REPORT

SIMULATING THE MAKRON WALL PANEL LINE AT GLAIZE COMPONENTS WINCHESTER, VA

ENERGY EFFICIENT INDUSTRIALIZED HOUSING (EEIH) RESEARCH PROGRAM

(The EEIH project is jointly conducted by the Center for Housing Innovation, University of Oregon, the Florida Solar Energy Center and the Department of Industrial Engineering and Management Systems, University of Central Florida.)

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EXECUTIVE SUMMARY

The Energy Efficient Industrialized Housing (EEIH) research team was recently tasked by the U.S. Department of Energy (DOE) to provide assistance to Glaize Components, a high volume wood frame homebuilding component manufacturer based in Winchester, Virginia. The assistance was provided as part of DOE's innovative Process and Energy Efficiency Review (PEER) outreach program, designed to provide technical support to industrialized housing manufacturers interested in upgrading their products and processes. Glaize recently purchased the first Makron Wall Panel Line, the first practical application of advanced CAD/CAM and flexible manufacturing technologies available to U.S. industrialized homebuilders, and sought to increase line capacity.

The EEIH team used Generic Industrialized Housing Manufacturing Simulation (GIHMS) concepts to model the new wall panel line. Simulation results suggested that line capacity could be increased by 8% by introducing a simple line balance scheme. After implementing the necessary software changes, Glaize demonstrated a 7-10% increase in line capacity, with minimal increases in capital and labor.

From DOE's perspective, this study is the first step in introducing simulation modeling techniques into an industry that is only now acknowledging the benefits of innovative manufacturing process technologies. It is much easier for the industry to embrace new equipment which can build houses than to accept (and pay for) systems analyses. Yet, it is absolutely critical that the industry and its suppliers understand the important role of modeling in supporting the introduction of new process technologies. Glaize management has repeatedly stressed that the simulation model would have been extremely valuable early in the design of the new line. In summary, the industry still has little inclination to invest in technologies which do not produce immediate, eminently practical results. Therefore, our analytical tools and approaches must be structured to meet the demands of the industry.

Introduction and Background

Glaize and Bros. was founded in 1854 as a lumber yard, serving early homebuilders in central Virginia. Their newest division, Glaize Components, was established in 1972 to provide the Virginia, Maryland and West Virginia housing markets with factory pre-fabricated homebuilding components, including roof trusses, wall panels and floor trusses. A typical customer uses Glaize components to build two-story homes ranging from 2,000 to 3,500 square feet, selling for $150,000 to $400,000. The advantages of building with these large scale components instead of traditional stick-building on the construction site include: reduced dependence on weather, shortened construction cycle time, higher quality, reduced waste, and, on the bottom line, increased cost effectiveness. Glaize's continued success in the marketplace and its resulting growth are compelling evidence that it has been successful in communicating and delivering on the promise of industrialized homebuilding.

A key element of the Glaize strategy is to advance manufacturing technology to the highest level possible. The foundation for this strategy is management's belief that many of the promised advantages of industrialized homebuilding can only be delivered with technology-driven factory rationalization of construction site processes. This contrasts with the conservative, quasi-traditional approach common throughout the industry, to simply move inefficient, loosely organized and variable quality stick-building processes under roof. While capturing some of the obvious weather-related benefits, this traditional approach has left untapped much of the potential offered by advanced manufacturing technologies such as CAD/CAM [Bedworth, Henderson and Wolfe 1991] and flexible manufacturing [Nyman 1992].

Meanwhile, international homebuilders in Scandinavia [Kando 1988] and Japan [McKellar 1985] have led the way, producing a substantial percentage of their housing in highly automated factories. However, much of this computer integration and automation has come at the expense of design flexibility. For example, one automated plant in Finland is limited to 54 configurations of a wall panel. Conventional wisdom in the industry is that the U.S. housing market will not accept the design limitations commonly associated with automation.

Implementing their technology strategy, Glaize recently purchased the first Makron Wall Panel Line [Makron U.S. Inc. 1994], a production system developed specifically for the U.S. housing market. The line is arguably the first practical application of advanced CAD/CAM and flexible manufacturing technologies available to U.S. industrialized homebuilders. It can produce both interior and exterior panels in an infinite variety of configurations to meet virtually any architectural design need. The line is a true CAD/CAM system. COMSOFT Wall Builder [COMSOFT Inc. 1994] CAD software is linked by local area network (LAN) to the line's programmable logic controller (PLC), which drives both assembly and material handling equipment. The line's computer integration and cost effective automation combine to provide square and accurate framing in a highly efficient, paperless, continuous production operation.

