Estimating, Planning and Controlling Labor in the Industrialized Housing Factory

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Abstract

Industrialized housing manufacturers build large-scale, custom housing components on near synchronous production lines with negligible automation. While labor represents a relatively small fraction of production cost, it has a substantial impact on operations. If the labor provided does not match production needs, bottlenecks form and quality suffers. The numerous production operations, lengthy cycle times and extensive product customization have discouraged manufacturers from accurately estimating labor needs as a function of product mix. This paper describes a spreadsheet based labor estimating and planning system based on expert opinion. The Expert Labor Forecaster (ELF) is meant to be a first step in an evolutionary process toward more rigorous labor estimating, planning and control. The paper also describes a concept for efficient, real time labor data collection and reporting. Using wireless laser scanners, a wireless LAN and database technology, the system gathers and summarizes data that can be used for real time shop floor control and for supplementing the expert opinions used in ELF.

Keywords
Homebuilding, industrialized housing, labor, estimating

1.0 Introduction
The key to success for any manufacturing organization ultimately depends on the quality of management decision-making, which is itself driven by the timely availability and quality of information [1]. Industrialized housing manufacturers are no exception. Housing manufacturers produce large-scale, custom housing components on near synchronous production lines with negligible automation. While labor represents a relatively small fraction of production cost, typically 10-15%, it is a critical resource for housing manufacturers. Skilled, motivated workers are hard to get and even harder to keep. Not only must overall labor needs be met, but the workforce must be properly allocated to production activities along the line. If labor does not satisfy production needs, at any point on the line, a bottleneck is created and quality suffers as workers rush to finish their assignments. Labor planning is made even more challenging by a highly customized product mix that changes daily and the resulting 'shifting bottleneck' phenomenon [2].

Sound labor planning begins with the development of labor estimates or standards. There are three general approaches for developing standards [3]: 1) estimation – looking at a job and judging the time required to complete it, 2) using historical records, such as time clock data, to estimate labor required in the past, and 3) work measurement – measuring the actual work content of the job. Manufacturers have increasingly adopted work measurement techniques such as time studies, predetermined time standards, and work sampling, since they yield a more objective measure of how long a job *should have taken* [3]. Work measurement techniques work well for situations involving a limited number of products and product variants and production processes with a limited number of well-defined and measurable elements. Neither is the case for a typical housing manufacturer, who produces one-of-a-kind custom homes on a production line that resembles a construction site as much as a manufacturing line. For example, a typical housing manufacturer has more than 60 internal subcontractors or teams, each responsible for a specific construction trade, such as floor framing or rough electrical. Each team of up to 20 workers performs a wide variety of trade-related tasks on each house, depending on the unique home design and features specified by the customer. While the output of each task may be described in the product specifications, process methods are typically not well defined. The team operates over a wide area, often working on different parts of the same house and even on different houses at the same time. Line cycle times vary with the firm's production rate, typically ranging between one and four hours per unit.

Work measurement techniques are not widely used in the construction industry. Instead, the industry has turned to two methods of cost estimation, unit pricing and resource enumeration [4]. The unit pricing approach focuses on cost instead of labor hours, calculating cost as the $ per unit of work times the units of work in the job. The $ per unit of work is normally maintained within the company or in standard references, such as R.S. Means. The resource enumeration approach is more detailed. The estimator assumes a given resource group (crew, equipment, etc.), estimates its average production rate, and then modifies the rate to reflect the specific conditions of the project. Regression modeling and neural net techniques have been used to improve the accuracy of these estimates [5]. These construction estimation approaches were developed for firms with a relatively small number of large jobs. Housing manufacturers produce up to four to five houses per day, each involving 60+ activities.

