Building America Technical Systems Project Description

1. Project Title: Manufacturing/Construction Productivity

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3. Other Participating Organizations: All American Homes, Avis America Homes, Cardinal Homes, Epoch Homes, Excel Homes, General Housing Corporation, The Home Store, Nationwide Homes, Penn Lyon Homes
NOTE: This work was performed as part of two Building America teams – 1) Hickory Consortium and 2) Building America Industrialized Housing Partnership

4. Project:

1. Schedule
   1.a. Initiation Date: 1998, (initiated prior to current contracting period under previous contract).
   1.b. Typical intermediate dates have been Final Reports for project, due in third quarter of each year.
   1.c. Estimated Completion Date: August 2005.
2. Funding Status
   2.a. Teams are competitively awarded multi-year task ordering agreements, with annual negotiated contracts. The funding for this work has been provided. No additional funding is anticipated at this time.
3. Project / Technology Maturity
   3.a. Applied Research

5. Statement of Problem: Industrialized homebuilders strive to meet homebuyer needs, while minimizing their first cost. Building America seeks to broaden this narrow perspective, encouraging homebuilders to incorporate innovations that will yield substantial improvements in overall home performance. However, industrialized homebuilders are reluctant to adopt innovations without a better understanding of how they will impact their operations.

6. Project Objectives:

1. To improve the quality, capacity and productivity of modular homebuilders.
2. To develop tools that assist modular manufacturers in understanding the impact of innovative production processes and materials.

3. To identify root causes of waste on the construction site and related factors that contribute to poor long term home performance.

7. Project History & Relationships: From the inception of the Building America program, researchers interested in modular homebuilding recognized the need for an organized collaboration with modular producers. As a member of the Hickory Consortium, our research team helped to establish the Quality Modular Building Task Force in 1999. Composed of top executives from twelve of the largest modular producers in the U.S., the Task Force served as an active industry advisory board for modular research. The Task Force met once annually to review research findings and assist in developing the research agenda for the coming year. Companies involved in the Task Force also served as sources of industry data and test beds for research recommendations. Task Force members were active participants in all modular manufacturing/construction productivity research performed by the Hickory Consortium and the Industrialized Housing Partnership.

Related research currently being conducted by the UCF Housing Constructability Lab for other federal agencies include:

- NSF PATH – "Collaborative Research: An Integrated Interior Infill System for Mass Customized Housing**"** in collaboration with MIT School of Architecture
- HUD - "Lean Thinking in Manufactured Housing" in collaboration with Manufactured Housing Research Alliance

8. Technical Approach: Our technical approach consisted of two major thrusts, the first targeting factory innovation and the second focusing on set and finish improvements on the construction site. The factory strategy was structured in four stages:

1. Visit each manufacturer, listen and begin to understand production challenges and opportunities.
2. Assist manufacturers in solving small scale problems to build trust and develop process knowledge.
3. Use process knowledge to develop modeling tools to study factory-wide performance.
4. Use modeling tools to help manufacturers design new factories and upgrade existing operations.

After visiting modular manufacturers and observing their operations, researchers documented different production processes and factory layouts (1,2,3). Several small scale studies were performed targeting specific problems (1). Recommendations to improve flow around a roof framing jig resulted in significant reduction in congestion, and recommendations to increase productivity of finish drywall sanding resulted in a 50% labor reduction. (1)

Using detailed knowledge of modular production processes, researchers developed the Generic Modular Manufacturing Simulation System (GMMSS), a novel approach to speed development of complex housing factory simulation models (4). GMMSS uses EXCEL, VISUAL BASIC, and the PROMODEL simulation modeling language to automatically generate simulation models. Simulation modeling is widely used throughout industry to assess impacts from product, process and operating changes. The simulation model serves as a virtual laboratory, capable of representing all key entities and resources in the factory: process/material handling equipment, workers, production orders, parts, and production paradigms.

