# IMPROVING MANUFACTURING OPERATIONS THROUGH COMPUTER SIMULATION:

## *A DOWN-TO-EARTH APPROACH*

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**ABSTRACT**

Computer simulation of discrete manufacturing operations has gained wide acceptance among large manufacturing companies. Its use as a tool to help in the design of new facilities and improvement of existing installations has been well documented. However, many companies have been hesitant to view computer simulation as anything more than an exotic technology that "wouldn't have any use in our shop." This paper describes an approach to using simulation as a continuous improvement tool in the "real world" of manufacturing where resources and time are in short supply. A detailed discussion of this simplified approach to the use of factory simulation and its benefits is presented. Several examples of actual implementation are discussed in detail, along with results and financial outcome. Finally, a plan of action is given for those manufacturing concerns that want to investigate factory simulation for their own operations.

**IT'S ROUGH OUT THERE, FOLKS**

For those of you in manufacturing, how many have scratched your heads while trying to answer questions like these?

> ***"Will I have enough capacity in that machining cell to handle the increased sales?"***
>
> ***"I know that the processing area is not as productive as it could be, but how can I improve it?"***
>
> ***"The new owners insisted that we improve our process efficiencies by 20% or else! How in the world do they expect us to do that?"***

Sound familiar? No one who is engaged in manufacturing for a living is going to deny this simple fact: in today's Global Economy, ***manufacturing is a tough business, and it's going to get tougher in the future.***

We are all under pressure to keep our customers delighted, or someone else will steal them from us, right? These days that usually means ***increasing*** quality levels and ***decreasing*** prices. To get those prices down, we must reduce our manufacturing costs. This takes the form of reducing our cycle times and Work-In-Process (WIP) levels, increasing our process efficiencies and yields, and decreasing our scrap rates and direct labor content. This is what ***continuous improvement*** is all about, and manufacturers who fail to embrace this philosophy are destined to be left in the dust of those who do.

A very effective tool in this ongoing battle of continuous improvement of manufacturing operations is computer simulation. Most articles on simulation that extol the benefits of simulation usually deal with the implementation or retrofit of entire factories. This usually is the domain of the large manufacturing organizations. This article is written for the vast majority of manufacturers, the 98.5 percent of the U.S. manufacturing base, companies with 500 employees or less, representing 63 percent of the nation's work force.[1] Here we will attempt to put the power of computer simulation into the hands of America's greatest asset, the small manufacturer.

## LET'S BE DEFINITIVE ABOUT THIS

But first, let's have a quick discussion: what, exactly, is computer simulation? Here are some of the best interpretations given by the industry:

> ***"A process involving the imitation of a real world system, through the application of models. These models may be simple, analytical assumptions, or complex, computer based systems."*** [2]

> ***"Simulation involves the modeling of a process or system in such a way that the model mimics the response of the actual system to events that take place over time."*** [3]

> ***"The process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of a system and/or evaluating various strategies for the operation of the system."*** [4]

These are all excellent views on the nature of simulation. Perhaps an example of the process of simulating a system will provide an even better understanding.

Computer simulation involves using a software package to model a manufacturing process or system. In its simplest form, computer simulation can be broken down into the simulation system structure shown in **Figure 1.**

OK, now how can a simulation project like this actually be conducted? Let's build a model. First, we need to analyze our manufacturing system and collect data. For our purposes, a very simple manufacturing system with some of its associated data could look like **Figure 2.**

