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# DIGITAL AND PHYSICAL SIMULATION OF MANUFACTURING SYSTEMS

P. H. Cohen
R. A. Wysk
Department of Industrial and Management Systems Engineering
The Pennsylvania State University
University Park, PA 16802

## ABSTRACT

The introduction of expensive computer-integrated manufacturing systems in industry has created a need for new planning, design, analysis and implementation. Problems in the planning of these manufacturing systems which need to be addressed are identified along with the needed characteristics of the models used to describe them. Various modeling and simulation procedures are identified and discussed in terms of how effective these procedures can be to model modern manufacturing systemss. The fidelity of the models will also be addressed.

## PROBLEMS IN THE DESIGN, ANALYSIS AND IMPLEMENTATION OF COMPUTERIZED MANUFACTURING SYSTEMS

The complexities of planning, design, analysis and implementation of computerized manufacturing systems are manifold. The use of automated machine tools, material handling systems and storage systems in a flexible manner has created a wide variety of manufacturing solutions, but has brought several new problems ranging from the effective design of these systems through their expedient implementation and use.

In the planning phase, one must initiate the configuration process by making a tentative selection of machine tools for a set of products which may change over time. The capability of the equipment selected to perform the desired operations must be assured. In the design phase, the physical arrangement of machine tools, storage areas, tooling, etc., must be considered along with the material handling system. Spacial characteristics of the plant, processing times and routes, expected product mix and other factors which influence the design must also be considered.

After this lengthy process, one must consider the methods for controlling this complex system. Real-time scheduling algorithms must be tested and adopted. Subsequently, the architecture for computer control of the system must be decided and control software developed. Human intervention may, at times, still be required for appropriate system response to certain situations. These situations must be identified along with the status information to be presented to the operator, and how he may interrupt and alter the system.

After the acquisition of the equipment selected, all software identified (including NC part programs) must be developed and implemented. Further, operators, engineers and managers associated with the system must be trained for its efficient operation.

The overall process defined above is expensive, with current systems costing from $1-50 million and requiring up to five years to implement [1]. With the enormous cost and resource requirements needed for successful implementation of a flexible manufacturing system of this type, it is clear that methods for the planning, design, analysis and implementation are of paramount importance.

## MODELING AND SIMULATION OF MANUFACTURING SYSTEMS

The planning, design and analysis of complex systems of any type requires a model of that system where the term "model" refers to a formal, abstract representation of the system. There are three general classifications of these models [2]: Schematic models that include engineering drawings, charts, etc.; physical models which are typically scaled-down replicas; and symbolic models which are based upon mathematics or computer codes which implement a structured set of rules.

For appropriate model selection and development, one must consider the important characteristics of computerized manufacturing systems. First, they are highly complex systems with many components. The number of controllable variables for each individual machine and device (let alone all of the system variables) is large with complex interactions. The number of possible states becomes quite large, even for small systems.

In addition, the three-dimensional spacial characteristics are important for equipment layout and to avoid potential collisions since some components will move over time. Thus the temporal or dynamic characteristics of the system must also be modeled.

### Schematic Models

Schematic models are good for representing the static and two-dimensional spacial characteristics of a manufacturing system. They have very limited three-dimensional spacial representation capabilities and are unable to effectively display dynamic behavior of complex manufacturing systems. Thus schematic models may be adequate to represent part prints and 2-D layouts but are unable to aid in the solution of the myriad of time-dependent problems posed by system design.

### Symbolic Models

Symbolic models may be divided into analytic and numeric representations [2]. In analytical models, one may determine a solution based on a mathematical representation. This representation has the advantage of being able to describe time-dependent behavior and can be easily changed. However, it is an extremely abstract representation and generally requires many simplifying assumptions to be made mathematically/computationally tractable. It is also difficult to model human intervention and to use the model to expedite control software development.

Numerical representations such as digital computer simulation have received far more attention in the design of manufacturing systems for several reasons. First, it is good at representing time- dependent behavior and at recording the state of the system over time. In addition, it is very easy to reconfigure the manufacturing system under study in terms of the type and number of work stations, type of material handling systems, size of buffer storage, etc. It is also possible to investigate the effectiveness of various scheduling heuristics. Computer simulation thus becomes very important for studying the operational effects of various alternatives.