As is common with new, highly integrated manufacturing systems, the line experienced start-up problems. While most have been resolved, the system has yet to reach expected capacity. The Energy Efficient Industrialized Housing (EEIH) research team was tasked by the U.S. Department of Energy (DOE) to assist Glaize by modeling their manufacturing operation. The assistance was provided as part of DOE's innovative Process and Energy Efficiency Review (PEER) outreach program, designed to provide technical support to industrialized housing manufacturers interested in upgrading their products and processes. A critical caveat was that our involvement was limited to 4 days on site, constrained by DOE funding limitations.

Approach

We set three objectives for the modeling effort: 1) to model the existing line, 2) to validate the model using a full day's production data, and 3) to use the validated model to assess the impact of enhancements intended to increase line capacity. Our modeling approach was driven by two obvious challenges, time and client skepticism. We developed an ambitious project plan (Figure 1) which comprehended the time constraints. The plan assumed that we would receive detailed product and process information from Glaize, allowing us to develop a preliminary model of the line before arriving on site. Glaize, however, did not respond immediately to our request for information, perhaps indicating skepticism about the value of simulation and suspicion of another "we're the government and we're here to help" exercise. Lacking specific information from Glaize, we developed a preliminary model using general process flows derived from marketing brochures and a brief video tape provided by Makron, the system supplier.

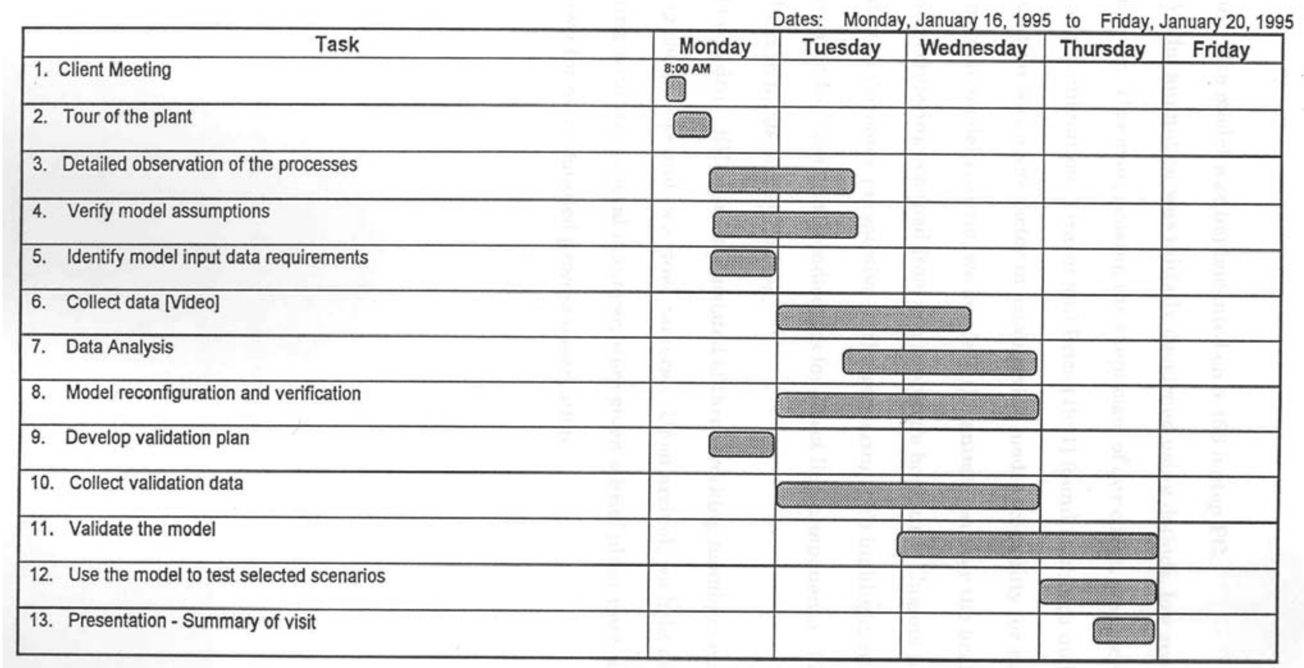

Figure 1: An ambitious 4-day on-site project schedule was developed and followed to meet DOE-imposed funding constraints. A preliminary version of the model was developed in advance of the actual visit.

