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EXTENDSIM ADVANCED TECHOLOGY: DISCRETE RATE SIMULATION

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ABSTRACT

ExtendSim is used to model continuous, discrete event, discrete rate, and agent-based systems. This paper will focus on the ExtendSim discrete rate capabilities for modeling high-speed and rate based systems. Continuous, discrete event, and discrete rate simulation models will be compared.

1 INTRODUCTION

When building a simulation model, it is important to match the correct simulation technology to application of the model. In using ExtendSim, the simulation analyst has the widest range of technologies available within a single family of simulation tools. This single simulation application contains continuous, discrete event, discrete rate and agent-based simulation. Each of these technologies has its appropriate areas of application. Here we will be focusing on high speed, continuous flow, and rate based systems using the ExtendSim discrete rate capabilities.

Processes that are event driven, rather than time driven, do not lend themselves to continuous modeling. Yet systems where there is no "thing" that can be identified and tracked, or where there are so many "things" that identification is meaningless, are not well suited to discrete event modeling. In these situations, discrete rate modeling is a more natural fit compared to using continuous or discrete event modeling.

ExtendSim discrete rate models represent a unique type of modeling that combines the rate-based capabilities of continuous models in an event-based environment. This model type is especially useful for simulating high-speed and/or high-volume processes that have flows, rates, events, constraints, storage capacity, and routing. Discrete rate modeling eliminates the rounding errors caused by mismatches between discrete events and continuous time steps and it runs a lot faster than discrete event models. So accurate answers are quickly achieved (Damiron and Nastasi, 2008).

As is true of continuous models, state variables in discrete rate models depend on rates – the level of inventory, the number of riders, and so forth. The primary difference is the event mechanism driving the changes to state variables. In continuous simulations, the state variables change at equal time intervals during a simulation run. These state-change events are externally imposed by the modeler and thus are independent of the system behavior. However, in discrete rate simulations, as in discrete event models, the state variables only change at discrete points in time. (For discrete event the state variables change when events occur; for discrete rate they change when their associated flow rates change.) These state-change events are internally generated by the model and thus are dependent on the behavior of the system being modeled.

In an ExtendSim discrete rate model, quantities of flow (material, product, data, and so forth) are located in one or more parts of the model. During the simulation run, the flow moves from one block location to another at a certain speed or effective rate. The movement between blocks that hold or route the flow follows paths, rules, and constraints that are set in the model. Behind the scenes, the model is divided into areas where the included blocks are part of a global system. The blocks within each area are controlled by an internal linear program (LP) that provides the global oversight for that area. Each block in an LP area contributes a part of the LP equation for the area; the result of the LP calculation is the effective rate for that part of the model. This global oversight of calculations is unique to ExtendSim; it preserves mass balance while resolving contentions when flows are merged or diverged, such as in feedback loops.

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2 EXTENDSIM: INVENTING MODERN SIMULATION

ExtendSim (or Extend as it was first known) was not only the first "drag and drop" simulation program, it was the first graphical simulation tool to embody the concept of modeling components as objects. ExtendSim ships with libraries of blocks containing their own behavior, responses to messages, interface, and data. This creates a very flexible modeling architecture. Complex processes can be modeled by combining existing blocks together. Once a process has been defined it can be encapsulated in a hierarchical block and saved in a library for re-use. Even the newest simulation tools are merely variations on the basic theme developed by Imagine That Inc. in 1989 (Pegden 2008, Hughes 2009). With over 20,000 full commercial licenses, ExtendSim is one of the most popular simulation programs today.

The ExendSim rate architecture continues this tradition of innovation. The combination of simulation and linear programming technologies is a ground-breaking development in the modeling of high-speed and rate-based systems.

