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A CONTINUOUS PROCESS SIMULATION USING GPSS

Robert Greer Lavery P. Eng.
Ryerson Polytechnical Institute
Toronto Ontario Canada

ABSTRACT

This paper describes the methodology and results of a simulation of an oil purification process used by a food processing company in Toronto, Ontario. The process involves reacting a mixture of edible oils with a caustic solution to precipitate out various free fatty acid and gum components in the oils in the form of soap solids.

The process is discrete in that batches of crude oil are processed individually but the processing of each batch is done on a continuous basis.

The simulation model developed for this process simulates one crude oil batch at a time. Thus the model simulates an essentially continuous operation. The success of GPSS, a discrete event simulation language, in simulating this continuous process forms the basis of this paper.

INTRODUCTION

In July 1980 the author received a request to design a simulation model of an oil purification process being used by a food processing company in Toronto. A condensed flowchart of the process is shown in Figure 1. Various amounts of a number of different oils are mixed together, heated and then reacted with a caustic soda solution. The resultant mixture of purified oil and precipitated soap solids is then fed to a centrifuge which removes the bulk of the precipitated impurities. The oil stream is then washed with warm water and the mixture fed to a second centrifuge. This takes off most of the water before a drier removes all remaining moisture as vapour leaving the pure edible oil product.

Total batch sizes of oil were in the range of 100,000 - 200,000 pounds per batch, a batch run being made approximately twice per week on average. The company was finding that oil losses in the process were high at times and since this particular item was a high profit product, the yearly dollar cost of these untraced losses was quite significant.

The bulk of the oil losses were thought to be in the soap solution stream removed at centrifuge #1 with the remainder occurring in the downstream washing process. Preliminary investigations had indicated that the degree of separation between the oil and soap solution streams was related to the back pressure in the centrifuge and that this in turn was a function of the amount of sediment collected in the centrifuge. Furthermore, a direct relation was known between the rate of sediment formation and one of the impurities in the original crude oil components.

The company had a number of alternatives it could use to try to reduce the oil losses in each batch run. To avoid the more costly piping and equipment changes (with accompanying profit reductions due to loss of production time) it was decided to try to build a simulation model of the process and investigate the effect of various process modifications via the simulation model.

DESIGN OF THE SIMULATION MODEL

Ryerson Polytechnical Institute had installed GPSS-H in the Spring of 1980 and because of successful experience with it, it was chosen as the language for the simulation model. The company requested that the model be as self-contained as possible so that the eventual users would require only a minimum of data specifications for each simulation of a batch run.

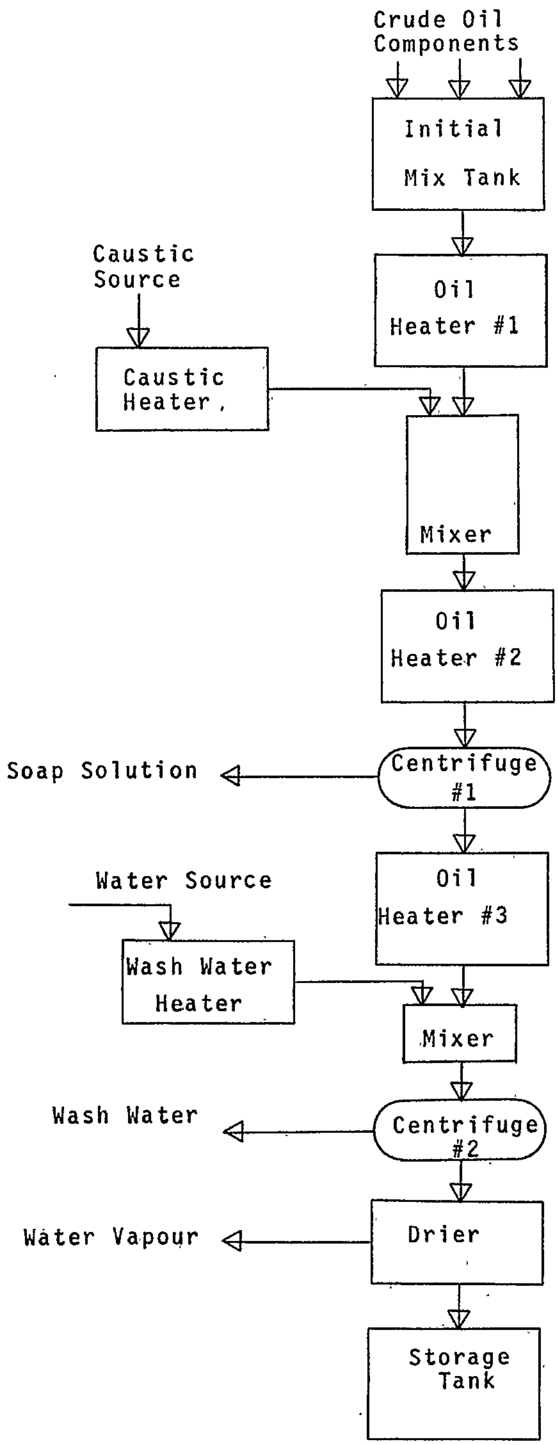

Figure 1: Stages in the Oil Purification Process.

