder to replenish an item. The objective should be transparency. Workers should immediately be able to find all necessary items and out-of-standard situations should be obvious to everyone.

Shine and inspect—the workplace should be well maintained.

Figure 43 Dull stud cutting wheel

Observations:

i. Operators were observed using poorly maintained equipment: saw blades in the ceiling framing and floor framing workstations were dull, increasing cutting time; clamps on the wall framing table were loose, increasing assembly time and reducing quality; the gypsum board installer used a malfunctioning electrical screw driver, increasing attachment time (see Figure 43).

ii. The operator was attaching insulating foam sheets with screws using a manual feed drill because the power stapler normally used was broken. The drill was used for the entire three day study period.

Recommendation: Operators should regularly inspect their equipment using an inspection checklist. They should be able to recognize tool and equipment wear and perform routine maintenance when required. More extensive equipment maintenance should be completed by others in a timely manner, with suitable back-up equipment available for use during this period.

Figure 44 Wall framing station

Standardize—apply routine and consistent methods to production processes

Observation: There appeared to be little standardization throughout the Capsys production process. Design drawings were often unavailable, incomplete or incorrect. No standard work instructions documenting materials, tools/equipment, and methods were posted. The result was substantial variations in production methods, inefficiencies, and rework. Wall framing and electrical seemed to be particularly plagued by inadequate shop drawings, resulting in lengthy discussions to resolve design details and substantial rework (see Figure 44). Examples of waste included the following:

Figure 45 Wall panels

- When two operators lifted a ceiling frame on top of the jig, they noticed that insufficient gypsum board had been pre-positioned on the jig. They had to relift the frame and position additional gypsum board.
- When wall panels were set on the main line, workers noticed that window framing was incorrectly sized (see Figure 45). To repair the problem, workers had to tear out the gypsum board, rebuild the window opening to the correct dimensions, and then re-install gypsum board. A follow-up investigation indicated that the framers did not have a complete set of drawings.
- As wall panels were set on the main line, workers sometimes noticed that wall dimensions were incorrect. Line workers with the help of wall framers had to rebuild the panel before set. A follow-up investigation indicated that dimensions on the drawings were either incomplete or incorrect.

- In an effort to expedite the installation of electrical wiring in walls, wall framers tried to install electrical boxes while walls were on the framing table. Since framers did not have drawings showing the location of boxes, boxes were installed in the wrong location, causing later disruption on the main line. Framing activities were also disrupted during follow-up discussions with electricians (see Figure 46).

Figure 46 Relocating an electrical box

- Framers identify and mark panels to indicate which side should have gypsum board installed first (see Figure 47). Incorrect marking contributed to gypsum board being installed on the wrong side of the frame twice. In each case, gypsum board was removed and reinstalled on the correct side.
- Operators installed the wrong type of gypsum board on the exterior of a marriage wall. Rework required 4-¼ labor hours.
- Two incorrect closet doors were installed, requiring removal and replacement.

Figure 47 Wall frames ready for gypsum board

<u>Recommendation</u>: A standard work plan should be documented for each major activity and posted prominently in the appropriate workstation(s). The plan should utilize graphics (e.g., pictures, drawings) whenever possible to communicate instructions. When multiple floor plans are produced for the same project, a unique work plan should be developed for each floor plan. When module variation (including customization) is allowed, the variation will be described in the traveler – the paperwork that accompanies the module through the process. The standard work plan should specify precisely how to efficiently fabricate, assemble and/or finish the module. It should include the sequence of manufacturing steps and the details of each step as follows:

1) the materials (with dimensions), tools and equipment and their location;
2) the method – how the work will be performed; and,
3) the logistics – who, where, when and at what rate the work will be performed.

When the production rate changes during a project, the TAKT time or line cycle time will change, necessitating a change in these logistics and an update of the standard work plan. For example, an increase in production rate will require a reduction in line cycle time resulting in an increase in labor requiring specific labor assignments within an activity to be rebalanced.

Sustain—sustain and expand upon the benefits derived from 5S and other lean production efforts. Involving workers and managers impacted by the changes in often the key to sustaining 5S improvements.

<u>Recommendation</u>: Capsys management should empower workers, set expectations, provide resources and hold workers accountable for their workplace.

3.5.2 Energy Recommendations

Energy recommendations have been divided into three categories: the thermal envelope, the HVAC system, and lighting.

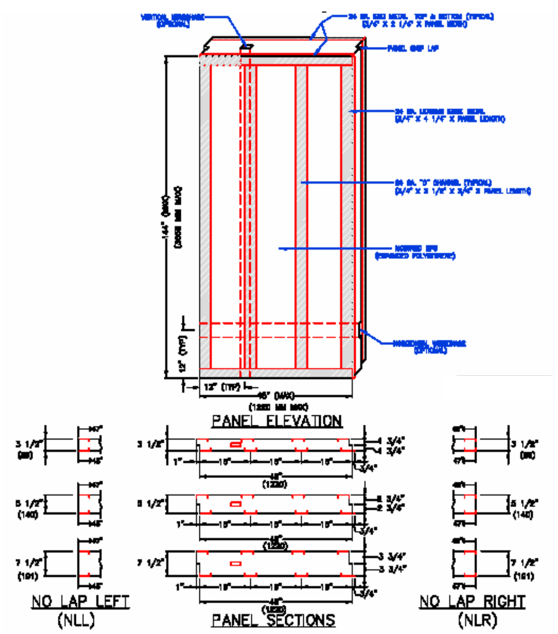
Thermal Envelope

The typical Capsys product consists of a module with a structural steel perimeter frame and light gauge steel infill walls. Fiberglass batt insulation is used in the wall and floor cavities. Additional rigid wall insulation is used on the exterior of the walls for the Oceanview project. Roof insulation is rigid polyisocyanurate. Modules are typically stacked two to three high and placed over a vented crawlspace. Most Capsys residential projects are attached townhouse type configurations, resulting in a mix of end units and interior units, with an occasional stand-alone unit. This construction system required careful detailing to reduce thermal gaps and bridging, as well as ensure air leakage is minimized.

Recommendations related to improving thermal envelope performance include the following:

- Use advanced steel stud and floor joist designs that reduce thermal bridging. Designs with larger openings in the web of the stud or joist reduce thermal bridging and can simplify the installation of wiring and plumbing through walls, floors and ceilings. Additional research is needed to determine if the additional cost of these (proprietary) products can be sufficiently offset by labor savings in the plant and tradeoffs for other energy design features.
- Consider replacing steel stud infill walls with foam steel wall panels such as those manufactured by Thermasteel Corporation (see Figure 48). These panels eliminate thermal bridging in most locations because there are separate and discontinuous steel members on the interior and exterior faces of the wall. Significant changes to Capsys' manufacturing process would be required to implement this type of product. While the use of Thermasteel panels would simplify the Capsys wall construction, they are a costly tradeoff.

Figure 48 Thermasteel wall panel



- Evaluate the production ramifications of eliminating fiberglass batts in the walls and increasing the rigid insulation outside of studs (see **Error! Reference source not found.**). This would improve the wall's thermal properties by eliminating thermal bridging caused by steel framing members and reducing insulation voids. It would also eliminate one production step (placement of insulation batts) without adding another because the rigid insulation already being used could simply be replaced with a thicker board. These advantages would have to be weighed against the higher cost of the rigid insulation.

Figure 49 Insulated module

- Add loose-fill insulation in roof cavity and reduce cost by reducing rigid roof insulation. This may require adding a provision for venting the cavity or other moisture mitigation strategy.
- Remedy insulation gaps and thermal bridging.

- Replace bituminous black roofing with elastomeric reflective white to reduce summer roof
- Temperatures and potential cooling loads in top floor units.
- Locate the electrical panel on a party wall rather than on the exterior wall to prevent the resulting insulation void (see Figure 50**Error! Reference source not found.**).
- Convert the foundation to a conditioned crawlspace with perimeter foundation insulation and no floor insulation.
- Replace fiberglass batts with rigid insulation under the floor joists.
- Make mineral wool batts continuous around perimeter of party wall airspace.

