Proceedings of the 1983
Winter Simulation Conference
S. Roberts, J. Banks, B. Schmeiser (eds.)

THE FACTORY OF THE FUTURE AND SIMULATION: AN OVERVIEW

Charles H. White
Engineering Department
E. I. du Pont de Nemours and Company
Louviers Building
Wilmington, Delaware 19898

The Factory of the Future is possible with current hardware and software technology. It may include many different components but such manufacturing complexes must be planned, designed, and operated as coordinated systems. They will be information oriented; careful planning and design is critical to the operational and financial success of such systems. System simulation is proving to be an effective tool for dealing with these large and complex systems. This paper presents an overview of this increasingly important area of application and is intended to serve as an introduction for the other papers in this session.

INTRODUCTION

What is the "Factory of the Future"? Many facets of this modern factory can be identified; I plan to discuss several of these. However, to put the topic into perspective, we should start not with "what" but with "why". The objectives of this Future Factory are to (1) reduce manufacturing costs, (2) increase overall productivity, (3) improve product quality and bottom line, (4) increase the competitive edge and profitability.

The unifying or common element of the many facets of this modern factory is better use of information. Computers, robot-type devices, and the use of data base technology appear in most of the components that will make up this Future Factory. As these components are developed and improved, the emphasis is shifting to the integration of these components into manufacturing systems that will be flexible enough to produce goods cheaply in small volumes.

It is increasingly recognized that short run cost reduction steps without a strategic plan for the total manufacturing system can lead to long run failure. All too frequently, the focus is not on the total system but rather on just one or two component areas or aspects. However, it is easy to be a critic and point to the potential value of a "total system viewpoint" and quite another to offer a practical way to help plan, design, and evaluate large integrated systems.

My objectives today are (1) to describe several facets of this so-called "Factory of the Future", (2) to focus on the need for an integrated viewpoint in designing, operating, and evaluating such a system, (3) to describe, with examples, the role and potential benefits of simulation in the design, operation, and evaluation of such a factory, and (4) to set the stage for our other two speakers, who will be describing specific efforts that are part of the Factory of the Future modeling effort.

WHY IMPORTANT

As emphasized above, when considering the "Factory of the Future", we should first focus on "Why" and then discuss "What" and "How". This new factory is being developed because current US factories are increasingly unable to compete successfully in the world marketplace. The question of "Why" is not easy to answer; and the easy answer of "cheap foreign labor" is not the correct answer.

Here (Figure I) we see a breakdown of manufacturing costs as they were in the 1920's. Direct labor, material costs, and burden costs were all about equal. American industry focused on the direct labor and the work of Galbraith, Taylor and others resulted in direct labor measurement and cost cutting programs that were labeled Industrial Engineering. Investment in labor saving machinery and process procedures were successful, and the manufacturing cost picture (Figure II) has changed as we see here.

Material costs and burden/overhead costs have increased rapidly and now account for 55% and 35% of the total manufacturing costs. Ingersoll Engineering Company points out that "even if we eliminate every man and woman in our direct labor