Researchers used a simulation model generated using GMMSS to assist in the design of one of the newest and most innovative modular manufacturing plants in the U.S., Excel Homes' factory in Ghent, WV (3,5,6). The new factory increased Excel's total production capacity by about 50%. (6) Researchers incorporated lean production principles into the design, contributing to safety, flexibility, responsiveness, and productivity. The new factory pioneers the use of a multi-station, floor-level, progressive roof line that allows safe and efficient roofing. It also was an early adopter of supersize drywall for both ceiling and walls. Mechanization was provided to improve the ergonomics of drywall handling and most mechanical fasteners were replaced with foam adhesive. The drywall innovation resulted in less drywall handling and a sizeable reduction in drywall finishing effort. Finally, a customization bay was added to allow more extensive, value added customization without degrading line movement. Flow innovations were modeled and evaluated using the factory simulation model. GMMSS allowed researchers to develop the complex model in a fraction of typical model development time while improving modeling consistency and quality. The model was also used for training production staff.

A second major research thrust targeted set and finish operations on the construction site. The research strategy was structured in four stages:

1. Observe module set operations for each modular homebuilder and document performance
2. Benchmark set performance across modular homebuilders and identify improvement opportunities
3. Targeting a large modular homebuilder, perform a kaizen improvement study of the complete modular finish process; document performance and identify opportunities for improvement
4. Assist the homebuilder in implementing improvements:

Researchers observed six modular home sets representing four manufacturers (7). Three-person research teams spent one to three days per set, documenting all set activities: start/stop times, labor use, problems encountered and best practices. A full benchmarking analysis was presented to all manufacturers and major improvement opportunities were highlighted

- Design – Eliminate/combine components (e.g., combine modules) to reduce cycle time, site labor, enhance quality and improve energy efficiency
- Manufacturing - Improve quality (e.g., roof framing) and increase factory content (e.g., shingling) to speed set
- Site logistics – Provide the right equipment (e.g., bulldozer) at the right location (e.g., numerous cases of cranes and modules being repositioned)
- Fit – Improve accuracy (e.g., foundations, set location, gasket installation) to enhance visual appearance and increase energy efficiency

The on-site finish process in modular homebuilding is often imagined to be much simpler than site building, since most work is performed in the factory. The reality is that site finish operations are not simple and can be a source of imperfections in airsealing and system installation that reduce the energy efficiency, quality, and profitability of modular homebuilding. To further our understanding of the finish process and demonstrate opportunities for improvement, a kaizen rapid improvement event was undertaken (8,9,10). A kaizen event is a continuous, highly focused, action oriented, 3-5 day exercise where a team plans and takes immediate action to improve a process.

Researchers enlisted the aid of one of the nation's largest modular homebuilders, The Home Store, to serve as the focal point of the exercise. The objective of the kaizen was to improve the finish process for builder, shortening the construction cycle and improving quality, safety, energy, and productivity. Included on the kaizen team were the builder and his production manager, the production manager and production engineer from the builder's modular manufacturer (Avis America), a consultant specializing in lean production, and members of the research team.

A key finding was that the conventional batch production process in which each Homestore construction crew worked on 7-8 homes simultaneously resulted in unnecessarily long cycle times, averaging 13 weeks per house. Using lean production concepts such as Value Stream Mapping, single home flow, and project scheduling, the kaizen team devised an approach for shortening the cycle time from 13 weeks to 3 weeks. The team also recommended numerous improvements involving both the builder and the manufacturer to improve productivity (e.g., factory to optimally locate shiploose materials in each module) and seal the home (e.g., double sealing marriage joints with gaskets and foam and providing backers to provide better foam seal).

After implementing many of the recommendation, the builder's president reported a 59% labor productivity gain and a 22% cycle time reduction. Subsequent blower door testing on two homes indicated airtightness scores less than 5 ACH50, the best in an industry-wide benchmarking study (11).