Figure 50 Insulation void at electrical panel

HVAC system

The typical Capsys product utilizes a hydronic baseboard system supplied by a natural gas furnace. A single furnace serves both units in the two-family buildings of the Oceanview project. Cooling equipment is homeowner installed.

- Evaluate converting to a forced air system with ducts running in the ample ceiling cavity. The benefits of forced air include flexibility to add central cooling (if ducts are sized properly), fresh air ventilation, air filtration, and/or humidification. The production implications of replacing plumbing with ductwork should be evaluated.
- Consider an on-board heat pump for any Capsys projects that utilize electric heat.
- Upgrade to programmable thermostats.

Lighting

Most lighting in Capsys projects is standard incandescent.

- Install compact fluorescent bulbs.
- Install timers and/or photocells on exterior lights.
- Install dimmers on living area lighting.
- Install fluorescent lighting in kitchen, mechanical room, storage room, bathrooms.

3.5.3 Structural Recommendations

Capsys modules are constructed from structural post and beam steel frames with cold-formed steel framing for infill walls and component and cladding support. Based on in-plant observation of modules with both concrete and plywood deck floors and a review of Capsys project drawings, the following design and production changes should be considered.

- The top one or two floors of a structure may be able to be framed out of load bearing cold-formed framing. This would eliminate the vertical tube steel used to support the floor or roof system directly above each module (used on some projects). In many cases, the same size and gauge material that would be required for this solution are already being used to meet deflection criteria and cladding attachment requirements. The elimination of some structural steel would save material, fabrication time and labor.
- Use cold-formed steel for the floor framing rather than structural tube steel. Cold-formed steel joists work for Capsys' typical plywood deck floors, and may also be more efficient for

the concrete system. The material costs would be slightly lower and the use of recently developed hangers would simplify installation.

- Alternatively, if structural steel is found to be more efficient for the concrete floor system, the use of a proprietary form deck product, such as Epicore, should be considered (see Figure 51 and Figure 52). This might permit longer spans of concrete slab, minimizing the number of structural steel beams required.
- Investigate the use of alternative fasteners in cold-formed steel connections (see below). Compared with screws, these fasteners have similar or superior structural capacities, but can be installed faster and more reliably.

Figure 51 Floor frame for concrete floor module

Figure 52 Floor ready for concrete pour

In addition to these design changes, a number of technologies are available that may enable Capsys to increase production efficiency, such as automated design and layout software, specialized panelization techniques for cold-formed steel framing, and the efficient fastening technologies for cold-formed steel framing suggested above. Many of these technologies are proprietary and some are not yet mature. More detailed information is provided in Appendix C.

3.6 IMPLEMENTATION OF SELECTED RECOMMENDATIONS

3.6.1 Redesign of the Ceiling/Roof System

Design problem and opportunity

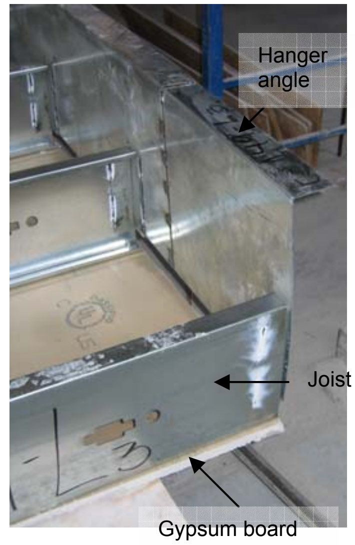
The concurrent engineering team investigated a promising design change to the Capsys product, involving the method by which the Capsys ceiling and roof system are engineered.

Constructing the Capsys roof and ceiling systems require outsourced custom-fabricated parts (steel Hanger angles) and time-consuming welding in the plant. The plant benchmarking process identified ceiling and roof build as an inefficient and time consuming operation compared to other steps in the Capsys production process. The current design is driven by the need to assemble the ceiling/roof as a single unit that can be lifted in place into the module, and to maintain a continuous foundation-to-roof gypsum board firewall that bypasses roof and ceiling intersections.[8]

[8] The driving code requirement for the hanger angle is the New York City Building Code requirement for a fire division, specifically Section 27-340 of the Building Code requiring that when a roof deck is of combustible materials a continuous fire division must extend from the foundation to four inches above the finished roof. In site-construction, the joists are usually framed into the wall and then gypsum wallboard installed in two-foot sections between joists, a very labor intensive process.

The roof and ceiling assemblies consist of joists (18 to 20 feet long) connected to a hanger angle (38 to 40 feet long made up of welded 10-foot sections) at each end. The hanger angle is an upside-down L-shaped steel section with the short (approximately 3") leg of the L wrapping over the top of the module sidewalls (Figure 53). The ends of the joists are welded to clips that are in turn welded to the long leg of the hanger angle. Gypsum board is screwed to the underside of the joists. The entire assembly consisting of hanger angles with joists and drywall is lifted by a crane and placed in between the module sidewalls with the overhanging lip of the hanger angle resting on the top plate of the walls. In the final configuration the joists run perpendicular to the module sidewalls and the hanger angle runs the length of the module.

Figure 53 Detail at corner of ceiling framing.



In the case of the roof, the pre-assembled roof unit is placed on walls that slope gently from front to back of the module to achieve a roof slope for drainage. The slope is achieved by varying the length of the sidewall studs in the top floor module. Preparing and keeping track of numerous stud lengths is time consuming, complex, error-prone and results in large in-process inventories of studs (see Figure 54). It also results in a difficult connection detail between the studs and wall top track.

Also as a result of the sloped wall, Capsys builds a shallow wedge-shaped wall panel to place on top of the sidewall after the roof is installed. The only purpose of this wedge-shaped wall is to square-off the sidewall for aesthetics (see Figure 55).

Figure 54 Studs for building sloped wall prepared and stored

The goal of this redesign effort is to develop an alternative design that uses standard components, reduces welding and labor and eliminates the need to slope the walls. The alternative design should improve production efficiencies and structural performance, while lowering costs. It should be implement-able in the current production process with existing equipment.

The team's strategy was as follows:

1. Develop one or more design concepts
2. Review these concepts with Capsys for initial feedback. Discuss proposed impact on material use, fabrication methods and production sequences.
3. Based on feedback from Capsys, engineer and document a proposed design solution.
4. Present the revised design and production strategy to Capsys.

Figure 55 Triangular parapet wall

Design Concepts

Following are six design strategies considered by the team. Each of them can use welding or mechanical fasteners for the connection between the joists to the rim joist or hanger:

1. **Spliced hanger**. Use the hanger angle in ten foot lengths. Splice the hanger sections together with light-gauge material and screws (without welding). To achieve the roof slope, either slope the walls as is currently done or create a slope with built up insulation (draining to the rear, or to the center with a roof drain, the latter approach requiring less insulation than draining to the rear).

   Conclusion: While screwed splices may be sufficient for transferring loads across the joints in service, the screwed connections may not be stable enough for in-plant transport where welded connections are preferable. No further consideration was given to this option.

2. **Angled hanger.** This is a variation on design concept 1 for the roof. To achieve the slope, use a hanger angle that graduates in depth from the shallow to the deep end of the roof. The assembly would be placed on level, rather than sloped, parapet walls.

   Conclusion: The hanger angle would most likely need to be trimmed after the ceiling is assembled, a problematic proposition.

3. **Hanger plus track (rim joist).** Use the hanger angle in ten foot lengths. Incorporate a continuous track purchased in full-length sections. Leave the hanger angle in discontinuous sections to eliminate welding. Achieve the roof slope as in design concept 1.

   Conclusion: Welding the hanger angle is much less costly than purchasing additional track material. No further consideration was given to this option.

4. **Longitudinal joists.** Rotate the roof joist orientation 90 degrees so that the joists run parallel to the long side of the module (as the floor system does). This will require adding a beam across the middle of the roof system, which would be supported at its ends by the existing columns provided currently as pick locations for crane installation. Additional headers will be required around openings in the front and rear end walls, because these walls would support the roof or ceiling. In the case of the roof, the slope would run down the length of the joists (thus in a sense making them very shallow slope rafters). The triangular-shaped wall would no longer be needed because the module side walls would not be sloped.