Extensive customization, construction-like production processes, and lengthy cycle times coupled with relatively high production rates have discouraged housing manufacturers from using either conventional manufacturing or construction estimating approaches. Consequently, there is little systematic planning to recognize and respond to varying labor needs. At best, manufacturers use crude rules-of-thumb and ad hoc planning methods to respond to changing labor requirements. There is a need for better tools to estimate labor needs and plan production activities, recognizing varying product mix. This paper describes two software tools under development at the UCF Housing Constructability Lab to assist the housing manufacturer: the Expert Labor Forecaster (ELF) and the Status Tracking and Control System (STACS). The tools are described in the context of modular manufacturing, in which 3-dimensional sections of a house (modules) are totally assembled and almost 95% complete before being shipped from the factory [6]. Once on the construction site the modules are set using a crane and finished by the builder. Sections 2 and 3 describe the functionality of the individual tools. Section 4 gives an integrated view of the two systems and suggests conclusions and future research.

2.0 Expert Labor Forecaster

The Expert Labor Forecaster (ELF) is a spreadsheet based labor estimating and planning system based on expert opinion of experienced manufacturing staff.

2.1 Labor Estimation

The overriding assumption behind ELF is that the labor required for any manufacturing activity is dependent on the design of the module. The underlying structure is suggested in the key driver input sheet shown in Table 1. For each of the 65 manufacturing activities in the modular factory, key drivers (design features) are identified that are believed to impact the labor required to perform that activity. For example, joist hangars, narrow joist spacing, insulated floors and underlayment are thought to impact the time required for the floor framing activity. The marginal cycle time associated with each key driver is estimated. This cycle time assumes a given staffing level for the activity specified elsewhere in the spreadsheet. The cycle time is specified for three different module lengths, the minimum practical length (32'), the average length (48'), and the maximum length that the factory can produce (61'6"). Linear interpolation is used to estimate cycle times for module lengths between these points. Cycle time is assumed to be additive over all active key drivers. For example, the floor framing cycle time for a short 32' floor requiring insulation will be 80 minutes basic framing time (the time for a basic floor with no active key drivers) plus 30 minutes to install insulation to the underside of the floor.

Expert opinion was used to identify the key drivers and their marginal cycle times. Two highly experienced Assistant Production Managers, one each from the rough and finish ends of the production line were interviewed to obtain the expert information. Two interviews were conducted for each expert. In the first interview, researchers explained the process and led the expert through each manufacturing activity in his domain. Within several cycles, the experts were able to provide the needed information with no coaching. In the second interview, researchers asked the experts to review and refine earlier estimates. A small number of additional key drivers were identified and numerous cycle time estimates were adjusted. Additional expert input is planned as ELF begins to be used and additional refinements are identified.

Table 1. Example from key drivers input sheet

Activity Times: Impact of Key Drivers				
		Min. Required by Module Length		
Activity	**Key Driver**	**32'**	**48'**	**61'6"**
Floors	Base time	80	120	160
	Joist Hangers	20	30	40
	Joist Spacing (< 16" OC)	40	60	80
	Insulated Floors	30	80	160
	Underlayment	30	45	160

ELF also requires inputs describing the design specifications and options for each module to be manufactured, specifically, those related to the key drivers. These parameters and module start times are input into the production scheduling sheet by order processing or engineering. Using this information, ELF estimates the labor hours for each activity for each module. Estimates are provided in two forms, labor hours and labor cost, shown in the labor hours and labor cost sheets respectively.

2.2 Labor and Module Scheduling

Most housing manufacturers use a near-synchronous production line to pace production flow. Activities ideally take place at pre-determined locations on the line and therefore at constant time offsets from module start. ELF uses this knowledge, coupled with the estimated module start time to perform a static analysis of the production and labor schedule. The daily scheduling analysis sheet shown in Figure 1 is useful in describing the results of this analysis. For each activity, ELF provides the available number of workers and the cycle time. More importantly, it anticipates which module will be using the activity for each production cycle (in this case hourly) of each production day. At the same time, it estimates the cycle time required to complete the activity, given the module's unique design features. To assist in identifying potential problems, ELF highlights modules in red when they are expected to exceed the available cycle time and in green when excess cycle time is available. To transform the problem into the labor dimension and suggest potential solutions, ELF estimates the optimal labor (number of workers) required to complete the module in the available cycle time. To assist in more aggregate planning, ELF estimates the total man-hours and workers needed per activity over the entire day and the associated cost. It also provides the total number of workers required to perform all activities during each production cycle.

