

THE ROLE OF OBJECT ORIENTED CAD IN A GENERIC SIMULATOR FOR THE INDUSTRIALIZED HOUSING INDUSTRY

R. Armacost, M. Mullens and W. Swart

Department of Industrial Engineering and Management Systems, University of
Central Florida, P.O. Box 162450, Orlando, Florida 32816-2450, USA

Abstract

This paper describes a simulator-based decision support tool for manufacturers of prefabricated homebuilding components. The Generic Industrialized Housing Manufacturing Simulator (GIHMS) serves as an experimental factory, capable of simulating factory performance under various product design, factory design, and operations management scenarios. GIHMS' unique strength lies in its user-friendly WINDOWS-based "point-and-click" user interface. The interface allows the user to configure a factory and specify products for production without programming in a simulation language. The heart of the user interface is a specialized object oriented CAD system. This paper describes the GIHMS structure, focusing on the specialized CAD system, and demonstrates its functionality by describing the factory modeling process.

1. INTRODUCTION

Previous research efforts have identified well-established housing industry trends toward factory pre-fabrication, increasing the usage of value-added components and reducing construction site work. Examples of these value added components include structural foam panels (Toole and Tonyan 1992) and the innovative new net-shaped roof component system under development at MIT (Crowley, et al 1993). The trends benefit homebuilders and homebuyers by reducing construction cycle time and first cost. Recent research has also suggested the potential for homes which are inherently more energy efficient than conventional stick-built competitors.

This paper describes a simulation-based Computer Aided Engineering (CAE) tool, the Generic Industrialized Housing Manufacturing Simulator (GIHMS), designed to provide decision support to manufacturers of prefabricated

homebuilding components. Serving as an experimental factory, GIHMS is capable of simulating factory performance under various product design, factory design, and operations management scenarios. This allows integrated/concurrent decision-making addressing both product and process design issues. A unique feature of GIHMS is that, unlike most commercial simulation tools, it is structured to permit the rapid development and deployment of realistic simulation models.

GIHMS' unique strength lies in its user interface, which allows the user to configure a factory and specify products for production without programming in a simulation language. The heart of the user interface is a specialized object oriented CAD system. The paper first provides a brief overview of generic simulators and describes the GIHMS structure, focusing on the object oriented CAD system. Next, GIHMS functionality is demonstrated by describing the factory modeling process. Finally, conclusions are discussed and future research directions indicated.

2. GENERIC SIMULATORS AND THE GIHMS STRUCTURE

Generic simulators differ from general purpose simulation languages (i.e., GPSS, SIMAN, SLAM) in that they use domain-specific modeling constructs to provide increased modeling power and efficiency to the analyst. They are generic in the sense that, within the specific domain, they are capable of modeling a range of design options. Researchers have developed simulators for a variety of specialized

domains. CYCLONE (Halpin 1973), MICROCYCLONE (Halpin 1990), DISCO (Huang and Halpin 1993), and RUBICON (Stouffs et al 1993) were developed for construction applications. Simulators have also been developed for modeling flexible manufacturing systems (Medeiros and Sadowski 1983, Haddock 1988), electronics manufacturing (Cochran and Mackulak 1990), light assembly (Schroer 1988), distribution systems (Reddy et al 1986), and general manufacturing (Ozdemirel and Mackulak 1993).

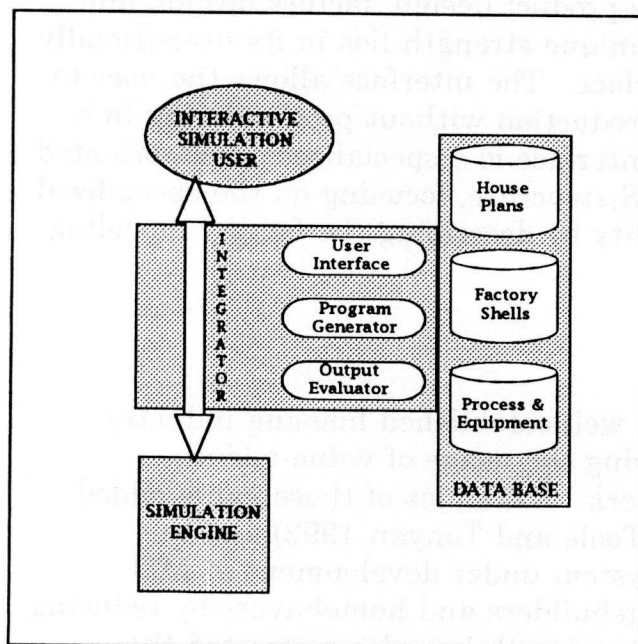


Figure 1 GIHMS Structure

A common thread linking most of these diverse efforts is the general structure of the simulator. The GIHMS structure, shown in Figure 1, is typical. The interactive simulation user is defined to be an expert in the specific

