



Simulations- und Automations- Technologie GmbH  
Gesellschaft für IT-Consulting und System-Integration

## Effective Simulation of High Speed Systems

David T. Sturrock  
Systems Modeling Corporation  
504 Beaver Street  
Sewickley, PA 15143 USA  
Email: [DSturrock@sm.com](mailto:DSturrock@sm.com)  
Internet: [www.sm.com](http://www.sm.com)

### KEYWORDS

Industrial engineering; Simulation; Decision support systems; Discrete simulation; Real-time simulation; High-speed processing

### ABSTRACT

This paper introduces simulation and its application to high speed processing. It discusses how simulation can help solve common problems and demonstrates some common approaches to modeling high-speed applications. It then illustrates the concepts with discussion of a new modeling tool.

### 1 INTRODUCTION

Simulation is a tool that is used to predict performance and help understand the impact of change. It has many important and well-recognized benefits. It allows you to test out system designs before they are built, and reduces the risk and time associated with implementing new systems (or changing existing ones). To those familiar with the technology, it is inconceivable that any significant new system would be designed and built without the aid of simulation modeling.

Although the use of simulation has grown significantly over the past 35 years, there are still many instances where major investments are being made in new or modified systems without benefiting from the predictive power of simulation. In some cases, these systems lack the initial capacity that their designers intended, and the systems must be modified after they are built. Certainly this is costly and time-consuming and can cause significant delays in bringing new systems online. However, a more common occurrence—often done unconsciously to avoid the risk and cost of having too little capacity—is to design systems with excess capacity. Although these oversized (and typically unbalanced) systems initially perform up to specification, they make inefficient use of expensive resources and are far more costly than they need to be. A simulation study can often save significant capital resources by removing the risk factor and allowing the designers to size the system properly and uniformly to meet the requirements.

Over the past five years there have been dramatic changes and improvements in simulation technology that are broadening the use of simulation throughout the world. The tools that are being used today are greatly improved over their predecessors, and the domain of application is expanding rapidly.

Simulation tools have evolved from rudimentary language-based modeling systems to very powerful and flexible graphics-based simulation and animation environments. The tools are becoming dramatically easier to learn and use, and as a result, the barrier to new users has been reduced significantly. Along with the widespread availability of personal computers, this ease-of-use component has been the primary factor creating the rapid expansion of technology in enterprises throughout the world.

In addition to providing a dramatically simplified modeling environment, these tools also provide a total project orientation that supports the simulation process from initial data collection and analysis through model building, verification and validation, design of experiments, and analysis of results. The environments also provide computer-directed tutorials, online documentation, context-sensitive help, and highly focused examples. The role of graphics in simulation has continued to expand and improve.

The synergistic effect of all these developments is a dramatic reduction in the learning curve for the new user, as well as a significant increase in efficiency for the experienced user. As advances in simulation tools continue at an ever-increasing rate, we are rapidly approaching the point where the tools are both powerful and flexible and, at the same time, very easy to learn and use. This combination is the key to expanding the use of this technology.

## 2 HIGH-SPEED APPLICATIONS

High-speed processes typically take place at hundreds, sometimes thousands, of entities per minute. Typical examples include cans or bottles in food processing, pills or packages in pharmaceuticals, and cigarettes in the tobacco industry. Simulation studies of these systems usually have many of the same modeling objectives as studies of other industries. Typical problems to be solved include:

- Where are the bottlenecks in the system?
- Why is my line running slower than design speed?
- Will an accumulator increase system throughput? By how much?
- How can I reduce the run-up time after my next equipment change?
- Where should the sensors be placed to optimize performance?
- What is the best staffing configuration?
- What will be the cost if the new equipment doesn't meet the reliability specs?
- How can I sell my approach in the organization?

Simulation can help address all of these questions.

What should you look for in a simulation product? There are many different factors you should consider, including product features, cost/benefits and the vendor. Some fundamental issues include:

The Product: No tool is worth investing in unless it can solve your problems. Look for a tool that can model not only your present facilities, but also one that can help you with future problems that might arise. Consider your system carefully and evaluate the products to find a product that will fit your needs, rather than being forced to change your needs to fit the tool. Is the product intuitive and easy to use? Does it have clear reports, using your terminology and providing the information you want? Can you build/modify models quickly? Do they execute (provide results) quickly? Does the tool provide for equipment reliability, labor constraints, costing, multiple products/sizes, changeovers, and similar features you might need?

