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SIMULATION FOR PLANNING AND OPTIMIZING OF MANUFACTURING ENTERPRISES

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Abstract

This work is thought of as an introduction and invitation to simulation and is aimed at presenting the current status of the simulation techniques seen through requirements set by the manufacturing environment. It should not be seen as a complete overview of simulation technologies. It just treats selected subjects, which are important for understanding simulation problems. It should connect available simulation techniques and tools with the issues arising in contemporary manufacturing facilities. It compares simulation methods with its competition, shows the advantages and disadvantages of simulation techniques and present a wide scope of possible applications. As a bottom line the importance of the simulation techniques for developing countries is discussed.

In general this paper should give readers a better understanding of simulation; it should show that these techniques are not just computer games or "Star Wars" animation, but that simulation is a serious, useful and very powerful tool, which can and has to be used in the planning, monitoring and optimizing of contemporary manufacturing systems and processes.

1 Introduction

Introduction of electronic computers caused huge changes in almost all the fields of men's activity and could be compared with the invention of steam machines at the turn of the 18th century and electric power and combustion engine on the turn of the 19th century - it started a new industrial revolution. In manufacturing, it began with developing and extensive usage of computer controlled machines and manufacturing systems. The use of NC and CNC system induced important improvements in quality and quantity of the products, but also caused many new organizational problems. Machines became faster, more flexible and could be used for manufacturing of a wider range of different and more sophisticated products. At the time of their introduction, capabilities of new machines were far ahead of their actual utilization. Computer controlled machines replaced the traditional ones in job shops but the ways of planning and controlling of manufacturing processes stayed almost unchanged.

The real challenge came in 1970s. The oil crisis, declining demand and oversupply forced traditional manufacturers to search for new organization forms. The market studies showed that the best chances for winning over competitors and staying on the surface would have companies able to:

- Produce in short series,
- Manufacture a wide variety of product types and variants.
- Produce with short lead and delivery times.
- Offer lower prices than the large series manufacturers.
- Flexibly extend and reduce manufacturing capacities in accordance with the market situation,
- Flexibly extend the product palette
- Take additional order and carry them out within a reasonable time and price frame.

Of course the listed requirements were in many points contradictory. The available hard-ware (machines and technologies) allowed fulfilling of all of them, but it had to be done within an acceptable economic frame. Examining the ways the most competitive companies planed, manufactured, delivered and priced their products showed that solution could be find in employing Just in Time or kanban manufacturing. Interesting is that these methods were worked out in Japan not as means for conquering the markets. They were the only way that made possible surviving in the harsh years after the II World War. The lack of money for raw materials caused the necessity of keeping inventories at the minimal level and not allowing the production of goods, which could not be immediately delivered and paid.

But what was possible and simple within small "family oriented" companies was not necessarily available for hierarchical structures of the most of the enterprises. Their organization with the controlling instruments based on the file cabinets, manually constructed flow-charts, calculations, list and diagrams could not react flexibly enough to the market and manufacturing environment changes.

First the dissemination of computers not only in manufacturing departments, but also in forecasting, planning, and controlling, together with progress in simulation and data analysis brought foundations for the real flexible manufacturing.

2 What is Simulation

Simulation is an expression which is well known, and used by many people, at least in a general way.

The Webster Unabridged Dictionary describes this term as:

Simulation -- from Latin "simulatio", a feigning.

1. The act of feigning: pretense.
2. False resemblance, as though imitation.

The Random House College Dictionary defines simulation as:

1. The act or process of pretending, feigning
2. The assumption or imitation of a particular appearance or form.

Dictionary definitions suggest that simulation involves imitation or mimicking, giving the appearance or effect of some elements. It can be also taking on the characteristics of reality and usually involves a sham object, a counterfeit, a replica, or a model. Simulation brings to mind the idea of pretending, or feigning.

These definitions are perhaps too general, too universal for our "technical" purposes, but they support the initial, basic understanding of simulation's meaning. As a technical term, simulation will be defined as imitation of the behavior of a real-world process or system over time. By a real-world system is mean some part of the real-world, which is of interest.
The system may be natural or artificial, in existence presently or planned for the future. For imitating (simulating) purposes, a model of the previous defined real-world system has to be developed and its behavior under various conditions analyzed.

3 Historical Scope of Simulation Techniques

Simulation (imitation) is not a new technique. From ancient times, inventors have tried to apply available technologies to depict physical and even mental processes. Prior to the computers, this necessitated applying the state-of-art in mechanical techniques. Archytas of Tarentim. Greece (c.400-350 BC) fabricated a pigeon whose movements were controlled by a jet of steam or compressed air. Even more elaborated automata, including an entire mechanical orchestra, existed at the same time in China. After studying and entertaining phase, inventors began to develop simulation systems for trade and industrial purposes. Calculating machines such as Napier's Bones, the Pascaline, and the Analytical Engine of Charles Babbage were early efforts to simulate and extend human computational abilities. The rapid grow of the United States population in the late 1890s led to developing of new machine that could accurate and timely handle the census data. Edmund Hollerith's creation of punch cards and an electronic device for interpreting the encoded information helped resolve this dilemma.

Henry Ford, determined to sell his Model T to average Americans, especially to millions of farmers, needed a plant that could produce his cars more effectively than his Highland Park facility. He believed that this problem could be solved only by employing steady flow of materials and half-products through a manufacturing system.
In planning the great River Rouge plant, which displaced Highland Park in the 1920s as the heart of the Ford system, Ford insisted on having scale models of machine tools, conveyors, windows, pillars, and floor space, so that these could be moved around to test ideas about production. Between 1922 and 1926 he and his engineers designed and had constructed at the Rouge site a coke-oven plant, a foundry, a cement plant, an open-heart steel plant, a motor-assembly building, and several other plants, which built one of the most important industrial complexes of its day.

The huge net of facilities at Highland Park and River Rouge with well organized, simulation-tested manufacturing allowed cost and time effective mass-production of the Model T. In the five succeeding years of increasing production efficiency and savings, he cut the price of the basis car from $900 to $440, well below the price of the nearest comparable automobile. The average monthly number of unfilled orders grew to almost sixty thousand. In that time the Ford company had a fifty-five-percent share of the automobile market and production of the Model T climbed to two million cars and trucks a year.

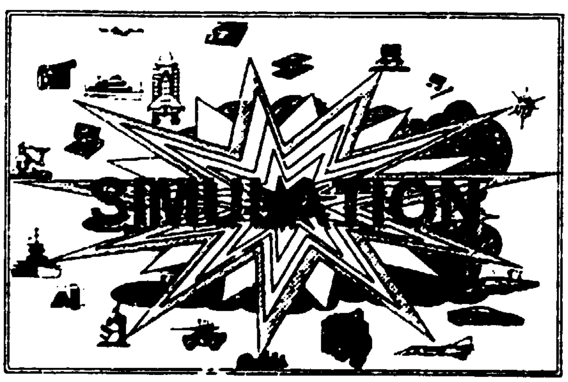


Fig. 1

Simulation of the complex missile trajectories was the main reason for developing the first computers. Development, which in the next few years brought immense change in all the fields of social and industrial life - called the 3rd Industrial Revolution which opened the information age. It could be said that all the chips used in almost all present day products from washing machine through CNC tool machines, telecommunication systems to space shuttles are the direct descendants of hunger for a capable simulation tool.

4 Classification of Simulation Methods

To bring better understanding of the simulation terminology and to narrow down the meaning of this term as it will be used in this paper the following distinctions should be discussed:

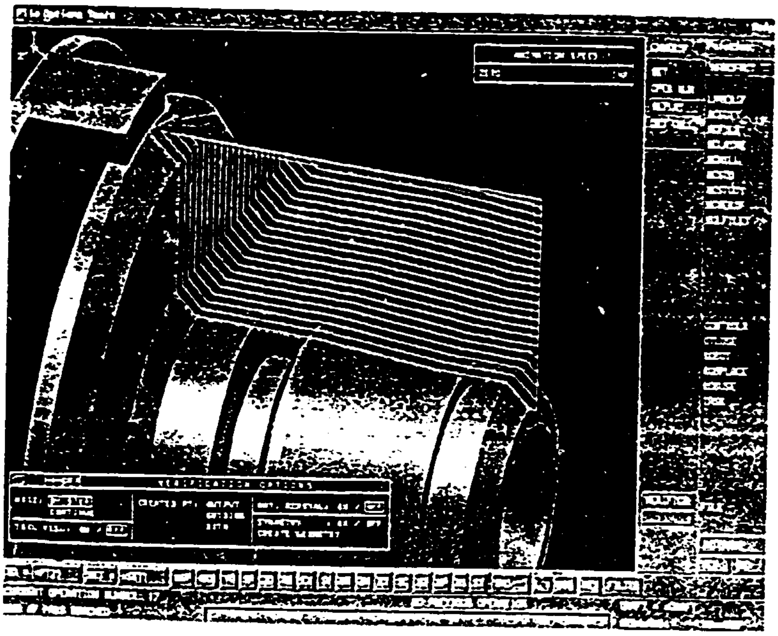
dynamic vs. static simulation
space behavior vs. logical relationships simulation
discrete vs. continuous simulation.