9. Technical Work Plan: The work plan is described in Section 8. above.

10. Technical Problems/Barriers: There are several critical challenges facings researchers interested in improving manufacturing/construction productivity. The first is the difficulty in obtaining activity process times for analysis and planning (12). Contributing factors include: frequent changes in work force size, movement of workers between stations, long cycle times, and visual obstructions (e.g., walls). Traditional approaches to collecting housing process times are cost prohibitive and unreliable – current data are simply not available. One answer may lie in real time data collection tools such as automatic identification (e.g., bar code scanning, radio frequency identification). Significant challenges lie in developing ubiquitous, unobtrusive systems that work in dirty, rough, open (even outdoor) environments.

A second serious challenge is the tenuous link between modular homebuilders and their subcontractors. Builder-subcontractor relationships are challenging for all builders, but modular homebuilders face a unique challenge: most of the work is done in the factory, leaving relatively little work, little profit, and little commitment for the site subcontractor. This fragile relationship is a serious impediment to achieving one of the greatest lean opportunities – a shift from conventional, multi-home batch scheduling to single home flow. During our kaizen exercise, the builder was reluctant to reduce the number of concurrent homes under construction, expressing an unwillingness to approach subcontractors to seek the tighter scheduling required by single-home flow. As a result, implementation results indicated that the construction cycle was reduced 22% (from 90 to 72 days), far from the theoretical ideal. To move closer to the lean ideal, a follow-up exercise was held with the builder, the modular manufacturer and key subcontractors.

After discussing the concept of single-home flow and the tighter scheduling it requires, several subs indicated a willingness to schedule each home earlier and a to honor the schedule.

11. Status Research Projects: Research tasks involving manufacturing/construction productivity were performed between 1997 and the present. Research plans and results are documented in project reports, journal articles, and presentations (1-12). Research in this area is expected to end in August 2005.

12. Commercialization Plans: Many of the recommendations developed in this research are already in place or are under active consideration by modular manufacturers. Research findings and recommendations are readily available on the Housing Constructability Lab website (http://hcl.engr.ucf.edu/).

13. Efficiency Improvement Metrics: Manufacturing/construction productivity metrics are multi-dimensional (customer satisfaction, operational performance, financial performance and team member satisfaction) and multi-attribute. Working closely with modular manufacturers, researchers identified the metrics described in Figures 1 through 5.