Cost/Benefits: Look at cost in terms of not only the product cost, but also the total project cost. The training and time required to build and analyze a model can dwarf the cost of the software. How long will it take to build your first model? What is the effort to build a complex model? Can you pick up the software six months later and get back up to speed quickly? Now look

to the other side of the equation — what do you hope to accomplish? A model used during design can yield significant reductions in capital expenditures and faster, smoother start-ups. A model used to analyze an existing operation can improve the throughput, yield, labor utilization, and downtime, and can provide substantial reductions in operating cost. An animated model can also be used to improve communications within a team or across an organization.

The Vendor: Is the vendor reliable? Will they be there next month? Next year? Are they known in the industry? What is the quality of their technical support? Are they regularly improving the product? Are they open to your feedback? Responsive to your needs? Look for a vendor who can provide consulting to assist you in getting started as well as help you model a complex or rush project if necessary.

### 3 APPROACHES TO MODELING HIGH SPEED SYSTEMS

Modeling high-speed processes involves additional modeling obstacles due to the high speeds and large volumes of entities. There are three primary approaches to modeling high-speed systems – each has its own advantages and disadvantages.

A common modeling approach is called *discrete-event simulation*. In this approach, every activity or status change of every entity is individually tracked and represented. This allows you to capture a very high degree of detail. Indeed, in some facilities, this is the only approach that provides the flexibility needed to model the facility accurately. Unfortunately, the high volumes of a typical system often overwhelm a discrete event approach. Individually tracking the exact position of each of the thousands of entities can result in very slow execution times, even for the fastest discrete event simulation engines.

To effectively use discrete-event simulation in high-speed applications you must often resort to a technique called *aggregation*. Aggregation works by allowing each logical entity to represent a quantity (or lot) of real entities. For example, each entity might represent 24 cans or 500 candies. Aggregation improves model execution speed and generally retains good modeling flexibility. However, sacrifices must be made in model accuracy and detail. For example, if each entity represents 500 candies, then all processing must be rounded to the nearest 500 candies. Furthermore, it may be very difficult to implement accurate control logic. For example, continuing the problem above, it would be difficult to model the placement of sensors on a conveyor line to determine when there is a backup of 400 candies or when the conveyor is backed up to a point 7 feet from its end.

A second approach sometimes used instead of/in combination with discrete event simulation is *continuous equations*. Continuous equations can be used to model either the entire high speed line, or just portions of it (e.g., a single conveyor). Modeling a system with continuous equations typically has the advantage of very fast execution speeds. And modeling individual, simple machines is generally quite easy. However, the complexity of mathematical equations increases rapidly for all but the simplest of models. Thus, the detail necessary to solve real problems can often not be represented by a set of equations.

A third approach is a *high-speed process simulator* based on an algorithmic approach, rather than only discrete event simulation. These tools generally have modeling constructs that focus on the particular problems encountered in modeling high-speed systems. They use intuitive terminology and make it easy to model common situations. This makes simulators easier to learn and use, and models can typically be built in much less time. Model output is also presented in an easy-to-understand format. In addition, simulators have the advantage of custom algorithms to enhance execution speed. They still generally have limits to the system complexity that can be accurately modeled, especially when dealing with unusual or discrete system components or advanced control logic.

