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MODELING CONTINUOUS FLOW WITH DISCRETE-EVENT SIMULATION

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ABSTRACT

This paper describes the application of discrete event simulation to study continuous material flow. Logistics is an integrated part of most manufacturing companies. The purpose of this study is to determine the required logistics operations to allow continuous operations of a chemical manufacturing plant. The application has been used to provide critical decision support.

1 INTRODUCTION

Logistics has to do with the procurement, storage, and transportation of goods and people (Pritsker, Sigal, and Hammesfahr 1989). Strategic and tactical logistics has to do with what and how much transportation equipment, loading and unloading mechanisms, and storage is needed to meet logistics objectives. We have developed and applied modeling, simulation, and analysis capabilities for addressing strategic and tactical logistics problems in the chemical industry. These problems have to do with determining capital equipment requirements and assessing alternative strategies for logistics operations.

Most chemical production involves continuous material flows. Moreover, it is very costly to restart the production processing. Therefore, we want to ensure nonstop operation, once the production process is started. Because the operational complexities and stochastic nature, it is difficult to reach closed-formed analytical solutions. Simulation provides feasibility to study complex systems analytically. Most models are used to simulate discrete events. Discrete-event simulation has a commendably long and successful track record in the improvement of manufacturing processes (Law and McComas 1997).

This paper describes the application of discrete event simulation to study continuous material flow. Pritchett et al. (2000) describe the fundamental differences between discrete-event and continuous-time models. It has been proven possible to incorporate models of either type into simulation software intended for the other (Pritchett et al. 2000). However, it has also been noted that such cross-implementation often requires restrictive assumptions on the models, limits their accuracy, increases the complexity of the software, and does not result in a computationally efficient simulation (Fahrland 1970).

The simulation model was built using eM-Plant^{TM}. The modular simulation environment approach has been used to manage a set of simulation objects. Objects can be divided into sub-objects or components. New objects can be built from the components of previous objects with modification and extension as necessary plus new components as required. This environment supports quick model development and delivery of simulation results. The simulation model is comprised primarily of four distinct functional "frames": the plant frame, the silos frame, the bagging frame, and the trucking frame. The product is produced at the plant frame and flows to silos. It then goes to rail car for shipment, or goes through bagging frame. The bagged product will be sent to the trucking frame for shipment.

Section 2 provides an overview of the logistics system under study, Section 3 describes the development of the simulation model. Section 4 describes the results of experimentation with the model. Section 5 summarized and concluded.

2 OVERVIEW OF THE LOGISTICS SYSTEM

The plant produces three different grades of a dry chemical (denoted as A, B, and C) at a specific production rate. These three different grades are produced in a continuous cycle with fixed quantity for each grade. A larger portion of products is sent to rail car for shipment, and the rest is sent to truck for shipment. This is random and mixed.