However, there are several areas in which it does a less than adequate job. It is not good in validating the 3-D layout of the facility in terms of spacial considerations. Nor does it aid in the implementation of the desired solution since it is not necessary to develop any software for real-time control of the system. The debugging of control software can be a long and arduous task, taking as much as a year or more. The lack of control software also deters the development of a real-time scheduling heuristic as well as the possibility and study of the need for human intervention.

### Physical Modeling

With respect to automated manufacturing systems, physical modeling (simulation) is the process of constructing and controlling (using a computer) a miniature of the real system with physical, working models of all system components. Thus physical models are functional iconic models, and as such, can aid in determining operational layouts. With scaled models which can move in coordinated real or accelerated time, layouts may also be evaluated for 3-D collision avoidance.

Determination of the computer network configuration as well as the development of real-time control software on the physical system can greatly speed-up the implementation process and can allow the system to be run in miniature for the development of appropriate real-time scheduling heuristics. The effectiveness of these heuristics can then be benchmarked on the actual configuration using the software that will run the implemented system. This can also allow validation of the digital simulation model of the system by comparing the output of both under identical operating conditions and the digital simulation model can be updated as needed.

Scenarios for human intervention in the scheduling, maintenance and control of the proposed manufacturing system may be investigated and implemented in real time. This can potentially be of tremendous benefit and is possible due to the reasonably close fidelity of the real and miniature systems coupled with the low level of abstraction of the physical model. The physical model can then serve as an outstanding "sales device" to obtain top management support for large-scale, high capital projects, as well as to train operators, engineers and managers in the use of the system.

## CONCLUSIONS

The debate about the merits of physical simulation over digital simulation continues. Perhaps the most constructive solution is not to pit one against the other, but to learn to use them together in the planning and design of modern manufacturing systems. They are both powerful tools with unique and compatible capabilities.

The strengths of digital simulation lie in its ability to cost effectively and quickly allow the user to evaluate the operating characteristics of various configurations. Physical simulation's major strengths are its ability to allow the development of the control software for faster implementation, the development of human intervention systems and real-time scheduling in a model of high fidelity. Clearly, all of these issues are important for the effective design and subsequent control of these multi-million dollar systems.

As is the case of any model, any gain of modeling detail that can be made is made at a specific cost. As modeling detail increases, the computation time required for execution also increases. Certain model types cannot be used for specific design and control analyses. The analysis, however, does bring about other requirements. These requirements are classified in Table 1.

Table 1. Model Characteristics

| | Schematic | Symbolic | Physical |
|---|---|---|---|
| System Detail | Little | → | Much |
| Control | No | Some | Yes |
| Resource Plans | Yes | Yes | Yes |
| Fidelity | Low | → | High |
| Computation Requirements | Small | → | Large |
| Modeling Time | Variable | Moderate | Usually Large |
| Model Cost | Low | → | High |

With increased detail comes closer fidelity between the model and the real system. This fidelity gives a clearer vision of the operational characteristics of the system, especially since the same control software and strategies which govern the real manufacturing system will be duplicated on the physical simulator. Unfortunately, there is a substantial price to be paid for this level of fidelity. The time required for development of a physical model is typically much greater than for a symbolic model such as digital simulation due to the construction of hardware as well as the development of detailed software. In addition, due to the need to control individual work stations, store and execute part programs, monitor system status, schedule incoming orders and control inter-station material handling, the computational requirements for physical models will generally be much greater than the computational requirements of a digital simulation of the same system. For these two reasons, the physical models of manufacturing systems typically cost much more to construct than computer simulation or other symbolic models.

The extreme cost and human resources required for the successful design and implementation of automated manufacturing systems necessitates sophisticated, precise tools for their analysis. In the design of other complex systems such as chemical manufacturing facilities and automobiles, physical and symbolic models are used in concert. In the case of chemical manufacturing, the laws of chemistry form a portion of the symbolic model while a pilot plant is normally constructed and operated to determine operating characteristics. For automobiles, mathematical models for the aerodynamic characteristics are normally developed and wind tunnels used for experimental verification. The cost and complexity of automated manufacturing systems certainly merits the compatible use of physical and symbolic models as in other aspects of engineering endeavor.

## REFERENCES

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