Dynamic simulation describes the behavior of a system of interest over time. Using this type of simulation, changes occurring in the model can be observed as they take place in different points of time. To this group belongs majority of simulation oriented solutions like flight simulators, war games, weather forecasts, robot movement, collision analysis, manufacturing processes, transportation systems, etc. Fig. 2

Source Pritsker Co. IN

Fig. 2

Static simulation describes the status of a system at a given point of time, and represents a marginal part of simulation field. For the static characteristics of this family of solutions the predicate "simulation" is seldom used. To this class of the applications belong CAD systems, urban and building planning, interior design, architectural modeling, and many similar cases, where time related behavior has no meaning for the performed analysis. Fig. 3



Source International Business Machines (IBM)

Fig.3

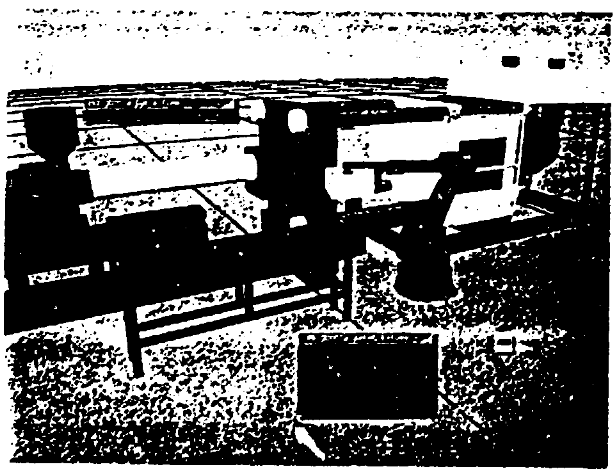


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Fig. 4

Simulation of space behavior allows examining of 3D or 2D space relationships between system elements. Time is usually used as an independent variable. Studies of space behavior can be seen as an advanced version of dynamic simulation. For the complexity of analyzed processes and required computer power, it usually deals with reduced size systems. In manufacturing this kind of simulation is represented by robot navigation, robot off-line programming, robot or transportation system collision examination, assembly animation, etc. In non manufacturing areas examples like Spacelab or Space Schuttle simulation, flight simulation, war games, weather analysis, etc. can be named. Fig. 4

Logic relationships simulation concentrates on observing mathematical, logical or causal relationships between system elements. Spacial relations between elements are usually treated as secondary issues and are not taken into account. Examples of issues being examined within this frame are material flow in manufacturing systems, transportation systems, decision games, flow charts analysis, etc.

Continuous simulation describes systems by means of sets of mathematical equations. These may be algebraic or differential, usually using time as the independent variable. It is often used for analyzing fluid-flow, hydraulics problems, ballistics, calculations of satellite orbits, description of continuous manufacturing processes (blast furnaces, petrochemical plants, etc.). Fig. 5

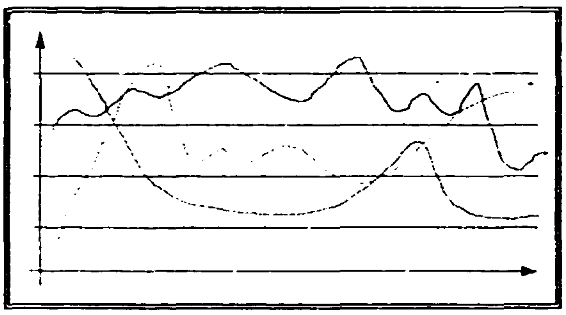

Fig 5

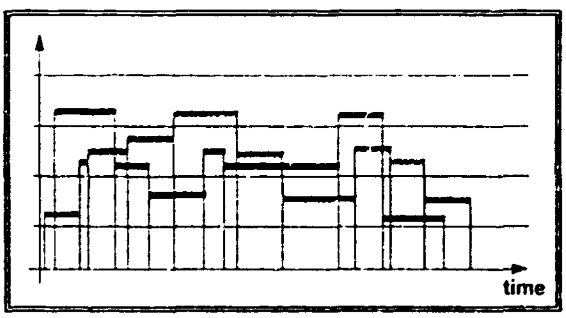

Fig. 6

Discrete-event simulation describes a system in terms of logical relationships that cause changes of state at discrete points of time rather then continuously over time. Examples of such systems are: material flow in a manufacturing system, services at the gas station, operation of the transportation networks, etc.. Discrete-event simulation assumes the lack of importance of occurrences happening between defined time points of interest. For example, examining a manufacturing systems, we like to know what happens in the system as immediately consequence of a product arrival, freeing a resource and starting an operation and are not interested in observing status (usually a constant one) between these singular events. Fig. 6

5 Simulation and the alternative methods.

Simulation is just one of many means, which can support system analyses. In general, a given system of interest can be examined by means of :

- Experimenting with the real system,
- Experimenting with the physical model of the system,
- Solving a set of mathematical equation describing the system,
- Simulating behavior of the system.

The dependencies of the available approaches are presented at the Fig. 7

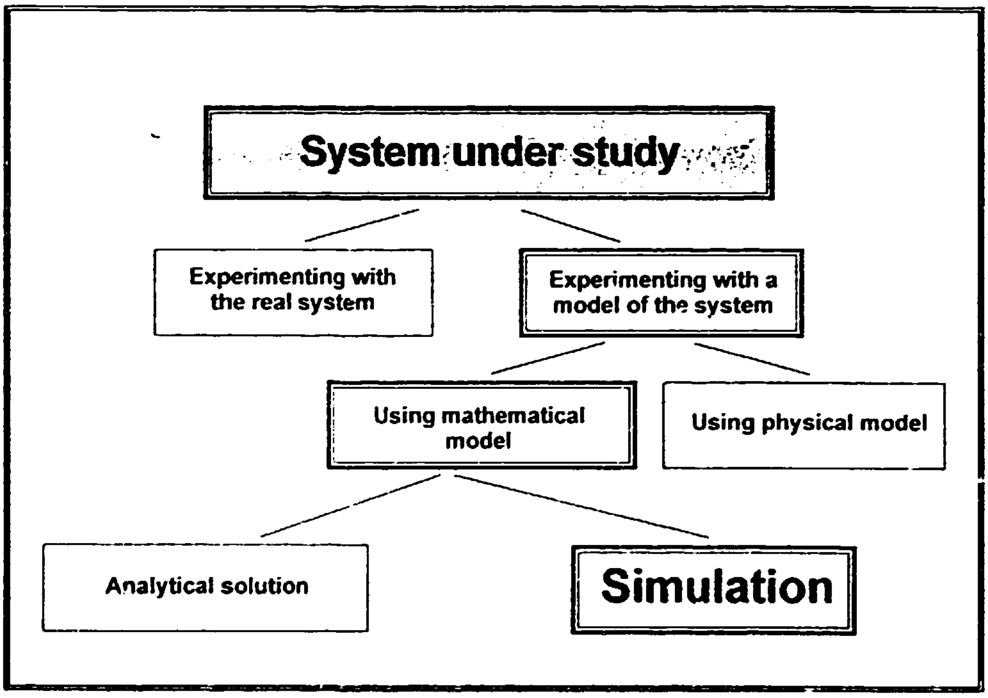

Fig.7

The simplest and the oldest method of system investigation is experimenting with the system itself. It is the natural way, but unfortunately cannot be always used. The disadvantages of using a real system will be discussed later in this chapter.

As alternative to the real system experiments, model based analysis can be employed. The behavior of the system is studied by observing the work of the model describing the whole or the part of the system of interests. The model of the system can be constructed as a physical one or as an imaginary, mathematical description of its elements. Experimenting with physical model of the system of interest is the nearest to investigating the real one. Unfortunately these method can be used just for reduced family of issues. In most of the cases building of a physical model is too expensive and too complicated and the obtained data do not exactly represent the aspects of behavior of the system of interest.

The abstract, mathematical description of the system can be realized in two ways:

Elements of the system and their behavior will be described in form of a set of mathematical equations. The observations of the dependent variables, usually as functions of time, form a base for equations design. This set of methods is often referred to as Mathematical Programming, which is the most widely used method of this family.

A computer simulation model is not based on equations set but employ other techniques to describe logical and causal relations among the systems elements. Analysis of the system behavior is performed through conducting time oriented experiments and observing status of the selected model parameters.

In the following parts of this chapter simulation and alternative methods will be compared, showing the reasons why the ranking of the simulation among the methods of system analysis is steadily growing.

5.1 Simulation vs. experimenting with the real world systems

Experimenting with the real system is the simplest and the most natural way of studying its behavior. As a matter of fact, simulation is just a mimicking or feigning of a given system. And the mimic, even the best one, stays just a mimic and can barely match the operation of the real system. Unfortunately experimenting with a real system is connected with some disadvantages that in many cases make such examination impossible, or the obtained results inapplicable. In the following, some disadvantages of real system experimenting are discussed.

The real system must exist before experiments on it can be performed, whereas the objective might be to design a system that does not yet exist. This property of real system experimenting excludes these methods explicit from problems involving planning of new or extending of existing systems. Of course, the experimenting with a system similar to the planned one could be attempted; it would be not experimenting with the real system but with just the approximation of the system, or its physical model.

