Proceedings of the 1993 Winter Simulation Conference
G.W. Evans, M. Mollaghasemi, E.C. Russell, W.E. Biles (eds.)

MODELING BEVERAGE PROCESSING USING DISCRETE EVENT SIMULATION

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ABSTRACT

While most presentations on simulation in manufacturing tend to focus on traditional manufacturing industries, one tremendous potential for applying simulation is in beverage processing. Beverage processing poses questions that can be readily answered using simulation modeling. This presentation shows how a discrete event simulation language (ProModel) can help provide insights into the complex behavior of beverage processing. An example model is developed to illustrate the use of discrete event simulation for determining the impact of alternative sequencing and batch sizes.

1 INTRODUCTION

Beverage processing has become a highly sophisticated and automated operation in recent years. Capability exists to process beverages on demand, and to quickly change over from one flavor type or container size to another. Modern processing facilities enable beverage to flow through a flexible pipe network rather than through dedicated pipe connections. The sophisticated operation and complex networking poses a real design and management challenge that can prevent one from taking full advantage of the available technology. Added to this complexity is the fact that beverage processing exhibits both discrete and continuous change.

Simulation can provide valuable insights into the complexities inherent in beverage processing. While it may be supposed that modeling such activities requires a combined discrete/continuous simulation language, the nature of the continuous activities are such that they may just as easily be modeled with the right discrete event simulation language.

2 CHARACTERISTICS OF BEVERAGE PROCESSING

In beverage processing, beverage is processed and packaged according to some schedule or production plan. Each beverage product usually begins with either a partial or complete mixing of the ingredients comprising the beverage (e.g. sugar, flavoring, water, etc.). Depending on the batch size, this mixing may require more than one mixing tank or perhaps even more than one mix in the same tank.

As each batch of a particular flavor is mixed, the beverage is often routed or pumped through one or more pipes and tanks until it reaches the fillers where the final containers (e.g. bottles or cans) are filled. As the beverage flows through the system, other ingredients may be blended in such as water or carbonation.

The routing sequence for a particular beverage is often dependent on which tanks, pipes and fillers happen to be available at the time. In fact, splitting or branching the flow to alternate or even to multiple tanks and fillers is not uncommon.

While consecutive tanks of the same flavor may have overlapped processing, it is essential that dissimilar flavors be kept completely separate. To insure product integrity, great care is taken to insure that a tank or pipe finishes one flavor before introducing a new flavor. Where product integrity is especially critical, or where heterogeneous beverages follow one another, tanks and pipes are cleaned when changing to a new flavor batch.

In addition to coordinating the flow of beverage through the appropriate tanks and pipes, there may be operating or maintenance personnel that factor into the operation of the system.

From the preceding description of beverage processing, several basic activities are apparent that would typically need to be included in a simulation model of a beverage production facility.

- Filling mixing tanks.
- Mixing ingredients.
- Transferring beverages from tank to tank through piping networks.
- Blending in of additional ingredients.
- Cleaning tanks and pipes.
- Assigning operating personnel

Control or operating decisions that need to be incorporated into a simulation model of a beverage processing system include:

- Which flavor to process next and how much (i.e. batch size).
- When to shut off the flow of input and output from tanks.
- What the rate of flow is between tanks.
- Which tank(s) should be selected for input flow.
- Which tank(s) should be selected for output flow.

Depending on the objective of the simulation, output measures of interest may include:

- Time to process a particular mix of products
- Tank utilization
- Throughput capacity

In conducting simulation experiments, the following variables may be changed to analyze their impact on the above performance measures:

- Batch sizes
- Sequencing of batches
- Overlapping of batches
- Routing rules
- Blending amounts (When should dilution be done and how much dilution should occur at each stage)

3 CONTINUOUS ASPECT OF BEVERAGE PROCESSING

Beverage processing exhibits certain continuous characteristics such as in the filling and emptying of tanks and pipes. Such continuous activities require continuous change state variables (as opposed to discrete change state variables) that are updated through the passage of time rather than by the occurrence of some system event. These state variables are monitored until they reach or exceed a target or threshold value which usually triggers some event. While one might tend to think that the time to fill or empty a tank is predictable given a constant fill rate, unforeseen interruptions due to upstream and downstream flow controls make fill and empty times indeterminate.