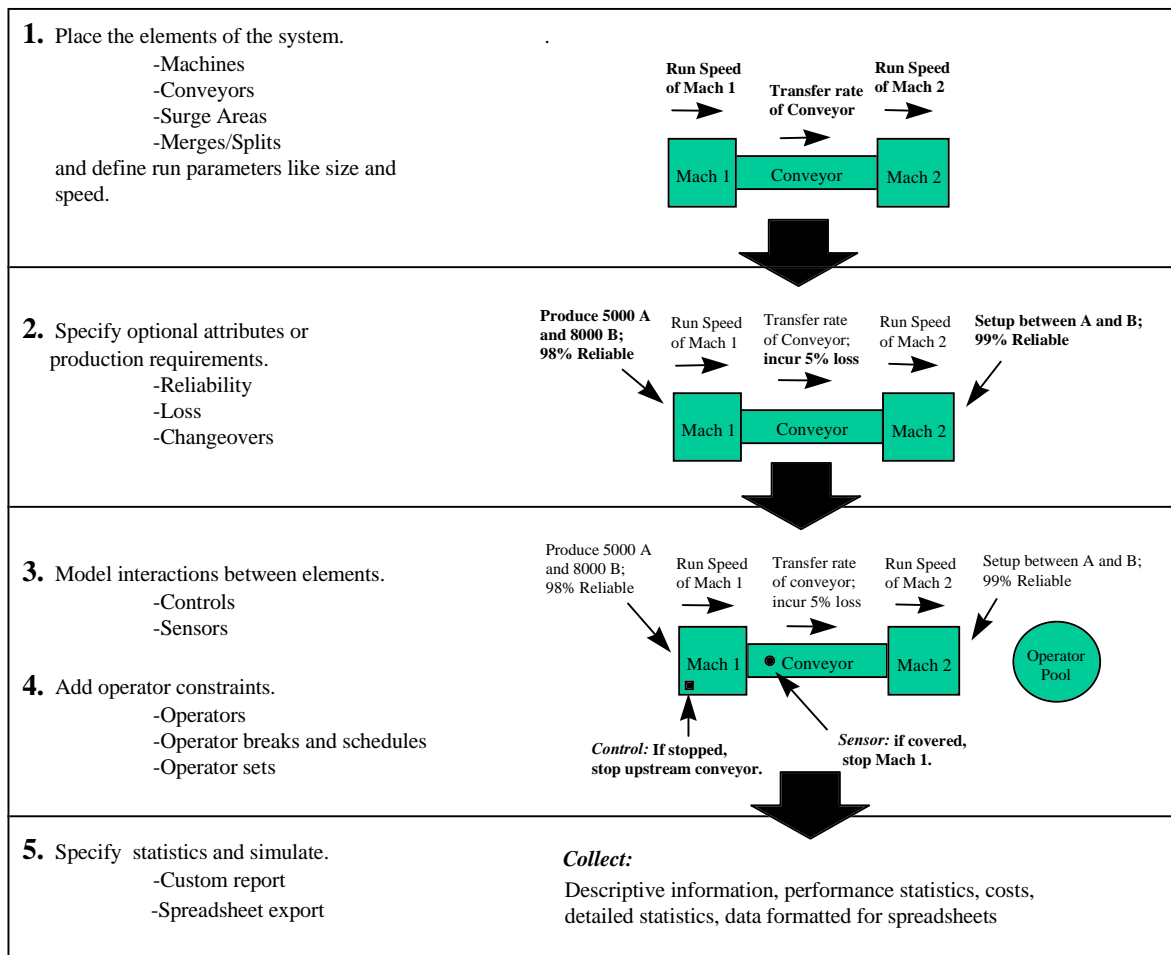
Some simulators make more extensive discrete event simulation capabilities available. These tools still provide the ease-of-use, analysis, and speed advantages of a simulator, while adding the flexibility of user-specified discrete event simulation. This provides two main advantages:

- First, you can model all pertinent components of your system without encountering any brick walls. Discrete interactions such as inbound and outbound materials, labor constraints, and operating schedules can be modeled with the discrete event component.

- Second, a simulator, by design, is created to make common situations easy to model. If your system does not “conform,” it can not be accurately represented. With proper hooks between the algorithm and the discrete world, you can supplement the design with discrete logic to model more advanced controls and unusual or complex systems.

#### 4 A SIMULATOR WITH DISCRETE CAPABILITIES

This section will discuss the modeling constructs in a high-speed process simulator that features extensive discrete simulation capabilities. It will be illustrated by discussing HiSpeedSim™, a recently introduced high-speed process simulator. HiSpeedSim (from Systems Modeling Corporation) is a collection of modules specifically designed for modeling high-speed operations. Each module incorporates all aspects of a particular system element (e.g., a machine). The modeling approach is illustrated in Figure 1.