Using the information provided by ELF, one can envision a scheduling strategy in which managers first sequence modules on the line to smooth overall production loads and then schedule labor to minimize specific bottlenecks. One approach for labor scheduling would be to set initial team sizes based on the average number of workers needed by each team for the day. Then, cross-trained workers can be shifted between activities during the day to reflect anticipated cycle-to-cycle needs.

3.0 Status Tracking and Control System

ELF is, admittedly, a primitive tool for labor planning. However, more sophisticated tools require substantial data. To date, housing manufacturers have not been willing to invest in systematic, extensive labor data collection. Ad hoc efforts have resulted in incomplete, unreliable, and inconclusive data. This section of the paper describes a concept for efficient, real time labor data collection and reporting. Using wireless laser scanners, a wireless LAN and database technology, the system can gather and summarize data that can be used for supplementing the expert opinions used in ELF and for real-time shop floor control. The Status Tracking and Control System (STACS) concept is shown in Figure 2.

Real-time elemental data is collected on the manufacturing floor each time an operator changes status, typically when an activity is about to begin on a given module. The operator uses a handheld, wireless laser scanner to scan barcodes that indicate operator ID, module ID and activity ID. The scanner transmits each

Activity Name	Available # Workers	Available Cycle Time (min.)	2:00 PM Module #	2:00 PM Cycle Time (min)	2:00 PM # Workers	3:00 PM Module #	3:00 PM Cycle Time (min)	3:00 PM # Workers	4:00 PM Module #	4:00 PM Cycle Time (min)	4:00 PM # Workers	Total Man Hours	Daily Labor Cost ($)	Average # Workers
Mill	3.0	60	02216B	102	5.1	02216A	103	5.2	02215D	104	5.2	45.0	$337.50	5.0
Floors I	5.0	60	02216C	90	7.5	02216C	90	7.5	02216A	152.5	12.7	109.0	$817.19	12.1
Floors II	5.0	60	02216D	90	7.5	02216B	90	7.5	02216B	90	7.5	109.4	$820.31	12.2
Exterior Wall Framing I	3.5	60	02216E	30	1.8	02216D	20	1.2	02216C	20	1.2	17.4	$130.16	1.9
Exterior Wall Framing II	3.5	60	02216F	30	1.8	02216E	30	1.8	02216D	20	1.2	17.9	$134.53	2.0
End Walls	3.0	60	02216C	90	4.5	02216B	90	4.5	02216A	60	3.0	34.5	$258.75	3.8
Interior Wall Framing	7.0	60	02216C	72.5	8.5	02216B	92.5	10.8	02216A	42.5	5.0	57.9	$434.06	6.4
Marriage wall framing	3.0	60	02216E	90	4.5	02216D	35	4.1	02216C	65	7.6	68.7	$515.00	7.6
Interior wall set	4.0	60	02216E	72.5	3.6	02216D	42.5	2.1	02216C	42.5	2.1	33.9	$253.88	3.8
Exterior & marriage wall set	2.0	60	02216G	60	4.0	02216F	60	4.0	02216E	60	4.0	36.0	$270.00	4.0
Squaring & plumbing	1.0	60	02216H	60	2.0	02216G	60	2.0	02216F	60	2.0	18.0	$135.00	2.0
Lagging & strapping	1.0	60	02216H	60	1.0	02216G	60	1.0	02216F	60	1.0	9.0	$67.50	1.0
Foam seal (walls and ceilings)	1.0	60	02216H	60	1.0	02216G	60	1.0	02216F	60	1.0	9.0	$67.50	1.0