The model was developed using ProModel for Windows™ [ProModel Corporation 1994], a manufacturing simulator featuring an object oriented graphical user interface and extensive custom programming constructs. Previous EEIH research [Mullens, Armacost and Swart 1995] had resulted in the development of numerous higher level modeling constructs which simplified model development. An EXCEL™ [Microsoft Corporation 1994] spreadsheet was used for production order input. The model was implemented on a 486 laptop PC.

Model animation was initially developed using default, low resolution icons in plan view. However, sensing the skepticism of our client, we elected to provide an enhanced animation. Gravel and Price [1991] found that high quality visual simulation was a key factor in establishing model credibility for skeptical clients. To improve model realism, we overlaid the animation over the background of an artist's rendering scanned from the supplier's brochure. Custom product icons were created in the same perspective as the rendering. To highlight suspected problems, we created location status indicators for select line components. Finally, "running" production totals were provided.

The visiting EEIH team consisted of three working members equipped with two laptop computers and two video cameras. Upon arrival, we held an introductory meeting with the general manager, were given a brief plant tour, and then left on our own for more detailed process observation.

System Operation

Detailed process observation yielded the process flow shown in Figure 2. When a home order is received from a builder, the design staff translate architectural drawings into accurate CAD representations (Figure 3) of manufactured wall panels. A typical house is constructed from 100 wall panels, equally divided between interior and exterior. Most panels in a home are unique and even standard house plans are highly customized. Panels range from 1' to 12' in length, from 4' to 12' in height, and use either 2x4" or 2x6" dimensional lumber.

Panels are automatically sequenced for production in the reverse sequence of assembly on the construction site. The first two production operations, component cutting and sub-assembly, are manual. Operations are batched by home and performed off line, using paperwork prepared by the CAD system.

Completed sub-assemblies (window, door and fireplace openings) and studs (vertical framing members) are placed on their respective conveyors by an operator directed by an on-line display. These components flow to the extruder where they are framed (assembled) with top and bottom plates (horizontal framing members). The extruder operator is directed by an on-line display to retrieve the proper component and position it for framing. The extruder automatically clamps the component and nails both top and bottom ends. A clamping bridge then pulls the panel forward for the next component or, if complete, pulls it clear of the extruder. A sensor mounted on the clamping bridge prevents the outgoing panel from contacting a previous panel queued on the extruder exit conveyor.

Interior panels are complete when they leave the extruder and flow directly to the interior wall line offload position. A two person offload team palletizes all panels. The conveyor uses "zone" accumulation controls, which prevent a panel from entering the next station until the previous panel has exited. Exterior panels cross over to the exterior wall line where sheathing ("skin") is applied and stapled to the exterior side of the skeletal panel. The "cross over" location shown is only a link, not a queuing position. In the sheathing station the panel is automatically clamped and squared while two operators apply and tack the sheathing. Sheathing is staged on a sheathing supply bridge which automatically positions itself at the edge of the panel. After sheathing is retrieved from the bridge, the bridge is released to return to its home position. After tacking is complete, the panel is released for transport to the stapling station. In the stapling station, the panel is automatically clamped and squared. A nailing bridge then automatically staples the sheathing as specified by local building codes. After stapling, the nailing bridge indexes to its home position, allowing the panel to be offloaded. The operator must actuate a release button after lifting the completed panel to allow the next panel to flow into the stapling station.

Glaize uses innovative personnel management techniques such as teaming, cross-training, and daily production improvement meetings. The floor supervisor is an active member of the team, responsible for identifying and solving line problems on a real-time basis, before they impact production.