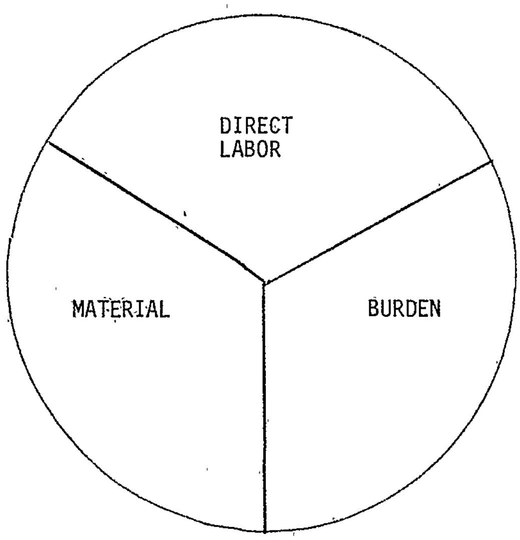

Figure I

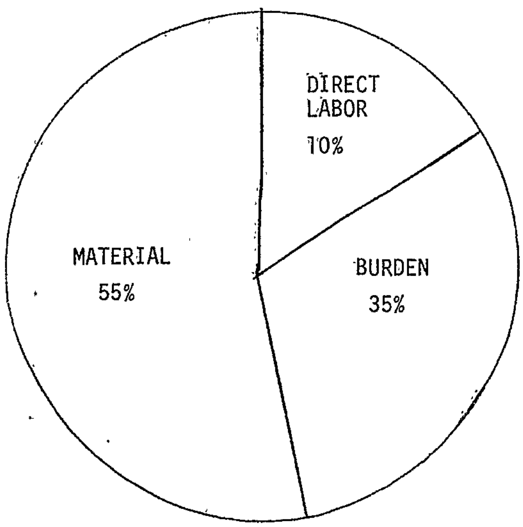

Figure II

force, we would only reduce from 40% to 30% the cost advantage that some of our overseas competitors enjoy".

In a recent speech, J. F. Lardner, Vice President of Manufacturing Development of Deere & Company, noted that for several years he has been engaged in a corporate program directed to achieve superior manufacturing performance. Lardner relates "It was clear that we needed a way of looking at the whole manufacturing activity if we could. To this end, we turned to a simplified version of value added analysis. Analysis of the past 15 to 18 years showed: (1) physical transformation of material made up only a small portion of the total cost, (2) these costs had been shrinking as a relative percentage of the total cost, (3) there had been a remarkable growth in the indirect labor and salary costs per unit of output." In pursuit of "Why", Lardner reports paydirt. The increase in indirect workloads at first appeared to result from tremendous increases in the complexity of manufacturing. In further digging, it was ultimately concluded that this complexity had been unintentionally compounded because of the conventional "divide and optimize" theory of manufacturing Deere had been following. A reorientation toward a total system viewpoint is paying off: (1) tooling costs have been halved, (2) manufacturing costs have been reduced 10 to 15%, (3) plants have been rearranged to make flowthrough manufacturing possible, (4) equipment is up 15%, (5) material handling has been reduced 40%, (6) defective material and work is down 40%. Lardner concluded his speech to the Conference Board by saying "In summary, we are working hard to simplify the total manufacturing problem by pulling together the pieces that have been so carefully separated over the past forty years".

CONTRIBUTION OF SIMULATION

Lardner has given us some specific manufacturing system improvements achieved by John Deere from an integrated approach. It is my contention, indeed my main point, that one of the most valuable contributions of simulation is the ability it gives us to <u>model and study total systems</u>. In many manufacturing environments, it is possible to gather and analyze data about the current system performance. However, if the performance is not adequate, it often ranges from difficult to impossible to determine what factor, factors, or interaction of factors is causing the system to perform poorly.

Simulation models can be used both to predict how future system will perform and to study why a current system performs as it does. Another of my main points is that <u>the behavior of current systems should be thoroughly analyzed and explained before extensive action is taken to change the system</u>.

Certainly if a completely new "cornfield" plant is being built, it is often not possible to study the current system; however, it cannot be overemphasized that a system must be understood and described before it can be adequately modeled.

WHAT IS THIS "FACTORY OF THE FUTURE"?

If a Factory of the Future model is being developed, it is reasonable to talk about (1) types of components that could be in that system, (2) types of questions that one might wish to study about a specific system, (3) how one should go about building the model, and (4) the potential role such a model could fill. I will cover these areas with the objectives of (1) increasing your understanding of the multiple facets of this Factory of the Future, (2) of illustrating how simulation can play a valuable role, and (3) of laying some groundwork for introducing the other two speakers in our session.

What are some of the possible components (Figure III) that could be part of our Future Factory. Here we see but a partial list of some of these. Now given this rather formidable list of technology areas, one could come to the conclusion that more technology development is the key to returning the competitive edge to US industry. It appears this answer is not much better than the

- Numerical Control (NC)
- Computerized Numerical Control (CNC)
- Distributed (DNC)
- Computer Aided Design (CAD)
- Flexible Machining Systems (FMS)
- Flexible Manufacturing Systems (FMS)
- Automatic Guided Vehicles (AGV)
- Automatic Storage and Retrieval Systems (AS/RS)
- Programmable Controllers (PC)
- Materials Requirements Planning (MRP)
- Manufacturing Resources Planning (MRP II)
- Master Scheduling (MS)
- Distribution Resource Planning (DRP)
- Group Technology (GT)
- Data Base Management System (DBMS)
- Computer Aided Inspection and Reporting (CAIR)
- Product Quality Management (PQM)
- Coordinate Measuring Machines (CMM)
- Computer Aided Layout (CAL)
- Computer Aided Quality Assurance (CAQA)
- Computer Aided Assembly (CAA)
- Materials Handling System (MHS)
- Robots
- Computer Integrated Manufacturing (CIM)