The system has to be available for experimenting. Even if the system does exist and is in use, then often for economic and/or political reasons it might not be possible to interrupt its ongoing operations. This paper should concentrate on comparing simulation with its alternatives in industrial application. For this reason the classical examples like experimenting with GAU in a nuclear plant or ecological catastrophe won't be discussed. Manufacturing systems, even if they exist, are seldom accessible for full scale experimenting. It is almost unimaginable that a manufacturing line or cell would be stopped just for performing some investigations, even if these are aimed at facility or process optimization. Additionally, the lead times of manufacturing operations are usually long and in order to collect the necessary amount of data, the facility has to be out of service for at least several days or weeks. Most of the job shops are facing very tough competition and have to operate with very thin or without any security nets. Stopping manufacturing means losses, and these can be justified only when the improvements are clearly predictable.

No time scale of the experiments. Even if the real system can be used for experimentation, the lack of time scale analysis remains one of the biggest obstacles for the proper examination of the system. In many systems, especially manufacturing ones, a system must operate for days or weeks before the necessary amount of data can be collected. This reduces the number of alternatives which can be investigated, diminishing the chance of finding the optimal one. Similar problems occur when the activities in an analyzed system are too fast or too complex. It is almost impossible to properly monitor and investigate processes in manufacturing of integrated circuits, where thousands of operations take place every minute. It allows just observation of some trends but not the single events.

Unavailability of the data. Many manufacturing systems are so complicated, that defining the data which should be analyzed and preparing the instrumentation for its acquisition create problem for itself. Selecting the data and building the monitoring system take so much time and can cause such costs that there is not enough left over for the planned experimentation. Additionally, the monitoring elements can change the analyzed system so far that the obtained data can not be used for analyzing the behavior of the original one.

Real system experimenting despite its disadvantages has been used in many cases, where the proper planning and predicting of the system behavior could not be reached using any other analytical tools. In many cases the experimenting with the real system has been replaced with experimenting with its physical model. It was the way Ford built his River Rouge plants; the elements of the Fisher-Technics allow building manufacturing facilities on the desk top and connecting them with the real controlling systems; the architects are building their urban projects. Physical modeling was popular in manufacturing till 1980s and created a kind of bridge between real system experimenting and the "real" computer simulation. Computer simulation, using steady improved hardware and software platforms, became simpler and cheaper and could successfully replace almost all cases of real system or real model experimenting. At the time, real world experimenting is often used in order to obtain the data describing unique systems. This data constitute then the base for further simulation studies.

5.2 Simulation vs. Mathematical Modeling

Elegance of the method. Mathematical Modeling is a very elegant and scientific method. It allows describing a system of interests as a clean set of mathematical equations.

Generality of the solutions. Once defined a set of equations describing a system can be used for various sets of parameters describing the properties and number of elements of the system. It allows the diverse configurations of the system, as long as they are in conformity with the assumptions of the model, to be analyzed without redesigning and reprogramming the base equations.

Optimizing abilities. For the system of interest is described as a set of equations, an optimum for a given set of parameters can be easily found. Being able to generalize the sets of equations and the solutions, mathematical modeling supports finding an optimum (an absolute one) for any valid set of conditions. It allows use of mathematical modeling for answering not only simulation questions „What if...?", but also delivering solutions for „What will the best in...?" cases. This characteristic is often named as a deciding factor for employing mathematical modeling for solving various problems.

High grade of abstraction. This attribute of mathematical modeling can be as well an advantage or a disadvantage of mathematical modeling. The high grade of abstraction allows describing any of the problems through the same or just slightly modified equations. It means a high grade of flexibility of employed methods. but on the other hand is very sensitive to changes in meaning of the parameters and their dependencies. It permits that the same set of equations can be manifold interpreted, allowing drawing of false conclusions and recommending wrong solutions.

Reduced complexity of analyzed systems. Mathematical equations support a description only of a reduced set of problems. It means, that just a selected spectrum of systems can be adequately described, their behavior observed and conclusions drawn. The complex systems must be reduced to the describable and solvable ones. if they are to be analyzed by means of mathematical modeling. It is connected with the necessity of simplification of the problem and reduction of the parameters. This can often lead to inaccurate or false description and as result to wrong predictions of system behavior. Additionally a high grade of abstraction reduces the readability of the model, impeding the recognition of the syntactic and semantic errors.

Reduced ability to describe discrete systems. Our main field of interest - the manufacturing systems are mostly discrete ones. It means their behavior has to be described by unsteady functions Additionally, the dependencies between system components are also discrete and build a set of triggers for the secondary discrete processes. Such systems can be hardly precisely described using traditional continuous equation sets. The necessary assumptions and approximations lead very fast to incorrect descriptions and false results.

Low transparency and "market value" of the problem description and solutions. Mathematical modeling is a very scientific and sophisticated family of tools. The complex sets of mathematical equation very often can not be understood and interpreted without deep mathematical studies. For this reason these methods can be employed only be highly sophisticated staff of system analysts. The end user of the analysis results, mainly the manufacturing engineer, usually is not able to interpret the presented description of his problem. He can hardly cooperate in the process of model validation and experiment design. For the lack of transparency of the problem description, it is very difficult to obtain the necessary model credibility and convince the end user about the results of analysis. It also can lead to misinterpretation of the analysis goals, ways and outcomes, resulting in false conclusions and implementation of wrong measurements.

6 Advantages of Simulation

Simulation, using for investigation a computer model of system of interest combines advantages of experimenting with the real system, or its physical model, with the scientific methods of mathematical modeling. Some of the most visible advantages represented by this combination are presented below.

Investigating nonexistent systems

In simulation studies, experiments are performed using not the real system but just its model. This means that the system does not have to exist. A model can by build based just on ideas, or description of the planned system. Unlike the physical modeling, where the model can be hardly modified or "destroyed" experimentally, computer simulation allows almost unlimited extendibility and modifiability of the model. It allows relatively simple and inexpensive testing of system design, before the first steps in its realization are done. Experimenting with the imaginary system environment supports building of just imaginary system extensions, interfaces or environmental elements and events.

Realism of experiments.

Simulation, especially the one using animation, performs experiments in very realistic and easy to understand way. It presents not only the actual status of the system in form of parameter values and selected statistics but also shows in movie-similar manner reaction and interactions of the system elements. This way of analysis allows observing and understanding of processes and dependencies, which are usually not visible using numerical outputs. Easy to use results come together with the user friendly model building and experiment control elements which can be understood and used by non-mathematical professionals. It allows that the manufacturing engineers are able to take an active part in simulation study. Such cooperation results in high credibility models that can be easy validated, verified and modified even on the job shop level.

Conducting experiments in time-scale

Many experiments which are possible to carry out using real systems or processes are very often too fast or too slow to make a proper observation, data collection or analysis. A complex process in a microprocessor with millions of operations and interactions of different elements takes only milliseconds. To monitor a real manufacturing system and collect an appropriate amount of data an analyzer needs weeks or months. Time can be compressed or stretched in simulation experiments. The equivalent of milliseconds and seconds in real system time can be simulated in minutes or hours on a computer. On the other hand the equivalent of days, weeks, and months of real-system operation can be simulated in seconds, minutes or hours on a computer. Such flexible handling of time scale allows in manufacturing examining a large number of alternatives and finding an optimal one.

Total control of experiment conditions

In simulation experiments, every parameter describing a system of interest can be artificially held constant. Such "freezing" of parameter values can not be performed in a real system. This feature allows reduction of "noise data" which do not have a direct impact on the experiment results, and step by step analysis of the single correlation of the system elements. Additionally every variable, also an artificial one which does not occur in a real system but which has an impact on understanding and performance of simulation study, can be set up, monitored and collected during experiments thus improving results of the analysis.

Reproducibility of the experiment conditions

In a real or imaginary system there are two kinds of events. They are deterministic events which occur in predefined conditions and at points of time and stochastic events that occur randomly with a given or assumed distribution. Because of true randomness of events in a real system, it is almost impossible to repeat a real-world experiment with the same characteristics and conditions. In the artificial, mathematical world of simulation there are no true random values or systems. They are replaced by pseudorandom numbers that are generated using a given mathematical formula. Which means that they are repeatable. This feature, together with the previously described possibility of freezing selected parameter values, allows repeating the same experiment conditions each time focusing on different parts of the system. It improves the and support extensive analysis of complex systems or processes.

Inexpensive training tool

Since the simulation is based on feigning, mimicking of depicted systems, it can communicate with the user using language of simulated system and does not require from the user a higher level of scientific sophistication to be properly employed. This simplifies not only the training of simulationists concerned with the system analysis, but also system users working daily with the real system. The rule of wide use of simulation in military training (flight simulators, battle field war games, etc.) can be easily adopted by manufacturing. Simulation offers a huge training potential as for e.g. operating of expensive and sophisticated tool machines or other elements of manufacturing systems, working out break down strategies, planning system maintenance, product, process or order changes, etc. Powerful computers and software tools using Graphical User Interfaces, multiprocessing and high resolution graphics deliver reality-similar conditions and very often do not require other knowledge than he or she needs for handling of the real-system. This way, after a short introduction time, it is possible to replace costly training done with real-world system or processes through simulation-based training courses.

Simulation as a marketing and presentation tool

Simulation is an ideal marketing tool. It usually works using elements and terms from the system being investigated. It builds a common communication level between the system analysis and the customer. On the one hand - if the study is performed together with the client, he or she can be directly involved in the model and experiment development, his acceptance of the results can be easily gained. On the other hand, when just the results of the study are presented to him - he would be more receptive to the simulation findings than to the numerical description of the proposed system. As a result, it is much easier to sell a product or idea, when the client can quickly understand it and get involved in, than to win him showing just the flow charts, spreadsheets, 2D-drawings, etc., which always can contain some hidden errors and can not be completely trusted.