3 EXTENDSIM STRUCTURE

An ExtendSim model is created by adding blocks to a model worksheet, connecting them together, and entering the simulation data. Each type of block has its own functionality, help, icon, and connections. Each instance of a block has its own data. Blocks perform a number of functions in a simulation model including:

- Simulating the steps in a process (Queue, Activity)
- Performing a calculation (Math, Random Number)
- Interfacing with other application or data storage (Read, Write)
- Providing a model utility (Find and Replace, Count Blocks)
- Plot model results (Plotter, Histogram)
- Tools for interface creation (Popup, Buttons)

The source code for all of these blocks is available and can be viewed or modified by the end user. Blocks can be created from existing blocks or created from scratch.

Hierarchical blocks contain other blocks (either programmed or hierarchical). This helps to organize the model. Hierarchical blocks can be stored in a library and reused in the same or different models. ExtendSim has tools for creating an interface within the hierarchical block, making it easy for the modeler to expose important parameters and results.

ExtendSim includes a relational database for organizing and centralizing simulation information. The use of a database in a model allows the modeler to separate the data from the model structure. This database has become a core feature in ExtendSim models, large and small. In many cases, the ExtendSim model building process begins with the conceptualization of the database. Once the database design has been completed, the model is built to support the data organization. This approach leads to more scalable and better organized models.

4 DISCRETE RATE AND CONTINUOUS SIMULATION COMPARED

If all we are modeling is rates, why not use continuous simulation? The answer lies in the nature of the system and when the system variables are recalculated. A continuous system advances the clock in uniform time-steps, recalculating the entire system state at each step. In the kinds of systems that the ExtendSim discrete rate technology is best suited for, there are typically threshold values for the rate-based variables. In response to a variable reaching the threshold, an event must be generated. For example a tank may become full, closing an input valve. Or a photoeye may become uncovered, changing a downstream machine's operating rate. With the time-step approach, it is difficult or impossible to detect the threshold crossing at exactly the time that it occurs. Instead, the crossing is nearly always detected sometime after it has actually happened resulting in a calculation error. Figure 1, a simple model that alternately fills and empties a tank, shows this effect. In this continuous model, the tank is consistently filled to slightly above its full level of 10 tons and emptied to just below 0. The simulation program can be set with a smaller time-step, but this has a negative effect on performance and there will still be error in the calculation. Without the ExtendSim discrete rate technology, the modeler simply has to live with this error.

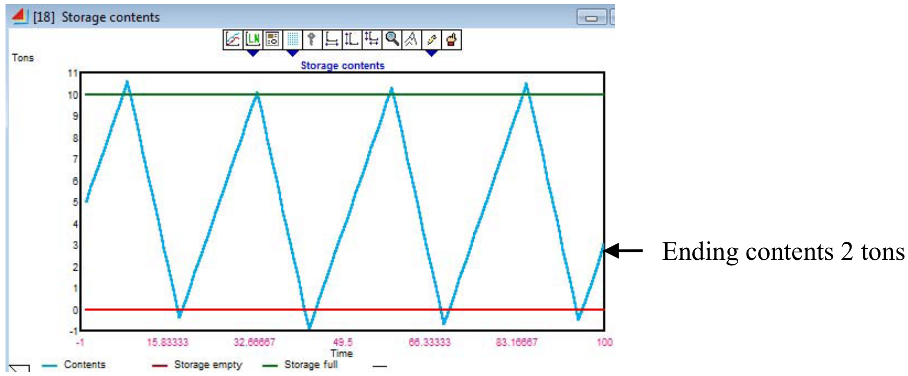


Figure 1:Continuous simulation of filling and emptying a tank

The ExtendSim discrete rate engine predicts the crossing of a threshold and schedules an event at that time. Because of this, the point at which the rate variable hits the threshold is detected at exactly the right moment. In addition, because the rate variables are calculated at events and not at regular intervals, the performance is much better. Figure 2 shows the precise calculation of the level of the tank crossing the full and empty thresholds. The accumulated error in detecting the crossing indicates a final volume in the tank of approximately 2 tons rather than the true value of 9.5 tons. Each small error in calculation contributes to a much larger error in the model results.

