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A SIMULATION ANALYSIS OF THE EFFECTS OF TRANSPORTATION SYSTEM PARAMETERS ON INVENTORY LEVELS

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ABSTRACT

This paper describes the investigation of various aspects of operation of a combined truck/trailer-railroad transportation system. The system involves shipment of manufactured parts from Mexico through the United States and into Canada. Railroad transportation is used across the United States while truck and trailer mode is used from Mexico into the U.S. and from the U.S. into Canada. An unlimited number of trucks are available at both the northern and southern ends of the railway route. The objectives of this study were to investigate the effect of a number of variables in the transportation system upon inventory level at the Canadian distribution warehouse and to determine the minimum number of trailers required to operate the system without introducing delays which would cause the warehouse inventory to fall below a predetermined minimum level.

The model is coded in GPSS/H. The paper describes some of the design features of the model including the use of the BSTORAGE block in GPSS/H to implement the changing capacities for trailers on the railway trains used. The simulation of transportation system variables, such as border crossing delays, train delays or crashes, and national holidays in all three countries, are also described. A summary of the results of the various test runs of the model and the conclusions reached are also given.

1. INTRODUCTION

A major manufacturing company in Canada is planning to relocate one of its component-manufacturing operations to Mexico, beginning in January 1991. The component factory is to be located just south of the Mexico-U.S. border, i.e., within a few minutes travelling time of the border. As finished parts are produced at the factory they are loaded onto truck trailers for transportation north across the border to a railway depot in the southern United States. There, the trailers are loaded onto railway flat-cars for shipment north to the U.S.-Canadian border. At that point the trailers are unloaded from the train, reconnected to trucks and driven across the border into Canada to the company's distribution warehouse. After the parts have been unloaded from the trailers, the trucks return the trailers to the northern U.S. railway yard where the empty trailers are loaded onto southbound trains for return to the southern rail depot. At that point trucks which have delivered full trailers to the depot pick up the empty trailers and transport them back to the production factory in Mexico, thus completing the cycle for the trailers.

Since this operation places the production facility a considerable distance away from the consumption site, with almost a week's delivery time between factory and warehouse, the company is concerned about the effects of variation in the delivery time upon the inventory level of manufactured parts in the Canadian warehouse. A stockout situation in the warehouse would result in an almost immediate shutdown of the Canadian production operation, the cost of which would quickly offset the savings incurred by the shift of manufacturing operations to Mexico. Thus before committing to this plan, the company wishes to study the effect of various potential problems in the transportation system on the stock level in the warehouse and also to investigate various scenarios regarding system start-up conditions.

2. PHASE I

Initially, the simulation model is designed to investigate the following aspects of the system:

- The minimum number of trailers necessary in the system to prevent shutdown or delay in any part of the system.
- The minimum initial inventory in the Canadian distribution warehouse necessary to prevent stockout from occurring before parts from the Mexico factory begin arriving through the transportation system.
- The effect on inventory level of (i) a substantial delay of a northbound train and (ii) a crash of a northbound train with complete loss of all loaded trailers on board.
- The steady-state inventory level in Canada, once the production-transportation system has been in operation for six months or more.

Although the system does not currently exist, considerable data are available regarding operating parameters. Mexican production rates, Canadian consumption rates, train schedules and capacities, distribution of travel times between all points of the system, border crossing hours, and delay distributions are all known or have been estimated. In addition to these somewhat standard variables, the schedule of national holidays in both Canada and Mexico is known, i.e., days when the factory and/or warehouse are shut down. The only all-U.S. aspect of the system, the railroad transportation, operates 365 days per year, thus national holidays in the U.S. have no direct effect on the system being simulated.

2.1 The Model

The model is coded in GPSS using the floating-point version of GPSS/H. A total of 360 statements, 220 of which are block statements, are used to construct the initial model. Eight segments (plus a timer segment) are used to represent the entire system. Separate segments are used to simulate the Mexican production system, the Canadian consumption system and the north and southbound railway systems. The other segments act as controllers for the factory and warehouse hours of operation, the Mexico-U.S. border hours of operation, the warehouse receiving hours and the national holidays in Canada and Mexico. The controller segments use logic-switch – GATE block combinations to coordinate actions between different segments.

In the main model segment (Mexican production), transactions representing parts are generated continuously at a rate matching the production rate. A BOTH model TRANSFER block preceding a TEST block operating in refusal mode is used to filter transactions out of the model when the factory is shut down, (overnight, on weekends, summer or national holidays). A block diagram segment illustrating the logic of the first few blocks in the model is given in Figure 1.

Beyond this point in the model, transactions are filtered twice again. First, a transaction comes to represent a trailer-load of parts rather than just a single part when the trailers are loaded onto the northbound train and then when train departure occurs, only the last transaction ENTERing the STORAGE representing the train is kept. The other transactions (the remainder of the trailers loaded onto the train) are discarded. The number of trailers originally on each train is stored in the kept transaction's byte parameter 1 so that when the train "arrives" at the northern rail yard, a SPLIT block can be used to expand the 'train transaction' back into individual trailers.