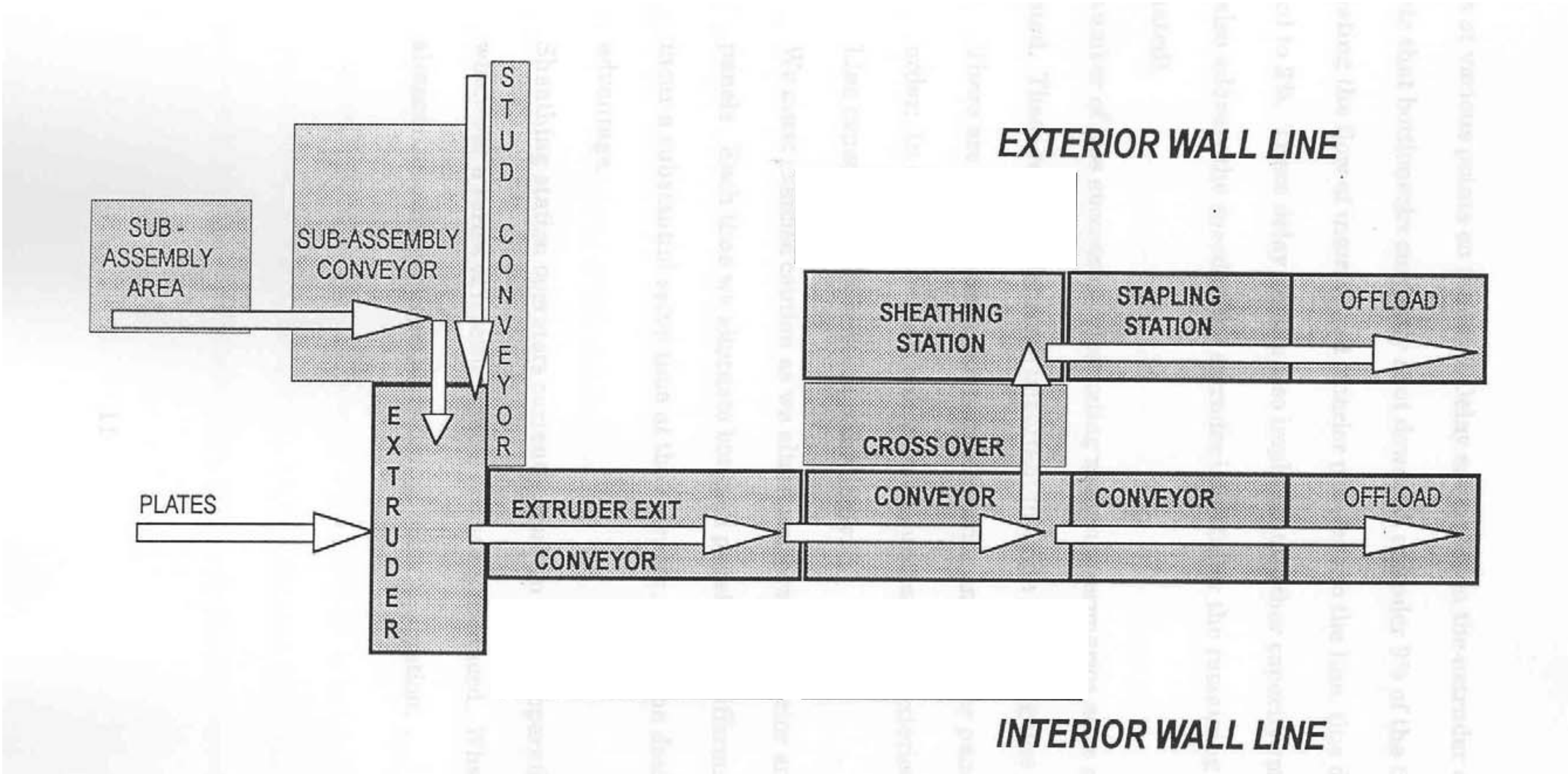

Figure 2: Process flow for the Wall Panel Line begins with assembly of the wood frame at the extruder. Interior walls immediately exit the system, while exterior walls require exterior sheathing before exiting.

Panel Production Sheets

Job #W1549 WHI JEFFERSON II (M) 5-BDRM W1549 Date: 01/17/95

Standard Bottom Plate View Level 2 Page: 16

*** Bundle #2

Panel #55 Studs 2"x4" x 7' 8-5/8" (STD SPF) [6] 1' 4" o.c.