domain to be simulated and proficient in PC skills, but not necessarily an expert in simulation modeling. The simulation engine contains the actual simulation computer code. It executes the simulation and generates simulation results. The integrator provides the link between the user and the simulation engine. The integrator is also referred to as an interface, simulation generator or an intelligent front end. Treu (1988) provides an excellent discussion of the structuring of tasks within an intelligent front end. The interface maintains and uses a data (or knowledge) base of permanent domain specific information, user-supplied information and raw output data from the simulation engine. Centeno and Standridge (1993) discuss the use of databases in simulation modeling environments.

The simulation engine is written using the PROMODEL manufacturing simulator which runs under WINDOWS. This is the first known generic simulator developed using a commercial manufacturing simulator as the simulation engine. This approach was chosen to take advantage of PROMODEL's many high quality manufacturing constructs accessible through a user friendly WINDOWS-based visual interface. The structure of the simulation engine is largely driven by PROMODEL's programming constructs. The simulation engine is a single pre-coded PROMODEL program consisting of a series of high level modules. A single core module houses a series of support activities common to most factories, including order arrival and release, inventory management and control, routing, and other miscellaneous simulation housekeeping tasks. The simulation engine also contains a variety of process modules, one for each potential process or piece of equipment. There are two generic classes of process modules, fabrication modules and assembly modules. All modules of a given class are essentially the same and are customized at run-time through input of specific parameters such as process times, resource requirements, etc. Since each potential machine has a unique process module, unique behaviors may also be hard-coded into the corresponding module.

The integrator links the simulation user with the simulation engine, providing three primary services: user interface, program generator and output evaluator. GIHMS' strength lies in its user interface which allows the user to configure a factory and specify products for production without programming in a simulation language and with minimal data entry of process parameters. The heart of the user interface is a specialized object oriented CAD system. Although appearing to the user as "seamless", it is actually a highly-integrated virtual system, consisting of a customized CAD front-end, a relational data base management system (RDBMS) and the visual interface from a commercial manufacturing simulator. The structure of the user interface is best described relative to its functionality.

To configure a factory, the user first defines a sequence of manufacturing operations for each class of component to be manufactured. This is accomplished on a customized CAD window. The user is then prompted to select specific manufacturing equipment to perform each production operation. The user interface allows the user to select from comprehensive equipment libraries which are permanently maintained on a data base. As equipment is selected, it is instantiated in a second custom CAD window as well as in a data base associated with this specific factory configuration. The second CAD window represents a rough layout of the manufacturing facility. Material handling equipment selection is performed in a similar manner, resulting in directed material handling arcs between equipment icons. Correspondence is maintained between objects in the first CAD window (operation icons and precedence arcs) and objects in the second window (process equipment icons and material handling arcs).

Characteristics and behaviors associated with each equipment instance are maintained in a data base corresponding to this factory configuration. Default behaviors are inherited from the permanent equipment library as equipment is instantiated. Specific behaviors may be reviewed and modified by selecting the desired equipment icon in the CAD window. Note that each equipment instance in the factory configuration data base corresponds to a unique equipment object in the second CAD window and to a unique equipment module in the simulation engine. GIHMS uses the factory configuration data base and routing information from the CAD window to produce a data set which configures the simulation engine to represent the factory being modeled. Much of the integrator functionality described above is developed in PARADOX, a multi-media RDBMS which runs under WINDOWS. It was selected in recognition that the integrator functionality is primarily data display and management. Elements of the custom CAD windows are developed in C++ wherever PARADOX programming constructs proved to be inadequate.

Upon completing the rough-cut factory configuration, the user proceeds to final factory configuration. Here, the user arranges equipment on the factory floor, identifies physical paths (aisles, conveyors, etc.), schedules labor and refines material handling equipment specifications. The user is presented with a scaled factory template complete with the same equipment icons which were active in the earlier CAD window. Note that each icon corresponds to a unique equipment object in the second CAD window, a unique equipment instance in the factory configuration data base and to a unique equipment module in the simulation engine. This correspondence is maintained throughout the final factory configuration phase, as equipment objects are relocated and physical paths are developed. This final factory configuration phase utilizes the object oriented visual interface of PROMODEL.

After factory configuration is completed, the user selects customer orders from a library of house plans, tailors the orders to builder/customer needs and, finally, schedules manufactured components for production. GIHMS then prepares a data set from the scheduled orders. The factory order data set is used to drive the simulation engine. PARADOX is used to provide this functionality. The simulation engine is then run. PROMODEL displays an animation of the running simulation and generates output data which it maintains for further analysis. The PROMODEL visual interface is used by GIHMS to allow the user to generate reports.