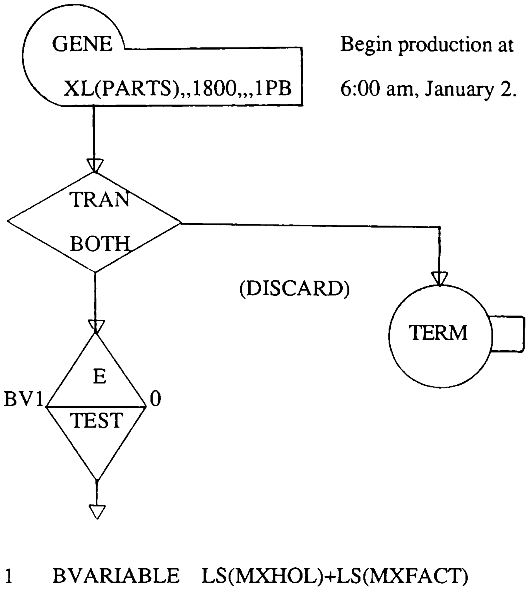

Figure 1. Model Logic for Discarding of Superfluous Parts

A block diagram segment illustrating this reconversion is shown in Figure 2.

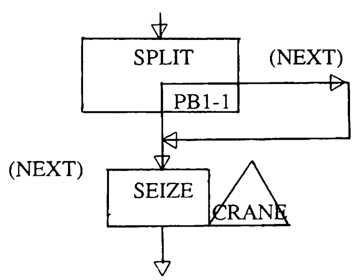

Figure 2. Reconversion of "Train" Transaction to "Trailers"

A useful application of the GPSS/H BSTORAGE block is made to change the capacities of the trains for loaded trailers. Once the refusal-mode GATE block which delays the 'train-transaction's' departure is opened (by SET-ting a logic switch in the train controller segment), the single proceeding transaction enters a BSTORAGE block and redefines the train STORAGE capacity to a value calculated by a FUNCTION. Three trains depart in each direction each week, departure times and trailer capacities of each train being the same from week to week. Thus the capacity of each train for trailers cycles through the three values and an arithmetic VARIABLE, i.e.,

1 VARIABLE N(TRAIN)@3

is used as a FUNCTION pointer to set the STORAGE capacity of the next train. A block diagram segment illustrating the implementation of this logic is shown in Figure 3. The FUNCTION used to return the train capacities is of the form

NTRAIN FUNCTION V1,E3
0,XB(MONTR)/1,XB(WEDTR)/2,XB(FRITR)

A typical control segment is shown in Figure 4. This segment

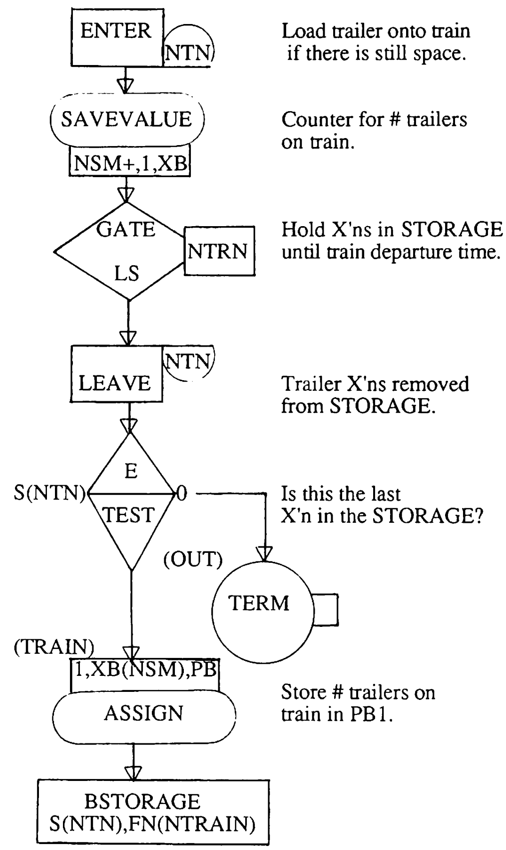

Figure 3. Use of BSTORAGE to Change Train Capacity

is used to control the receiving hours at the Canadian warehouse. The warehouse receiving are operates 17 hours per day, five days per week. The controlling transaction is activated 205 minutes before the warehouse receiving area actually opens. This is the expected traveling time for the trucks departing the railway yard in the U.S. to cross the border and arrive at the warehouse. Similarly, the transaction also closes the receiving area 205 minutes before the true closing time to prevent truck transactions from departing the railway yard at a time when they could only arrive at the warehouse after it had closed. A single transaction is used in this segment, looping indefinitely while counting both weekdays and weekends.