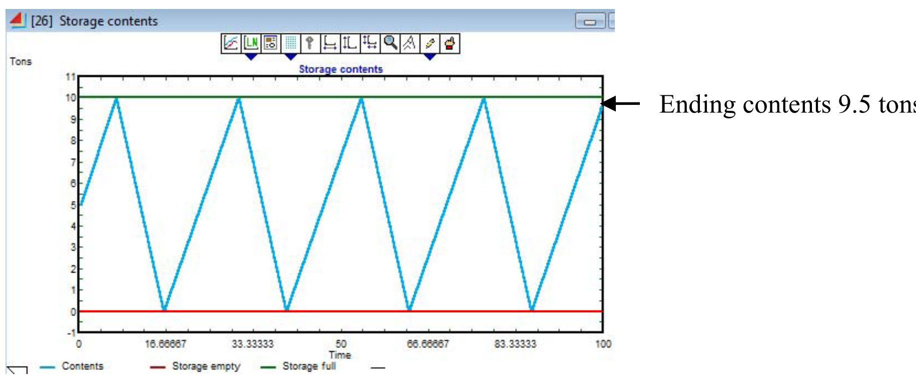


Figure 2: Discrete rate simulation of filling and emptying a tank

The graphs in Figure 1 and Figure 2 also illustrate the number of calculations required over the course of the simulation. The continuous simulation has a time-step of 1 time unit and therefore requires 101 calculations to complete the simulation. In the discrete rate example, calculations are only performed at the beginning and end of the simulation and at event times. Since there are 4 full threshold crossings and 4 empty threshold crossings, there are 8 events for a total of 10 calculations. In this model the discrete rate is 1000% more efficient than the continuous model … and it's more accurate!

5 DISCRETE RATE AND TRADITIONAL DISCRETE EVENT COMPARED

Discrete event simulation is a well-tested technology that accurately simulates a wide variety of processes. However, for high speed and rate based systems it is not the best approach. In a discrete event model, the flow would be converted to discrete units known as entities or items There are three basic problems with discrete event simulation for these types of applications:

- If the model is processing continuous material movement (such as ore or liquids), a unit of material must be "discretized" into items. This reduces the accuracy of the model and requires the modeler to choose an appropriate unit for aggregation.
- Because the throughput of these types of systems is high, the processing time required to move hundreds of thousands or even millions of items through the model is significant. Simulation run times can take hours to run even for relatively small models on fast computers.

- The terminology in a rate based system is often different than in a discrete event based system. For example, processing times are thought of in terms of units per hour (or units per minute) rather than a time delay. Also rate based systems often contain process control elements such as photo-eye timeouts that do not appear as often in other types of models.

The ExtendSim Rate library is specifically designed to handle these considerations. Inputs and results are in terms of rates and levels. The terminology is natural for an engineer working with this type of process. The ExtendSim message architecture lends itself to modeling the control logic of these types of systems - when a change occurs in a block, a message is generated that notifies any connected blocks. In addition, blocks can register to monitor any data or structure changes in the ExtendSim database. For example, the current machine status for a number of machines can be written to a database table. A controller block can be registered to receive a message whenever one or more of these database value changes. The controller block can react immediately to a change without having to scan at the end of each event.

It is easy to build a model that combines traditional discrete event and rate based modeling. The ExtendSim Rate library contains an Interchange block that convert items to flow and flow to items. This block can be used to represent a tanker arriving to load or unload or a pallet that is filled with boxes of soap. Figure 3 shows the Interchange block and its connectors.

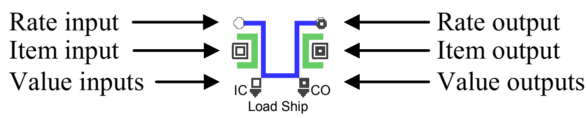


Figure 3: Interchange block

Figure 4 shows a simple loading and unloading process. Here, a ship is represented by an item. The ship is loaded at one port, travels to another port, unloads, and then returns to load again. The loading and unloading times are a function of the rate at which material can be moved on to and off of this ship. This is governed by the Valve blocks connected to the Interchange blocks.