Figure III

"cheap foreign labor" one. James Harbour spent five years with Ford and 23 years with Chrysler. He was director of manufacturing engineering before forming his own consulting firm. In a study of the American and Japanese auto industries, Harbour found when he added up all of the white-collar and blue-collar staff hours put in by vehicle assemblers and all of their parts suppliers, that it takes 160 man hours in the US and 95 in Japan. Harbour claims the differences is not due to technology but rather is due to how the two industries are organized and managed. The key is not to develop new technology but rather to more effectively implement technology that is available now.

To effectively implement technology of the sorts we saw listed, we must first know how our systems are working both technically and operationally. Carter found that in a typical batch-type metal cutting production shop that an average workpiece spent only 5% of the time on machine tools and only 30% of that time is actually productive metal-cutting time. Since only 1.5% of the overall time is true productive time, speeding up the cutting certainly won't impact the time work spends moving through the shop. Carter and others have found that average machine tool utilization is about 50% and that the average worker spends 50% of his/her time waiting for parts, tools, or instructions. Once again there is significant productivity improvement potential in changing how the resources are utilized and the way materials flow through the shop. Ingersoll Engineers found for a large plant that the inventory holding costs for work-in-process amounted to 12% of the total manufacturing cost which was double the direct labor cost. Once again note the tremendous opportunity for productivity improvement in the burden area.

ILLUSTRATION

At this point, let me cite a specific case I worked on where the objective was to help evaluate the potential impact of several technical development projects. The environment was a metal stamping operation where nine presses produced 19 products. Ten operator activity states and fifteen stamping press activity states were identified. Extensive operational logic and data was gathered and a detailed simulation model was developed and validated. Here (Figure IV) we see an average profile of the operator activities for a specific product mix and production schedule. Note that more time is spent repairing dies than

PRESSROOM LABOR PROFILE

% of time spent doing product changeovers	1.4
% of time spent cleaning chip bins	0.3
% of time changing finished product reels	7.4
% of time changing inter. paper reels	0.5
% of time changing raw material reels	3.5
% of time changing wire supply spools	2.7
% of time spent repairing dies	15.6
% of time spent cleaning tools	1.1
% of time changing cleaning fluid	2.1
% of time gone (lunch, breaks, etc)	13.0
Total Time Utilized	47.5
Time Available for Other Activities (%)	52.5

Figure IV

on personal time. In fact, repairing dies takes almost as much time as all of the routine service tasks added together. Here (Figure V) we see a stamping press activity report for the nine presses. The details are not really important for our purposes, but it is worth noting that the machines lost almost 5% of the total time waiting for an operator; recall that the average operator utilization was less than 50%.

For this area, one proposed project was an automated raw material feed device that would eliminate the feed splice time. The impact of such a device would be about 1% which did not justify the development effort. Note that an improved die maintenance program would have a significant potential impact. This model was used to determine (1) why the machine utilizations averaged only 48%, (2) to determine what had to be done to get total productivity up to meet a specified task, and (3) to help evaluate the potential impact of several proposed mechanical development projects. The key point is that better scheduling and better die maintenance had more potential than most of these development projects.

FLEXIBLE MANUFACTURING SYSTEMS

Let us shift to a more exotic topic; that of Flexible Manufacturing Systems. In the widely publicized Fujitsu Fanuc Factory at the foot of Mt. Fuji, a staff of 100 produces 50 robots, 100 wire-cut electric discharge machines, and 100 mini-CNC machine tools each month. This plant has 29 machining cells with robot load/unload capabilities, unmanned material/part carriers, automatic warehouses for materials-parts-subassemblies, and a central control room for managing and monitoring the total system. This plant has become famous for running with 100 workers on the daytime shift and with only one