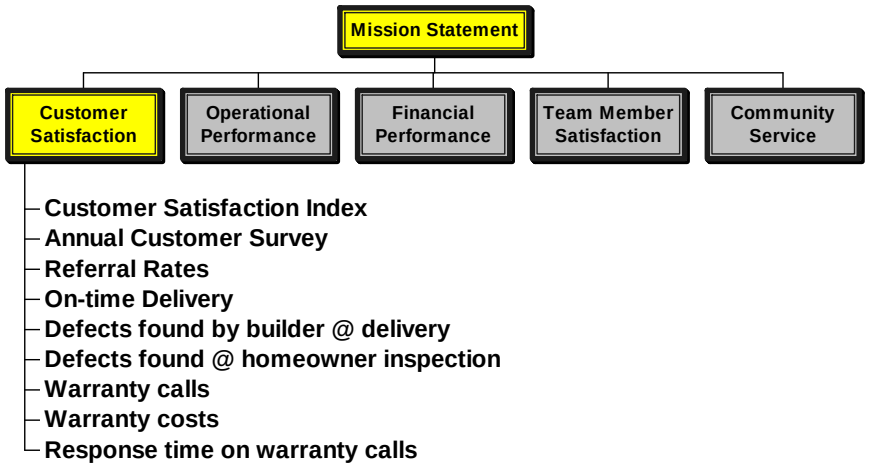

Figure 1. Customer satisfaction metrics

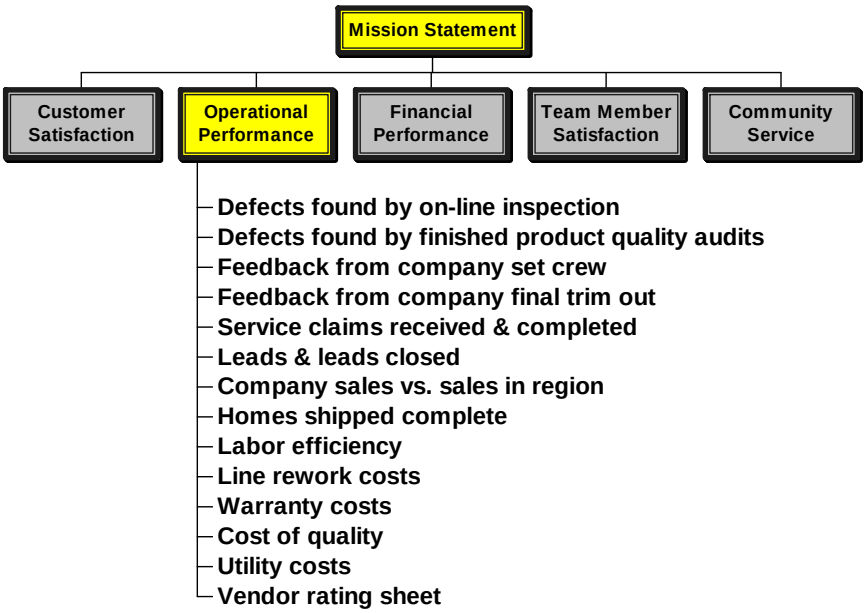

Figure 2. Operational performance metrics

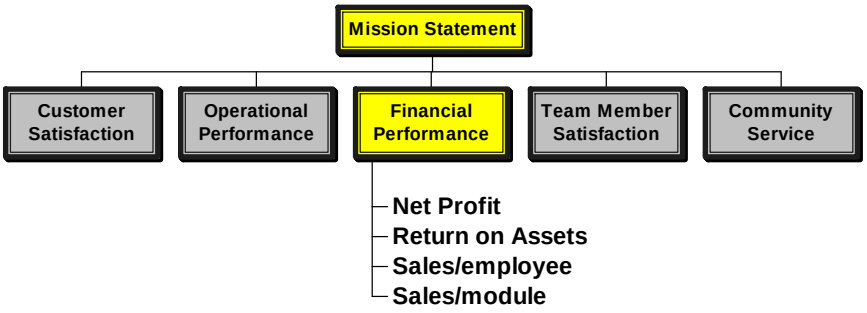

Figure 3. Financial performance metrics

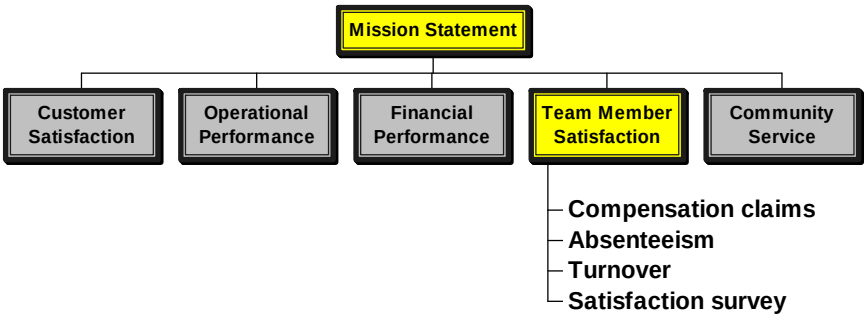

Figure 4. Team member satisfaction metrics

14. Project Output: The research findings are published on the Housing Constructability Lab website (http://hcl.engr.ucf.edu/) and in formal reports and papers (1,2,3,4,5,6,8,9,10,11,12)

Major Accomplishments:

Output	Significance	Contained in Contact Deliverable #
Implementation of small scale productivity improvement projects	Demonstrated opportunities for improvements in the factory.	FY97-98
Development of Generic Modular Manufacturing Simulation System (GMMSS)	GMMSS allows engineers to develop complex models in a fraction of typical model development time while improving modeling consistency and quality.	FY00-01
Design and implementation of new modular factory	Demonstrated incorporation of lean production techniques in modular manufacturing and use of simulation modeling in assessing innovative processes and materials.	FY00-01
Modular home set recommendations	Raised manufacturer awareness of improvement opportunities on the construction site.	FY00-01
Kaizen rapid improvement event	Introduced a new process improvement tool to modular manufacturers and builders.	FY00-01
Implementation of kaizen recommendations	Demonstrated potential for further improvements in productivity, quality and energy efficiency during finish on the construction site.	FY01-02

15. Budget: This activity was initiated in 1998 and was in full gear during 1999 through 2003. The following table shows the approximate budgets for this activity. Please note that our accounting system **does not** keep track of budgets by task, so these are estimates.

