Shop-Floor Information Systems for Industrialized Housing Production

R. Scott Broadway and Michael A. Mullens, Ph.D., PE
Department of Industrial Engineering & Management Systems
University of Central Florida
Orlando, FL 32816-2450, USA

Abstract

Competitive pressure in the industrialized housing industry is resulting in an increasingly complex mix of custom home designs and homebuyer options. While good news for the homebuyer, this is often problematic on the production floor, which must respond to design variations without a substantive understanding of how they impact the roughly fifty production activities. This paper describes an approach for collecting, analyzing, reporting and using labor data to manage shop floor operations for housing manufacturers. The approach couples barcode scanning and wireless communications technologies with custom software, enabling employees to easily record their activities on a real-time basis. Web-based software provides analysis and reporting of production performance from either a real-time or historical perspective. The paper summarizes lessons learned from early implementation efforts, including both technical and organizational concerns affecting data accuracy and user acceptance, and suggests future improvements and integration with other management systems.

Keywords
Shop-floor control, lean labor management, modular homebuilding, industrialized housing, barcode.

1. Introduction
In any enterprise, the term "resource" refers to both the assets and competence of an organization [1]. By this definition, the managers of these resources should constantly seek to improve the quality of assets and the competence by which the resources make decisions. Opportunities exist to improve the competence of decision-making in industrialized housing and modular home construction, both manufacturing processes characterized by producing large components of homes produced using traditional home construction techniques in a factory environment [2]. Such homebuilders construct personalized or custom homes, usually built on synchronous production lines in a factory, and then ship the housing components to be installed and finished on a home site.

Perhaps the single greatest production challenge faced by modular manufacturers is how to maximize production capacity and increase quality, while expanding production flexibility to deliver the widening product mix and customization demanded by homebuyers. These conflicting goals arise from the production process. Home factories use many interdependent activities on their assembly lines, often with complex relationships between assembly steps. Process time variability is exacerbated by highly customized and variable product designs, executed by labor teams that are often self-directed and sometimes struggling with absenteeism. The combination of complex process interdependencies, highly variable process times and near-synchronous production lines create floating bottlenecks that limit capacity and create quality problems. We believe that better management of floating bottlenecks is key to enhancing production performance.

Controlling process times means paying closer attention to labor resources. Historically, this industry values labor resources for their competence at a task, but treats them as a minimal cost driver – typically 10-15% of total operating costs. Overtime pay is often utilized to make up for inadequate production planning or high turnover among skilled workers. Labor teams are generally allowed to self-manage their hour-to-hour operations, while management pays much closer attention to material and overhead concerns. However, in a low-automation environment like this, labor resources are prime drivers of process flow, plant capacity, and product quality. If floating bottlenecks can be managed more effectively by gathering data on process times, each of these three challenges can be met. More specifically, process time data can be used to drive continuous improvement efforts and predict future process times. Previous research efforts that focused on simulation and scheduling technologies [2] were seen as ineffective by industry professionals, because models were based on expert estimates, not data observed in their factories.

In this paper, we will first review previous findings on labor management and data collection. Design details are then presented about STACS (Status Tracking and Control System), a shop-floor data collection system created to increase the quality and timeliness of decision making for homebuilders. A major modular homebuilder helped in the first data collection project using STACS, and the new discoveries build a case for further development of this integrated information system.

2. Literature Review

According to Liu [1], organizations manage strategically by sensing, perceiving, developing models, interpreting findings, and conceptualizing new plans. The author uses the term "strategic scanning" to build a case for more automated methods of sensing and perceiving the organization's environment, both internal and external. It is a justification for first looking at managers' needs in predicting the future, making better decisions, or supporting their intuition with actual findings, and then creating a system that specifically satisfies their needs. In the construction field, modeling methods like neural networks have already been shown to reliably predict the labor requirements for each unit of a project, given the characteristics of the design and environment [3]. If predictions are available, task and manpower scheduling methods [4] become available for the organization to better make decisions. A framework for discrete-event simulation in construction [5] could help managers model these schedules or verify their design ideas within the safety of a simulation. These examples from construction-industry research satisfy the three functional goals of a "strategic scanning" system.

To build such a decision support system, data are needed from the actual production system. The first published attempt at comprehensive process time data collection across an entire construction project came in a 1997 study comparing Israeli construction methods [6]. Researchers used the work-sampling method to manually record the tasks of all employees every 30 minutes at the site of a future apartment building. This method offers a labor-intensive data collection strategy that may overlook activities that happen within the 30-minute observation cycle. The author of that study is currently interested in more automated data collection techniques, using global-positioning system (GPS) and radio-frequency (RF) data to record how long workers spend at defined jobsite locations [7]. This system attempts to predict what activity each worker is doing, based on a set of inter-related activities that are either complete or pending; the likely outcome is a live project status and a log of labor inputs to each activity.