The following items were listed as quantities which would have to be set for each individual batch run.

(a) Weight of each of the possible oils in the initial mix.
(b) Percent of free fatty acids in each of the initial components.
(c) Percent of sediment-forming material in each initial component.
(d) Output temperatures at each process heater.
(e) Controllable flow rates.

GPSS SAVEVALUES were used to specify all of these quantities so that they could be easily set for each run by INITIAL statements. Fullword savevalues were used for item (a) because of the large numbers involved, halfword savevalues for items (d) and (e) because of the relatively small numbers involved and floating-point savevalues for items (b) and (c) because of the fractional values involved. A total of 26 FVARIABLES and 4 VARIABLES were defined to calculate the process parameters which had to be determined dynamically for each run. A separate model segment, activated by a single transaction was used to trigger the calculation of several of these parameters, storing them in savevalues until needed. By placing this model segment at the beginning of the coded model, placement of the controlling transaction at the beginning of the Future Events Chain and (subsequently) the Current Events Chain is guaranteed, ensuring that the needed calculated values will be available when needed.

Three FUNCTIONS were defined to return the flow rate of the soap solution off centrifuge #1 based on known flow rate ranges for various free fatty acid levels in the mixed crude oil. A call to the appropriate function was made in this calculation segment after the weighted average free fatty acid level in the crude mix had been evaluated.

The latter portion of this segment was then used to shut off the simulation. TEST blocks operating in refusal mode prevent the controlling transaction from entering the simulation-ending TERMINATE block until the total material flow out of the system model equals the total amount of material that entered the system from all sources. Just before the simulation is stopped, the percentage loss of oil is calculated as

$$\frac{(\text{Lbs. Crude Oil} - \text{Lbs. Refined Oil}) * 100}{\text{Lbs. Crude Oil}}$$

and stored in a floating-point savevalue for inclusion among the output statistics.

A block diagram for this model segment is shown in Figure 2.