1998 Funding:	DOE ~$40,000,	Cost Share ~$10,000
1999-2003 annual funding :	DOE ~$80,000/yr,	Cost Share ~$20,000/yr
2004-2005 Funding (Total for both years) :	DOE ~$80,000,	Cost Share ~$20,000.
Total Lifetime Funding:	**DOE~$520,000**	**Cost Share ~$130,000**

16. Principal Project Personnel:

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Role in the project: Principal Investigator. **Principal areas of research and expertise:** Modular manufacturing and construction, lean production, simulation modeling. **Time/Hours devoted to project:** 1 man-year **Education:** Ph.D. Georgia Tech – Operations Research, MSIE Georgia Tech, BSIE Mississippi State University. **Relevant employment history** (list places, dates, and position held): University of Central Florida, 1990 – present, Associate Professor; SysteCon/Coopers & Lybrand, 1980-1988, Detroit Diesel Allison Div. of General Motors, 1978-1980. **Relevant professional activities and honors:** Senior Member of the Institute of Industrial Engineers, Member of Society of Manufacturing Engineers and Operations Research Society of America. **Relevant publications emanating from this project: See references in Section 17 below.**

17. Other Information Sources:
Website:
http://hcl.engr.ucf.edu/

References:
1) Mullens, M. *Milestone Report: Results of Industrial Engineering Studies of the Epoch Corporation Modular Manufacturing Facility*, Report to National Renewable Energy Laboratory, Deliverable 2.C.1 Task Order KAR-5-18413-02, December, 1998.

2) Hickory Consortium, *Milestone Report: Quality Modular Building Task Force Meeting Results and the Research Agenda*, Report to National Renewable Energy Laboratory, Deliverable 6.B.2b Task Order KAR-5-18413-06, November, 2000.

3) Mullens, M. Final *Report: Results of Industrial Engineering Study of Third Modular Production Partner*, Report to National Renewable Energy Laboratory, Deliverable 7.B.1, January, 2001.

4) Nasereddin, M.*, M. Mullens, D. Cope, "The Development of A Reusable Simulation Model for the Modular Housing Industry Using ProModel and Visual Basic," *Industrial Engineering Research '02 Conference Proceedings*, Orlando, May, 2002.

5) Mullens, M., *Progress Report: November 2000 – August 2001*, Report to Industrialized Housing Partnership, prepared by UCF Housing Constructability Lab, University of Central Florida, Orlando, FL, December 2001.

6) Mullens, M., *Progress Report: April 2001 – March 2002*, Report to Industrialized Housing Partnership & Building America Program - U.S. Department of Energy, University of Central Florida Housing Constructability Lab,Orlando, FL, August 2002.

7) Mullens, M. "Results from Studies of the Module Set Process," presentation given to the Quality Modular Building Task Force, Annapolis, October 2000.

8) Mullens, M., *Progress Report: November 2000 – August 2001*, Report to Hickory Consortium, prepared by UCF Housing Constructability Lab, University of Central Florida, Orlando, FL, December 2001.

9) Mullens, M., *Progress Report: September 2001 – November 2002*, Report to Hickory Consortium & Building America Program - U.S. Department of Energy, University of Central Florida Housing Constructability Lab,Orlando, FL, December 2002.

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

11) Mullens, M., Burdick, J., Energy Test Results and Recommendations for Avis America Homes –
Avis, PA, University of Central Florida Housing Constructability Lab, January 2003.

12) 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.

13) Hopp, W. J., and Spearman, M. L. (2000). *Factory Physics*, McGraw-Hill, New York.