Powerful forecasting - insurance - tool

It has been estimated that comprehensive simulation studies designed to work out the characteristics of a proposed system can cost 2 percent or less of the capital outlay involved in building the system. For example, it might cost $50,000 or less for simulation studies designed to evaluate a manufacturing system involving a capital outlay of $1,000,000. In this sense, simulation provides inexpensive insurance against building systems that are underdesigned and so will not perform to specifications, or that are overdesigned and so expensively provide more capacity than needed.

7 Disadvantages of Simulation

Along with its many advantages, simulation is subject to some disadvantages. Looking at the disadvantages that can be found in all the simulation literature a little bit more carefully and meticulously, one will notice that these disadvantages are not the disadvantages of simulation enterprise alone, they are disadvantages (and pitfalls) of using any system. This chapter should be seen as a kind of polemics with "disadvantages of simulation", that can be found in the basic work on simulation "An Introduction to Simulation using GPSS/H" by T. J. Schriber, Professor and Chairman of Computer and Information Systems in the Graduate School of Business at The University of Michigan, published 1991 by John Wiley and Sons.

Failure to produce exact results

Suppose a system is composed of one or more elements that are subject to random behavior. In a hospital system, for example, the time required by a doctor to examine a patient may vary at random. The various times required by a doctor to examine patients influence the waiting-time experiences of others waiting to be examined by the doctor. When a simulation is performed with a model of the system, the values of such variables as "the time a patient spends waiting to see the doctor" are recorded by the model, and the averages of these values are given in a postsimulation report. But the average in a sample of observed waiting times only provides an estimate of the expected (or long run average) time that patients must spend waiting to see a doctor. In this sense, a simulation only provides estimates, not exact results. [Schriber - "Introduction to Simulation...", 1991]

Simulation as depiction of a given real-world system is only a feigning of behavior of that system. This means, it can be in extreme cases a very reflection of the system, but it can not be better then the system itself. If a real-world system consists of a set of random events, it can not be predictable. For example, the measurements made in hospital in month A differ from the measurements in the month B and it is impossible to make an exact prediction for month C. The randomness only of one of the system parameters is the cause of the impossibility of making an unequivocal description of the system. Without the exact depiction of the real-world system, there can not be an exact model of it and simulation producing exact data describing its behavior.

Lack of generality of results.

Simulation results apply only to the situations that were simulated and do not lend themselves to generalization. For example, suppose as it assumed in a manufacturing system, that manufacturing resources include three machines of Type A, five machines of Type B, and two machines of type C. Suppose that a simulation study is performed on this basis, and the resulting manufacturing rate is estimated. What manufacturing rate will result if there is one

less Type B machine or if one of the Type B machines is replaced with another Type C machine? The results from the simulation study already performed cannot be used to answer these questions. Instead, the model had to be modified to correspond to these changed conditions, and then simulation studies must be performed with the modified models to estimate the resulting manufacturing rates.
By the way of contract, suppose a mathematical model has been built to express in the form of an equation or equations the manufacturing rate as a function of the number of Type A, B, and C machines. This model could be evaluated quickly and easily for all combinations of Type A; B, and C machines that might be of interest. [Schriber - "Introduction to Simulation...", 1991]

Generalization in manufacturing is a very sensitive problem. Through the high complexity of manufacturing systems and manufacturing processes, a slight change in parameters can have a large impact on system performance. For example, reducing a number of machines Type A building a bottle-neck in a system can lead to manufacturing disaster, while changes in the overdimensioned Type B have a slight impact on system work. In this case the lack of generality can be seen as advantage of simulation not allowing drawing false conclusions.
Changing number and kind of resources (machines) in a previously described manufacturing system can lead to completely new manufacturing configuration and can be often complicated. Changing a model doesn't have to be so complex. Defining machines as "independent" modules, we can simply replace one through another.
Mathematical modeling can seldom describe the complexity of manufacturing systems with all the dependencies not only between the machines and other hardware systems components but also between these elements and products that have to be produced on modeled facility. Additional problems are created during description of jobs, part priorities, time dependencies and from it followed waiting queues and manufacturing sequences.

Failure to optimize

Simulation is used to answer the questions of the "what if" type, but not of the "what's the best" type. In this sense, simulation is not an optimization technique. Consider the type of manufacturing system question posed earlier: "What combination of product should we produce if the objective is to maximize profit subject to the following machine, manpower, and marketing constrains?" Simulation can be used to estimate profit that will result when a given combination of products is produced. That involves a "what if" situation. In other words: "What if we produce this combination of products? What profit will result?" But simulation cannot be used to indicate which combination of products among all feasible combinations results in the maximum profit. This would involve a "what's the best" situation. In other words, "What combination of products is best in the sense of maximizing profit?" In simulation, the only alternatives considered are those that are directly investigated. Simulation does not generate solution; it only evaluates those that have been proposed. If six alternative combinations of products are investigated, then that alternative among the six considered that maximizes profit can be identified, but it is quite possible that one or more of the alternatives not considered result in larger profits than the best of the six that are considered. [Schriber - "Introduction to Simulation...", 1991]

Simulation alone is not an optimizing tool but can be a part of an optimizing system. In our example, we are looking for optimal product combinations for a given manufacturing facility, a simulation experiment will be conducted using as input a sequence of products to be made. After the experiment, input sequence together with the output parameter like system utilization, lead times, manufacturing costs, etc., etc. are analyzed by optimizing tool. It results in generating a proposal on new product sequence for the next simulation experiment. The new experiment will be performed, and then the analysis. Such a loop consisting of simulator and analyzing (optimizing) algorithms can lead to work out at least a very good solution for the stated problem. Finding the real optimum for a usually very complicated manufacturing system is in most cases a Sisyphus task. Therefore, we would like to talk about a very good one, a reasonable, or a satisfactory solution. If the term "optimal" is used in this paper than it always carries in one of mentioned (a very good, reasonable, or satisfactory) meanings.

Long lead times.

A simulation study cannot be conducted over a weekend. Months of effort can be required to gather data; build, verify, and validate models; design experiments, and evaluate and interpret the results. A simulation effort should be started well before the results are needed. In practice, unfortunately, the results of simulation are usually needed "yesterday". A simulation study may not be authorized until the project involving the system to be simulated becomes of urgent priority, and then there may not be adequate time to complete the study before the results are needed. [Schriber - "Introduction to Simulation...", 1991]

A simulation is a long process. It uses data describing a system, builds a model of it, performs a couple of experiments and analyses the results. For building a model, simulation professionals need a data about a modeled system. In many cases, that data is not available. The companies are working, in many cases, based not on reliable data but very often on the experience and feeling of its staff. There is never time to do measurements, complete and marshai the data. The analysis of the system has to be done, logical connections and operation times have to be determined. All the data should be obtainable a long time before the simulation study begins. But usually this is not the case. Searching data becomes a part of simulation study and prolongs the lead time of the study. Another very important factor of a simulation study is the cooperation with the examined system operating staff. In many cases, supporting the simulation team is only a side job with corresponding results. It is very difficult to define a simulation goal, obtain data, and check the model with the real-system if there is not appropriate collaboration with company staff. This same problem arises during analysis of simulation results. What is important for the company, which parameters don't match the reality, etc., etc.? It is difficult to answer these questions being an outsider. The bottom line is that the long lead time is not a peculiar brand of the simulation, it is more the result of falsely prepared and conducted study on the part of supervisors of an examined company or systems.

Costs for providing a simulation capability

Establishing and maintaining a simulation capability involves making a major and ongoing commitment with concomitant personnel, software, hardware, training, and other support costs. Many smaller organizations cannot afford to maintain a simulation capability. Some organizations may have one or two people who work on simulation projects from time to time. Such people may have to be supplemented by outside consultants on occasions when simulation projects are to be conducted. Other organizations may simply contract out their occasional simulation projects to consultants or firms specializing in simulation. They will then pay a premium to have a simulation study conducted and may wind up in a position of dependency and relative inflexibility if follow-on simulation efforts are required. [Schriber - "Introduction to Simulation...", 1991]

Every small or medium sized company lives in a net of dependencies. It is very rare when a firm is really independent. There is always a net of suppliers, dealers, contractors and subcontractors. If a company wants to introduce a new product, it hires a consulting company to make a market research examining the chances the product has. Product design is often done by a specialized company which has experience in 3D-design (It's too expensive to maintain its own staff of designers with appropriate hard- and software). Marketing campaign are almost always done be external marketing specialist. The taxes and payments are supervised by external experts and lawyers. All the external companies a firm is employing to carry out jobs create a dependency relationship, and employing a consulting company for performing some simulation studies will not endanger the client situation.

Misuse of simulation.