Modeling the types of continuous activities associated with beverage processing essentially requires the following capabilities:

First	the ability to have a variable represent a continuous change state (e.g. tank levels).
Second	a way to specify the rate at which the variable changes value (e.g. fill and empty rates).
Third	a suitable time step increment for updating the variable value (e.g. every minute).
Fourth	a way to monitor the value of the variable to detect empty, full, etc.
Fifth	the ability to gather relevant statistics on the variable (e.g. level history plot)

Initially one might conclude that a continuous or a combined continuous-discrete modeling package is the best suited for modeling a system which involves the continuous filling and emptying of tanks and pipes. Combined languages for modeling such mixed discrete and continuous processes have been in existence since 1981 (O'Reilly, Whitford, 1990).

Actually, these basic requirements for modeling continuous activities can be met by many discrete event simulation languages. Continuous or combined languages are primarily required only when there exist one or more variables whose rate of change varies over time and are defined by differential equations. Such languages utilize built in algorithms, typically

Runge-Kutta methods, for integrating the derivative values over time (Evans 1988). As Carrie (Carrie 1988) notes, integration algorithms are the primary characteristic which distinguishes continuous modeling from discrete event modeling. In beverage process modeling, however, the continuous change state variables such as tank levels can be updated directly given an appropriate time step increment and rates for filling and emptying.

Modeling continuous activities using discrete event simulation is not new, examples where discrete event modeling techniques have been applied to continuous processes have been successfully demonstrated (Parsons, Shires, Fletcher, Smith 1992).

4 THE PROMODEL "WORLD VIEW"

According to the ProModel "world view" (Harrell and Tumay 1992), discrete parts or entities move from location to location where one or more operations are performed. Locations have capacity allowing them to handle up to a certain quantity of entities at any one time. They also have scheduled availability and may have setup logic defined for entities arriving that are of a different type from the previous entity occupying the location.

The processing logic is defined from the viewpoint of the entity being processed. Operations for entities at locations are defined on an entity by entity basis although several entities may be grouped into a single entity for processing. Resources may be used for processing any particular entity or grouped entity.

The first inclination when modeling continuous processes using ProModel might be to force the system to fit ProModel's world view. This would involve modeling the substance being processed in terms of some unit such as gallons or some multiple of gallons (e.g. 100 gallons). While this approach works in some instances, there are situations where this approach is simply inadequate.

One of the problems with converting beverage to discrete units is deciding on an appropriate unit size. Modeling the beverage in 100 gallon units, for example, assumes that 100 gallons is small enough to never require a partial batch size. Making each entity represent smaller units such as individual gallons can remedy this problem. This, however, slows the simulation down significantly given the hundreds of entities that may be processed per minute in some beverage processing facilities.

The other difficulty in following the ProModel world view strictly is that entities in ProModel move through the system based primarily on the available capacity of the location. This poses a problem because location capacity cannot be utilized in anything but discrete units. In continuous modeling, there is always the possibility that there may be remaining fractional units that need to be considered.

5 DEVELOPING A MODELING STRATEGY

In typical discrete part manufacturing systems it is natural to view material flow from the perspective of the product. For example, we think of an individual product or product batch progressing through the various production stages that might include such processes as machining, inspection, assembly, packaging and shipping.

With beverage production, it is more natural to describe production from the perspective of the flow control at the system management level. We look at the equipment and how it is to be used. We say that a tank is filled to a specific level, that ingredients are mixed, and the tanks is emptied. The substance being produced is often in more than one state and place at the same time.

This difference in perspective between discrete part manufacturing and continuous processing becomes apparent as soon as one attempts to model a continuous system using a product flow oriented simulation tool. The complexities of continuous flow systems become even more pronounced when dealing with partial filling and simultaneous inputs and outputs.