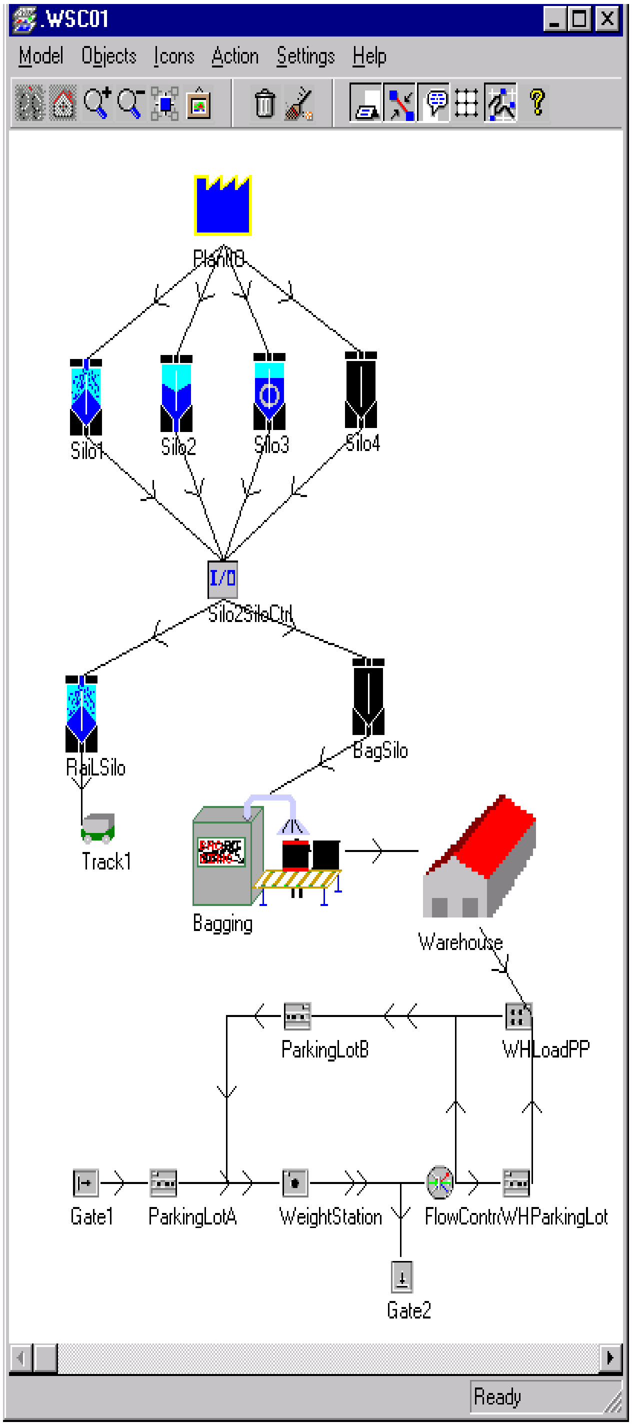

Figure 1: Snap Shot of the Simulation Model

There are four large volume silos connected with the plant. However, only one silo can be used to receive the product outflow from the plant at any given time. The outflow from the silos cannot take place until the silo has completely filled. Only one outflow from the silos can take place at any given time. Grade A of the product requires special blending and needs to be kept in the silos for at least twenty-four hours. The status of the silos are: empty, loading, processing, full, unloading, blocked, and maintenance. "Blocked" indicates outflow has started, but cannot continue because down stream is not ready to receive inflow yet. The rest of the statuses are self-explanatory. There is also one RailSilo used to load rail cars, which has a loading capacity. The RailSilo also cannot have flow-in and flow-out at the same time. There is one BagSilo used for the bagging process. The BagSilo can have flow-in and flow-out at the same time. The flow-out rate from all the silos are all fixed.

While rail car shipments do not require special packaging, truck shipments need to be bagged first. The bagging-process will produce a certain volume of bagged product every few minutes. The machine requires a few minutes of maintenance after processing a certain volume of the product. It takes a few minutes to change over between different grades of products. The bagging machine breaks down occasionally and needs to be stopped for repair. The arrival of rail cars and trucks are modeled as Poisson processes with mean inter-arrival time of a few hours. Previous experience indicates that the stochastic arrival process can be simulated with the Poisson process, i.e. exponential inter-arrival and the interval between break down and the time required to fix a machine can be simulated with a Weibull distribution (Law and Kelton 2000).

Every arrival truck is weighed at the weigh station, and the process take a few minutes. A fixed fraction of the arriving trucks are here to pick up our bagged product. The remaining fractions are here for other purposes. There are a fixed number of loading docks and it takes a few minutes to load the truck, which also has a fixed capacity. Once the truck is loaded, it needs to be weighed again before it can leave the premises. Both the inbound and outbound trucks use the same weigh station. If there are more than one truck waiting for the weigh station, the order of trucks go to weigh station will be based on first come first served rule.

3 DEVELOPMENT OF THE SIMULATION MODEL

The structure of the model is built to mimic the real material flow. Figure 1 shows a snap shot of the simulation model. The icons indicate the status of silo1 is loading, silo2 is unloading, silo3 is processing, and silo4 is empty. The RailSilo is loading and the BagSilo is empty. The user may observe the model interaction at various levels. Each facility on the top level of the model can be opened to display the detailed level down to the material movement through various processing steps: products being loaded onto rail cars, trucks and such.

We discretize the continuous material flow to a unit with a fixed volume. The volume is determined somewhat arbitrarily and is initialized from a data table in the model. In general, with a smaller volume, the simulation model can better simulate the continuous material flow. However, it will require longer simulation time to run the model. On the other hand, with a large volume, the simulation model will not be accurate, but it requires less run time. Therefore, if the purpose of the model is to find out the long-term effect, then a larger volume should be used to shorten the execution time.

Several data tables store scenario details and reference data that is used during the simulation run. The data tables are embedded in the model, and can be changed with user interface. For example, a data table is used to store the production volume of each grade. The production volume is then divided by the capacity of the silos to determine how many silo-load there will be. Once the number of silo-load is determined, a uniform (0,1) random variable is generated for each silo load. The main silos have more capacity than the RailSilo. To avoid less than a full load of the rail car, a fraction of silo load is first sent to the RailSilo, and the rest is sent to the BagSilo. The sequence of the silo load is then sorted so that the order of the destination is random.

One of the purposes is to find out the minimum required number of silos, therefore, the outflow control from the plant will always search the available silos from left to right as the downstream station. Thus, excessive silos will not be used by the system. The I/O control between the main silos and RailSilo, BagSilo determines which main silos should have outflow and which downstream silos the material should flow to. The outflow of main silos follows the First In First Out rules. However, the flow-in time is recorded when the material in the silo is ready to flow out. For example, grade A product may be stored in silo1 before grade B product is stored in silo2. But the flow out of grade A product cannot take place until the material has been processed in the silo for at least 24 hours. Therefore, the I/O control will select silo2 for outflow instead of silo1.