3. FACTORY MODELING USING GIHMS

The user begins the modeling effort by defining the technological constraints (e.g., panel size, panel depth) which will limit equipment and product selection options. The user then can define the set of production orders which the factory will run. The user may select specific orders or allow GIHMS to generate orders randomly (according to user defined probability distributions). To select specific orders, the user selects homes from a library of house plans, tailors the order to builder/customer needs and, finally, schedules manufactured components for production. To assist in home selection the user is provided a wide range of real estate and construction related data, including pictures and houseplans. After selecting a home, the user can specify the components to be manufactured (exterior walls, roof, etc.) and their characteristics (size, depth, etc.)

Next, the user configures the factory. First, the user defines a sequence of manufacturing operations for each class of component to be manufactured. Default operations process charts common to various homebuilding technologies are provided on a CAD window. The user is then prompted to select specific manufacturing equipment to perform each operation. As equipment is selected, it appears in a second CAD window which represents a rough layout of the manufacturing facility. The user may select new equipment from comprehensive equipment libraries or choose previously selected equipment from the CAD window.

To simplify selection, video segments, still-frame pictures and vendor spec sheets are available. Material handling equipment selection is performed in a similar manner, resulting in directed material handling arcs between equipment icons. As equipment is selected, default parameters describing equipment behavior are obtained from the permanent equipment library. These include inbound and outbound queue size and discipline, equipment loading and unloading methods, and operations which the machine has been selected to perform. Each operation is described by a series of elemental tasks which comprise the operation, as well as the corresponding labor requirements, process times, etc. for each elemental task. The user may review and modify these parameters by selecting the desired equipment icon in the CAD window.

Upon completing rough-cut factory configuration, the user proceeds to final factory configuration.

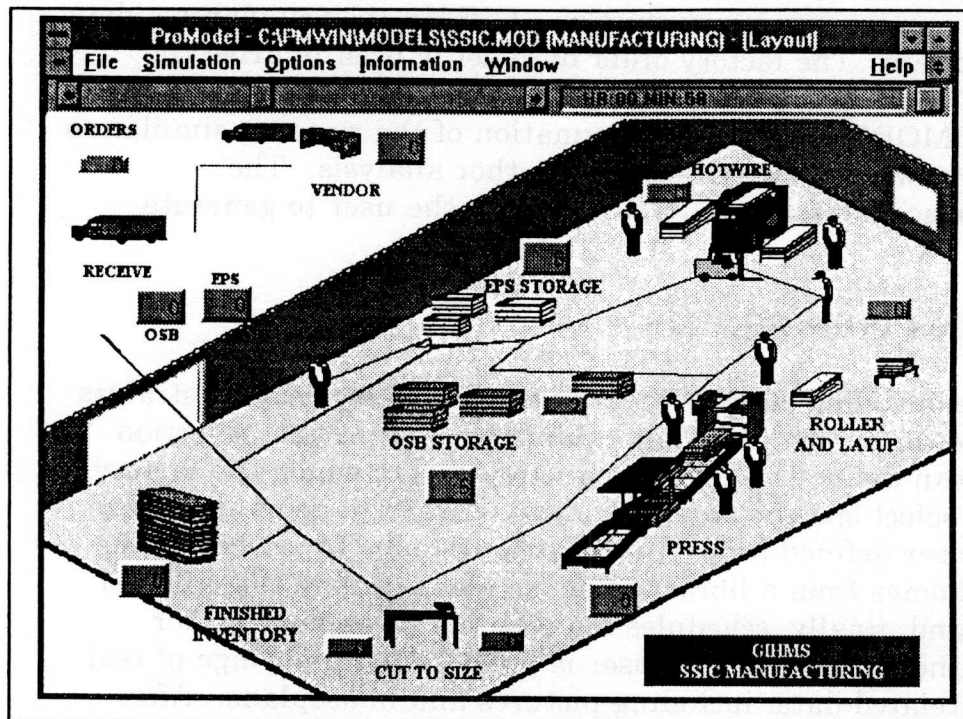


Figure 2 GIHMS CAD and Animation Window For Foam Core Panel Manufacturing

factory configuration. Here, the user arranges equipment on the factory floor and identifies physical paths (aisles, conveyors, etc.). The user is presented with a scaled factory template (Figure 2) complete with the same equipment icons which were active in the earlier CAD window. Each icon is surrounded by the appropriate labels and counters which will be active in the real-time

simulation animation. The user is allowed to move equipment icons to any location on the template. The user then utilizes simple drawing constructs to identify physical path networks which link equipment icons at their pickup and delivery points. As path networks are developed and modified, the system automatically updates travel distances. During the final factory configuration phase, the user may also define and schedule factory labor, including daily and weekend overtime. Various material handling system specifications, including top speeds, acceleration and load/unload times may also be refined.