   Conclusion: This concept achieves the goals of reducing welding and eliminating custom-fabricated parts as well as the sloped walls. Further cost analysis is merited to evaluate the trade-off with the additional framing required.

5. **Ledger.** During wall framing, install an L-shaped ledger (e.g. a horizontally mounted steel member with an angle cross section) to the studs behind the wallboard on the walls running the length of the module. The horizontal leg of the L would project through the wallboard and support the roof/ceiling in place of the hanger. A continuous rim joist would frame the roof/ceiling unit. To achieve the roof slope, the ledger can be installed on an angle or the roof insulation can be used as in design concept 1.

   Conclusion: Two problems with this design eliminate it from contention: 1) the continuous angle (even with 12 gauge material) is not strong enough to carry the load of the roof, and 2) complications with wall and ceiling gypsum board installation and taping would require substantial additional labor. No further consideration was given to this option.

6. **Connect track (rim joist) directly to studs.** Use a standard joist connection detail where the track is fastened directly to the studs. Track and fire rated caulk serve as draft stopping. Heat transfer protection to achieve a 2-hour rated wall must be worked out (may require installing pieces of drywall inside the track or on the backside of the wall, or applying spray-on fireproofing). The entire assembly would be installed at a slope.

   Conclusion: Problems with this solution include that the wallboard must be cut at an angle under the roof and the wallboard above the roof or ceiling must be installed after the roof or ceiling is installed (also at an angle in the case of the roof). Spray-on fireproofing is costly, tends to be messy, and may stain the drywall (it is typically used on steel). Installing pieces of drywall between studs (on the backside of the wall) leaves gaps where the studs are located; installing them between the joists inside the track is labor intensive. No further consideration was given to this option.

Design Selection

The longitudinal joist design (Design Concept 4) was deemed to be the most promising. A more detailed structural and cost analysis was conducted to evaluate it against the current design. Table 4 shows the estimated costs of the current practice design versus the new design. Costs are shown only for the aspects of the designs that differ from the original design. Material costs were provided by Capsys. Labor costs are based on estimates by Capsys management, the research team and in-plant observations by the team's industrial engineers.

The results of the analysis in Table 4 indicate that a slight cost savings may be achievable by modifying the roof design with longitudinal joists rather than transverse joists. However, converting to longitudinal joists for the ceiling (in an effort to maintain a consistent construction type in the roof/ceiling station) would likely increase costs. The primary reason for this difference is the additional benefits realized by eliminating the wedge wall and simply building a straight (rather than sloped) module side wall.

This is a preliminary analysis. The specific construction details must be developed and analyzed to determine if they add additional labor. For example, the center roof beam is deeper than the surrounding roof joists. This may require a more complex detail, or a conversion to structural tube steel for this beam.

Table 4 Roof/ceiling design cost comparison

		Roof		**Ceiling**	
Add for design change	**Unit**	**Qty**	**Cost**	**Qty**	**Cost**
Materials					
Track (roof: 10" deep 16 ga (1000T150-54); ceiling: 8" deep 18 ga (800T150-43))	linear foot	80	$120.00	80	$81.12
Center beam (roof: (3) 1400S200-97; ceiling: (2) 800S200-97)	linear foot	18	$192.90	18	$91.74
Header above 6' window ((2) 600S162-54)	linear foot	6	$13.38	6	$13.38
Header above 3' windows ((2) 362S162-54)	linear foot	9	$15.29	9	$15.29
Jack studs (362S162-33)	linear foot	42	$22.05	42	$22.05
Labor					
Assemble center beam	per beam	1	$12.50	1	$8.33
Connect (weld) center beam to posts	per connection	2	$6.25	2	$6.25
Patch drywall around beam-post connection	per patch	2	$4.17	2	$4.17
Connect roof/ceiling to end walls	linear foot	36	$4.95	36	$4.95
Total added cost			**$391.49**		**$247.28**

Deduct for design change					
Materials					
Hanger angle (roof or ceiling)	linear foot	80	$197.76	80	$112.88
3.5" track for top of slope wall & wedge wall (362T150-33)	linear foot	80	$34.40	n/a	n/a
Joists (roof: 1000S200-54; ceiling: 800S200-43)	linear foot	36	$71.28	36	$39.24
Labor					
Cut and organize studs for sloped wall	linear foot	80	$38.17	n/a	n/a
Cut and assemble wedge wall components	linear foot	40	$37.50	n/a	n/a
Install wedge wall	linear foot	40	$5.50	n/a	n/a
Sheath wedge wall	per wall	1	$12.50	n/a	n/a
Weld hanger angles	per weld	3	$4.17	3	$4.17
Fasten hanger to sidewalls	linear foot	80	$11.00	2	$10.73
Total deducted cost			**$412.27**		**$167.01**
Balance			**$(20.78)**		**$80.27**

3.6.2 Rationalization of Materials Handling for Electricians

To follow-up on the lean production study and to demonstrate how lean production improvements can be implemented, MHRA conducted a two-day rapid process improvement event (RPI) (also referred to as a *kaizen*) at Capsys. The RPI focused on one of the top ten recommendations developed for Capsys: material replenishment for electricians. The topic was selected because of its perceived simplicity coupled with the opportunity for significant performance improvement.

3.6.3 RPI event agenda

The research team, in collaboration with Capsys management, prepared a plan for the event, including the scope and agenda, participants and materials needed. Following is an outline of the steps in the event.

Day 1, afternoon

1. Presentation by researchers to discuss lean philosophy, observations made with respect to electrician work flow and the implications of interruptions in supply of parts to electricians.

   Capsys participants: All electricians, production manager.

   Duration: Approximately 30 minutes.

2. Detailed discussion of the issue followed by brainstorming session to develop potential solutions.
   - Researchers seeded the discussion with preliminary ideas based on lean production approaches such as the 5Ss.
   - Workers were encouraged to develop additional ideas.
   - Organized and consolidated ideas to the two to three best ones.

- Discussed costs and benefits of the ideas.
- Developed consensus on which ideas to try.

Capsys participants: Lead electrician, one other experienced electrician, production manager.

Duration: Approximately 90 minutes.

3. Developed implementation plan for selected ideas. The plan included all tasks that needed to be completed to implement the plan: supplies and equipment (such as bins) required, time commitments from personnel, research on materials, timeframe, etc.

   Capsys participants: Lead electrician, one other experienced electrician, production manager

   Duration: Approximately 60 minutes.

Day 2, morning

4. Implementation. Mocked up the plan to demonstrate it and to permit workers to begin using the new system.

   Capsys participants: Lead electrician.

   Duration: Approximately 120 minutes.

5. Meeting to present plan to complete group.

   Capsys participants: All electricians, production manager, plant engineer.

   Duration: Approximately 30 minutes.

3.6.4 Detailed description of the RPI event

Researchers began the exercise by presenting several instances of waste that had been observed to be associated with the replenishment of electrical parts.

- One cart was used by all four electricians to stage electrical parts and tools. Since the electricians were scattered among different modules, they often left their workplace to walk to and from the cart.
- This initial observation was presented to Capsys management a few months prior to the RPI event. In response, a cart was provided to each electrician. However, cart usage was inconsistent. One operator maintained only tools on his cart (see Figure 56). Another carried some parts, but they were mixed together with tools in a pile (see Figure 57).
- Electricians left their workplace and traveled to the electrical stockroom for various parts such as boxes and connectors.

Figure 56 Cart with only tools

Figure 57 Cart with parts and tools in pile

- Electricians left their workplace and traveled to other carts to obtain wire and tools, such as a hole saw.
- Electricians did not use a tool belt for tools or parts. Instead, they traveled more frequently to their tool cart.
- Some needed parts were out-of-stock. In one case an electrician left the building to install a newly received out-of-stock part into a module staged in the yard.
- The electrical stockroom was disorganized. Identical parts were scattered throughout the stockroom. Often more than one carton of the same part had been opened and was being used. Different parts were piled together (Figure 58). Unused parts from previous projects were mixed with current parts. In Figure 59 the currently used parts are marked with red tape. They are interspersed with parts remaining from previous projects.