Technology for more automated labor data collection has been available for some time. In a 1993 electronics assembly facility, a system of barcode scanner terminals at each workstation, all networked to a personal computer, kept track of the times employees took to complete parts and batches for each activity [8]. The most current shop-floor data collection systems are usually tightly coupled into an ERP (Enterprise Resource Planning) system, integrating work order assignment, labor time allocation, tracking of work-in-process (WIP), and quality management [9].

3. Design of the STACS Data Collection System

The HCL research team sought to create a system that was built for the specific needs of modular and industrialized homebuilders. ERP-integrated solutions have little appeal to the industry since their operations seldom conform to a process manageable by ERP shop floor control modules. Workers in a home factory do not currently bill time to specific work orders, nor are each employee's activities currently capable of being scheduled – two typical requirements of the costing and scheduling sub-systems of ERP. Since workers "float" to various workstations where they may be needed, this requires a more flexible way of logging their activities on orders (homes). Additionally, the labor force available is usually very skilled at homebuilding, but manufacturers stress that they are not skilled with computers.

STACS grew out of these design concerns. Figure 1 shows the architecture of how labor activities are logged to a database and viewed over a network. The actual data collection employs wireless barcode scanners placed near major work centers on the production floor. The scanners only have one button: the trigger to scan a barcode. Employees use the scanner nearest them to record changes in their activities; an employee scans his or her employee badge, an activity code denoting the specific activity they are now beginning, and the barcode identifying the exact home module they are currently building. There is minimal feedback to the user, so each set of several scans must be preceded and suffixed by “BEGIN” and “SEND” barcodes, respectively. Small industrial computers located on the shop floor interface wirelessly to several of these scanners and intercept their scan codes. Each “scan” sequence of an employee, an activity, and a module is immediately time-stamped at its reception, and is keyed to a specific scanner’s location; the record is then queued to send across a wireless network installed in the factory. A relational database stores the scan records, checking them for integrity and trying to diagnose erroneous scans. At that point, the database tells a story of what activity happened to each module by each human being at each moment in time, provided the workers record whenever they switch activities or go on breaks. This database can be used to view real status of the production floor, report on the labor assigned to each order, or be used to model and predict future labor requirements on orders.