**Figure 1: HiSpeedSim Modeling Approach**

You build a model by placing and connecting modules to represent the elements of the system in a flow-chart-like representation. Then, fill in the descriptive information in the module dialogs. A good approach is to start simple and then, as your study develops, select options to specify more advanced features (e.g., sensors, failures, etc.). Model animation is automatically generated with each module, but these may be customized to your exact system.

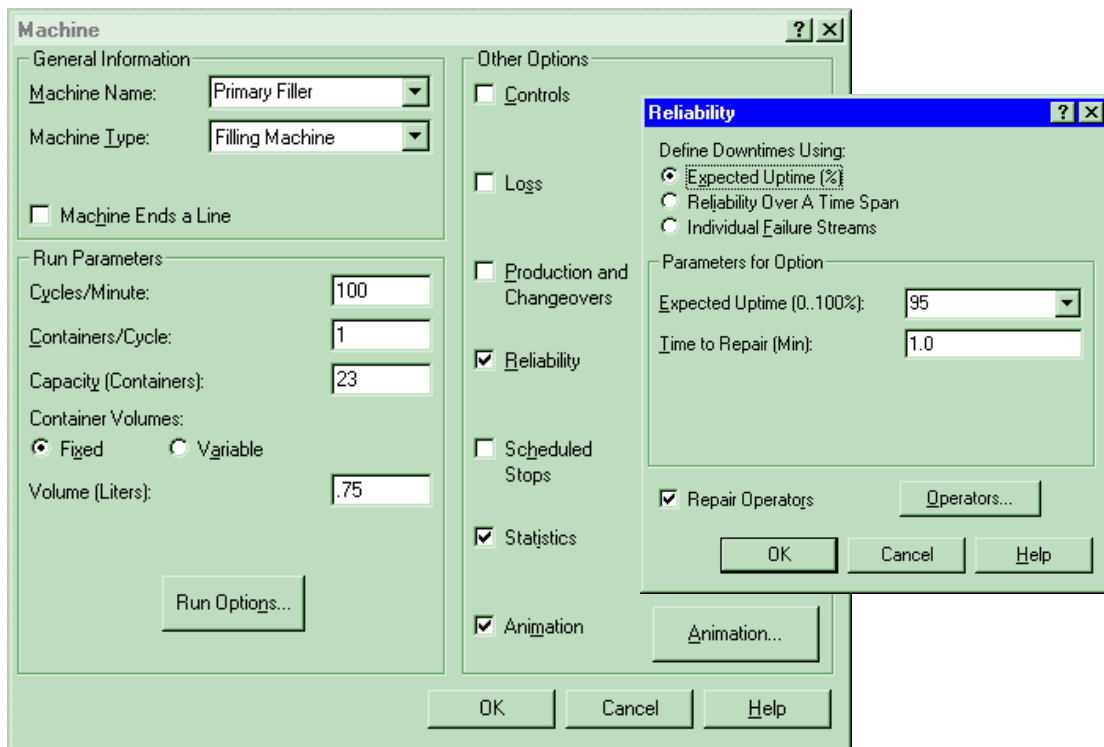
The dialogs are self-contained and designed with terminology for high-speed applications. Through a point-and-click graphical interface, you can develop models of sophisticated systems without writing any code. If the “built-in” operation of

HiSpeed\$im does not entirely address your operation, you can interface to modules of other products, such as the Arena® template, to model the discrete portions of your logic exactly.

The main system elements in HiSpeed\$im include Machines, Conveyors, Operators, and other devices — such as Split and Merge.

#### 4.1 Machines

Machines are the starting point for most models. This is where most of the actual processing or entity conversion takes place. After placing a machine its description, run parameters and options can be accessed via the dialogs illustrated in Figure 2.



*Figure 2: Machine Module Dialog*

HiSpeed\$im supports four types of machines:

- Basic Machines for standard processing;
- Assembly Machines for merging input from two or more lines (e.g., packaging processes);
- Conveying Machines for processes that involve significant product movement (e.g., washing or drying);
- Filling Machines for combining fluids with containers.

Depending on the machine type, the run parameters will change to prompt for only the appropriate information. For example, Cycles/Minute applies to all machines, but Container Volume applies only for filling machines.