After discussing these and other problem relating to the replenishment of electrical parts, the RPI group brainstormed alternatives in order to reduce waste. These alternatives were consolidated into two primary initiatives: 1) standardize the use of the electrical supply carts; and, 2) organize the stockroom layout and usage. In addition, the RPI group suggested the use of rubber grommets for use in the one inch diameter punch-outs in the light gauge steel ceiling trusses to facilitate pulling television cable and telephone wiring and reduce the risk of cutting those wires.

Figure 58 Mixed parts in electrical stockroom prior to the RPI event

Figure 59 During the RPI event, use of red tape to identify currently used parts (inside circles)

These two primary initiatives both seek to bring order to a chaotic workplace by providing structure. Lean production initiatives often address this problem by establishing a system of visual management, a self-managing work environment that is self-explaining, self-ordering and self-improving. The 5Ss are used to create this environment. The following sections address how the 5S process was used to address the two initiatives.

Electrical Supply Carts

- **Sort.** All parts and tools needed to perform rough electric activities for the current project were added to the cart in quantities to support at least one day of production. All parts and tools that were not needed were removed from the cart.
- **Set in order.** Parts and tools were organized on the cart using plastic storage bins of various sizes. With several minor exceptions (e.g., drill bits and hole saws), items were stored with one item per bin. Bins are to be marked to indicate contents.
- **Shine and inspect.** All tools (drills/bits/saws and conduit cutters) are to be regularly inspected and maintained by the electrician.
- **Standardize.** All carts are equipped with the same parts and tools. However, each electrician can arrange their cart. Each electrician replenishes their cart once each morning before beginning work on the line. After moving to their workplace on the line, electricians keep

their carts staged near them, perhaps near a door or low window to improve access. Electricians should not need to return to the stockroom during the workday to replenish parts.

- **Sustain.** The electrical lead monitors electrician use of their carts, including trips to the stockroom. Root causes of further waste are continuously identified and eliminated by the electrical team.

The resulting standardized supply cart for rough electric activities is shown in Figure 60.

Figure 60 Standardized supply cart for rough electric activities

Electrical Stockroom

- **Sort.** All parts needed to perform rough electric activities for the current project were identified. All parts that were not needed were identified and removed from the shelving.
- **Set in order.** All parts needed for the current project were placed in the most accessible "golden zone" – the middle two levels in the shelving. Each part number was consolidated into a single location. When possible, multiple opened boxes of the same part were consolidated into one. Shelves were marked with the part number and the replenishment point indicated by a strip of red tape. All supplies that were not needed by the current project were moved to less accessible locations in the back of the stockroom and on high shelves.
- **Shine and inspect.** Shelves were dusted and unused boxes were discarded. Part numbers from previous projects were removed (or covered) from where they had been written on the shelving.
- **Standardize.** The lead electrician is responsible for maintaining and replenishing the stockroom. Periodically, the lead will pass through the stockroom and visually identify the parts that are below their replenishment points (typically one to two cartons of stock). The item is checked on a reorder checklist and the list returned to material control for purchasing. When the purchased item is received, the lead will place the new stock into the shelves, being sure to rotate older stock so that it can be used first. Each electrician replenishes his/her cart once each morning before beginning work on the line. The electrician pulls replenishment stock from the open carton first and only opens a new carton when the previous open carton is empty. The empty carton is then discarded. When the open carton is pulled from the shelving during the replenishment process, it is returned to its proper location.

- **Sustain.** The electrical lead maintains the stockroom. Root causes of further disorganization and waste are continuously identified, problem-solved, and eliminated by the electrical team.

The resulting organized electrical stockroom is shown in Figure 61 and Figure 62.

Figure 61 Organized small parts shelving (left) and floor stacking (right)

Figure 62 Organized shelving for larger parts: "golden zone" (left) and typical shelf with three cartons, only one of which is open, and red replenishment point marked on shelf

3.6.5 Future Activities

The research team believes that the modest improvements implemented during the RPI event are an important first step in a longer journey toward becoming a lean enterprise. There is much to be gained if the recommended follow-up activities listed below are carried out including the following:

1. Institutionalize continuous improvement in electrical parts replenishment. Identify and document continuing instances of waste (parts and labor) resulting from parts replenishment

issues. Electricians working with the production manager will continue to make improvements in this process.

2. Using findings from the electrical parts replenishment prototype and expand the continuous improvement effort to other parts replenishment areas (e.g., fasteners in ceiling drywall).
3. Using findings from parts replenishment expand the continuous improvement effort to other opportunities for continuous improvement. These might include addressing some of the following issues:
    a. Although drywall finishing is starting much further up the line than when observed during initial plant visits (4 to 5 stations from the end of the line), drywall finishing is still not being completed until the next-to-last station. Painting and all subsequent finish activities are still occurring in the last line station.
    b. Electricians are still pulling some wire in the ceiling after the ceiling is set, counter to initial recommendations.
4. The ceiling area is still not synchronized. Ceiling area workers are not balanced and are being widely used in other parts of the factory.

4

NEXT STEPS

Based on the experience of the benchmarking survey and the application of lean thinking to one case study plant, a strategy for the future development and application of lean techniques to factory homebuilding was developed (Phase 2 research). The strategy consists of expanding the pilot application of lean production techniques from a single plant to initially six to eight additional plants. Experiences gained by working with these plants can then be generalized to the industry at large.

Across the factory homebuilding industry there are a wide variety of market strategies, product designs, level of product customization, manufacturing approaches, and management and labor utilization practices, all of which potentially impact the ways in which plants might apply lean production techniques. By increasing the number and variety of plants that participate in this effort, researchers will gain a broader understanding of the range of improvement opportunities for lean production techniques. Experiences gained by working with the six to eight plants can then be generalized to the industry at large.

In Phase 2, the research team will work with selected manufacturers in areas that are likely to hold great strategic value in improving overall factory performance, with special consideration given to areas known for poor quality, low productivity, capacity bottlenecks and constraints to customization. These areas will be selected with the assistance of participating manufacturers based on the benchmarking results and plant-specific value stream mapping.

Gaining the commitment to and ownership of the lean production process by the manufacturers will be of critical importance. This will be accomplished by requiring that participating companies invest time and resources in the project and assign a senior staff member as the lean advocate for the plant. The lean advocates will be central members of the project team and ultimately responsible for transferring the knowledge gained through the project to the plant and to the company as a whole.

While the work conducted in Phase 2 will be reported and documented, the emphasis will be to transform the way homes are manufactured, reducing housing costs and improving quality. As such, the focus will be on implementing changes to the production process and developing a system to institutionalize these changes within plants and spreading the knowledge to other companies.

An expanded industry oversight committee (referred to as the manufacturing process engineering or MPE group) that was formed in Phase 1 of the lean production research will be re-convened for Phase 2. This group will help set project direction and discuss alternatives for deriving maximum value from the project.

Tasks to be conducted as part of Phase 2 activities are described below:

1. **Select plants for lean production study**

Six to eight plants will be selected to participate in a demonstration of the value of lean thinking applied to manufactured housing production. Based partly on the benchmarking study results, researchers will consider how these plants compare with other operations serving similar markets and home types to determine where the opportunities exist for efficiency improvements. Plant visits and detailed review of efficiency metrics will help focus these investigations and identify additional opportunities for investigations.

In selecting plants to participate, the researchers will consider a mix of characteristics that impact production efficiency. Involving different types of operations may suggest the most favorable environment for applying lean thinking. The plants selected will be different in several important respects including current performance as measured in the benchmarking effort, home price point, product mix, geographic location, and company size.

Criteria will be developed for selecting plants on a competitive basis. Participating plants will be selected based on upper management's commitment to lean production methods, the plant's willingness to assign a staff person as the plant's lean "advocate" to assist in carrying out the tasks described below, and the plant's willingness to provide the resources (people, time, materials, etc.) to carry out the tasks described below.

2. Identify and train lean advocates

Each plant will identify a key staff member as their lean advocate. The lean advocate will have several responsibilities including:

- Participating in an approximately one-week training session at a location to be determined;
- Creating a value stream map for the plant and documenting other key measures of performance;
- Reporting results and together with the project team identifying an area of operations for potential improvement; and,
- Implementing the improvement and coordinating the participation of associates in applying lean strategies within the plant.