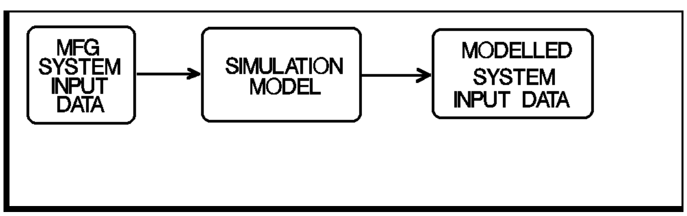


***Figure 1: Simulation Structure***

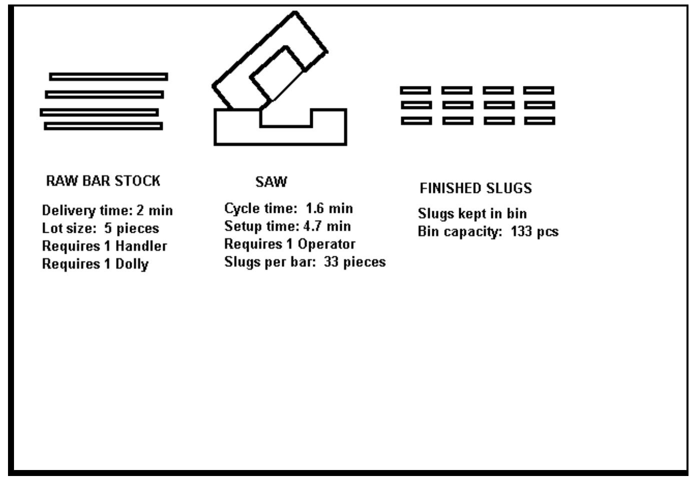


***Figure 2: Simple Manufacturing System***

Now that we have the data, what can we do with it? A model must be built and the data input to the model. From the model we obtain output data that can be interpreted. But how is a model built? We must use a computer simulation program to build the model. There are generally two types of computer programs that can be used to conduct simulations. These are ***languages*** and ***simulators.***

## LANGUAGES

Consider the simple system shown in **Figure 2.** Suppose we develop an imaginary simulation language, but one that is made up of elements of real simulation languages on the market today. Then a simulation model written in this imaginary language for this simple system may look something like that in **Figure 3.**

```
BAR_BUFFER:
        CREATE:  5 bar TO bar_buffer
        GET:  dolly
        GET:  handler
        MOVE:  bar TO saw WITH TIME = 2
        RELEASE:  handler
        RELEASE:  dolly
SAW:
        GET:  saw
        GET:  operator
        DELAY:  setup_time
        DESTROY:  bar
                IF:  slug_count = 33
                THEN:
                        DELAY:  saw_cycle_time
                        CREATE:  slug TO saw
                        MOVE:  1 slug TO
slug_buffer
                        REPEAT
                ELSE:  END_IF
        RELEASE:  saw
        RELEASE:  operator
SLUG_BUFFER:
        IF slug_count = 120
                THEN:  END
        ELSE:  CONTINUE
```

***Figure 3:  Typical Simulation Programming***

A simulation programming language allows the user to "build" a model of a real world system.  Specifically developed programming  functions or "constructs" allow the user to accurately depict events such as cycle time delays, material movements from location to location, and part creation.  More sophisticated constructs allow users to depict events such as machine breakdowns (based on Mean Time Between Failure data), shift changes, scheduled maintenance shutdowns, and complicated part routings, among others.

The languages allow ***operations statistics*** such as throughputs, efficiencies, and actual cycle times to be calculated as the simulation runs through its computations.  These outputs can be analyzed by the manufacturing engineer to provide insight on how the workcell design is going to behave.

Programming languages require a certain amount of programming expertise and data gathering skill for effective modelling.  On the other hand, the "general purpose" nature of most simulation languages allow the user to build models for very complicated systems of all types.  Models can be written to mimic the behavior of almost anything, from entire factories to fast food restaurants, from telephone switching systems to hospitals.

**(Languages have been overtaken by Simulators due to advances in computer technology. *Author, Oct-2001*)**

**SIMULATORS**

A "graphical" simulation package (commonly called a "simulator" in the industry) is a powerful simulation tool while also being more user friendly.  The price the user pays for this ease of use is the reduced modelling scope.  That is, instead of being general purpose, its capabilities may be best suited for traditional manufacturing operations providing ready-to-use programming constructs such as conveyors, robots, and the like.  It allows the user to graphically represent the manufacturing system using icons or other graphical entities created on the computer's monitor.  These entities would be the machines, people, parts, and so forth,  that make up the system.  These graphical representations could be as simple as that shown in **Figure 2** or highly realistic and three-dimensional "pictures."  Menus are typically provided to accommodate simple entry of system data (cycle times, etc.) that describe the behavior of the system.  Just as in the use of simulation languages, the simulators can calculate and output almost any system operation statistic the user requires for analysis.  This output information provides the user with important clues about the behavior of the system under study.

**OUTPUT**

So, what is done with the output information?  The manufacturing engineer uses the output information to determine if the system as designed will achieve its goals.  If a manufacturing cell requires a certain throughput to achieve sales requirements, then the engineer will be able to determine this from the output data.  The real beauty of this approach is the engineer can change the design ***in the computer*** and try it again if it doesn't work the first time.  Or second, third, or seventeenth time, for that matter.