STAMPING PRESS ACTIVITY

Press Activity	P1	P2	P3	P4	P5	P6	P7	P8	P9
% Of Time Running	39.3	28.8	26.6	68.0	63.3	68.2	65.9	52.0	15.6
% Of Time Scheduled Idle	0.	53.1	37.0	0.	0.	0.	0.	0.	79.0
% Down Waiting An Operator	8.5	3.4	6.8	8.1	7.3	6.4	6.6	4.7	1.5
% Down Due to Product Changeovers	3.2	1.0	1.4	5.9	0.5	4.6	0.1	1.7	0.5
% Down For Chip Bin Cleanout	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0
% Down For Finished Prod Reel Change	1.9	0.8	1.4	2.9	2.6	3.0	2.9	1.8	0.4
% Down Interleaving Paper Reel Change	0.1	0.0	0.1	0.2	0.2	0.2	0.1	0.1	0.0
% Down Waiting Die Maintenance	23.9	4.0	12.3	7.4	9.2	5.0	4.6	6.2	0.4
% Down Raw Material Reel Changes	0.9	0.3	0.7	1.4	1.2	1.4	1.3	0.8	0.2
% Down Wire Supply Spool Changes	0.6	0.6	0.4	0.9	1.4	1.0	1.0	0.5	0.2
% Down Due to Press/Die Failures	20.2	7.0	12.5	3.1	13.1	8.0	9.3	31.3	2.0
% Down Due to Tool Cleaning	0.3	0.1	0.2	0.4	0.4	0.4	0.4	0.3	0.0
% Down Changing Cleaning Fluid	0.6	0.3	0.4	0.7	0.7	0.7	0.7	0.7	0.2
% Down Waiting For An Inspector	0.	0.	0.	0.	0.	0.	0.	0.	0.
% Down For First Piece Inspection	0.3	0.2	0.2	0.9	0.0	0.8	0.9	0.2	0.0

Exhibit V

control room supervisor on the night shift. Such an unmanned factory may be what some think is the ultimate Factory of the Future. However, the motivations for this Japanese plant may have been to (1) develop a showcase plant to attract attention and help develop business for Fanuc robots and (2) to help meet the labor shortage problem in Japan and the resultant problem of getting skilled workers to work the night shift.

Flexible Manufacturing Systems are not unique to Japan. Kearney & Trecker had installed their commercial FMS system in a half a dozen factories by 1981. These systems contain between 5 and 12 machine tools, including complex machines called head changers. The latter can shift the heads on cutting tools to perform different tasks, such as drilling, boring, and milling. Parts loaded onto pallets are moved from one machine to another through use of an automatic towline system. A typical FMS system produces a family of parts, such as crankcases. Because of the much higher proportion of machine time spent cutting metal, the 15 stations of this system can replace about 90 stand-alone tools - a great savings in capital.

In 1981, it was reported that Japan had 30 FMS units at work in its industries, while the US, Western Europe, and Eastern Europe including the Soviet Union each had only about a dozen such systems apiece. It seems recently that the pace in US industry is quickening. It is important that these systems both operate efficiently and that they fit well into the customers overall manufacturing system; the first issue is a vendor concern, the second is a client/purchaser concern.

What is the potential role of simulation vis-a-vis FMS. It can be used to determine how effectively such a system will operate as a function of product mix, cutting speeds, tool change times, etc. Many of the vendors of such systems use modeling to ensure that their system meets the customers specifications. An even more important question is how well the FMS will fit into the customers manufacturing system and help move product smoothly through the shop at a lower unit cost. Many customers don't develop adequate requirements and thus don't adequately plan for the operational control of the FMS.

Caterpillar Tractor Company is one of the US leaders in successfully implementing FMS. Gerald C. Freeman, Corporate Manager for Planning and Tooling, says "The Caterpillar approach is to buy a system to do a specific job; the size of the system is geared directly to the job at hand". Freeman feels the key is good systems planning and reports that in most cases "the systems approach utilizes less manpower, occupies less space, reduces production costs, and provides a better return on investment than conventional technology". A necessary ingredient in getting a successful system with a good ROI is careful planning; simulation is necessary to evaluate the dynamic operational behavior of such systems under a range of conditions.

MATERIAL HANDLING

Materials handling and storage/retrieval has become recognized as a major component of an integrated manufacturing system and a major productivity improvement opportunity area. In many shops, large work-in-process inventories are held and parts spend 80 to 95% of time waiting for further processing. If we are successful in reducing these inventories, it will become increasingly critical to get the right material to the right machine at the right time. The system must have effective scheduling and control and also adequate capacity to meet the fluctuating workloads in the operating areas. Having too few Automatic Guided Vehicles (AGV) to move material can result in lost machine productivity; having too little conveyor lag space for queuing materials can cause interference interactions and could shut down a complete area if really inadequate. Automatic storage and retrieval systems act as buffers and if they are either too slow or too small they too can cause a complete manufacturing system to shut down.