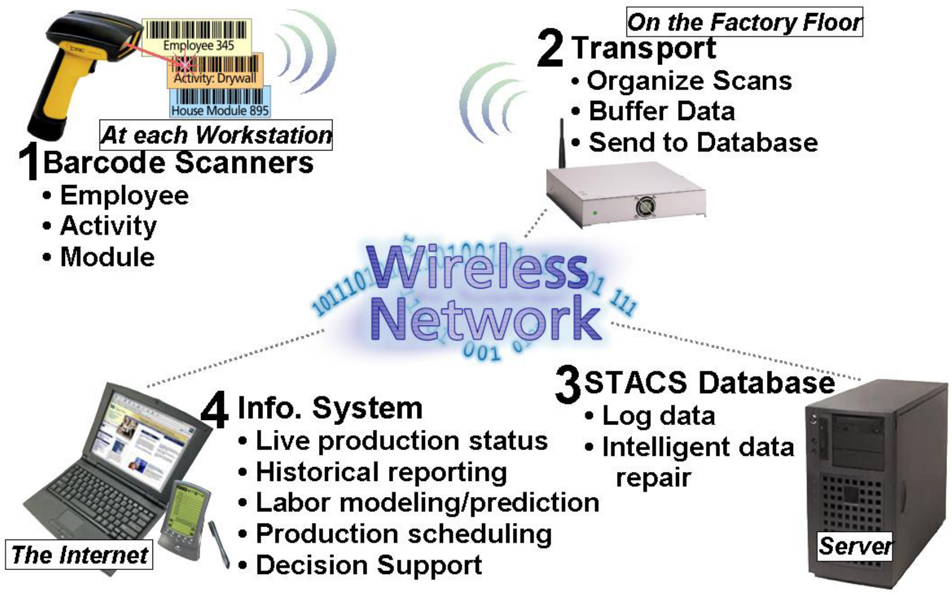


Figure 1. STACS System Architecture

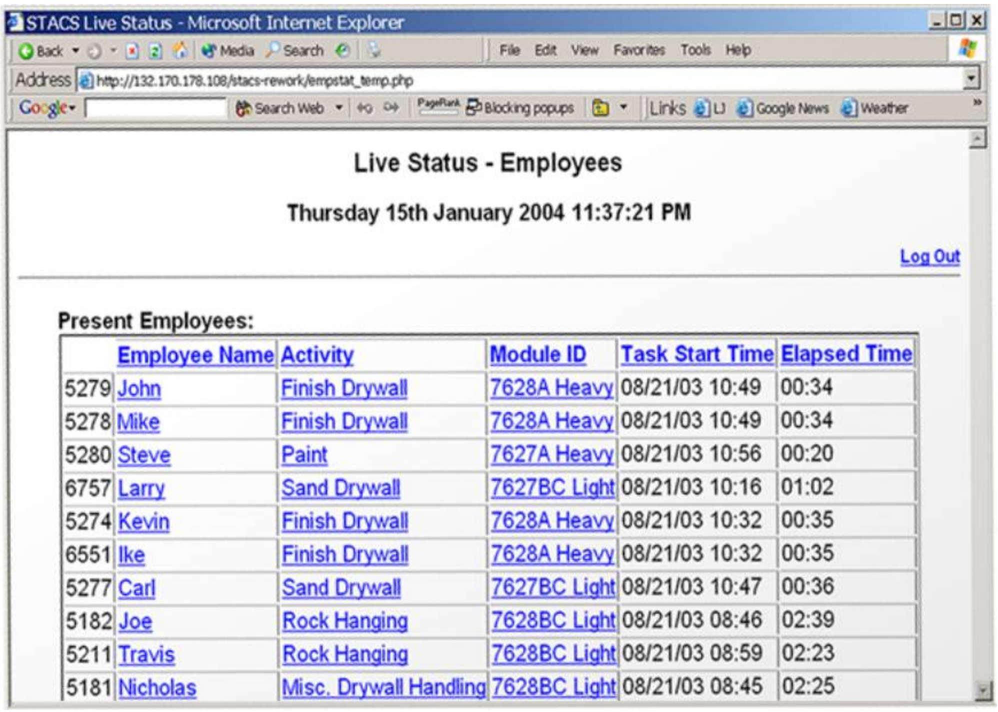
4. Alpha-Test Results

The STACS system was built between 2001 and 2002; the first test of the system came in late 2002 and mid 2003 at a major modular housing manufacturer. During the first test, the wood-framing department used STACS to record process times; the second test examined the drywall installation and finishing activities. The second study lasted for 4 full weeks of data collection, encompassing 24 workers on a single shift who recorded data on six drywall activities across nearly 80 home modules.

4.1. Technical Outcomes

The system design functioned well in its first test, with industrial-quality computers and equipment operating continuously and reliably on a shop-floor filled with sawdust, gypsum dust, debris, and aerosol paint. Since the system was designed to be wireless between any two nodes, it was easy to install and remain in the plant. The Linux operating system proved both its stability and affordability, as it powers all of the computers in STACS. The PostgreSQL relational database management system, an open-source database product for Linux, showed its reliability under moderately heavy loads and performed data storage and query tasks accurately. For two week in the middle of the study, HCL researchers could not monitor STACS on-site, but a virtual private network (VPN) was built temporarily on the STACS server enabling real-time access to all STACS computer resources from the lab 800 miles away.

STACS also contains a web-based reporting application to enable managers to view real-time status and look at historical performance. The deployment and maintenance of the management information system inside STACS becomes easier due to its web-based nature. An example of a live employee status report is shown in Figure 2.



	Employee Name	Activity	Module ID	Task Start Time	Elapsed Time
5279	John	Finish Drywall	7628A Heavy	08/21/03 10:49	00:34
5278	Mike	Finish Drywall	7628A Heavy	08/21/03 10:49	00:34
5280	Steve	Paint	7627A Heavy	08/21/03 10:56	00:20
6757	Larry	Sand Drywall	7627BC Light	08/21/03 10:16	01:02
5274	Kevin	Finish Drywall	7628A Heavy	08/21/03 10:32	00:35
6551	Ike	Finish Drywall	7628A Heavy	08/21/03 10:32	00:35
5277	Carl	Sand Drywall	7627BC Light	08/21/03 10:47	00:36
5182	Joe	Rock Hanging	7628BC Light	08/21/03 08:46	02:39
5211	Travis	Rock Hanging	7628BC Light	08/21/03 08:59	02:23
5181	Nicholas	Misc. Drywall Handling	7628BC Light	08/21/03 08:45	02:25

Figure 2. STACS Web-based Status Report

4.2. Organizational Outcomes

The STACS system is not only a technical challenge; it presents organizational challenges to both the shop-floor employees doing the scanning and the managers monitoring STACS. The employees who used STACS had mixed opinions about its ease of use. Some employees used the system honestly and frequently while others viewed the scanning as a chore. During this alpha test, the managers advised employees to use the system, but assured them that the numbers gathered in the study would not be used to establish work standards or pay them differently; the managers also did not monitor employee compliance, instead leaving monitoring to HCL researchers who could only encourage employees to scan at their convenience. Thus, the data gathered in this experiment are probably not an accurate representation of the labor times on each product. Without management involvement and coaching, the employees can choose not to gather accurate data. The STACS web-based reports encourage managers to monitor the live-status of the system by presenting a consolidated display of production as it happens.