(1) Top and (1) Bottom Plates: 2"x4" x 12' 0" (STD SPF)

Insert	Start	End
SBS	@ Start	4-1/2"
TEE(2X4) Down	3' 3"	3' 9-1/2"
3440	4' 9-1/8"	8' 7-1/8"
TEE(2X4) Down	9' 6-3/4"	10' 1-1/4"
EBS-WHI	Flush	Flush

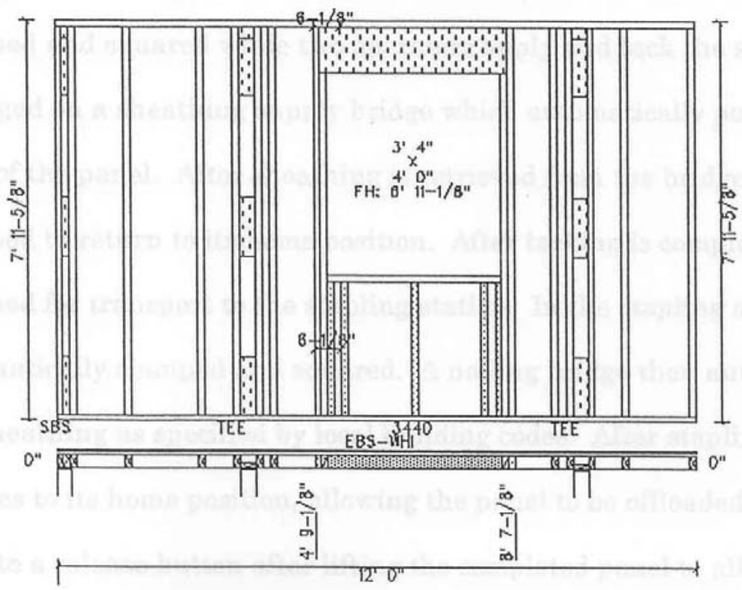

Figure 3: Typical panel design. Note window sub-assembly and multiple column sub-assemblies.

Verification and Validation

The second day on site was devoted to collecting empirical data for parameter estimation and model validation. The day's production schedule was typical: two two-story homes, 1,188 lineal feet of wall, 91 interior panels and 102 exterior panels. Detailed data were captured in written logs and on video tape. Logs documented entry time, exit time and process time at each assembly station, by panel. They also documented off-standard occurrences such as equipment downtimes, operator absences, staple gun reloads, etc. Video cameras were used to record representative operations at each station. Production was completed in 374 minutes of line operation, for a daily production performance of 3.17 lineal feet of wall per minute of operation (not including breaks and downtime). Only one significant unexpected interruption was observed. A steel conveyor belt which had not been properly tensioned slipped off its rollers on the extruder exit conveyor. Eighteen minutes of line production capacity were lost.

The third and much of the fourth day were dedicated to revising and verifying the model, preparing the input panel order data set, estimating model parameters, and validating the model. Based on our findings, we concluded that the preliminary model needed major revisions. We concluded that model scope should be limited to the line itself. Therefore, off-line/batch operations were removed. We also determined that additional modeling depth was required to represent on-line assembly processes and control logic. We explicitly modeled the relationships between panel configuration, material flow and timing.

Our strategy was to utilize the 193 panels produced during the validation period to drive the model during model validation and systems analysis. Each panel and its attributes (dimensions, components, etc.) were entered in the EXCEL™ spreadsheet. Model parameters were estimated using empirical data developed from the logs and video tapes. Linear regression was used to estimate model parameters whenever panel dimensions appeared to be a factor. Process times were assumed to be deterministic.

Validation involved running the model for the validation period and comparing model results with actual documented production results. Like the actual line, all model runs started with an empty line. Table 1 summarizes validation results for the observed Base Case and the A. Simulated Base Case scenarios. Results suggest a high degree of modeling precision, largely attributable to the highly structured and focused modeling approach.

Scenario_	**# of Panels_**	**Lineal Feet_**	**Total Process Time**	**Average Production _Rate (Lineal Ft./Min)**	**Production Capacity Increase [%]**
Base Case: As observed on 1/17/95	193	1187.89	6 hrs 14 mins (374 mins.)	3.17	----
A. Simulated Base Case	193	1187.89	6 hrs 11 mins (371 mins.)	3.20	----
B. Production Sequence Alternating External & Internal Panels	193	1187.89	5 hrs 45 mins (345 mins.)	3.44	7.50

Table 1: Summary simulation results suggest a high level of model precision (Base Case versus A. Simulated Base Case). The increase in average production rate (A. Simulated Base Case versus B. Production Sequence Alternating Exterior and Interior Panels) indicates the potential to increase line capacity by sequencing production to minimize line balance problems.