There are many facets to a balanced, comprehensive simulation study. As a result, a person should be educated in a variety of areas (e.g., analysis of input, design of experiment, analysis of output) before becoming a simulation practitioner. This fact is sometimes ignored, however, resulting in situations in which people who only know how to build simulation models and make runs with them are cast in the role of simulation professionals, even though their education and training may not have prepared them adequately for this designation or for these responsibilities. Such people may not be in a position to conduct balanced and comprehensive simulation studies. As a result, such studies may be incorrectly performed, or may be incomplete, or may fall short in other ways, perhaps resulting in failure of the simulation effort. [Schriber - "Introduction to Simulation...", 1991]

There is a need for understanding that simulation is not a game, it is a serious tool that can have a huge impact on decisions made. People are used to employ machines, and nobody would be set up as an operator without appropriate knowledge and experience. Nobody will be hired as manager without references and researches concerning his career. Why should a simulation tool be employed by staff without corresponding knowledge? If simulation is used by wrong people there could be a disaster, but the same, or similar disaster could take place if complicated and expensive machinery is exploited by the wrong people, or when the company is directed by the wrong managers. It is not only in simulation that misuse is a disadvantage, it is a disadvantage in any system that could be used in right or wrong ways.

In conclusion, simulation is not a panacea. It offers powerful advantages, but these advantages can only be utilized through a proper employment of this tool. Simulation has its own disadvantages, as every system has. Fortunately, most of the disadvantages connected with system performance and usefulness are diminishing in importance with time, thanks to improved simulation tools, methodology, education and computer performance, and decreasing computing costs. On the other hand many of the disadvantages imputed to simulation alone, are simply shortcomings connected with false employment or the misuse of any system.

8 Simulation Application Fields

Defining the fields where various simulation based techniques are used is a complicated task. Through defining simulation as imitating, this term can be used for almost all the activities man or a system is involved in. Reading a book we imagine (simulate) in our mind the scenarios described there. Going to the movies or watching TV, we live lives of screen characters, feeling their loves, problems, stresses and thrills. Philosophically, it could be said that we are simulating our lives in a simulated world.

In technique and science the scope of simulation use is very wide and is steady growing. This expansion is caused by increasing complexity of faced problems, that can hardly be solved using other means. Additionally progress in both: hardware and software fields make simulation tools more powerful, flexible and user friendly. Table 1 presented some of the fields where simulation techniques are wide used.

1. Aerospace – military – undersea

Space system reliability
War games / Strategies
Search and rescue strategies
Space defense system
Combat vehicle training
Radar and communication
Navigation systems
Undersea vehicles
Weather
Equipment replacement policies
Armed forces recruiting strategies
Equipment distribution
Satellite positioning
Flight simulators
Ballistics and missile systems
Undersea cable development
Target localization

2. Health Care

Health care planning
Organ transplantation strategies
Disease control strategies
Hospital admissions
Diet management
Patient flow
Emergency room design
Hospital staffing
Drug interaction control policies
Blood bank management
Ambulance crew scheduling
Emergency situation planning

3. Urban-social

Emergency-response vehicle location
Traffic lights
Mass transportation systems
Air pollution control
Air traffic control
Urban development and dynamics
Garbage collection routings
Educational planning (schools, buses)
Population planning
Weather
Airport and its environment design

4. Services and communication

Fast food facilities and nets
Local Area Networks
Supermarket planning
Telephone systems
Highway toll collection
Communication networks
Airport networks
Fleet scheduling
Harbor planning
Bank teller scheduling
Facility location and environment
Parcel Service
Telephone switching
Freeway traffic

5. Politic and administration

Political redistricting
Economic condition
Portfolio management
Insurance and risk management
Labor planning
Political campaign strategies
Business games
Auditing strategies
Negotiation strategies

6. Industrial

Facility planning
Manufacturing optimizing
Repair and maintenance scheduling
Machine and tools monitoring
Quality control
Process scheduling
Inventory management
Distribution channels design
Process and product safety testing
Staff scheduling

Robots collision examination	Staff training
Off-line programming	Power plant emergency strategies
Control system design	Robot navigation
7. Product design	
Engine design	Nuclear and power plants
Computer networks	Product design
Product testing	Design adaptation
Computer and Integrated Circuit (IC) design	
8. Education and Science	
Heat and mass transfer	System dynamics
Hydraulics	Cell grow simulation
Cardiovascular systems	Genetic
Sonar systems	Isotope separation
Soil and water systems	Vibration
Chemical processes	Propulsion systems
Training	Educational simulators

Source - Budnik, McLeavey, Moyena (1988). Principles of Operation Research for Management. Richard D. Inwin. Homewood IL

Table 1.

The use of simulation is not restricted to the classes showed in Table 1. This table should just demonstrate the versatility of simulation and the possible range of applications and although suggestive, is by no means exhaustive.

9 Simulation in Manufacturing

With the growing importance of simulation in almost all the fields of the man's activities it became also an integral part of manufacturing enterprises. Four main factors could be named as reasons for such rapid grow and omnipresence of simulation based tools:

- The scope of the faced problems overgrows possibilities offered by traditional planning and analyzing tools.
- The steady growing sophistication and sinking price of the offered simulation packages and computer systems allows for access and utilization of these tools also for small and medium size companies.
- Generational changes in manufacturing created a new class of engineers not restricted to purely mechanical solutions and willing and accustomed to use computer based tools.
- The growing competitiveness forced manufacturing companies into quick, flexible and economically acceptable responses to the market changes.

As result, the following areas emerged, where simulation became an integrated part of the facility life cycle:

- Planning of the new manufacturing facilities
- Planning of the manufacturing processes
- Extending and optimizing of existing manufacturing systems
- Monitoring of the manufacturing processes
- Product design (CAD),
- Robots controlling

This study is aimed at discussing of tools for analysis of manufacturing logistics. For this reason just the first four of the above listed fields will be discussed. Computer Aided Design and robot controlling represent quite different approach to manufacturing and simulation methodology and should be presented in a distinct paper.

9.1 Simulation in facility planning

Facility planning was the first family of applications, where simulation techniques were wide employed and for which the first commercial simulation systems were developed. In facility planning the simulationist assumes that a defined set of workpieces - described through manufacturing processes and a defined demand (number of parts to be produced in a given period) is given and treated as a constant. As a goal of a simulation study, the working out of a manufacturing system layout is defined. A layout containing detailed description of machines, transport systems and their positions, tools, calendar, shifts, required staff, etc. The number of variables, a system analyst is working with, is relative small, simulation runs are usually long, and the changes of the model parameters does not require extensive user interaction. Facility planning usually takes place far from the job shop floor and is performed by people already used to working with computers and sophisticated mathematical methods. Such configuration allowed in the past a conflictless employment, initially difficult to understand and to handle simulation tools. Industrial engineers were just confronted with the results of the studies and were not directly involved in a simulation process. It caused that comfortable user interfaces were not seen as one of the most important features. The growing popularity of simulation studies caused firms to try to carry them out on their own, employing not external experts but company staff. This has brought a new breed of simulation systems, making extensive use of graphical user interfaces, animation and languages of the problems to solve. New simulation system "talks" with the analyst using his terms like shift, machine, operation, breakdown, maintenance, off-shift, etc. These communication rules are employed not only to model building and conducting of experiments. They are also applied to all the communication, optimization and analysis modules, allowing work with the simulation tools without necessity of additional theoretical studies. The concurrent developments done in hardware design allow comfortable performing of extensive simulation studies with on line data base, optimizer or external interfaces even on Personal Computers.

9.2 Simulation in process planning

The way the simulation is used in process planning is in general very similar to its application in facility planning. While in facility planning the goal is defined as working out a facility layout taking as given the processes and the manufacturing objectives; in process planning various process alternatives are analyzed assuming that the facility shape and the manufacturing objectives stay constant. This change of the perspective brought about a rapid increase in number of variable system elements (the number of parts, number of manufacturing processes, number of singular operations, etc.). Their frequent changes caused a sophisticated system interface to become an urgent necessity. The already implemented user friendly interfaces had to be extended by interfaces to data bases, MRP (MRP II) and data collection system, improving not only the handling of the experiments but also the analysis speed.

9.3 Simulation in dynamic optimizing of existing manufacturing systems

The employing of simulation tools in process planning was for sure an important step into extending the range of simulation application but was still embedded in large series manufacturing. Like in the facility planning where simulation was just used once for settle layout of analyzed manufacturing systems: process planing employed simulation once for defining suitable configuration of the manufacturing processes. Once implemented, the system of interest had been seldom reanalyzed and changed. The sluggishness of the traditional large series manufacturing caused that the changes were not only too complicated to implement but were also connected with huge expenses.

The introduction of short series manufacturing with the wide product diversity, low inventories, short lead and delivery times has also brought a new requirements and new quality in the field of simulation. The changes in product demand should cause an almost instant adaptation of the manufacturing environment. Adaptation that comprises introduction of new product, dynamic adjustment of manufacturing capacities, on-line design of new processes and manufacturing plans, etc. The traditional methods of manufacturing planning and controlling were not able to deliver appropriate solutions for that type of environmental conditions. A remedy can be found in employing the new generation of simulation based systems. The already exiting features of graphical user interfaces, animation and connection with the other manufacturing systems prepared for extensive facility and process planning could be used as a base for more dynamic and sophisticated purposes. Embedded in JIT planning and controlling system, simulation lost its independent, local character.