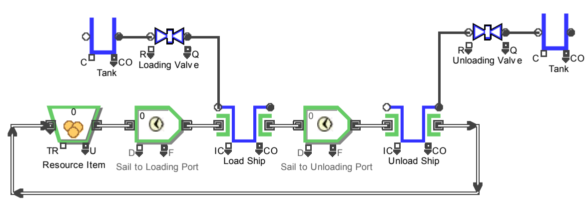


Figure 4: Converting between flow and items

6 A CASE STUDY: BOTTLE MANUFACTURING

A good example of the use of the ExtendSim rate modeling technology is the manufacturing of bottles. While the bottles are all discrete objects moving through the production system, the rate of flow, approximately 40,000 units per hour, makes using traditional discrete event simulation cumbersome. This system is based on a model presented at the 2009 Institute of Industrial Engineers Annual Conference and Expo (Vasudevan 2009). The data and results from the actual process have been adjusted to protect proprietary information. Bottles are manufactured on a high speed production line, in the following basic sequence of operations:

- Forming
- Blow molding
- Leak testing
- Palletizing

Some of the major pieces of equipment are subject to random failures. A standardized hierarchical block was created in ExtendSim to represent the major components. Each of these hierarchical blocks references the ExtendSim database for rate and reliability information. Through this architecture, an enhancement or change to the structure of the block representing one piece of equipment is automatically inherited by similar operations. However, because the information specific to that equipment is stored in the database, this data is preserved. This capability is crucial for creating reusable, data-driven modeling components. Figure 5 shows this hierarchical block. The popup menu (in this case “Forming” is selected), allows the modeler to select the database location that corresponds to this piece of equipment.

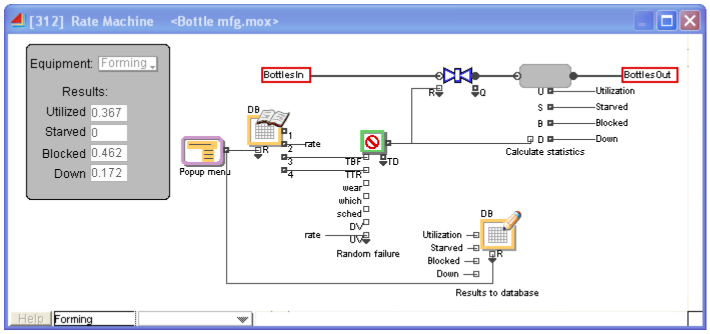
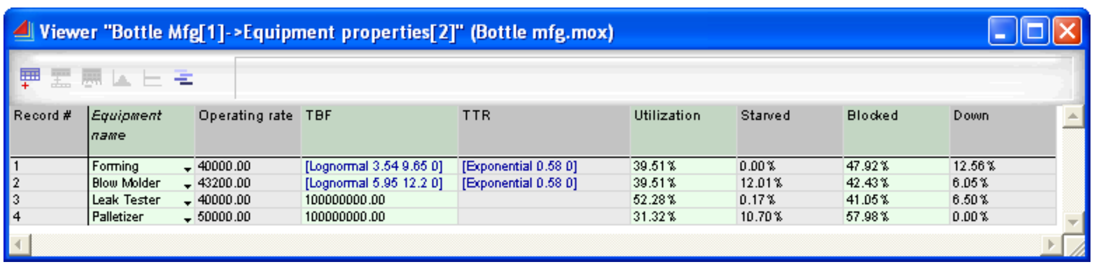


Figure 5: Bottle manufacturing machine

In Figure 6, we see the equipment database table. This table stores the properties of each major operation and the simulation results. It provides an easy interface into the model. Information in this table is accessed through the Read and Write blocks as seen in Figure 5.