Analysis and Findings

Model results were presented to senior Glaize management and DOE representatives during a lengthy meeting on the fourth day. Discussion of results from each simulation scenario was prefaced by running the simulation and viewing the animation (Figure 4). To improve clarity, the laptop PC was linked to Glaize's large screen high definition CAD monitor. Key quantitative results were displayed using standard ProModel bar and pie charts. Questions were addressed using real-time computer animation and graphical output.

The most obvious factor affecting line capacity was a perceived line balance problem. The production sequence generated by the CAD software forced all exterior panels for each floor of a home to be run sequentially, followed by the interior panels. While this "reverse" assembly sequence was ideal from a builder's perspective, it resulted in severe bottlenecks when manufacturing exterior panels. Since downstream (sheathing and stapling) process times were often longer than upstream (extruder) times, bottlenecks formed. These bottlenecks eventually blocked the crossover position and caused delays at the extruder, resulting in lost line capacity. We hoped to improve line balance by re-sequencing panels, alternating between interior and exterior panels. Summary results from this scenario are shown in Table 1 under the B. Scenario. Results indicate that re-sequencing could increase system capacity by 8%. The process chart shown in Figure 5 provides additional insight as to how the alternating sequence impacts delays at various points on the line. Delay estimates on the extruder exit conveyor indicate that bottlenecks currently shut down the extruder 9% of the time. By alternating the flow of interior and exterior panels onto the line, this delay can be reduced to 2%. These delay results also imply that further capacity improvements must also address the speed of the extruder itself (after the remaining 2% delay is eliminated).

A number of less successful "alternating sequence" scenarios were also simulated. These results offer some important insights regarding line performance:

1. There are seldom equal numbers of interior and exterior panels in an order. In the worst case a builder may purchase only exterior panels. Line capacity will be reduced accordingly.
2. We must exercise caution as we alternate between interior and exterior panels. Each time we alternate between panels with different heights, we incur a substantial setup time at the extruder, losing the desired advantage.
3. Sheathing station operators currently work on off-line operations whenever a series of interior panels are being produced. When using an alternating sequence, operators cannot leave the station.