One of such employment of simulation methods is in intelligent schedulers, even if the word simulation is not emphasized. An intelligent scheduler takes as input the facility equipment, personnel, inventories, processes, orders, shifts, delivery terms and generate quickly and more of less automatically detailed plans for the future manufacturing. Simulation is the engine taking data from the data base, files or on-line interfaces, feeding the model, "manufacturing" the defined amounts of products, "delivering" them and analyzing the outputs. The most advanced schedulers are extended through optimizing elements. The scheduler answers not just the simple question „what if?" It combines a series of such questions into the process of finding the „which is the best?" Such schedulers do not take the predefined input data as an absolute constant. They are allowed to change them within a predefined boundaries in order to find an optimal configuration of the manufacturing conditions.

9.4 Simulation in monitoring of manufacturing processes

Simulation in general is a means which allows looking into the future and predicting consequences of predefined (scheduled or random) events. The first simulation systems delivered results of experiments in form of lists and tables, which were later extended through animation. Some of these animation modules were designed that way, that they could be used with any, not necessarily simulation originated output data. Such animation tools connected with data collection systems offers very flexible and inexpensive analysis of past manufacturing. A controlling system additionally writes out events which can be of interest to external files. These can be read by the animation module and movie-similar presentation of the past events executed. This kind of animation allows zooming of selected facility areas, repeating with various speeds the chosen situations and analyzing interconnections of just realized processes. The same tool can be also used for on-line monitoring of the facility status, building an inexpensive alternative for complicated and costly monitoring system offered by machine and control system manufacturers.

Simulation won in the last years steady growing weight in manufacturing enterprises and became an integral part of all the parts of manufacturing facility life cycle. The low price of the software and hardware, together with growing performance and user friendliness of the offered system, allowed them to be employed also in small and medium companies. The acceptance is coming slowly, but this same process could be observed in the past with introduction of NC, CNC, CAM/CAM, AGV, MRP and other computer oriented manufacturing tools. Today nobody thinks about giving them up. Conducted studies show that by the year 2000 simulation will replace spreadsheets as the analytical tool of choice for system analysis.

10 Application Examples

In this chapter, we want to show some applications where simulation has been successfully used. The case studies seldom contain detailed descriptions of the benefits reached using simulation techniques. The reasons are manifold. When the company "takes the risk" and employs simulation for solving a given problem, the same problem seldom has been approached using other methods. In such cases it is difficult to talk about comparisons and name the numbers (time, money, man power, environment, flexibility) showing the advantages of a simulation based solution. On the other hand, a typical manufacturing system is characterized by steady shortage of time and the piles of works which had to be accomplished "yesterday". In such environment the simulation team hardly gets enough time to do the "unproductive" work and prepare the analysis and comparison of the employed methods. Additionally such analyses are often not desirable. It shows the competitors which methods are used and which results are obtained, which reduces the advantages gained. It is typical, that the companies are talking openly about simulation at the introduction stage. They use external experts, discuss their situation and plans with universities. After the simulation study is completed, analyses done and the results implemented, the whole subject vanishes from the external discussion. New installations are purchased direct from the vendor, only real independent consultant are involved, and all the information connected with the simulation are treated as classified.

10.1 Final Assembly Scheduling for Automotive Engine Cooling Units

A division of a major automobile producer uses simulation tool to bridge the gap between existing planning system that provides assembly requirements in weekly buckets, as well as the operational necessity of meeting daily customer shipping requirements. The division manufactures about 75 different engine cooling units, that are assembled by a crew of 18 to 24 assemblers performing serial operations. There are typically 100 to 150 different orders in a system for given week. Missed shipment can result in assembly plant downtime, incurring costs of about $100,000 per hour. Minimal amount of finished goods inventory can be held, so a missed ship date will require the use of premium shipping modes, costing the division as much as $100,000 per month.

The simulation schedules are driven by the daily-bucketed customer shipping requirements. The task of scheduling the final assembly area is complicated by the transition of the facility form a traditional assembly line layout to a more flexible cellular assembly configuration. The original three assembly lines are being replaced with 18 assembly cells, leading to a level of complexity that requires the computer-aided decision support provided by simulation.

The primary objective is to provide scheduling decision support that allows the scheduler to produce achievable, capacity constrained schedules that:

- Meet customer requirements on ship dates;
- Minimize final assembly inventory levels;
- Maximize final assembly throughput.

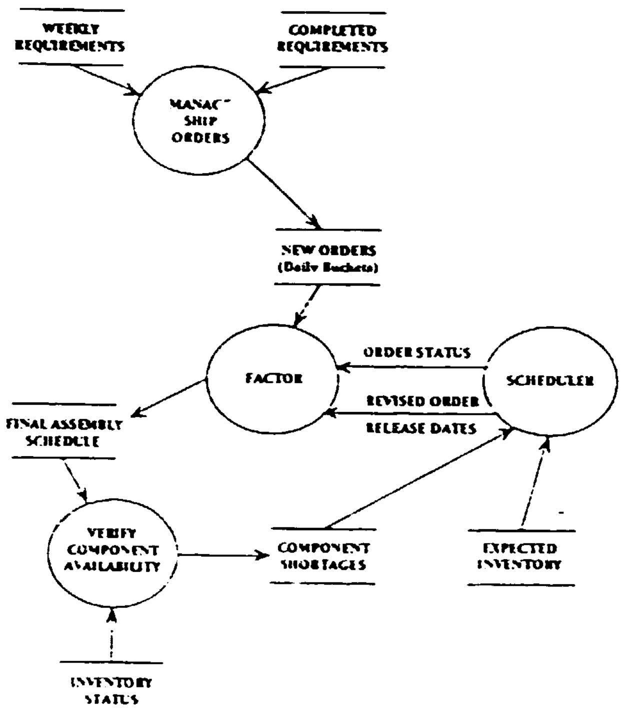

Fig.8

A simulation based scheduling system was developed to provide a sequence for each final assembly resource (cell or assembly line). The sequencing logic of the system evaluates the trade-offs between due date performance and changeover costs (as measured by the time required to make changeovers). The system captures all key constraints on assembly activities to ensure that feasibility schedules are produced. Final assembly schedules are produced with a one day (4 shift) horizon and a full week horizon for distribution to the shop floor. Reports of component part requirements for departments that supply final assembly are generated by the system as well.

Anticipated benefits from implementing a simulation based planning system include:

- Improved performance to customer ship date;
- Reduction in finished goods inventories;
- Improved communication between Manufacturing and Production Control;
- Added visibility, via simulation's "what if capability, of the impact of alternative scheduling decisions.

The final assembly schedule is run through a Bill of Materials explosion that provides a report of the components' parts (motors, screws, etc.) that are required to support the final assembly schedule. These requirements are automatically cross referenced against component inventory level to lag orders that cannon be run due to unavailability of component parts. The scheduler can then modify the FACTOR orders accordingly and re-run the should to ensure feasibility.

10.2 Printed Circuit Board Planning and Scheduling

The Circuit Center Inc. implemented the simulation based scheduling system in order to set realistic, achievable order due dates as well as to analyze the impact of premium order acceptance. Furthermore, the project allowed more effective management of order releases to the shop and provided detailed production schedules that were capacity constrained and coordinated to improve due date performance.

The manufacturer provided express services to customers by using a "launch and expedite" operating strategy. As demand grew and capacity remained relatively fixed, it became clear that improved planning and scheduling methods were required. The sales force was finding it increasingly difficult to assess the impact of accepting premium ("hot") orders. Production Control had little or no visibility of the effects of upstream sequencing decisions on downstream finishing operations, including the shipping of completed orders.

The facility operates mainly as a make-to-order shop with a small number of repeat designs, with sufficient flexibility to generate new routings as orders are accepted. The material flow overview is showed in Fig. 9

The facility consists of about 15 departments. The complexity of the boards typically manufactured at this facility ranges from to 10 to 30 operations. Almost all design work is done by the customer and supplied along with the order.

There are typically 250 open orders at any time for quantities ranging from 1 to 50 boards. The average order size is twenty boards. Average order delivery time is 5 days, but one or two day service is available at premium rates.

The simulation (scheduling) study was aimed at:

- Visualize the effects of accepting premium orders
- Predict order completion times for setting promise dates
- Produce achievable manufacturing schedules that improve performance to due date