As an illustration of this idea, we can use the example of a designer working with the tool shop to build a machine element.  Maybe the designer designed the part properly the first time and maybe not.  The machinist takes the drawings for the part and makes it.  During the initial attempt to assemble the part, it is discovered that the part doesn't fit.  So, back to the drawing board, back to the machinist, and back to the assembly area for fit up again.  The advent of Computer Aided Design (CAD) and sophisticated solid modeling software and powerful desktop computers have gone a long way toward eliminating this expensive and repetitive process.  Manufacturing simulation software, used in the design and setup of manufacturing systems, is a direct parallel to this.

**THE RIGHT TOOL FOR THE RIGHT JOB: BENEFITS OF USING SIMULATION IN SYSTEM DESIGN**

The greatest benefits from using simulation software to improve a manufacturing operation are the same as the selling points of financial spreadsheet software: it allows the user to construct models and do "what-if?" scenarios with little risk.

The manufacturing engineer would be able to answer questions like:

***Could we make our production schedule if we had three lathes instead of two?***

***What is the capacity of the assembly line?***

***How can the cycle time be reduced?***

***Which machines are going to be under-utilized in the new cell layout?***

***Should I buy the expensive automation or can I achieve my capacity using manual labor?***

Simulation can be used to provide data for feasibility studies. It can be used to optimize a manufacturing system design before anything is built. For example, how many machines (and of what type) should be used to produce our products?

Some of the disadvantages are that simulation packages sometimes impose a relatively steep learning curve. A substantial investment is usually required to get started, as is keeping an "expert" on staff who can remain familiar with the skills required to conduct the simulations. Certain data gathering and Manufacturing Engineering skills are required to be effective. For the small manufacturer, these are usually not luxuries that they can afford, and the most cost effective route to obtain these services is through consultants.

**THE "DOWN-TO-EARTH" APPROACH**

Using the techniques outlined in this paper, simulation can be effectively utilized by manufacturing organizations as a system design tool and a continuous improvement tool. The author's experience has shown that if these techniques are applied consistently, then they can be cost-beneficial to the organization.

In almost every problem situation, the problem has a variety of causes. However, there is usually only one cause which contributes the majority of effect to the problem. This concept is an application of the Pareto Principle, sometimes likened to the "80-20" concept. **Figure 4** illustrates this intuitive idea. The fundamental thought of this figure is that the ***majority of the problem effects*** are a result of a ***minority of the problem causes.*** The simulation techniques outlined here take advantage of this concept.

This philosophy is the basis for this "down-to-earth" approach to using computer simulation. In the hustle and bustle of the real world of manufacturing, manufacturing engineers don't have the time or resources to eliminate all of the contributors to problems immediately. Therefore, time could best be spent going after the ***majority*** of the problem, then moving on to "fight some other fire."

In today's manufacturing world, it is rare that a manufacturing engineer gets enough time or resources to achieve the "optimum" solution to the problem. Keep in mind that this approach does not try to trivialize the engineering process. The results achieved through application of the "down to earth" approach are still attained by hard and rigorous data collection and engineering analysis of the results. In the real world of profit and loss and limited resources, it isn't always necessary to be ***100% optimal*** in your solutions.