Int. Wall Drywall Hanging	3.0	60	02216E	42.5	0.7	02216D	42.5	0.7	02216C	42.5	0.7	8.8	$65.88	1.0
Bath drywall hanging	1.0	60	02217A	45	2.3	02216H	75	3.8	02216G	75	3.8	23.3	$174.38	2.6
Roof/ceiling Sub-Assembly	2.0	60	02216H	60	1.0	02216G	60	1.0	02216F	60	1.0	9.0	$67.50	1.0
Roof/ceiling Framing I	3.5	60	02217A	100	3.3	02213A	90	3.0	02213A	90	3.0	24.3	$182.50	2.7
Roof/ceiling Framing II	3.5	60	02216H	90	5.3	02216H	90	5.3	02216G	60	3.5	35.6	$266.88	4.0
Bottom Exterior Rough electric	1.0	60	02217A	60	3.5	02216H	60	3.5	02216G	60	3.5	31.5	$236.25	3.5
Sub-assy & install exterior box rough elect	1.0	60	02217A	60	1.0	02216H	60	1.0	02216G	60	1.0	9.0	$67.50	1.0
Top Rough electric	5.0	60	02217B	80	1.3	02217A	110	1.8	02216H	110	1.8	12.3	$92.50	1.4
Hook up; install interior box; fish wire	5.0	60	02217B	60	5.0	02217A	60	5.0	02216H	60	5.0	50.0	$375.00	5.6
Pre-test; dielectric & polarity	1.0	60	02199C	80	6.7	02199B	81	6.8	02199A	82	6.8	58.5	$438.75	6.5
Wall Rough Plumbing & Tub Set	3.0	60	02216F	60	1.0	02216E	60	1.0	02216D	60	1.0	9.0	$67.50	1.0
Roof Rough Plumbing	2.0	60	02217B	60	3.0	02217A	60	3.0	02216H	60	3.0	30.0	$225.00	3.3
Roof/ceiling Set	3.0	60	02217B	100	3.3	02217A	100	3.3	02216H	60	2.0	23.3	$175.00	2.6
Roof Insulation	1.0	60	02217C	93	4.7	02217B	94	4.7	02217A	95	4.8	41.0	$307.13	4.6
Sheathing & overhang installation	5.0	60	02217D	15	0.3	02217C	75	1.3	02217B	75	1.3	10.5	$78.75	1.2
Shingling	6.0	60	02196D	140	11.7	02217D	30	2.5	02217C	120	10.0	77.5	$581.25	8.6
Overhang build	1.0	60	02217C	93	9.3	02217B	94	9.4	02217A	95	9.5	81.9	$614.25	9.1
Wall insulation	1.0	60	02217C	115	1.9	02217B	115	1.9	02217A	60	1.0	10.8	$80.63	1.2
Wall sheathing	5.0	60	02217D	60	1.0	02217C	195	3.3	02217B	75	1.3	11.7	$87.50	1.3
Windows, doors	2.0	60	02196D	660	55.0	02217D	660	55.0	02217C	600	50.0	485.0	$3,637.50	53.9
Siding & trim	3.0	60	02197B	45	1.5	02197A	105	3.5	02196D	135	4.5	28.8	$216.25	3.2
Drywall Taping Int. Walls	3.0	60	02216H	85	4.3	02216G	42.5	2.1	02216F	42.5	2.1	30.2	$226.31	3.4
Drywall Taping Ext. Walls	3.0	60	02216H	60	3.0	02216G	60	3.0	02216F	60	3.0	27.0	$202.50	3.0
2nd,3rd coat walls	2.0	60	02217D	60	3.0	02217C	60	3.0	02217B	60	3.0	27.0	$202.50	3.0
finish screw holes	1.0	60	02216G	60	2.0	02216F	60	2.0	02216E	60	2.0	18.0	$135.00	2.0
Ceiling corners Drywall Taping & Finish Co	4.0	60	02217B	60	1.0	02217A	90	1.5	02216H	90	1.5	10.5	$78.75	1.2
Mud mixers	2.0	60	02197C	60	4.0	02197B	60	4.0	02197A	60	4.0	36.0	$270.00	4.0
Touch up	3.0	60	02197A	60	2.0	02196D	60	2.0	02217D	60	2.0	18.0	$135.00	2.0
Wall Corner beads	1.0	60	02216H	60	3.0	02216G	60	3.0	02216F	60	3.0	27.0	$202.50	3.0
Soffitt installer (installing frame, drywall &	1.0	60	02217A	0	0.0	02216H	0	0.0	02216G	0	0.0	4.0	$30.00	0.4
Sand & paint	9.0	60	02197C	60	1.0	02197B	60	1.0	02197A	60	1.0	9.0	$67.50	1.0

dules / STACS / calculations / Activity by hour_B / Activity by hour / Days_Weeks / ELF / Monday / Tuesday / Wednesday / Thursday / Friday /