The lean advocates from each plant will be brought together at a central location for approximately one week of intensive training. The training will cover the concepts and techniques of lean production, including value stream mapping, observation analysis, cycle time analysis, visual control, TAKT time, product flow and pull via a kanban system. The training will be lead by the project team. Each lean advocate will receive assignments described in Tasks 3 and 4 below.

3. Value stream mapping and other data collection

Each of the plant's lean advocates will collect information about the plants, based partly on the Phase 1 benchmarking work. Information collected and developed to describe operations might include the following:

- A high-level value stream map of plant operations,
- Plant-wide metrics (cycle and lead time, labor requirements, inventory levels, space requirements, quality metrics); and
- For selected areas, detailed process flow maps (labor and material utilization, replenishment time, product variation, storage requirements and changeover times).

This information will be reported back to the project team for discussion. Working with guidance from the lean experts on the team, the plant through its lean advocate will rigorously ferret out problem areas and identify opportunities for improving operations through the application of lean methods. The team may follow up by asking plants to provide additional information.

Documentation might include historical/measured performance on key process metrics and identification of critical strengths and weaknesses in the manufacturing process.

4. Select areas for improvement, conduct Rapid Process Improvement events and evaluate results

The detailed analysis of plant operations, particularly the value stream mapping, will suggest opportunities for applying lean techniques. Working closely with the lean advocate, the team will select operations within the plant that can be improved through a rapid process improvement (RPI) event employing lean techniques. These will be prioritized and a plan will be developed for carrying out an RPI event in each of the participating plants. The value stream map will provide the metric against which improvements resulting from the RPI event will be compared.

The goal of the RPI event may include the following: increase productivity, reduce or eliminate waste, standardize building processes, reduce delays, bottlenecks and unnecessary material handling, raise skill levels, reduce inventories, address defects and problems, optimize space usage, and many other interrelated factors.

The RPI event in each plant will initially be facilitated by a member of the project team. Later this responsibility will be assumed by the plant's lean advocate. There may be several iterations of RPI events within the plants for the purposes of transferring the process of continual improvement to plant staff. During these iterations, the project team will evolve from active facilitators to a resource for the lean advocate and finally to observers. The RPI events will be documented by the team.

The results of the RPI events will be evaluated by the team and discussed with each of the participating companies. The discussion will include: stumbling blocks to a continued commitment to lean production, improving the effectiveness of RPI events, opportunities for improving production going forward and related issues.

Results of the research will be documented and disseminated to industry through publications and briefings.

A

SAMPLE BENCHMARKING SURVEY FORM

Manufactured Housing Research Alliance

2109 Broadway, Suite 200
New York, NY 10023
212 496 0900 Tel
212 496 5389 Fax
info@research-alliance.org
www.mhrahome.org

Lean Production Benchmarking Plant Survey

Corporate information

1	The number of housing plants operated by the parent company of this plant. When answering the questions below use one column for each plant:		
2	a. Optional plant identifier for respondant's convenience (e.g. plant number):		
	b. The state in which this plant is located:		

Product

3	The percentage of homes produced in this plant in the last 12 months *(total should equal 100%)*:		
	a. HUD Code:	%	
	b. Modular	%	
	c. Commercial structures:	%	
	d. Park models:	%	
	e. Other (please specify here)	%	
	f. Other (please specify here)	%	
4	The number of models that are offered in marketing literature that are produced by this plant:		
5	The number of these models that represent 90% of this plant's production:		
6	The level of options/customization this plant provided on these models. Indicate the percentage of homes produced in the last 12 months in the following categories *(total should equal 100%)*:		
	a. No options/customization (no departure from base model shown in marketing literature). For example, no floor plan or structural changes. Selection of finish materials is permitted:	%	
	b. Minor floor plan changes such as stretches, flips, room additions/arrangements and other design options shown in marketing literature:	%	
	c. Extensive floor plan changes. For example, alternative kitchen layouts or room arrangements not shown in marketing literature:	%	
	d. Totally custom (blank sheet of paper or customer's design):	%	
7	The percentage of homes that featured finished gypsum board walls with tape and texture. Indicate the percentage of homes produced in the last 12 months in the following categories *(total should equal 100%)*.		
	a. No finished gypsum board walls with tape and texture:	%	
	b. Limited finished gypsum board walls (one or a few rooms):	%	
	c. Whole house finished gypsum board walls (except possibly wet rooms):	%	
8	The percentage of homes that featured the following unique design elements (total does not necessarily equal 100%).		
	a. Multi-story (including 1-½ story):	%	
	b. Hinged roofs:	%	
9	The percentage of homes produced last year that had the following number of sections *(total should equal 100%)*.		
	a. Single section:	%	
	b. Two sections:	%	
	c. Three sections:	%	
	d. Four sections:	%	
	e. More than four sections:	%	

Plant

10	**The annual production of this plant.**		
	a. Sales (dollars):	$	
	b. Floors:		
	c. Homes:		
	d. Square feet (total number of homes produced multiplied by the average square feet per home):	sf	
	You have indicated that the plant's annual sales dollars per floor is (see questions 10a and 10B):		
11	**The current production level in floors per week:**		
12	**The number of floors this plant could produce in a standard 40 hour work week (single shift) if orders (and labor) were unlimited? Assume that the model mix is similar to that of the past 12 months:**		
13	**The current backlog (in floors):**		
14	**This plant's annual production labor cost (total wages, including bonuses and overtime but excluding fringe benefits). Please answer for each of the following categories:**		
	a. Direct production labor (line workers who directly add value to the product on the production line):	$	
	b. Indirect plant floor labor (material handlers, QC inspectors, floor supervision, etc. - Do not include office staff, sales, or plant management):	$	
15	**The number of workers in this plant in each of the following categories.**		
	a. Direct production labor (line workers who directly add value to the product on the production line):		
	b. Indirect plant floor labor (material handlers, QC inspectors, floor supervision, etc. - Do not include office staff, sales, or plant management):		
	You have indicated that the plant's annual labor cost per direct production worker is:		
	You have indicated that the plant's annual labor cost per indirect plant worker is:		
16	**The size (in square feet) under roof of the plant, including all supporting buildings (such as, shops, warehouses, etc.):**	sf	
17	**The number of main production line floor stations in each of the following categories (excluding off-line feeder stations).**		
	a. Under roof:		
	b. Outside/uncovered (main line production stations only - not including storage):		
18	**The material inventory turns in the last 12 months (annual material cost/average inventory level):**		
19	**The primary and secondary production bottlenecks/problem areas that are most in need of improvement.**		
	a. Primary:		
	b. Secondary:		

Employee Satisfaction / Safety

20	**The number of OSHA recordable accidents (cases) reported in the last 12 months:**		
21	**The number of these cases that resulted in days away from work:**		
22	**The number of these cases that resulted in job transfer or activity restriction (light duty):**		
23	**The total number of workdays lost in accident-related days away from work in the last 12 months:**		
24	**The total number of workdays affected by accident-related job transfers or restrictions (light duty) in the last 12 months:**		
25	**The average percent absenteeism of production workers (not including accidents) in the last week or other period (please specify):**	%	
	Enter other period here if applicable.		
26	**The percent of production labor turnover in the last 12 months:**	%	

27	**List any continuous improvement programs used in the last 12 months. For example, quality councils, quality circles, continuous improvement teams, etc. For each, list the number of employees involved:**	
	Program 1	
	Number of participants	
	Program 2	
	Number of participants	
	Program 3	
	Number of participants	
28	**Current incentive pay programs for production employees (if applicable). Briefly describe specific measures used to determine rewards (for example, labor productivity/efficiency, weekly labor cost per sales dollar, etc.).**	
	a. Labor productivity/efficiency	
	b. Safety	
	c. Quality	
	d. Other (please specify here)	
	e. Other (please specify here)	

Customer satisfaction / Quality

29	**Based on the results from customer satisfaction surveys during the last 12 months, the percentage of customers satisfied. Enter n/a if data is not available:**	%
30	**The plant's annual service cost for the last 12 months (include direct warranty repair costs and goodwill repair costs/settlements only; do not include administrative overhead or legal fees/settlements):**	$
31	**Rank the top five discrepancies requiring service during the last 12 months. Rank highest to lowest. Be specific. Examples include floor squeaks, cabinet damage, wallboard cracks, difficulty opening/closing windows, etc. Do not provide general categories such as electrical, plumbing, etc.**	
	a. Most frequent discrepancy:	
	b. Second most frequent discrepancy:	
	c. Third most frequent discrepancy:	
	d. Fourth most frequent discrepancy:	
	e. Fifth most frequent discrepancy:	

Thank you for participating in this survey. Please add any notes or comments in the space below:

Comments:

B

CASE STUDY ENERGY USE SIMULATION OUTPUT

One of the goals of the concurrent engineering effort conducted at the case study plant was to investigate ways to improve the energy efficiency of the homes produced by Capsys Corp. As part of that effort a series of energy use simulations using REMRate energy analysis software were conducted on various home models built for the Edgemere-by-the-Sea development.