A machine's operation can be further customized by selecting from seven optional areas (see Figure 2): Controls, Loss, Production and Changeovers, Reliability, Scheduled Stops, Statistics, and Animation. Controls allows you to detect sets of conditions, such as a production levels or flow rates, and to take selected actions when such conditions occur. For example, when a machine's production rate is decreased, it may in turn dictate that an upstream machine or conveyor slows down. Or,

every time a target production level has been met (e.g., 1000 units), an entity might be generated to execute discrete logic such as operator intervention or custom statistics collection. Loss allows you to specify product that will be lost (spoilage) due to routine production or special events such as changeovers and stoppages. Production and Changeovers allows you to specify the products produced at a machine, the effect of changeovers, and whether operator intervention is required. Reliability (see secondary dialog in Figure 2) allows you to specify expected downtimes, repair times, and repair operators. Scheduled Stops specifies the times when a machine is scheduled to be out of service — such as for breaks or preventive maintenance. Statistics allows you to define the statistical reports for machines, and Animation specifies the dynamic animation to appear while the simulation is running.

## 4.2 Conveyors

Conveyors are the devices that move product between machines. Conveyor modules are placed the same way as machine modules and the dialogs have similar layouts and options (e.g., Controls, Reliability, etc.). Conveyors have an additional option called *Sensors*. An unlimited number of sensors may be placed at specified positions along the conveyor (see Figure 3). When a sensor is triggered, it can take actions identical to those described with controls above. Sensor triggering can be finely controlled. You can specify if a sensor should be covered or uncovered, the minimum time of the covering (uncovering), and whether additional conditions are necessary before taking actions.

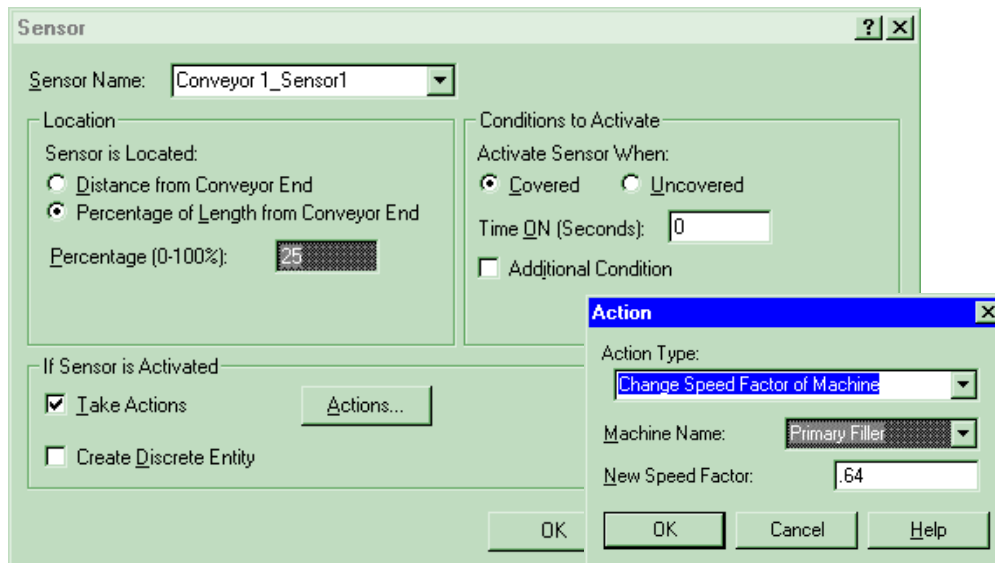


Figure 3: Sensor Parameter Dialog

## 4.3 Operators

Operators are the personnel who operate and maintain the equipment. Within equipment modules, operator involvement can be specified optionally for activities such as repairs, stoppages, and changeovers. They may also be controlled by discrete logic. Operators are defined in the Operators module.

Operators may have a fixed capacity or follow a schedule. For example, you might require four operators for the day shift and only one for the other shifts. Operators may also have random breaks defined that affect their availability.

Operators can be grouped into sets (e.g., a set of electricians). When operators are required, you can select members from sets using operator selection rules. Each operator also has a skill factor defined. This value establishes an operator's proficiency in relation to the "average" proficiency. Skill factors may be used to adjust the delay times of operator activities.