3. MODEL VALIDATION

Since the system being modeled is not yet in existence, data from the model cannot be compared to data obtained from operation of the actual system. Many aspects of the system operation are known with certainty however and verification that these parts of the model are working correctly was easily obtained using the interactive debugging features of GPSS/H. Logic switches are used to control most of the model operations and by detailed stepwise execution of the model, it was confirmed that all switches are being SET or RESET as required at exactly the correct time. Thus system parameters such as daily opening and closing hours of both the Mexico factory and the Canada warehouse, the Mexico-U.S. border, the Canadian receiving dock, the train departure times and loading cutoff times, the closing of factory and/or warehouse for weekends, national holidays, and summer holidays were all found to be working properly. Daily production rate at the Mexico factory (a constant) was exact and other items such as the total number of trailers in the system at any time, the changing train capacities, the consumption at the Canadian warehouse, etc. were all found to be oper-

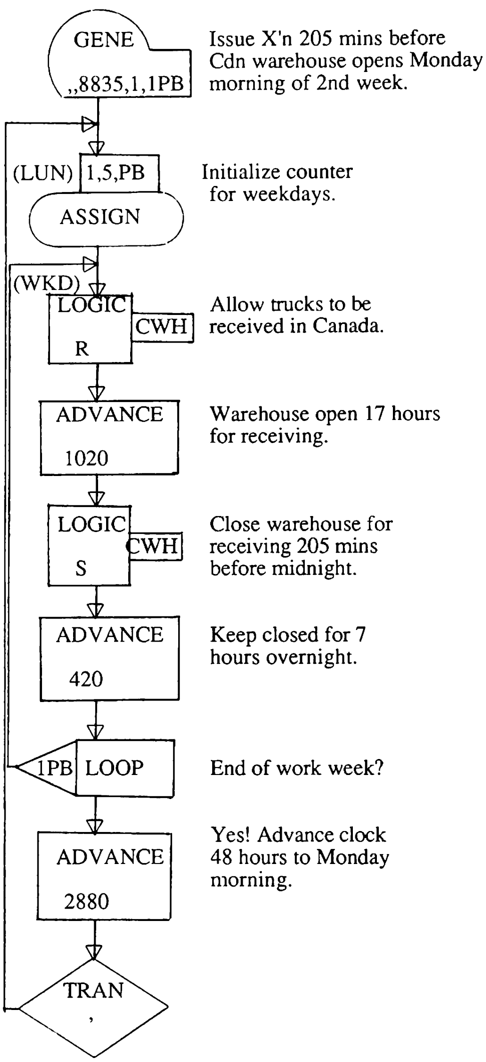

Figure 4. Canada Warehouse Receiving Hours Controller

ating as intended.

The system being modeled is not highly stochastic. Randomness occurs in only a few locations – travel times, border delays, etc. The complexity of the model derives from the coordinated control of several variables from different segments of the model. Thus verification of the model's validity is relatively easily accomplished.

Sensitivity analysis was performed on the model to evaluate the effect of variations in several system parameters on the model output. The output produced was essentially identical for all runs and it was concluded that the model is quite robust to changes in Random Number sequences. Various values for the Mexican production rates and Canadian consumption rates also produced results which were proportional to the input values.

4. EXPERIMENTAL DESIGN

Three consecutive experiments were used to investigate the parameters of interest in this study. First, eight model runs were made using different numbers of available trailers in order to determine the minimum number of trailers which would permit the system to operate without the number of empty trailers as the plant in Mexico ever falling to zero. The condition was imposed that there should be no avoidable delay in the shipment of parts to the distribution warehouse in Canada. Once the number of trailers was determined, this value was fixed in the model data and a second set of model runs made using different levels of initial inventory of parts in the Canadian warehouse (i.e., as of 1st January 1991). The objective of this experiment was to establish the minimum level of inventory necessary in Canada to prevent stockout of parts from occurring before parts from the new production facility in Mexico start arriving through the transportation system. With this value established a final experiment was run to establish the effect upon the system of (a) a 12-hour delay of a northbound (loaded) train and (b) a crash of a northbound train with complete loss of all loaded trailers aboard. Both of these scenarios were investigated after the system had been in operation for six months simulated time and was operating under equilibrium conditions. They were also investigated for each of the three northbound trains operating each week. All values were investigated by running the model for one year's simulated time, i.e., from 1st January 1991 to 31st December 1991.

5. RESULTS OF THE SIMULATION

The model predicted that by operating the system with a total of 200 trailers, all based in Mexico initially, the system would not experience any delays in shipment of parts from the factory in Mexico to the distribution warehouse in Canada. It also predicted that an initial inventory level of three day's production would be sufficient to allow the Canadian warehouse to meet its demand while the first manufactured parts from Mexico were in transit. They delay of a northbound train for 12 hours caused the inventory level in the Canadian warehouse to fall below its normal level a few days later but this decrease lasted only one day, after which the inventory level returned to the values in the regular model output. The simulated train crash which destroyed nearly three day's production supply of parts (in the worst of the three cases) caused inventory levels to drop to near zero for the remainder of the year but no stockout of parts occurred in Canada. Weekly production rates in Mexico were set to match Canadian consumption and no increase in production was simulated to replace the lost parts.

6. CONCLUDING REMARKS

The model performed well and this application of simulation provided answers for management to a number of "what-if?" and system design questions.