The following sample report details the construction characteristics and energy usage for a five unit townhouse structure. An ENERGY STAR Verification Summary report is also included, indicating that the structure meets the ENERGY STAR criteria.

BUILDING FILE REPORT

File Name: Edgemere 1F 5 unit facing north.blg   Date: June 08, 2005

Property/Builder:		**Rating**	
Building Name:	5 1F unit bdg fac N	Org. Name:	
Owner's Name:	Edgemere-By-The-Sea Corp.	Phone No:	
Prop. Address:	Beach Channel Drive	Rater's Name:	
City,St,Zip:	Edgemere, NY	Rater's No.:	
Phone No:			
		Rating Date:	
Bldr's Name:	CAPSYS	Rating Type:	Based On Plans
Model:	5 unit 1F	Reason:	New Home
Development:	Edgemere-By-The-Sea	Rating No.:	
Phone No:	(718)403-0050		

General Building Information	
Area of Cond. Space(sq ft):	7525
Floors on or Above-Grade:	Multi
Volume of Cond. Space:	60200
Number of Bedrooms:	15
Housing Type:	Multi-family, whole building
Level Type(Apartments Only):	None
Foundation Type:	Enclosed crawl space
Enclosed Crawl Space Type:	Vented
Number of Units:	5

Foundation Wall Info:	1		
Name			
Library Type	Uninsulated		
Length(ft)	260.3		
Total Height(ft)	3.5		
Depth Below Grade(ft)	0.0		
Height Above Grade(ft)	3.5		
Location	Enclsd crwl->amb/grnd		
Uo Value	0.625		

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BUILDING FILE REPORT

5 1F unit bdg fac N

Page 2

Foundation Wall: Uninsulated

Type:	Solid concrete or stone
Thickness(in):	8.0
Studs:	None
Interior Insulation:	
Continuous R-Value:	0.0
Frame Cavity R-Value:	0.0
Ins top:	0.0 ft from top of wall
Ins Bottom:	0.0 ft from bottom of wall
Exterior Insulation:	
R-Value:	0.0
Ins top:	0.0 ft from top of wall
Ins bottom:	0.0 ft below grade
Note:	

Frame Floor Info:	1	2	3
Name	1st floor	crawlspace	bay window
Library Type	Capsys Batt Only	crawl hatch	Capsys bay window
Area (sq ft)	3620	45	55
Location	Btwn cond & enclsd crwl	Btwn cond & enclsd crwl	Btwn cond & ambient
Uo Value	0.065	0.369	0.057

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BUILDING FILE REPORT

5 1F unit bdg fac N — Page 3

Frame Floor: Capsys Batt Only

Information From Quick Fill Screen:

Continous Insulation R-Value	0.0
Cavity Insulation R-Value	12.0
Cavity Insulation Thickness (in.)	9.5
Joist Size (w x h, in)	1.5 x 9.5
Joist Spacing (in oc)	24.0
Framing Factor - (default)	0.0988
Floor Covering	HARDWOOD

Note: R-value derated by 40% due to thermal bridging of steel

Layers	Paths	
	Cavity	Framing
Inside Air Film	0.920	0.920
Floor covering	0.680	0.680
Subfloor	0.820	0.820
Cavity ins	12.000	0.000
Continuous ins	0.000	0.000
Framing	0.000	11.875
	0.000	0.000
Outside Air Film	0.920	0.920
Total R-Value	15.340	15.215
U-Value	0.065	0.066
Relative Area	0.901	0.099
UA	0.059	0.006

Total Component UA: 0.065
Total Component Area: 1.0

Component Uo: 0.065

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BUILDING FILE REPORT

5 1F unit bdg fac N Page 4

Frame Floor: crawl hatch

Information From Quick Fill Screen:

Continous Insulation R-Value	0.0
Cavity Insulation R-Value	0.0
Cavity Insulation Thickness (in.)	0.0
Joist Size (w x h, in)	1.5 x 6.0
Joist Spacing (in oc)	24.0
Framing Factor - (default)	0.0988
Floor Covering	TILE

Note:

Layers	Paths	
	Cavity	Framing
Inside Air Film	0.920	0.920
Floor covering	0.050	0.050
Subfloor	0.820	0.820
Cavity ins	0.000	0.000
Continuous ins	0.000	0.000
Framing	0.000	0.000
	0.000	0.000
Outside Air Film	0.920	0.920
Total R-Value	2.710	2.710
U-Value	0.369	0.369
Relative Area	0.901	0.099
UA	0.333	0.036

Total Component UA: 0.369
Total Component Area: 1.0

Component Uo: 0.369

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BUILDING FILE REPORT

5 1F unit bdg fac N — Page 5

Frame Floor: Capsys bay window

Information From Quick Fill Screen:

Continous Insulation R-Value	2.5
Cavity Insulation R-Value	13.0
Cavity Insulation Thickness (in.)	3.5
Joist Size (w x h, in)	1.5 x 3.5
Joist Spacing (in oc)	16.0
Framing Factor - (default)	0.1300
Floor Covering	CARPET

Note:

Layers	Paths	
	Cavity	Framing
Inside Air Film	0.920	0.920
Floor covering	1.230	1.230
Subfloor	0.820	0.820
Cavity ins	13.000	0.000
Continuous ins	2.500	2.500
Framing	0.000	4.375
	0.000	0.000
Outside Air Film	0.920	0.920
Total R-Value	19.390	10.765
U-Value	0.052	0.093
Relative Area	0.870	0.130
UA	0.045	0.012

Total Component UA: 0.057
Total Component Area: 1.0

Component Uo: 0.057

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BUILDING FILE REPORT

5 1F unit bdg fac N | Page 6

Rim and Band Joist:	1	2	3
Name	crawl/1st	crawl/1st	crawl/1st
Area(sq ft)	89.5	81.8	89.5
Continuous Ins	2.5	2.5	2.5
Framed Cavity Ins	30.0	30.0	30.0
Cavity Ins Thk(in)	9.5	9.5	11.5
Joist Spacing	24.0	24.0	24.0
Location	Enclsd crwl -> ambient	Enclsd crwl -> ambient	Enclsd crwl -> ambient
Uo Value	0.030	0.030	0.029

Rim and Band Joist:	4		
Name	1st/2nd		
Area(sq ft)	178.5		
Continuous Ins	2.5		
Framed Cavity Ins	0.0		
Cavity Ins Thk(in)	9.5		
Joist Spacing	24.0		
Location	Cond -> ambient		
Uo Value	0.160		

Above-Grade Wall:	1	2	3
Name	front	side right	rear
Library Type	R-13 w/ 1/2" XPS *	R-13 w/ 1/2" XPS *	R-13 w/ 1/2" XPS *
Gross Area(sq ft)	1668.50	664.70	1428.50
Exterior Color	Light	Light	Light
Location	Cond -> ambient	Cond -> ambient	Cond -> ambient
Uo Value	0.096	0.096	0.096

Above-Grade Wall:	4		
Name	side left		
Library Type	R-13 w/ 1/2" XPS *		
Gross Area(sq ft)	664.70		
Exterior Color	Light		
Location	Cond -> ambient		
Uo Value	0.096		

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BUILDING FILE REPORT

5 1F unit bdg fac N

Page 7

Above-Grade Wall: R-13 w/ 1/2" XPS *

Information From Quick Fill Screen:

Standard Steel Frame

Continuous Insulation (R-Value)	2.5
Frame Cavity Insulation (R-Value)	13.0
Frame Cavity Insulation Thickness (in)	3.5
Stud Size (w x d, in)	1.5 x 3.5
Stud Spacing (in o.c.)	16.0
Framing Factor - (default)	0.2300
Gypsum Thickness (in)	0.6

Note:

Layers	Paths	
	Cavity	Framing
Inside Air Film	0.680	0.680
Gyp board	0.563	0.563
Cavity ins/Frm	5.980	4.375
Continuous ins	2.500	2.500
Ext Finish	0.940	0.940
	0.000	0.000
	0.000	0.000
Outside Air Film	0.170	0.170
Total R-Value	10.832	9.227
U-Value	0.092	0.108
Relative Area	0.770	0.230
UA	0.071	0.025

Total Component UA: 0.096

Total Component Area: 1.0

Component Uo: 0.096

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BUILDING FILE REPORT

5 1F unit bdg fac N

Page 8

Window Information:	1	2	3
Name	front	rear	side A
Library Type	1400 DH low-e argon	1400 DH low-e argon	1400 DH low-e argon
U-Value	0.320	0.320	0.320
SHGC	0.330	0.330	0.330
Area(sq ft)	435.00	300.00	16.50
Orientation	North	South	East
Overhang Depth	0.0	0.0	0.0
Overhang To Top	0.0	0.0	0.0
Overhang To Bottom	0.0	0.0	0.0
Interior Winter Shading	0.85	0.85	0.85
Interior Summer Shading	0.70	0.70	0.70
Adjacent Winter Shading	None	None	None
Adjacent Summer Shading	None	None	None
Wall Assignment	AGWall 1	AGWall 3	AGWall 4

Window: 1400 DH low-e argon

U-Value:	0.320
Solar Heat Gain Coefficient:	0.330
Note:	Silver Line Windows - LoE2 / Argon I.G.

Door Information:	1	2	
Name	front	rear	
Opaque Area(sq ft)	100.0	100.0	
Library Type	Steel-polystyrene	Steel-polystyrene	
Wall Assignment	AGWall 1	AGWall 3	
Uo Value	0.341	0.341	

Door: Steel-polystyrene

R-Value of Opaque Area:	2.0
Storm Door:	No
Note:	

Roof Information:	1		
Name	roof		
Library Type	3" polyiso roof		
Gross Area(sq ft)	3765.00		
Color	Dark		
Radiant Barrier	No		
Type(Attic)	Vaulted		
Uo Value	0.045		

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BUILDING FILE REPORT

5 1F unit bdg fac N — Page 9

Ceiling: 3" polyiso roof

Information From Quick Fill Screen:

Continous Insulation (R-Value)	19.5
Cavity Insulation (R-Value)	0.0
Cavity Insulation Thickness (in)	0.0
Gypsum Thickness (in)	0.625
Bottom Chord/Rafter Size(w x h, in)	1.5 x 9.5
Bottom Chord/Rafter Spacing (in o.c.)	24.0
Framing Factor - (default)	0.1100
Ceiling Type	Vaulted

Note:

Layers	Paths	
	Framing	Cavity
Inside Air Film	0.610	0.610
Gyp board	0.563	0.563
Cavity Ins/Frm	0.000	0.000
Continuous ins	19.500	19.500
Plywood	0.930	0.930
Shingles	0.400	0.400
	0.000	0.000
Outside Air Film	0.170	0.170
Total R-Value	22.173	22.173
U-Value	0.045	0.045
Relative Area	0.110	0.890
UA	0.005	0.040

Total Component UA: 0.045

Total Component Area: 1.0

Component Uo: 0.045

Mechanical Equipment: General

Number of Mechanical Systems:	2
Heating SetPoint(F):	70.00
Heating Setback Thermostat:	Not Present
Cooling SetPoint(F):	75.00
Cooling Setup Thermostat:	Not Present

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BUILDING FILE REPORT

5 1F unit bdg fac N Page 10

Heat: Slant/Fin S-60 DP

SystemType:	Fuel-fired hydronic distribution
Fuel Type:	Natural gas
Rated Output Capacity (kBtuh):	51.0
Seasonal Equipment Efficiency:	81.6 AFUE
Auxiliary Electric:	170 Eae
Note:	
Heater Location:	Conditioned area
Performance Adjustment:	100
Percent Load Served:	100
Number Of Units:	5

Water Heating Equipment: Bradford White 40 ga

Water Heater Type:	Conventional
Fuel Type:	Natural gas
Energy Factor:	0.57
Recovery Efficiency:	0.77
Water Tank Size (gallons):	40
Extra Tank Insulation (R-Value):	0.0
Note:	
Location:	Conditioned area
Percent Load Served:	100
Performance Adjustment:	100
Number Of Units:	5

Duct Leakage

Qualitative Assessment:	No observable leakage
Total Duct Leakage - Not Applicable	
Supply Duct Leakage - Not Applicable	
Return Duct Leakage - Not Applicable	

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BUILDING FILE REPORT

5 1F unit bdg fac N

Page 11

Infiltration and Mechanical Ventilation

Whole House Infiltration	
Measurement Type:	Blower door test
Heating Season Infiltration Value:	10000.00 CFM @ 50 Pascals
Cooling Season Infiltration Value:	10000.00 CFM @ 50 Pascals
Mechanical Ventilation for IAQ	
Type:	None
Rate(cfm):	0
Sensible Recovery Efficiency(%):	0.00
Total Recovery Efficiency(%):	0.00
Hours per Day:	24.00
Fan Power (watts):	0.00
Ventilation Strategy for Cooling	
Cooling Season Ventilation:	Natural Ventilation

Lights and Appliances

Using default values	
Oven/Range Fuel Type:	Natural gas
Clothes Dryer Fuel Type:	Electric

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ENERGY STAR

ENERGY STAR HOME VERIFICATION SUMMARY

Date:	June 08, 2005	Rating No.:	
Building Name:	5 1F unit bdg fac N	Rating Org.:	
Owner's Name:	Edgemere-By-The-Sea Corp.	Phone No.:	
Property	Beach Channel Drive	Rater's Name:	
Address:	Edgemere, NY	Rater's No.:	
Builder's Name:	CAPSYS		
Weather Site:	New York, NY	Rating Type:	Based On Plans
File Name:	Edgemere 1F 5 unit facing north.blg	Rating Date:	

Building Information

Conditioned Area (sq ft):	7525	Housing Type:	Multi-family, whole building
Conditioned Volume (cubic ft):	60200	Foundation Type:	Enclosed crawl space
Insulated Shell Area (sq ft):	12090	HERS Score:	86.4 *****
Number of Bedrooms:	15		

Building Shell

Ceiling w/Attic:	None	Window/Wall Ratio:	0.17
Vaulted Ceiling:	3" polyiso roof U=0.045	Window Type:	1400 DH low-e argon
Above Grade Walls:	R-13 w/ 1/2" XPS * U=0.096	Window U-Value:	0.320
Found. Walls (Cond):	None	Window SHGC:	0.330
Found. Walls (Uncond):	Uninsulated	Infiltration:	Htg: 10000 Clg: 10000 CFM50
Frame Floors:	Capsys Batt Only U=0.065	Duct Leakage:	No observable leakage
Slab Floors:	None		

Mechanical Systems

Heating:	Fuel-fired hydronic distribution, 51.0 kBtuh, 81.6 AFUE.
Water Heating:	Conventional, Gas, 0.57 EF.
Programmable Thermostat:	Heat=No; Cool=No

Note: Where feature level varies in home, the dominant value is shown.

This home MEETS the EPA's requirements for an Energy Star Home.

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This information does not constitute any warranty of energy cost or savings.

C

CANDIDATE STRUCTURAL TECHNOLOGIES FOR THE CASE STUDY PLANT

In addition to the primary structural and industrial engineering recommendations provided to Capsys and described in the body of this report, a number of more far-reaching changes to the Capsys production system were discussed during the concurrent engineering process. These fall into three categories (design and layout software, wall panelization equipment and fastening systems) and are summarized below.