While ProModel does not have a tank or other continuous constructs, it does have two constructs that, when combined, provide a completely flexible and straightforward method for modeling continuous processing. The first of these two constructs is the processing location which can be used to represent WHEN a particular beverage is occupying a tank, regardless of the tank level. The second construct is the global variable which is ideally suited to represent the level of a particular tank. Variable values can be easily modified and may be used in IF-THEN and WAIT UNTIL tests to control beverage flow.

From an animation standpoint, variables in ProModel may be displayed as counters or gages on the screen so that tank levels can be shown during the simulation. Pipes can also be made to change colors to represent the current beverage being processed.

6 EXAMPLE MODEL

To illustrate the use of ProModel in modeling a beverage processing, a beverage plant was modeled that has all of the characteristics described earlier. A production schedule was defined for twelve different beverages and ten different container sizes making 120 different product types. In many respects this model addresses the same kind of scheduling and sequencing problems associated with discrete part manufacturing. The objective, in this particular case, was to find the optimum batch size and production sequence that minimizes beverage production time.

Flavor batches were processed with the goal of keeping as many fillers busy as possible, thus minimizing production time. The size of a flavor batch had to be large enough to meet production requirements for a particular flavor while at the same time attempting to keep all of the fillers busy. In order to exactly meet required production quantities, the batch size for a particular flavor often required only partially filling a tank at the end.

After mixing beverage ingredients in an initial mixing tank, the beverage was pumped to one of six holding tanks in a round-robin fashion. The holding tanks each had a capacity of 5000 gallons and generally required more than one tank to hold a particular flavor batch.

From a holding tank, the beverage was sent as needed for filling to one of four blenders where additional ingredients were blended in. The rule for blender selection was to give first preference to a blender that had currently been processing the same flavor, then to the first one available.

From the blender the beverage was routed to one of ten different fillers with each blender feeding up to two different fillers at a time that might be requiring that particular flavor. When a flavor was finished at a particular filler, other fillers of that flavor were examined for possible routing. The fill rate at each filler changed with each change in container size that was being filled.

Cleaning and changeover time was required for each tank and pipe when a new flavor was introduced. Additionally, a setup was required for fillers when the container size changed.

7 BUILDING THE MODEL

Tanks and pipes were represented in the model using single-capacity locations that are essentially either idle, in use, or down for cleaning. These states proved useful in providing statistics to show tank and pipe utilization. The graphics representing the tanks were unimportant since it was actually the tank levels that were of interest to view during the animation. The level of each tank was represented by a variable displayed as a level gauge on the layout. Modeling the tank level as a variable provided an easy way for the level to be easily increased, decreased, monitored and tested.

Pipes were laid out using the path graphic that may be associated with locations. Modeling the pipes was necessary since pipes are sometimes unavailable for use when they are required.

A picture of the actual model layout is shown in figure 1.