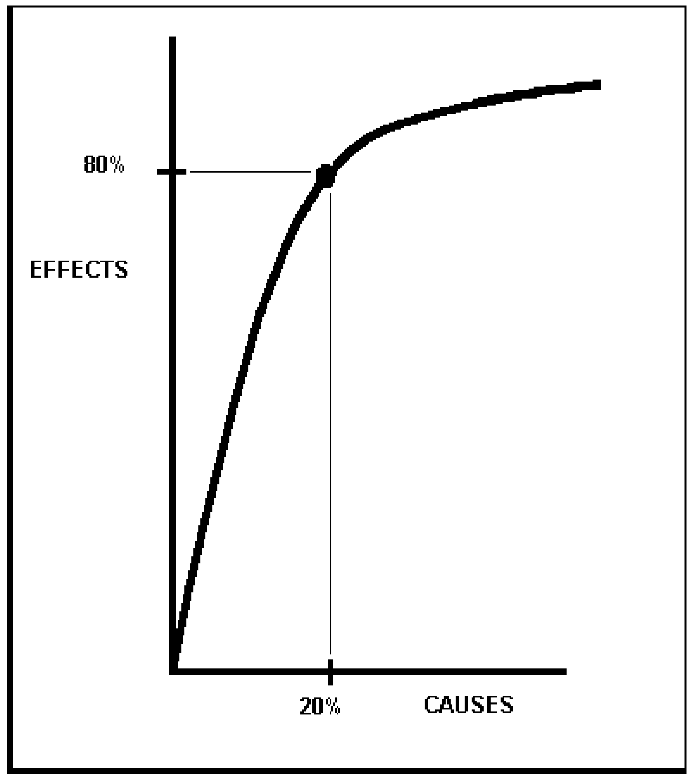


***Figure 4: "80-20" or Pareto Relationship***

**"DOWN-TO-EARTH" TECHNIQUES**

This technique is powerful in its simplicity. How do we go about applying it to the manufacturing problems that are faced everyday? The typical "down to earth" approach can be broken down into four simple steps.

***Step 1. Identify the real problem.***

This is usually the hardest part of the task, but is also the most critical. It is not always a trivial task to identify what the real problem is in a manufacturing system. To borrow the philosophy of our friend Mr. Deming, if the manufacturing engineer spends all of his effort on the wrong problem, then the effort is wasted. Generally, this step is usually carried out by trying to qualify the symptoms of the problem. Using the simplified approach, the manufacturing engineer should look for these typical ***symptoms***:

- production bottlenecks
- unacceptable WIP levels
- under- or over-utilized machines and operators
- unacceptable standard costs
- unacceptable cycle times

***Step 2. Identify the main causes of the problem.***

The manufacturing engineer will be required to collect data and conduct an analysis in this step. To identify the main cause or causes of the problem at hand, the manufacturing engineer may be required to use sophisticated problem identification techniques such as Design Of Experiments (DOE) methods. For a simplified analysis, the engineer can usually start with the production criteria which are the easiest to recognize:

- ***Production throughputs***. It is usually the goal to maximize this for the system under study.
- ***Lot sizes.*** The parts being manufactured may arrive at the cell or at each station in lot sizes that would best benefit the system operation. If the manufacturing engineer is allowed to change these criteria, then he must determine what the best quantity will be.
- ***Number of machines or operators.*** This will directly affect the systems throughput.
- ***Buffer lengths*** between stations. This is an indication of WIP, which means money being wasted if there is an excess. However, it must be properly sized to achieve maximum system throughput.
- ***Utilizations*** for machines and operators. A "down-to-earth" approach for this is to design for 80% to 90% utilizations. Any less, and the resources are being wasted. Any more, and the system can't respond to surges or fluctuations in the product flow or breakdowns.

Here is where we employ the Pareto Principle. The manufacturing engineer builds a simulation model of the system under scrutiny. A small number of the ***controllable criteria*** that drive the cell are selected. A "sensitivity analysis" is performed to determine how sensitive the overall system performance is when certain criteria are varied. Once the sensitive criteria are determined, the system is designed to exploit them. For example, assume cell throughput is directly affected by lot size of assemblies arriving at the cell. The behavior of the cell can be examined using simulation for many different values of lot size. These results can be plotted to determine a "resonance point" where the cell dynamics produce the greatest throughput. **Figure 5** illustrates this concept.

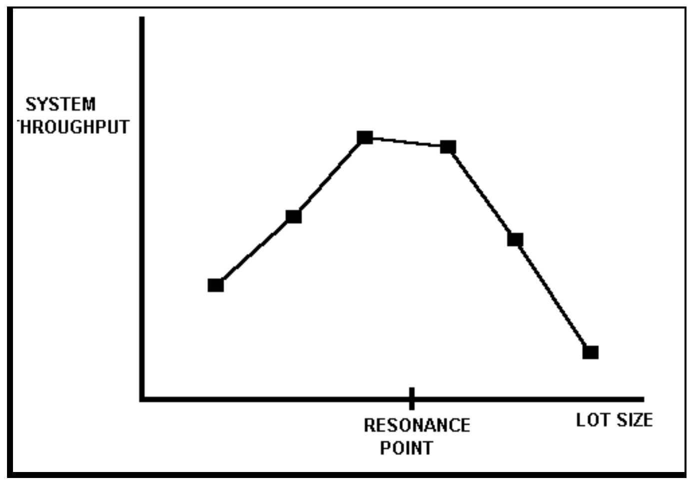


***Figure 5: System Resonance Concept***

***Step 3. Propose solutions to fix the problems or relieve symptoms.***

This is where the manufacturing engineer can draw on his education, training, experience, and creativity to generate possible solutions to his problem. The task at hand is to simulate the proposals to determine the one which best suits the goals. Care must be taken, however, to avoid the trap of chasing symptoms without identifying the problem. Remember to pursue the ***majority contributor***. Some typical results of using this step would are:

- cycle time reduction
- queue length modifications
- packaging multiples
- more or less machines and people
- higher throughput
- material handling changes
- addition of improved fixturing & automation
- change of current procedures
- move operations for line balancing
- component redesign or elimination

***Step 4. Implementation.***

This step usually entails getting project approvals, funding, and the like. Each organization has its own procedures. But then the fun really begins. A wonderful opportunity is presented here. We can now go and implement the system that, to this point, has only been a design in a computer. ***Good luck!***

## CASE HISTORIES

As the old saying goes, "The proof of the pudding is in the tasting." Our pudding is four case histories of how this "down to earth" approach has been used to improve different types of manufacturing operations.

## DESIGN OF FLEXIBLE ELECTRONIC ASSEMBLY LINE

The management of a large electronics company wanted to update its manufacturing system. Its existing printed circuit board fabrication facility was a large area of standalone component placement machines with most material handling done by hand. Management recognized that the facility required excessive WIP, lots of hand assembly, and slow cycle times. Management wanted to convert this to a fully automated, flexible manufacturing facility with full integration of machine control, communications, and material handling.

A team was set up to pursue the system design. The team started discovering problem areas early in the project. Budgetary quotations proved unacceptable to management. The team discovered that the system was going to require the flexibility to handle over 300 separate printed circuit board designs. The team used simulation to determine the feasibility of this project.

The simulation results showed the following:

- With over 300 separate designs, there was too much product variation to totally convert the existing system to a fully automated flexible manufacturing system that still was within budget.
- The desired system could not produce the desired throughput and remain within budgetary limits.
- Areas of concern came into focus: system complexity, material handling requirements, and heavy floor space demands required by additional equipment.

The application of the "down-to-earth" techniques provided a timely response to the managements request. The company management decided that it was not wise to commit the large amount of investment funds that would be required for a project of this scope, especially when it had such a high risk of failure. Instead, the resources were redirected to the design and implementation of a new Surface Mount Technology (SMT) assembly line. This proved a much more profitable choice for the company since it repositioned the company for the explosive growth in the SMT market. The company later won an award[5] for best electronics manufacturing facility.

***Simulation study cost: $8,000.***

## AUTOMOTIVE COMPONENT ASSEMBLY CELL RETROFIT

This organization, a manufacturer of automotive products, had made a substantial investment for an automated, computer controlled assembly cell. The assembly cell employed automated material handling, sewing and assembly operations, automated fixtures, and computer tracking of materials. After a long, difficult installation and startup, the management decided that the system did not live up to expectations. The company was faced with the unpleasant prospect of having a contract to deliver products to a major automobile producer with a system that did not perform as needed.

The system was modified sufficiently by the Manufacturing Engineering department to limp through the first production year and meet the company's contract requirements. The second production year, however, would require a ten-fold increase in the volumes of assemblies to be shipped. Management realized that it would be impossible to meet its customer's contract. A major system redesign and implementation was required immediately. Simulation was the tool used for this system redesign and played a large part in the ultimate success of the project.

The assembly process was analyzed. It was determined the product was not "mature" and did not lend itself to automated assembly yet. Sales forecasts, work schedules, and existing assembly operations were used to determine cycle time requirements. A simulation model was built, then iterated through the different process parameters using the "down-to-earth" techniques. This data showed where potential bottlenecks and process inefficiencies would occur. This determined the required number and type of assembly fixtures, machines, people, buffer lengths, and material handling that would be required for an optimized continuous flow manual assembly cell. The manufacturing engineer then used this information to procure suitable equipment to accommodate the ten-fold increase in production volume.

The new assembly lines were successfully introduced on time and with a minimum of difficulty. This allowed the company to satisfy its shipping requirements and keep its customer delighted. The total system implementation cost was $1.1 million.