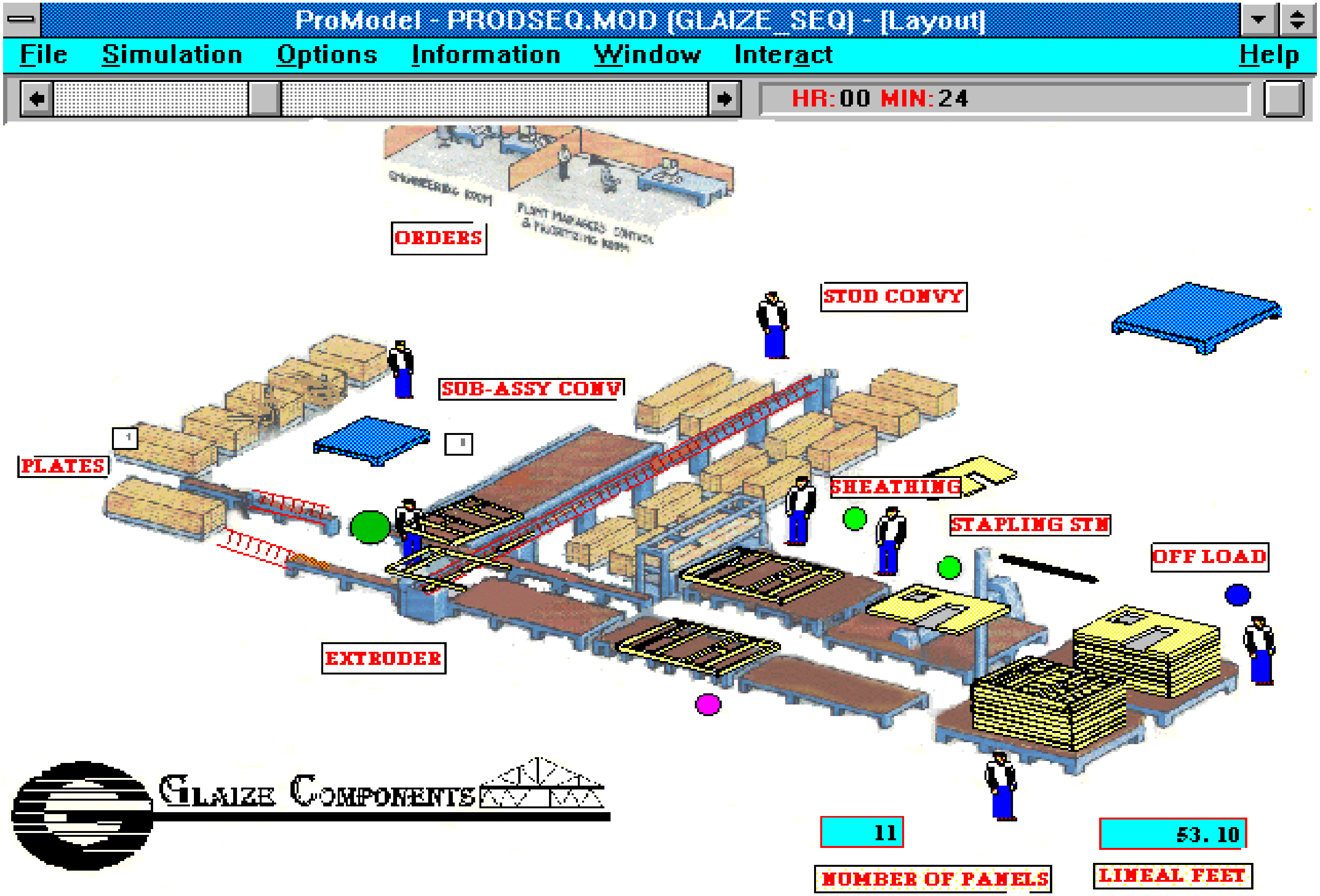

Figure 4: A high resolution animation shows the Wall Panel Line in operation. We overlaid the animation on the background of an artist's rendering scanned from a supplier's brochure. Location status indicators for select line components highlight suspected problems. Running production totals indicate real time production performance.