Although compliance with STACS was not 100%, the system recorded a significant amount of data for further analysis. Figure 3 shows the distribution of labor by activity for drywall related activities. Of the value added activities, drywall finishing consumed 28% of this labor. Non-value added delays consumed 11%. The HCL team also documented key design characteristics for each module built during the study. Efforts have begun to model activity process time as a function of module characteristics. However, much data was lost due to the experimental nature of the exercise. This left researchers with insufficient data to fit the model and validate results. Equation 1 is a typical result of this early modeling effort. It suggests that labor required for the drywall taping task is a function of drywall area, the number of rooms, and the number of closets in the module. It should be emphasized that these early results lack adequate data for validation.

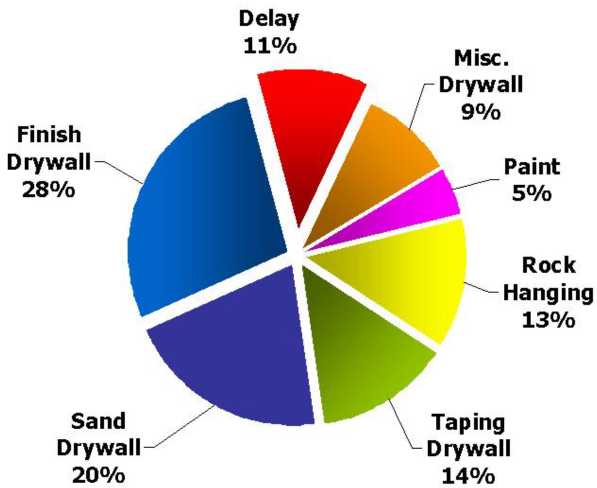


Figure 3. Activity breakdown report from actual data in alpha test

$$LaborHours = \left[0.58 + (0.00034) \cdot DrywallArea + 0.13 \cdot Rooms + (0.083) \cdot Closets\right]^2 \qquad \text{(Eqn. 1)}$$

Figure 3 provides a glimpse of both the challenging variability of the process and the vision for managing this variability by predictive modeling. Although there is still significant noise in the model, it shows that variation can be modeled and predicted given process data and design characteristics.

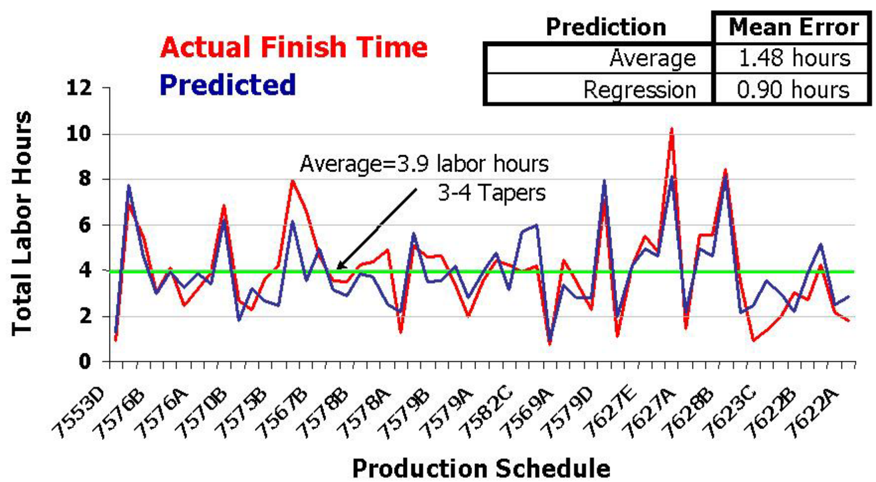


Figure 3. Predictive Modeling Example, Drywall Taping Activity

5. Conclusions and Future Research

The early study of STACS in a modular housing factory demonstrates that industrialized housing manufacturers can collect reliable production data and use it to predict process times. We believe that this information can be used to support decision-making, enabling better management of floating bottlenecks, and improving flow, capacity, and quality. Future research should take several directions. First, additional features must be added to better identify scanning errors and boost data accuracy. Second, a larger data set should be generated for use in further analysis. A full-scale, long-term test is scheduled for Spring 2004 at another modular home factory. Results will be used to build predictive models using linear regression and neural net modeling approaches. Finally, further refinement of the real-time reporting functions is needed to enable managers to integrate live STACS data into their decision-making.

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