Figure 1. Typical daily scheduling analysis sheet

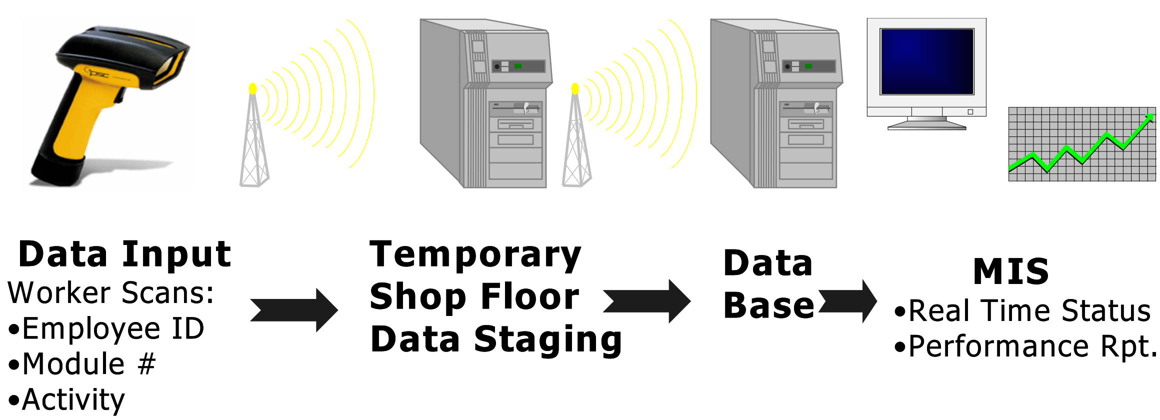

Figure 2. Concept for Status Tracking and Control System (STACS)

scan through a hub to a remote computer that is located on the shop floor. Here, the data is parsed, organized, time stamped, and checked for errors. Multiple hubs/remote computers are likely, based on scanner technology and configuration of the production facility. The remote computer periodically uploads data into the main computer via wireless LAN. Here, the data is organized and maintained in an MS Access™ database. Using a user-friendly interface, management can produce reports indicating the current, real-time state of the production process as well as its historical performance. An example of a historical report to support continuous improvement in shown in Figure 3. The pareto analysis ranks activities by performance to labor estimates, with potential problem activities ranked highest.