Design and layout software

There are a few developers of computer software specifically designed to aid in the production of pre-manufactured cold-formed steel wall panels. None of these software packages design the actual members, but they do optimize wall panel configurations and produce fabrication details, material lists and assembly plans. Three systems with some history in the commercial cold-formed steel industry are discussed below.

1. **Argos.** The most popular software for wall panel layout is the Argos system. This is well known in the industry as the most powerful program for wall panel layout and manufacturing. It can be integrated with AutoCAD, as well as other proprietary software packages for such tasks as roof truss and shear wall frame design. It can also be linked with software that controls roll formers, producing cut-to-length material right in a fabricator's shop. This software is sold to users, and is priced from approximately $7,000 to $12,000, depending on options and service plans.
2. **KeyPanel.** The second most popular software for wall panel design is the KeyPanel package by Keymark Enterprises. This is a recently upgraded product with more versatility than the Argos system and is designed for use by less technically adept users. It can be used in conjunction with other products by Keymark to design roof trusses, shear walls, joists and headers (although it cannot design the wall studs themselves). Keymark leases this software to users and provides technical support. Keymark also offers a plan processing service in which they will produce shop drawings for a panelizer who does not use the software in-house.
3. **Aegis Metal Framing.** A newcomer to the cold-formed steel frame wall panelization industry is Aegis Metal Framing. This company is a joint venture between two leaders in related industries; Dietrich Industries in the cold-formed steel framing industry and Mitek in the pre-engineered wood and steel truss industry. Primarily focused on their proprietary cold-formed roof truss system, the company also has many proprietary products including floor joists with large openings and economical and efficient header products. They do have a wall panelization layout program, but it is rather new and details are not easily available. To use this system, however, would require joining the Aegis group of fabricators and may necessitate utilizing their whole line of products, especially trusses.

All of these software packages, with the exception of the plans processing option by Keymark Enterprises, require employing an experienced designer with fabrication software experience and three to five days of off-site training at the software company's location.

Wall Panelization Equipment

The current Capsys panelization tables used for cold-formed steel framing wall panel production are crude assemblies constructed from structural steel members arranged to form just the outline of the wall segment being produced. There is limited ability to adjust for varying wall panel layouts, resulting in long changeover times when switching from one wall panel configuration to another. Production workers rely on handheld tape measures to position the framing members, and there is no means to compress and square the wall panel on the existing table setup.

Although there are many fabricators in the United States, the technology is not as advanced as it is for cold-formed steel framing as it is in Europe and especially in Australia. In the United States, the majority of wall panelizers fabricate their panels on homemade tables of varying styles and features. Most homemade tables consist of either an elevated plywood platform or Unistrut cold-formed framing members on posts spaced between 16" and 48" on center. Some facilities elect to have a separate area and employee who manufactures special wall panel components offline, such as headers and jamb stud assemblies.

1. **Plywood tables.** These are efficient and easy to construct, but they are extremely limited in adjustability. If a plant is always producing wall panels of approximately the same height and length, then this is a useful system. Cold-formed clips or block of wood can be screwed down to the plywood deck as required to form the perimeter of the panel. Marking can be used on the plywood to assist in layout.
2. **Unistrut tables.** Unistrut tables offer more flexibility than plywood. The Unistrut product line includes many types of quick-install clips that can be moved up and down the individual ribs of the table to form the perimeter of the panel. The fact that the ribs of the table are spaced out limits the ability to use markings on the table, but it allows the framers to easily move in and about the panel by walking on floor level, but working at a comfortable height for the use of screw guns.
3. **Triad Steel Stud Framing Table**. There is one manufacturer of specially designed wall panelization equipment for the cold-formed steel framing industry. Merrick Machine Company makes a panelization system called the Triad Steel Stud Framing Table. It is actually a multi-stage system with a variety of tables and automated equipment. The main table has many unique features. It has indexed tabs that can be set to show exact stud locations. Optional automated collated screw guns can be installed to move along a track on both the top and bottom, installing the screws between the studs and track from both side of the wall at the same time. The table also includes a compression mechanism to ensure that the studs seat properly in the top and bottom tracks to meet ASTM and AISI gap limitations. Other tables in the system that can be added include a table to install sheathing and one to route out openings in the wall sheathing.

Other notable pieces of equipment in established wall panel plants include a variety of cutting equipment and layout assistance devices. While a chop saw is the most common tool for cutting cold-formed steel, it is quite slow and expensive to maintain. High production facilities are starting to use water-cooled gang band saws. There saws can cut through stacks of material at the same time, cleanly and efficiently. On a swivel base, it can make miter cuts also. Plasma cutters operate similarly to torch cutters, but they can work on 110 volts AC and cut very quickly with little heat or burning of the material or its coating. Lastly, some high production facilities utilize laser layout projectors that are mounted above the framing area and project laser beams downward to show where the framing members are to be placed on the jig. This type of system is very expensive and requires a sophisticated software program like the ones discussed above to feed it the exact information for each panel.

Considering the lower production volume at Capsys compared to dedicated wall panelization plants, the plywood or Unistrut tables are the most promising candidates for Capsys.

Fastening systems

Capsys utilized welding and screws for fastening. There are a number of other technologies available that are designed to increase efficiency in both in-plant and field fabrication for steel-to-steel and steel-to-concrete connections. Some of these technologies are fairly young, however they are continually improving.

1. **Powder actuated fasteners (PAFs**). PAFs employ an explosive charge to propel a metal pin through a light gauge steel member into a substrate of either structural steel or concrete. The extreme heat and pressure generated by the charge provides a very strong bond. The pin and steel of the light gauge member (and structural steel substrate if applicable) are fused together. Unlike welding, the galvanization of the cold-formed members is not disturbed. PAFs are a well established and available technology.
2. **Pneumatic pins**. While PAFs are the most common type of fastener for cold-formed steel to either structural steel or concrete, a new, similar fastener has been developed that is propelled by air instead of an explosive charge. These pins are not as strong as PAFs, but they are easier, cheaper and safer to install. In addition to fasteners for connecting cold-formed steel to structural steel or concrete, two manufacturers, Aerosmith and Ramset, have employed this technology to develop pins for installing sheathing to cold-formed steel and for connecting two layers of cold-formed steel. While the capacity of these pins is not as high as PAFs or screws, for many applications it is sufficient, and much quicker to install.
3. **Clinching.** The most unique new fastening technology is clinching. Attexor, a European company, has introduced this technology in the United States. Clinching is a method of joining two layers of sheet steel by expanding one and bending it into the other. For heavier sheets of steel, one layer may actually be pierced and have the other layer bent through it in a tab-and-slot type connection. This technology has long been being used in automotive production. Unlike screws and rivets, this type of fastening uses no consumables. It does, however, require special hydraulic tools that have limited use in tight spaces and require maintenance. The strength of these connections is approximately the same as with screws, so they might be good for stud-to-track connections. It is not known how well clinches will stand up to the vibration experienced during the transportation of prefabricated panels or modules.

For Capsys' applications, pneumatic pins for sheathing-to-stud and stud-to-track connections are readily available and most promising.

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GLOSSARY

Cycle time: The time required to complete one cycle of an operation. If cycle time for every operation in a complete process can be reduced to equal takt time, products can be made in single-piece flow.

Just-in-time: A system for producing and delivering the right items at the right time in the right amounts.

Kanban: A small sign or signboard, an instruction to produce or supply something; usually a card; usually includes supplier and customer names, and information on transportation and storage; a central element of just-in-time system. There are two types: production and withdrawal kanbans.

Pull: To produce an item only when the customer asks for it. Typically, the customer "withdraws" the item and we "plug the gap" created thereby.

Single-piece flow: A situation in which products proceed, one complete product at a time, through various operations in design, order-taking, and production, without interruptions, backflows, or scrap.

Takt time: The pace of production synchronized with the rate of sales.

Value stream: The specific activities required to design, order, and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customer.

Value stream map: Identification of all the specific activities occurring along a value stream for a product or product family.

Visual control: The placement in plain view of all tools, parts, production activities, and indicators of production system performance, so the status of the system can be understood at a glance by everyone involved. Used synonymously with transparency.