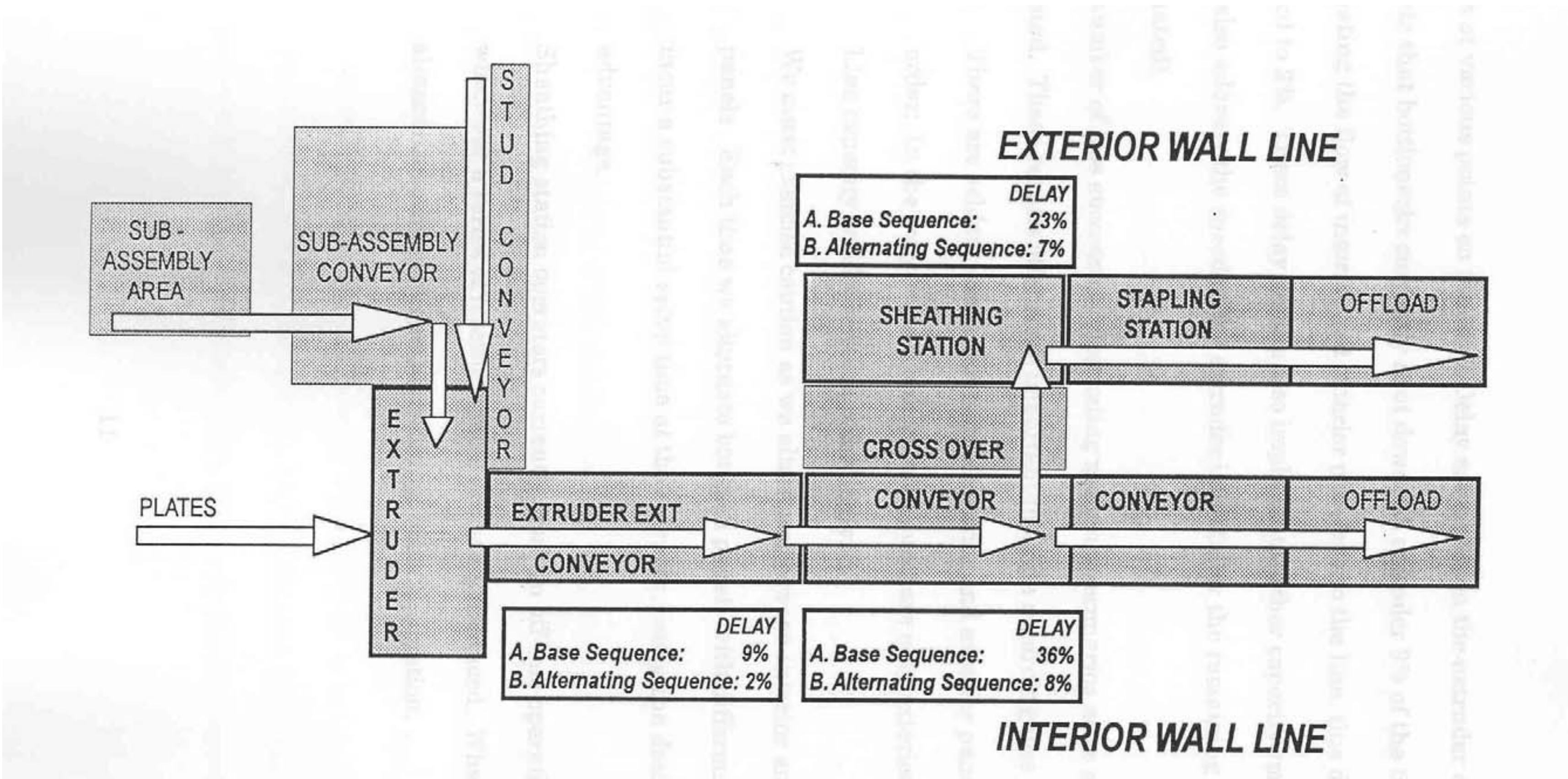

Figure 5: Process flow chart shows simulated delays for the current A. Base Sequence and the proposed B. Alternating Sequence. Delay estimates on the extruder exit conveyor indicate that line balance induced bottlenecks shut down the extruder 9% of the time. By alternating the flow of interior and exterior panels onto the line, this delay can be reduced to 2%.

Conclusions

The Wall Panel Line now has the ability to run custom production sequences. Production results have demonstrated that line capacity has increased by 7% to 10% as a result of alternating interior and exterior panels. This has been attained with no capital and little or no increase in labor, translating directly to increased profitability. The simulation has also provided important insight for prioritizing future capacity improvement efforts. Other issues which might be addressed through the simulation model include: incorporation of current off-line operations into the line through Just In Time (JIT) production techniques, more effective sequencing strategies to achieve better line balance, and improved product costing. We are currently investigating mechanisms to continue our work with Glaize.

From DOE's perspective, our study is the first step in introducing management science techniques into an industry that is only now acknowledging the benefits of innovative manufacturing process technologies. It is much easier for the industry to embrace new equipment which can build houses than to accept (and pay for) systems analyses. Yet, it is absolutely critical that the industry and its suppliers understand the important role of modeling in supporting the introduction of new process technologies. Glaize management has repeatedly stressed that the simulation model would have been extremely valuable early in the design of the new line. In summary, the industry still has little inclination to invest in technologies which do not produce immediate, eminently practical results. Therefore, our analytical tools and approaches must be structured to meet the demands of the industry.

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References:

Bedford, D., Henderson, M. and Wolfe, P. 1991, *Computer-Integrated Design and Manufacturing*, McGraw-Hill, Inc., New York, NY.

COMSOFT Wall Builder 1994, COMSOFT Inc., Birmingham, AL.

Gravel, M. and Price, W. 1991, "Visual Interactive Simulation Shows How to Use the Kanban Method in Small Business," *Interfaces*, Vol. 21, No. 5, pp. 22-33.

Kando, P. 1988, *When the Best Costs Less: An Economic Comparison of the Swedish Factory Crafted House Construction System and Conventional Homebuilding*, Center for the House, Washington, D.C.

Makron Wall Panel Line 1994, Makron U.S. Inc., Clifton Park, NY.

McKellar, J. 1985, *Industrialized Housing: The Japanese Experience*, Alberta Municipal Affairs, Edmonton, Alberta.

Microsoft™ EXCEL™ User's Guide, Version 5.0 1994, Microsoft Corporation, Redmond, WA.

Mullens, M., Armacost, R. and Swart, W. 1995, "The Role of Object Oriented CAD in a Generic Simulator for the Industrialized Housing Industry,"*Automation in Construction*, Vol. 4, No. 1, pp. 29-43.

Nyman, L. 1992, *Making Manufacturing Cells Work*, Society of Manufacturing Engineers, Detroit, MI.

ProModel for Windows™ User's Guide, Version 2.0 1994, ProModel Corporation, Orem, UT.