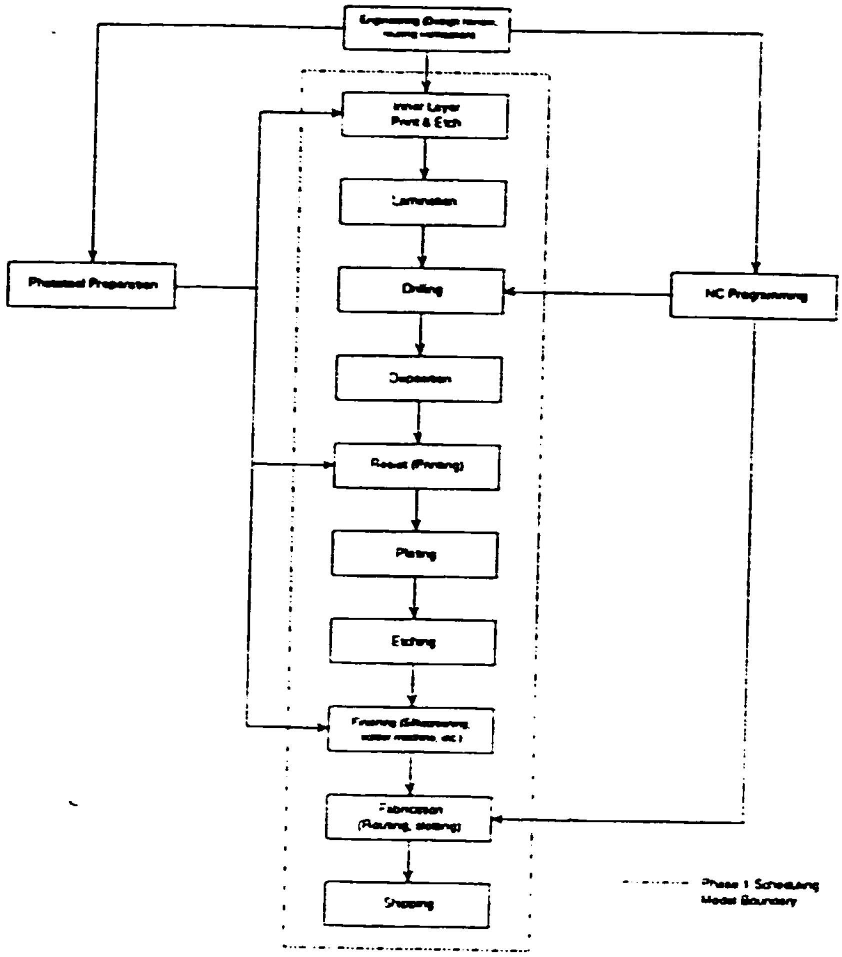

Fig. 9

The scheduling system was implemented in two steps.

First step included high-level facility model develcped for sales analysis of premium orders impact and estimation of completion date. The mode could be also used as tool for:

- Analyzing of decisions to be taken at key points,
- Generating a gross level production schedules to define the launching of new orders.

The initial model was designed as a stand alone solution, without connection with the other elements of the manufacturing system: Development and Procurement.

The second step led to build a more complex production model. This provided detailed workstation level schedules and was connected with work-in-process tracking, order entry and other systems developed and integrated during the first step of the scheduling system design.

10.3 Short term capacity planning in a paper plant

One of the major producer of paper products manufacturer suffered from a lack of planning and communication as a result of geographically distributed yet interdependent operations. The manufacturer is divided among three facilities, or mills separated by as much as 160 km. Each of the three mills has unique production capabilities required by orders originating at another mill. The company produces several product lines, each with a variety of specific products. The company is largely "make-to-order", with some "make-to-stock" to shorten lead times during high seasonal demand.

An order begins with a base paper which is coated, embossed, topcoated or printed, and the sheeted or slit. Order sizes vary from only a few hundred meters to tens of thousands of meters. An order requires only a few hours of machine time, but has a lead time of two to four weeks. There are 100 to 1500 orders in the system at any time.

Because of the physical separations, each facility had little warning of what demand other facilities had for its resources. This lack of visibility often resulted in the need for overtime or premium labor. The typical response was to carry work-in-process inventory to shorten the apparent lead time for a product, making it easier to satisfy the customer due date.

To solve these problems arousing in the company a scheduling system should be developed and implemented which was aimed at:

- Improving on-time delivery.
- Limiting work-in-process inventories.
- Reducing premium labor.

The employed system (FACTOR) performed short-term capacity planning. It captures the constrains of three mills, illustrating the effects a decision at one mill has on the other two mills and on the company as a whole. A report from FACTOR showing the expected utilization for each work center is also available helping to identify potential capacity problems.

The FACTOR scheduling system produces a schedule for each workcenter in the three facilities. The schedules show only start and end dates for each order in the system: to encourage "real-time" sequencing, no times are listed. The scheduling personnel in each facility are responsible for providing feedback to a central FACTOR analyst who incorporates their decision in the FACTOR model. Through this process, the demand across facilities is communicated and priorities and responses are negotiated. Scheduler is integrated with an MRP system which provides production routings, new orders and in-process order status. FACTOR schedules are distributed to the shop floor and are used as a list of jobs which must be completed each day. Within a department, however, the supervisor has flexibility to sequence the order as necessary, providing the day's demand is satisfied.

Through implementing of simulation based scheduler the following benefits were gained:

- Better performance to due date, resulting in improved customer satisfaction.
- Improved communication among the mills, reducing the need to expedite late orders and requiring less premium labor.

- Visibility of the impact of work-in-process inventory levels on due date performance and utilization. Reducing inventory results in lower carrying costs and shorter lead times.
- Day to day shift of operational focus from "local optimums" to more global, company wide objectives.
- Increased discipline regarding management of capacity, without the loss of flexibility needed to respond to changes in the production environment.
- Added visibility and communication which help to keep "hot" orders from getting overlooked.

10.4 Analysis of Robotic Palletizing Alternatives

A customer, being one of the major consumer products manufacturers, needed to choose a robotic palletizing system for one of their warehouses. The required system is presented in the Fig. 10.

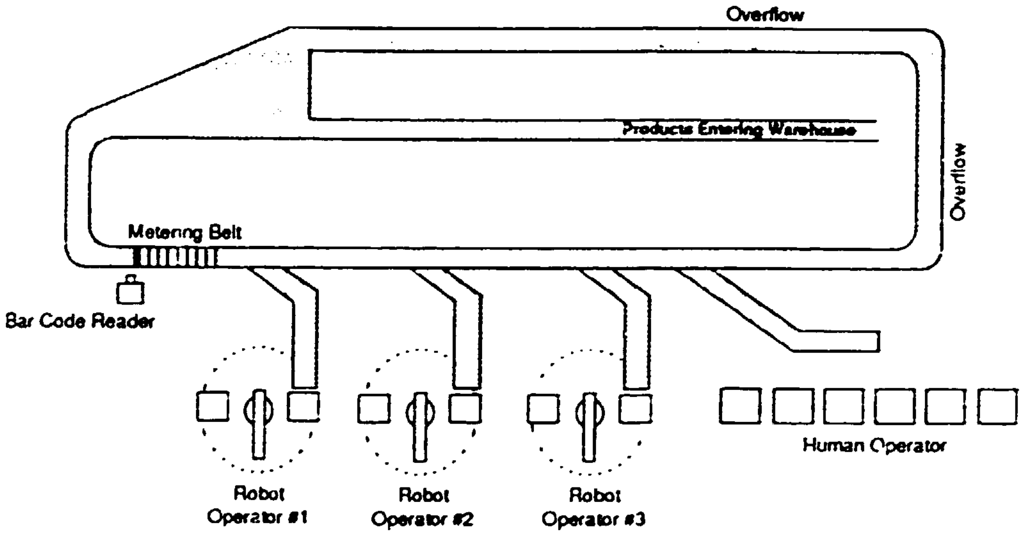

Fig. 10

Cases of the product enter the warehouse on a conveyor. Up to twelve different products may be present on the conveyor at any one time. The cases are spaced out evenly by the metering belt and then are palletized by the operator at the appropriate pallet cell. If space is not available at the required storage spur, the case will circle around on the conveying loop for another attempt. Once a pallet has been filled completely, it is either conveyed automatically from the cell or removed by fork list truck and taken to storage.

The system was required to handle a recent increase in production while meeting cost guidelines. The company management arrives at three alternative configurations, from three different robot vendors, and chose simulation to help decide among the systems.

The performed study had three main objectives:

- Evaluating the ability of each system to service the design load condition
- Using the model to fine tuning several of the system parameters
- Determining the material handling limits of each design.

The SLAM II model showed that configuration with three robots and one human operator would meet both production and cost requirements. A cost ceiling dictated that one human operator be used along with three robots instead of implementing a four robot system.

The model was also successful in fine-tuning system parameters such a robot cycle times, palletizing strategies, and case diversion logic. Because of the initial success of the model, it was used for further analysis of the system parameters and logic.

10.5 Total capacity management using simulation at Pratt & Whitney

In a project at Pratt & Whitney, a compressor blade manufacturing area which makes more than 50 parts was scheduled using simulation system. The area consists of a cropper, 6 extruder lines, 9 forge lines, 7 broachers and other stations that perform intermediate operations, such as machining, heat treat, and surface finishing. Material handling and storage is accomplished through integrated AS/RS and AGV systems. Altogether, the process includes 15 operations, with a manufacturing lead time of 8 to 12 weeks.

The broach is the bottleneck operation; its setup takes from 1 day to 2 weeks and is a key consideration in production planning. Lots for the broach are typically sized at 10.000; whereas lots for the extrude and forge operations typically run around 2,000 to 2,500. The smaller lot sizes are designed to reduce inventory levels, while insuring the bottleneck operation has materials when needed.

The objective of the scheduling project were:

- Automation of routine scheduling decisions;
- "What if" capabilities to evaluate scheduling decision alternatives;
- Extend the scheduling horizon for manufacturing support organizations, tooling in particular;
- Provide a capacity to evaluate reactions to unplanned events;
- Provide a single coordinated schedule of all departments.

Tooling was one of the manufacturing areas largest problems. Even though large tool inventory was carried, tool related production interrupts (wrong tools on hand) were experienced. Part of the long-range strategy is to provide sufficient forward visibility in the production schedule to support tool planning and scheduling. Purchased and fabricated tooling have lead times ranging from one week (expedited) to 6 months. In addition, forward visibility could benefit material purchasing since titanium stock lead time is about 16 weeks.