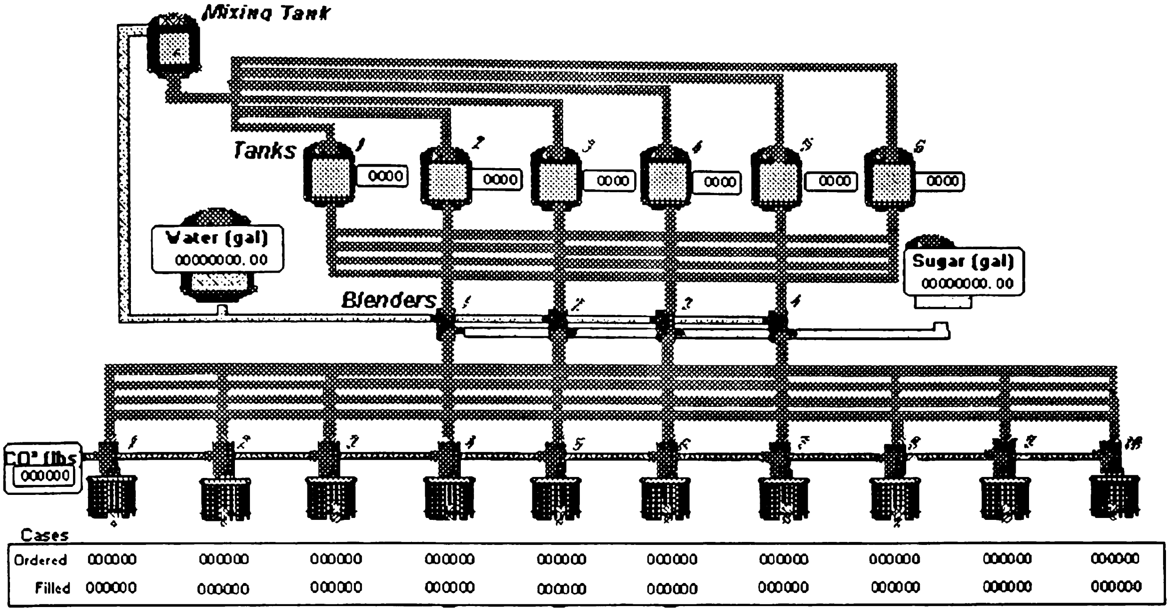

Figure 1.
ProModel Example of a Beverage Production System

After the system was configured, the routing for each substance was defined using ProModel's graphical routing tools. ProModel provides the capability of splitting entities to represent the fact that a particular batch was partially in one tank and partially in another. With the basic configuration and flow sequence defined, the only thing remaining was to define the actual flow control of the system. This was defined by specifying operation logic for each tank and pipe.

Since more than one tank and pipe shared the same operation logic, subroutines were defined for common logic which reduced the amount of data entry and made the model much more manageable.

Variables were defined to track the current number of beverage cases ordered for each filler and the number of cases completed.

8 STATISTICAL OUTPUT

By using a location to define each tank and a variable to track the current level of each tank, several statistical benefits are realized. First, the utilization statistics gathered on the locations describes how often tanks were being used and by what beverage. Since ProModel provides history statistics on selected variables, a plot of each tank level over time can be displayed showing the variation in tank levels over time as well as the periodic and overall production rates.

Following is a partial report of the simulation results.

ProModel 1.0 Results for Beverage Simulation.
Simulation Time: 1396 Hours 4 Minutes

Resource Usage

Name	Total Entries	% Empty
Tank1	4	3.20
Tank2	4	3.27
Tank3	6	4.24
Tank4	7	4.47
Tank5	3	3.74
Tank6	3	3.87
Blender1	11	4.30
Blender2	7	2.33
Blender3	5	98.41
Blender4	0	100.00

Filler Usage

Name	Total Entries	% Utilization
Filler1	11	99.57
Filler2	2	100.00
Filler3	1	99.57
Filler4	11	99.57
Filler5	7	99.57
Filler6	2	99.57
Filler7	9	10.31
Filler8	1	0.00
Filler9	4	99.57
Filler10	9	10.31

The results show that it took 1396 hours to process the orders. The six tanks were nearly fully utilized (i.e. there was at least some beverage contents in them) for the entire simulation time. Only two of the four blenders were being nearly fully utilized while the other two were hardly used at all. Products were at every filler except three for nearly the entire time either being filled or waiting to be filled. The other three fillers were limited to special products and therefore were only used as needed.

What these results indicate, and what was especially evident during the animation, is that there were multiple flavors waiting to be filled, but the tanks were providing no more than two flavors the vast majority of the time. This is why only two of the blenders were being used. Future experiments are planned to see if and how much smaller batch sizes can reduce total production time.

Another statistic of interest was the demand for water over time. The supply of water was assumed to be inexhaustible in order to find out the demand for water over time. This information will help in planning and managing the water supply for the system.

9 CONCLUSION

Efforts to improve the design and operation of beverage processing facilities require tools that are capable of modeling not only the continuous activities associated with beverage production, but also the sophisticated management and control strategies that are being implemented. Discrete event simulation technologies as well as combined discrete and continuous technologies offer tremendous opportunities for production improvements. This presentation demonstrated how ProModel, which is a discrete event modeling tool, can be used to successfully model the activities associated with beverage processing.

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