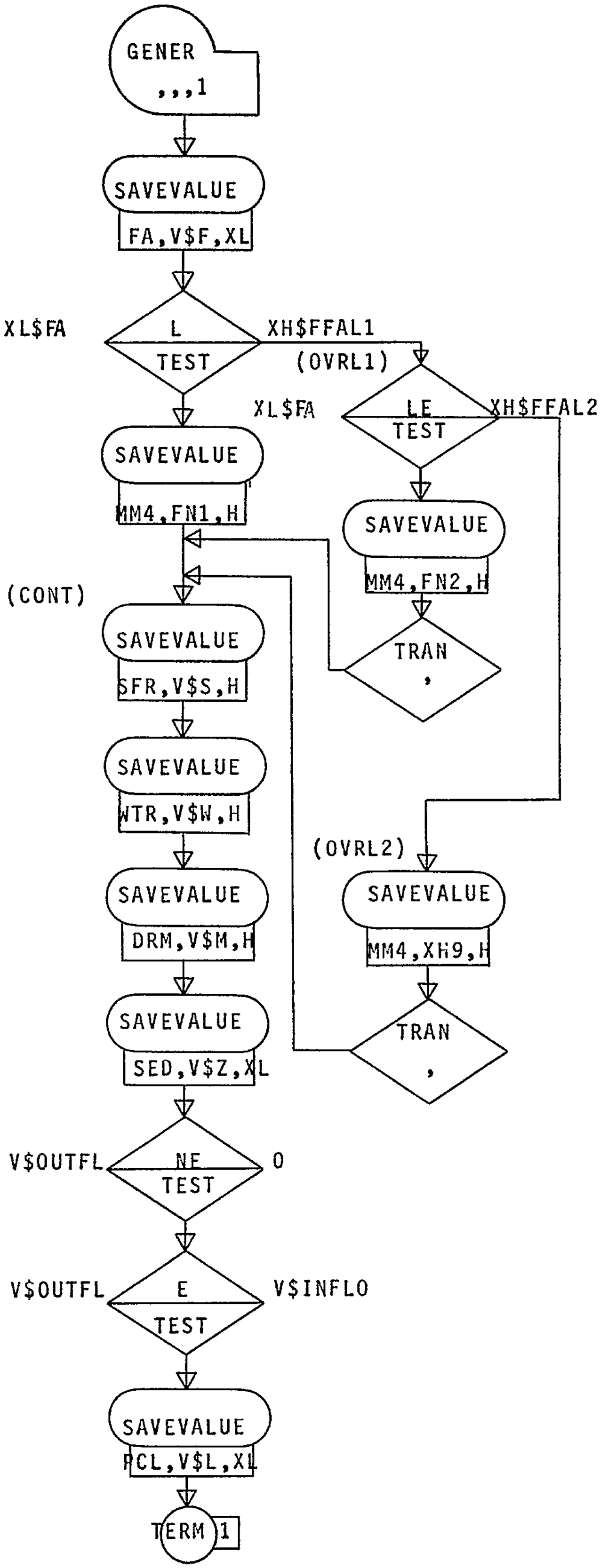

Figure 2: Block Diagram of Model Timer and Variable Evaluator Segment.

The quantities represented by the savevalues used in Figure 2 are as follows;

FA: % free fatty acid in crude mix.
MM4: Flowrate of soap solution off centr. 1
SFR: Fraction of caustic/o-l mix in soap solution stream.
WTR: Fraction of water/oil mix in wash water stream off centrifuge #2.
DRM: Parts per 1000 water in feed to drier.
SED: Pounds sediment accumulated in centr.1
PCL: Percent loss of oil in the batch run.
FFAL1: Upper limit of % FFA for first range of soap solution flowrates off centrifuge #1.

The main model segment, the simulation of the process flow, uses transactions to represent material flowing through the system. The process specifications provided by the company showed no hold-up or delay of the material in the process, permitting a small ratio between transactions and lbs. of material. This was essential since some of the auxiliary flows in the process were considerably smaller than the crude oil flow but still needed a sufficiently large stream of transactions representing them to avoid biased results in STATISTICAL - MODE TRANSFER blocks, total block counts, etc. A final ratio of one transaction to ten pounds of material was used. Since batch sizes usually ran between 100,000 - 200,000 pounds of material, total block counts of 20,000 - 25,000 were standard in parts of the simulation model. In effect, the model produces a "plug-flow" simulation of material flow by moving one transaction (or 10 pounds of material) through the model at a time, up to 25,000 transactions in succession.

No distinction is made among transactions which represent different types of material (oil, caustic, soap or water). Mixing of different streams, e.g. oil and caustic, oil and water, is simulated by routing transactions representing different materials into the same sequence of blocks while separation of streams into different components is accomplished by the use of stat-mode transfer blocks. The proportional separations of the oil-caustic mix into soap and oil streams, the oil-water mix into water and oil streams at both centrifuge #2 and the drier, change with changing flow rates. The 'A' or fractional operand of these blocks is a halfword savevalue giving the separation fraction in parts per thousand as originally calculated in a real variable.

The block diagram for the model of the basic portion of the material flow process is shown in Figure 3.

MODEL VALIDATION

The model was tested using data from actual batch runs as supplied by the company. Known crude oil mixture weights, impurity levels and flow rates, caustic and wash water flow rates and total weights were