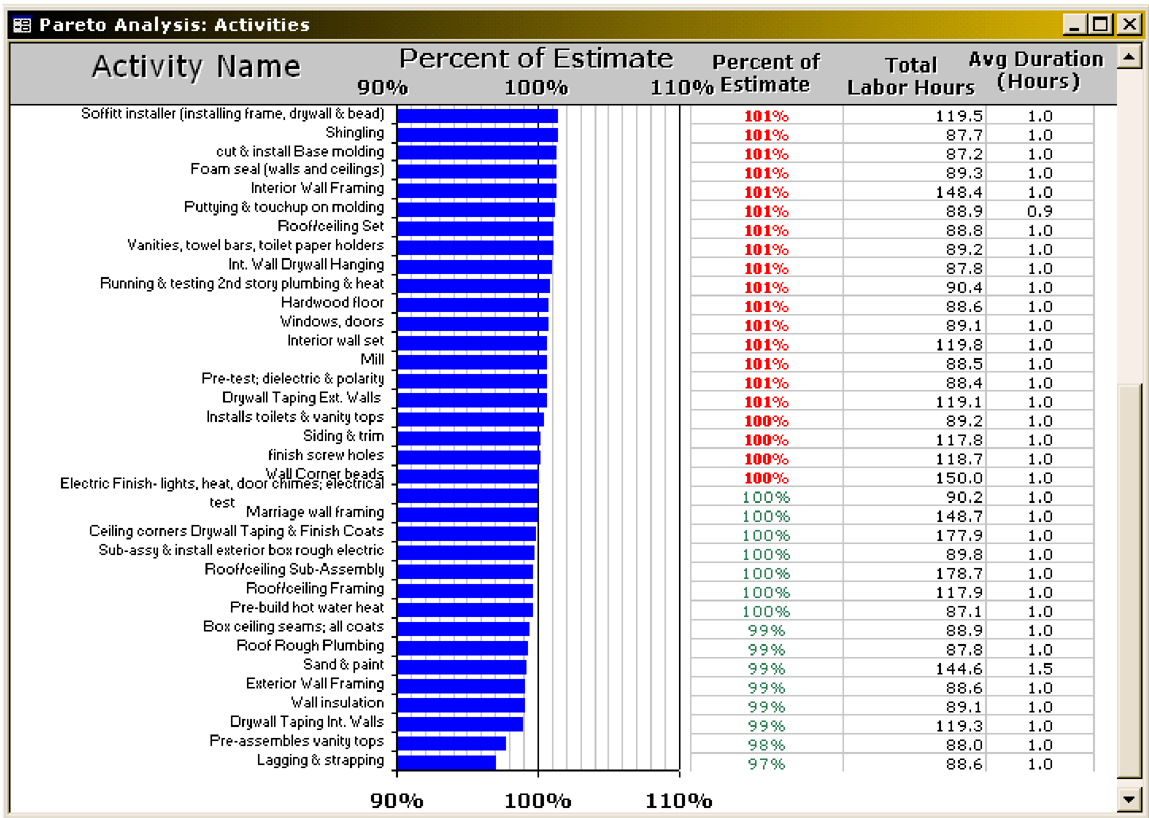

Figure 3. Pareto analysis ranking activities by performance to labor estimates

STACS results are likely to support housing manufacturers in three important ways. First, it will provide management with real time production results, allowing them to identify and react quickly to problems as they develop, instead of long after the damage has been done. Second, historical results can be used to drive continuous improvement efforts by: 1) establishing and maintaining a labor baseline for each manufacturing activity, 2) aiding in identifying improvement opportunities, 3) measuring the impact of implemented improvements, and 4) measuring the cost of quality. Finally, historical results can be used to supplement ELF and establish standards that can be used for better product costing, labor planning, and module sequencing and line balancing.

4.0 Conclusions and Future Research

ELF is, admittedly, a primitive tool for labor planning. However, it is likely to be an important first step toward more effective labor planning and control for the typical housing manufacturer. Perhaps the greatest weakness of ELF is its reliance on expert opinion for important labor estimating parameters. To address this shortcoming, this paper has also presented a concept for an automated data collection tool, STACS, capable of providing real time data to supplement ELF.

Housing manufacturers have been generally supportive of the ELF concept. One manufacturer has been instrumental in the development of ELF and plans to continue to serve as the test bed. Future research for ELF includes validating the prototype and then testing in the research partner's manufacturing plant. Validation will consist of running ELF using four weeks of recent production orders. ELF results will be compared with summary level production reports and the collective perceptions of company management. While admitting the need for better planning data, housing manufacturers have been more wary of the STACS concept. They have acknowledged concerns about system cost and reliability, both of the hardware/software and worker use of the system. Future research includes limited testing of the system at the research partner's plant, possibly using a single scanner to collect data on a series of single activities. System functionality and reliability will be assessed and improvement noted. Data from this exercise will also be collected and used in an attempt to improve the ELF forecasting model. Both regression and neural net techniques will be considered.

ELF and STACS are very flexible, robust systems. However, some modifications will be required as they are exported to other modular factories. Although designed for modular manufacturers, the systems are also believed to be compatible with other types of high volume homebuilding, such as production builders or HUD Code manufacturers.

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