#### 4.4 Other Devices

Other system elements are focused toward fulfilling specific needs. *Split* and *Merge* modules allow product flow to be separated and combined. The *Switch* module is similar to *Split*, but allows more sophisticated product or count-based flow control. Tanks and valves are used for modeling the flow of materials that behave like fluids.

The Palletizer module represents palletizers, depalletizers, and combined units as well as the associated storage areas. In addition to the standard machine control options, it has options for controlling the storage area using a discrete interface. This allows discrete system logic such as pallet removal or creation.

#### 4.5 Model Output

Model output takes several forms. The most obvious is animation. Animation of the machines and conveyors is automatically created as the logic is defined. This animation can also be customized by drawing your own pictures or selecting from supplied libraries. You may also import existing drawings from CAD packages. Business graphics like plots and histograms may be added to supplement the animation.

A second form of model output is summary report information. This report contains information about the system and its performance. The actual contents are customized by options in the appropriate modules. For each system element, you can choose to report descriptive information, production data summary, equipment performance summary, cost data, and detailed state statistics. Figure 4 illustrates part of a typical report for a machine.

Another output option is to export the summary report information to another program. This facilitates the use of a spreadsheet program to further sort or study the data and/or generate more extensive graphical analysis.

<u>SUMMARY FOR Filler</u>	
<u>Production Summary</u>	
Total Units Processed (units):	399807
Total Good Units Produced (units):	393587
Total Units Lost (units):	6200
Number of Failures:	0
Number of Changeovers:	0
Number of Scheduled Stops:	0
Total Time Working (min):	1303.33
Total Time Slow (min):	136.67
-- Total Time Blocked (min):	86.21
-- Total Time Starved (min):	0.91
Total Time Failed (min):	0.00
Total Time Changeover (min):	0.00
Total Time Stopped (min):	0.00
-- Total Time Waiting for Operators (min):	0.00
Total Time Speed Factor Greater Than 0 (min):	1353.79
Average Run Speed (units/min):	295.53
Average Speed Factor:	0.99
<u>Performance Summary</u>	
Total Time Output Rate Greater Than 0 (min):	1352.81
-- Utilization (%):	93.94

```
Average Output Rate (units/min):  
295.52  
Average Output Factor:  
0.99  
Average Good Output Rate (units/min):  
290.94  
-- Average Good Output Factor:  
0.97  
Yield (%):  
98.45  
Performance Index:  
91.11
```

*Figure 4: Summary Report Excerpt*

## 5 SUMMARY

The benefits of simulation are well known in the high-speed processing industry. You can use the power of simulation to help you:

- Generate and evaluate ideas, understand the impact of assumptions.
- Manage change, reduce risk, make better decisions.
- Eliminate bottlenecks, excess equipment, and unnecessary redundancy
- Reduce capital expenditures.
- Design line layouts and dynamic control systems
- Reduce start-up time
- Understand how your system's components integrate and interact together.

Even a small improvement to system performance can provide tremendous gains.

Integrated tools are a new approach to modeling high-speed systems that overcome the common difficulties. Because they are specifically designed for this industry and its challenges, difficult and complex systems can be modeled easily without writing code. Their intuitive interfaces allow non-simulationists to use simulation tools effectively.

## BIBLIOGRAPHY

- Markovitch, N., D. Profozich, 1996. Arena Software Tutorial, *Proceedings of the 1996 Winter Simulation Conference*, J. Charnes, D. Morrice, D. Brunner, J. Swain, Eds., IEEE, Piscataway, NJ.
- Pegden, C.D., R.E. Shannon, and R.P. Sadowski, 1995. *Introduction to Simulation Using SIMAN*, McGraw-Hill, New York, NY.
- Zepf, P.J., 1993. *How to Analyze Packaging Line Performance*, Institute of Packaging Professionals, Herndon, VA.

## AUTHOR BIOGRAPHY

DAVID T. STURROCK is the team leader of Vertical Market Solutions for Systems Modeling Corporation. Dave received his B.S.I.E. from The Pennsylvania State University with concentrations in manufacturing and automation. He joined Systems Modeling in 1988 after more than 11 years of manufacturing experience. Dave has applied simulation techniques in the areas of transportation systems, scheduling, plant layout, capacity analysis, process design, and real-time control. Dave is a member of IIE, SME, AMA, and APICS.