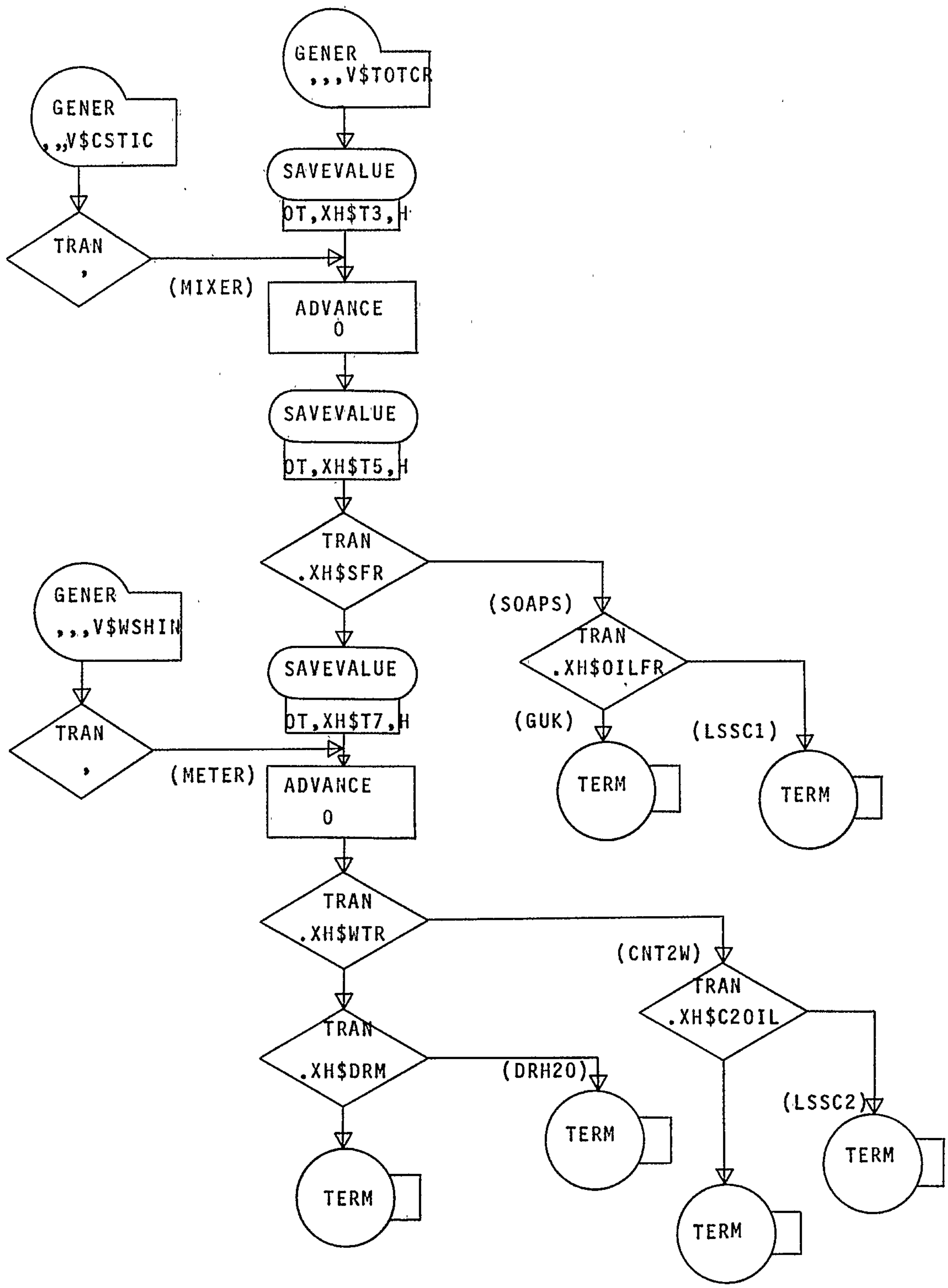

Figure 3: Block Diagram of the Simulation Model of the Oil Purification Process.

initialized for each run. Total block counts at the various TERMINATE blocks were converted into material weights and found to compare very closely with the corresponding true batch weights. The calculated percent loss of oil also matched the true value, usually within 0.5%. Sensitivity checks were performed on the model by making multiple runs of each batch simulation under varying RMULT values. Very little difference in the total statistics for these runs compared to the initial runs was noted and the model was accepted as valid by both the author and the company.

RESULTS AND CONCLUSIONS

The most noteworthy aspect of this simulation is the use of GPSS to simulate a continuous process. While batch runs are made at discrete intervals, each individual batch run is a continuous process and it was these continuous batch runs which were so satisfactorally simulated by the discrete-event language, GPSS. This is largely due to the GPSS feature of being able to subdivide a stream of transactions into two sub-streams according to a fractional split which can be evaluated dynamically.

It should also be noted that the company was not originally aware of what depth of knowledge of the process was required in order to build a simulation model of the process. Considerable additional data had to be obtained on the process during the design stage of the model, data such as flow rates of various streams and oil levels in the discarded effluent streams. As a result of the simulation study several additional sampling procedures were introduced into this process and new instrumentation was added to the equipment to measure flow rates throughout the system. I suspect that the realization of just how much was not known about the process led the company to examine their process more closely and implement the data gathering equipment and procedures, rather than hope for "magical revelations" from the computer.

A number of features were built into the model but not implemented in any simulation run due to the lack of data or the non-completion of anticipated process equipment changes. For example, the effect of back flushing centrifuge #1 to remove accumulated sediment on the soap solution flow rate was never determined, changes in the size of the oil-caustic mix pipe could not be made, etc. Variables and savevalues to accomodate these and other features were provided in the model however and can be activated simply by initializing the proper quantities to non-zero values.

All simulation runs were made using a GPSS-H processor installed on an Itel AS/6 computer using IBM OS level operating system. A typical simulation run contained 125,010 block executions and consumed 1.644 seconds of CPU time.