***Simulation study cost: $6,000.***

## PRODUCTION CELL IMPROVEMENT

The department manager of this automotive products manufacturer was under constraints to cuts his costs in his production cell and meet increased production volume. To meet the increased production volume with the existing cell design, the manager would be required to add an additional two operators to his payroll.

Product flow and operations were analyzed to determine the "as-is" conditions. This analysis showed that the majority of the operator's activity was material handling, leaving a minimum of time for actual production work. A new layout was proposed that incorporated simple material handling. Simulation was used to determine proper queue lengths between operations to produce the highest production rates through the cell.

A new cell layout was proposed that reduced the material handling by the operators. A simulation model was built for this proposed layout. The model and cell design were iterated to determine the best "down-to-earth" layout of people and equipment to meet the throughput requirements.

A final system proposal was then made to the department manager. An investment of $10,000 would be required for simple gravity roller conveyor units. The final layout would reduce floor space requirements by 33%, resulting in shorter material flow paths and less operator fatigue. A direct labor reduction of 40% would be attained while at the same time production throughput would be increased by 86%. By avoiding the addition of direct labor to meet production goals, the cell manager would save $81,000 the first year and $95,000 every year after that. Based on the results generated by the simulation study, cell management approved the proposal.

***Simulation study cost: $4,000.***

## CAPITAL EQUIPMENT SELECTION

This manufacturer of automotive components had a captive injection molding operation consisting of two molding machines running two-cavity molds. The manufacturer's sales forecast would require additional molding capacity. A larger, more automated, multi-cavity molding machine would be purchased to provide this additional capacity. The project began with an initial budget of $500K.

During the vendor and equipment evaluation stage, it was determined that the budgeted funds would not be sufficient. The new system would require sophisticated and expensive material handling and machine controls. The budget was increased an additional 25%. At the same time, the company was experiencing cash flow difficulties and there was heavy competition for available project funds. It was proposed to re-tool the existing molding machines from two-cavity molds to four-cavity molds. This would, in theory, solve the capacity shortage by almost doubling the existing machine capacity. Scarce funds could be used in other, more critical areas of the plant.

A simulation model was built to determine the feasibility of the four-cavity molding operation. The molding workcell required secondary operations on the parts, so the "down-to-earth" approach was employed. Simulation showed that because of the workcell dynamics, re-tooling the molding machine would almost double production capacity. This increase in capacity would just meet the production requirements with a slight excess. Preliminary quotations from molding tool vendors made it an even more attractive situation: re-tooling would cost less than $200K.

The final design of the re-tooling project was more efficient than anticipated due to the design expertise of the mold vendor. The vendor's design allowed the manufacturer to easily double molding production capacity. Using simulation to validate a proposed capital equipment purchase solved the production capacity issue and saved the company $500K.

***Simulation study cost: $2,000.***

## CONCLUSION AND CAVEATS

The previous examples have shown how simulation can be used to improve the manufacturing operations of any organization. The cost figures show how cost effective it can be. What is important to note here is the costs of the studies have decreased. This reflects the change in software functionality and computing power increases over the years.

Why should a manufacturing organization adopt simulation as a continuous improvement tool? The previous case histories show the power and utility of this effective technology. With limited resources available, and the competition of the global economy heating up, a company needs every advantage it can get. This is just one method of ensuring the best use of funds and personnel.

Adopting this technology is usually not a strain on a large organization, but what about the smaller manufacturer? Rarely are they allowed the luxury of having one employee dedicated as a simulation expert. For them the most cost effective solution is the use of outside consultants. These consultants will bring their expertise, experience, and, most importantly, an objective point of view to assist the smaller manufacturers. The cost of the study will almost always be minimal compared to the amount of savings generated or, worse yet, the cost and embarrassment of a bad equipment decision.

If simulation is to be adopted by a company, the company must be prepared for a committed approach. A small number of engineers should be designated as "resident experts" in order to keep them fresh and interested. Training and experience are essential for recognizing the difficulties in a manufacturing system and the programming "tricks" associated with any particular software package. And it is essential that management be aggressive about continuous improvement for simulation to really shine in their organization.

Using simulation as a manufacturing engineering tool is not a cure-all. It will never take the place of rigorous engineering training in data collection, systems analysis, and cost justification. Use of simulation will always require good, common sense judgement. Applied properly it can become a tremendous asset in achieving a world class manufacturing operation.

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