The blade area scheduling strategy used a combination of manual and computer-based step. Each quarter, a schedule is manually developed for the broach, based on orders form the corporate MRP system. The plan horizon is 18 months, and accounts for part sequences and setups. From this, 18 month cropper release schedule is manually prepared, using appropriate setback.

The simulation based scheduling system is used to develop a 30 day schedule for the remaining operations. Scheduling for the two forge and two extrude operations required the consideration of a large number of capacity and operation constraints, and involved logic relations to intelligently sequence operation and plan changeovers.

The 30 day schedule is regenerated daily, using current status information from a CIM data base. Production Control reviews the schedule to ensure tool availability and makes changes as appropriate. The schedule is then reviewed at the daily production meeting where further revisions may be made. Once accepted, the schedule is released to the production floor. Further adjustments are made manually. Simulation based scheduling system incorporates these decisions in the next run. The 30 day schedule provides information to expedite needed tools within the 30 day window.

The next step is to expand the model-based 30 day schedule into the Disk Manufacturing and Experimental Blade area and work out a generator for 18 month broad schedule.

10.6 Validation of Assembly Plan Design

The automobile manufacturer was preparing to retool one of its assembly plants for a new type of car. Design engineers were preparing bid packages for equipment vendors and needed to validate the proposed assembly conveyor system.

The simulation study addressed three specific questions:

- Can the proposed conveyor systems support the production objectives?
- Could any excess conveyor capacity be eliminated?
- What production rates were required for key assembly operations to meet production objectives?

The simulation model identified that, in order to meet the goal of 72 jobs per hour, part of the conveyor system would need to be increased. These increases were necessary to cover operations during breakdowns. The model also showed that other accumulation buffers were over-designed to cover operations breakdowns.

The simulation model showed that modifications to a proposed conveyor system for a redesigned body shop were required to meet the shop's' target production goal. the analysis also identified an excess number of carriers in the system. By eliminating these carriers alone approximately $225.000 could be saved.

10.7 Analysis of semiconductor wafer fabrication facility

Simulation has been used to solve problems in a large semiconductor wafer fabrication facility. Due to the high level of complexity in the manufacturing process, an accurate method did not exist to identify capacity constrains in advance to their occurrence. Also, when bottlenecks occurred there was no method of accurately analyzing the problem and identifying the most cost effective solution. Many times, very expensive equipment (>$1,000,000) would be purchased to solve a capacity problem. Because the proper tools were not available to properly analyze the cause of the problem, decisions were made on very limited information. Many times, the equipment that was purchased would not solve the problem.

To solve these problems a simulation tool was implemented. It provides a productive way to analyze the various areas within the wafer fabrication facility. With the use of it, production personnel can now:

- Predict production performance relative to expected demands;
- Test the results of decisions (i.e. equipment purchase) before committing capital and resources.

With the help of simulation, highly accurate, complex production flow analysis is completed in a matter of minutes. bottlenecks are identified and "what if" analysis is performed to identify the most cost effective solution.

The simulation tool implementation has provided the manufacturer the visibility and accuracy to make better decisions involving capacity planning and short interval scheduling and sequencing. Large cost saving have been realized due to the cost avoidance of several very expensive pieces of equipment. Several bottlenecks were minimized due to the ability to:

- Identify potential problems in advance and
- Test the result of a proposed solution before committing capital and resources.

The implementation of simulation tool has resulted in:

- Increased production throughput
- Decreased capital expenditures
- Improved resource utilization

Simulation is being used to help a large semiconductor manufacturer reduce costs by providing the ability to identify capacity constraints and test proposed solutions before committing capital and resources. Simulation model has been integrated to Consilium's COMETS to provide on-demand analysis. The model is currently being extended to provide daily production schedules.

10.8 Consolidating production sites of Fortune 500 company

A Fortune 500 manufacturer wanted to consolidate production from multiple sites into one optimized facility. The existing sites processed 300 different product types, each in various packaging configurations. Major consolidation issues revolved around feasibility design and scheduling questions. Could all the products be run on this same site? Which packaging lines could be configured to run from which processing operations? Could lines be staffed to satisfy demand without building up excessive inventories? To address these issues the company, together with a consulting partner built „Extend+Manufacturing" based models incorporating:

- Hierarchical submodels which could be connected in various configurations to evaluate total operations. This approach allowed the modelers to quickly explore alternative configurations at the system level without having to access the lower level details.

- Control logic that determined material movement after querying the database of materials and equipment information. Specific aspects of a product (such a moisture content) of equipment (such as tank cleaning time) were integral to how the product would be run.

- A custom build scheduling module for quick preparation of sequences of product runs. This provided a means to apply heuristic which sorted and arranged the product runs to satisfy demand, minimize changeovers, and achieve smooth loading across weeks. The data for the schedule was read from an Excel file and was used to drive the simulation. Separate schedules determined crewing levels and calculated utilization, idle time and overtime.

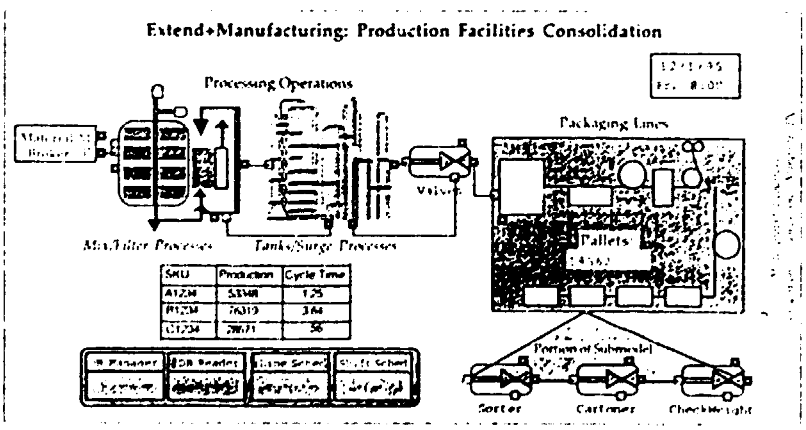

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Fig 11

Apart from promoting confidence in the consolidation strategy, the simulations determined the optimum buffer size between processing and packaging for each production line and convinced the company that the crewing schedules envisioned prior to the simulation study were unrealistic. In addition, the company avoided unnecessary and overly expensive production line changes. For example, the models were used to determine a better layout after one configuration was shown to cause severe long-term quality problems requiring a $4 million retrofit.

Based on the success of this project, modelers at the consolidated plant are now also modeling supply operations and the company has adapted the model for use in other plants worldwide. Scheduling portion of the model continues to be used for crewing allocations for this and similar operations. The „Extend" graphical user interface allows modified models to be used for training crew in the production and packaging areas.

11 Simulation for developing countries

Developing countries posses the international majority in human and natural resources. For various reasons their economies rely mostly on selling raw materials and importing industrial good. The changes in demand/supply trade-off resulting from growing inventories, application of substitutive materials, new material saving processing techniques, and the emerging of new suppliers cause a steady decrease in capital earned. At the same time expenditures connected with growing needs and increasing prices for industrial products bring about substantial expansion of expenditures. To stop this development some steps into extending local manufacturing capacities have to be done. It would add value to the exported domestic products and cut down import quotas. Additionally, a trend to wider openness of international markets offers new emerging economies many chances. They have, even if it is not visible at the first glance, a lot of advantages.

- The natural resources, which presently are exported, are available and cheaper than in other countries.
- The domestic demand for industrial products is steady growing,
- The labor costs are usually lower then in developed countries.
- The education level is usually high enough to set and run various enterprises.

These advantages are also recognized by international companies, that are likely to cooperate with the local enterprises and authorities to utilize the existing potential. Such partnerships bring necessary means like capital, technology, machinery, organization, experience, distribution channels, etc. But the presence of multinational companies brings not only opportunities. They also bring competition. Local companies, if they want to stay on the surface have to cope not only with the new products but also with the new economical conditions created by the opening of the market. They have to:

- Produce in short series,
- Manufacture a wide variety of product types and variants,
- Produce with short lead and delivery times,
- Offer lower prices than the large series manufacturers,
- Flexibly extend and reduce manufacturing capacities in accordance with the market situation,
- Flexibly extend the product palette
- Take additional order and carry them out within a reasonable time and price frame.

The best will be rewarded not only by domestic sales, but also by delivering to the world markets.

In addition to the above listed advantages that the new emerging economies have, they can also make use of each others very valuable assets. They can learn from the mistakes made over time in other countries and companies. They do not have to go through loop of sequences - „build, try, fail, analyze". They can just pick up the simplest and most effective way worked out and employed all over the world. To find new ways, simulation can be employed. The last years have brought a huge advance in this area. New high sophisticated hardware and software platforms and tool have been developed and disseminated. What is still to be done? Appropriate tools have to be selected, the necessary training conducted and the created capabilities employed. This process should be supported by institutions and organizations taking care of overall country development programs. It includes government sponsored chambers, professional societies, universities, research centers, and others together with and international organizations like UNIDO, UNDP, or World Bank.

In the next few years simulation is expected to be omnipotent in almost every process and development, saving time, money and resources. This insemination should take place not only in world giants like General Motors, Ford, IBM or Siemens but also in small and middle size enterprise all over the world as a planning, monitoring, controlling and optimizing tool.

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