Most of the larger material handling system suppliers have in-house simulation modeling groups. However, the first charter of these groups is to ensure that the system supplied meets the throughput capacity requirements specified by the customer. Once again, if the manufacturing system into which this materials handling system is going to be incorporated has not been adequately studied, it is not infrequent that the system can meet the contract requirements and still not meet the real need. Once again, system simulation is the tool of choice for helping to study the total system and specifying the requirements that must be met.

FLOW CONTROL

The term "islands of automation" is a well-phrased way of summarizing what could evolve if there is too much emphasis on equipment development and too little on the smooth and orderly flow of materials through the manufacturing system. As in-process inventories are reduced and resource utilizations are increased, it is more and more important to get material where needed as needed. The production scheduling and control system must be able to respond to changes in the operating areas. The cost of conveyor lag space, generally several hundred dollars per linear foot installed, dictates that queue build-ups be kept down. The mix of products that can be in the system requires reliable bar-code readers and intelligent routing switches be able to effectively control the flow of materials. The use of load/unload robots allows automatic guided vehicles to move materials from station-to-station; this requires that a flow management system effectively route the materials as needed through time. Once again, simulation models can help evaluate not only the system hardware capacity, but the control system logic.

COMPUTER INTEGRATED MANUFACTURING (CIM)

Ingersoll Milling Company won the 1982 LEAD award from the Society of Manufacturing Engineers (SME) for their computer-based system to improve productivity. George Hess is the vice president who guided the development of their Computer Integrated Manufacturing (CIM) system. Hess feels the three pivotal strategies in the evolution of this system are (1) the decision to adopt NC machining, (2) the decision to employ computer-aided design (CAD), and (3) the move to ensure that all of the information software systems were integrated so that a unifying Company-wide data base information system (DBMS) could be used. This allows for a coordinated effort to design products, produce NC instructions, cost out the product, schedule purchases, release orders, develop master scheduling, and control the shop floor movement of tools and materials. Such a system allows for an orderly flow of information and materials through the total system.

Not many companies are yet close to having an integrated system for manufacturing. However, not many companies will be willing to make such a big step without both a detailed analysis of the potential benefits of such a system and a thorough study of how to go about implementing such a CIM system. Once again, simulation modeling is an excellent tool for helping to address many of these questions and issues.

INTEGRATED SYSTEMS

We have seen a partial list of the possible components in a modern manufacturing factory. Which ones are best for a specific application depends on the job that needs to be done, the cost of the components, and the potential savings that can be realized. I recently saw an ad that caught my eye. It said "There are two approaches to plant automation. One of them is right". It went on to delineate one approach as the piecemeal approach where individual projects are carried out with no integrated plan. This approach creates the very types of problems that planned automation was intended to solve. As Lardner, of Deere, pointed out, their problem was compounded by the "divide and optimize" philosophy. The alternative approach is the coordinated systems approach where the flow of information and materials is planned so that intelligent and coordinated control policies can be used to ensure an orderly flow of materials throughout the system.

CONCLUSION

What is the Factory of the Future? It is a coordinated manufacturing system that incorporates advanced operating equipment, materials handling systems, automated testing and inspection devices, and perhaps most importantly, information gathering and processing systems to plan and control the flow of materials in response to both current needs and shop floor conditions. A detailed list of possible ways these components can be integrated is countless. As these systems become increasingly complex and expensive, the importance of thorough planning and intelligent control increases; simulation modeling is a valuable tool; but, it is necessary that the modelers understand the manufacturing needs and the models be designed to meet the real needs.

Why would anyone use the piecemean approach. Two answers jump out at me: (1) the Company has a short-term focus and is not concerned about long-term problems, (2) the system is so complex nobody really knows how to go about developing a sound coordinated approach. I don't claim that simulation modeling or systems engineers have all of the answers. I do suggest that simulation models can be developed that incorporate the understanding of many people who are knowledgeable about all aspects of the system and can, therefore, provide the best available tool/approach for studying a total manufacturing system. Simulation models can and are providing a mechanism for effectively dealing with the detailed interactions in large complex manufacturing systems.