The simulation is then run. GIHMS explodes each house into its component panels, explodes each panel into its raw materials and the simulated factory fabricates these parts and reassembles them to form the required panels. GIHMS displays an animation of simulated factory operation and generates output data which is maintained for further analysis. The user can request a wide variety of reports in both tabular and graphical formats. The user can continue to use this process, selecting new equipment and reconfiguring the factory, until the desired level of factory performance is attained.

4. CONCLUSIONS AND FUTURE RESEARCH

This paper has described a generic simulator-based decision support tool for manufacturers of prefabricated homebuilding components. The approach uses an object oriented CAD system as the interface between the user and the simulation engine. The interface allows the user to work with familiar domain-specific modeling constructs, to access comprehensive manufacturing equipment and product information, and to work in a user friendly "point and click" environment. The result is a significant enhancement in modeling power and efficiency.

While the research found the approach to be feasible, it identified several serious shortcomings, most software related. Commercial RDBMSs do not provide adequate CAD modeling capabilities. This forced the development team to front-end the RDBMS with a customized C++ CAD sub-system. PROMODEL was chosen for simulation engine development primarily because of its visual user interface which could be incorporated into the GIHMS user interface. However, its inability to link independent modules coupled with its inability to access key model entities and attributes using numerical indices, introduced severe coding penalties. It is expected that newer software versions will alleviate many of these problems.

Future research will consider extending the scope of GIHMS to the construction site. Currently, GIHMS is not able to model homebuilding operations occurring after manufactured components leave the factory, operations which often play an important role in the total house production/construction cycle. This enhancement will allow the assessment of various delivery strategies (factory vs. site-built) and associated construction automation options.

5. ACKNOWLEDGEMENTS

This research was sponsored by the United States Department of Energy, through the Energy Efficient Industrialized Housing (EEIH) research program. The EEIH program 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. (DOE Contract No. DE-FC03-89SF17960)

6. REFERENCES

- Centeno, M. and C. Standridge. 1993. "Databases: Designing and Developing Integrated Simulation Modeling Environments." *Proceedings of the 1993 Winter Simulation Conference*, San Diego, 526-533.

- Crowley, J. et al, "Reinventing Wood Frame Construction: Development of an Innovative Roof Component System." *Forest Products Journal*. 43(7/8)27-35.
- Haddock, J. 1988. " A Simulation Generator for Flexible Manufacturing Systems Design and Control." *IIE Transactions*. 20(1)22 - 31.
- Halpin, D. 1973. *An Investigation of the Use of Simulation Networks for Modeling Construction Operations*. Ph.D Thesis, University of Illinois, Urbana, IL.
- Halpin, D. 1990. *MicroCYCLONE User's Manual*. Div. of Construction Engineering and Management, Purdue University, West Lafayette, IN.
- Huang, R. and D. Halpin. 1993. "Dynamic Interface Simulation for Construction Operations." *Proceedings of the 10th International Symposium on Automation and Robotics in Construction*, ISARC, Houston, 503-510.
- Mackulak, G. and J. Cochran. 1990. "Generic-Specific Modeling: Application of AI to Simulation. 1990 IIE Integrated Systems Conference & Society for Manufacturing Conference Proceedings, 82-87.
- Medeiros, D. and R. Sadowski. 1983. "Simulation of Robotic Manufacturing Cells: A Modular Approach." *Simulation*. 40, 3-12.
- Ozdemirel, N. and G. Mackulak. 1993. " A Generic Simulation Module Architecture Based on Clustering Group Technology Model Codings." *Simulation*. 60(6)412 - 433.
- Reddy, Y., M. Fox, N. Husain, and N. McRoberts. 1986. " The Knowledge-Based Simulation System." *IEEE Software*. 3, 26-37.
- Schroer, B. 1988. *A Simulation Model of a Manufacturing Cell*. University of Alabama, Research Report No. 696.
- Stouffs, R. et al. 1993. "Construction Process Simulation with Rule-Based Robot Path Planning." *Proceedings of the 10th International Symposium on Automation and Robotics in Construction*, ISARC, Houston, 495-502.
- Toole, T. and T. Tonyan. 1992. "The Adoption of Innovative Building Systems: A Case Study." *Building Research Journal*. 1(1)21-26.
- Treu, S. 1988. " Designing a "Cognizant Interface Between the User and the Simulation Software." *Simulation*. December, 227-234.