Record #	*Equipment name*	Operating rate	TBF	TTR	Utilization	Starved	Blocked	Down
1	Forming	40000.00	[Lognormal 3.54 9.65 0]	[Exponential 0.58 0]	39.51%	0.00%	47.92%	12.56%
2	Blow Molder	43200.00	[Lognormal 5.95 12.2 0]	[Exponential 0.58 0]	39.51%	12.01%	42.43%	6.05%
3	Leak Tester	40000.00	100000000.00		52.28%	0.17%	41.05%	6.50%
4	Palletizer	50000.00	100000000.00		31.32%	10.70%	57.98%	0.00%

Figure 6: Equipment database table

Figure 7 shows the completed bottle manufacturing model. Most of the blocks shown are hierarchical representing specific operations in the process. Additional control and logic details contained within these blocks.

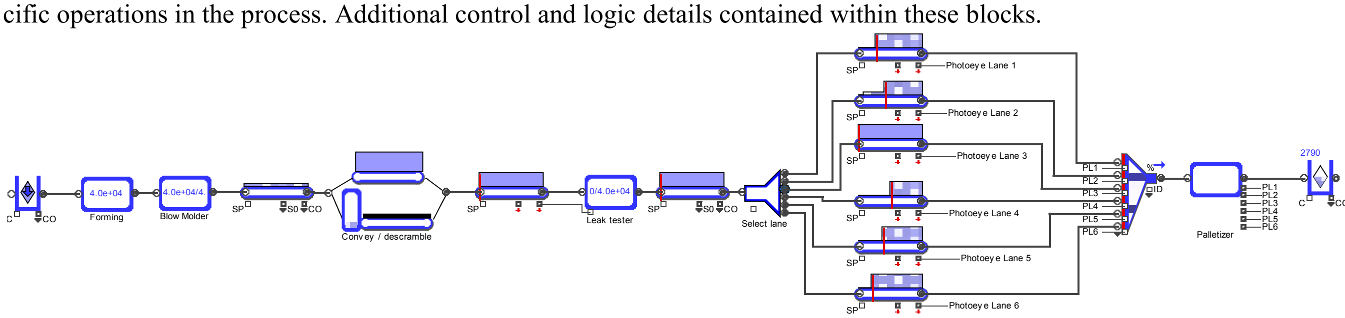


Figure 7: Bottle manufacturing model

In between each of these operations are accumulating tables and control logic that define the details of the process. The Rate library is designed to handle these type of considerations in a model. A good example is the palletizer that builds a 14 bottle wide by 15 bottle deep pallet from 6 conveyors. This is done by shifting the pallet sideways between the loading of the bottles. The resulting sequence is to load bottles from all 6 conveyors twice and then from two of the conveyors once. The goal feature, which instructs the Valve to process a specified quantity of flow, is used to automatically schedule an event whenever the lanes of the pallet have been filled. This goal is dynamically changed based on whether the pallet is loading 6 or 2 lanes of bottles. A second, time based, goal delays the pallet while it is indexed to a new position to accept new lanes of bottles.

7 OTHER APPLICATIONS

Although the ExtendSim Rate library is relatively new compared to the ExtendSim discrete event and continuous capabilities, it has been used in a variety of applications including chemical processing, pharmaceuticals, consumer product manufacturing, food manufacturing, mining, and the oil and gas industry. One example can be found in a reliability model of a chemical plant (Sharda and Bury, 2008). Here ExtendSim was used to improve operations by identifying how the reliability of its subsystems affected total production. The Rate library was used to model the plant components identified as continuous in the paper.

8 CONCLUSION

ExtendSim has a variety of technologies for simulation modeling. A more general overview can be found in the 2008 Winter Simulation Conference Proceedings (Krahl, 2008) Discrete rate is only one of them. It is, however unique in its implementation and capabilities. With the ExtendSim discrete rate capability, a modeler can create rate based models that run faster, are easier to construct, and are more accurate.

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