The model is designed as a pull system instead of a push system because the purpose of the study is to determine whether the production can be operated continuously. That is the material will attempt to flow to the next station as soon as they become eligible for outflow. However, once the product is bagged, the flow become a push system. The bagged product will be stored in the warehouse until a truck requests. To reduce the warm-up period, we assume that there is a certain volume of initial inventory in the warehouse.

One of the difficulties in developing this model is to simulate changes of the statuses of the silos. Once a silo is completely filled, there will be no further inflow until the silo is completely emptied. The outflow of the silo become available immediately when the silo is filled, except grade A which needs to be kept for at least 24 hours. A complication arises because there is a lag between the outflow from the upstream station to the inflow of the downstream station. It will be too late for us to switch outflow from the upstream station when the receiving silo is completely filled, because the material in the pipeline will be lost. Thus, it is important to synchronize all the processes in this model. For example, the plant needs to send its outflow to other silos when the material in the pipeline will fill the receiving silo completely.

The outflow control is embedded in the silo object, which can adjust the flow out rate. To synchronize the process, every unit is transferred to downstream immediately. For example, if the current material flow is from Silo2 to RailSilo, then one unit will be removed from Silo2 every few minutes. The unit is added to the RailSilo as soon as it has been removed from upstream. This is possible because the capacity of the inflow rate of downstream is always greater than the outflow rate of upstream.

The visualization of the simulation model tremendously helps users to believe the validity of the model. Visualization is also critical in communicating the outcome of a simulation to the non-technical audience. Decision makers often do not have the technical knowledge to understand the statistical outcome of a simulation. But when the outcome can be expressed using a simulation, a better level of understanding is possible. Managers can see the status of the silos, and the flow becomes more obvious than when viewing the statistics. Watching a few minutes of animation can eliminate hours of long tedious discussion. The animation can be presented to upper management or non-technical users directly, whereas statistics need to be presented, explained, justified, and questioned (Rohrer 2000).

During the process of building a simulation model for the logistics systems, we not only find out how the system functions but also help people at the plant level and upper management to understand the system better. The analysis of the results of the simulation model and watching the animation can provide insights.

4 RESULTS OF MODEL EXPERIMENTATION

Model performance has been validated through a simplified scenario, where the analytic solutions are attainable. The model output is then compared with the verified analytical results. Users agree the model is an accurate representation of the real system. To alleviate any concerns of the robustness of the results due to the random variations inherent in simulation, each scenarios is run multiple times with different time horizons. The results from the simulation provide a clear picture as to a best choice of planning.

The modeling approach described above has been used to evaluate various alternatives. Many of the alternatives are defined and modified only in the data tables. This flexibility allows the user to read in data tables, run a scenario, and get results very quickly. No scenarios require modifications to the model itself. Moreover, when the modifications are necessary, the model can be easily and quickly changed due to the de-coupled design of the model.

4.1 Silo Statistics

The model has been simulated with a one-year time frame. Table 1 lists the silo statistics for one particular replication. The report indicates the fourth silo has not been used, thus, it is possible to remove the fourth silo without causing disruption of the production flow. Several scenarios with a different number and different size of silos have been used in our experiments. The scenario study can provide valuable information, because the cost structure of the size of the silos is not linear. The optimal combination of the number and size of silos can be determined with simulation of a pre-determined set.

Table 1: Silo Utilization Statistics

Silo	Utilization
Silo1	63.98%
Silo2	63.91%
Silo3	10.93%
Silo4	0.0%

4.2 Bagging Statistics

Table 2 lists the bagging machine statistics. The report shows the utilization of the bagging operation is very low, this is a true reflection in this logistics system. Because the bagging facilities is set up to process materials from other plants and is designed to have capacity that is large enough to process 100% of the production, instead of 30% in our scenario. We spend only 0.07% of the simulation time in changeover between different grades of product and 0.28% in maintenance. The proportion of the time allocated for each product should be roughly the same as the proportion of the product being produced in the plant. Therefore, it is a good indication whether the model is correct.

The changeover information is stored in data tables. Therefore, the bagging process will be able to simulate multi-products without any modification. The simulation results also provide information regarding the number of changeovers and the average time between changeovers. This information is important in determining the campaign volume. If there is excess changeover then we should have larger campaign volume per product or grade.

Table 2: Bagging Machine Utilization

Bagging Machine	Percent
Idle	93.15%
Changeover	0.07%
Bag Changeover	0.28%
Grade A	0.89%
Grade B	3.26%
Grade C	2.35%

5 SUMMARY AND CONCLUSIONS

The use of a simulation-based model to assess the operational requirements and impacts of logistics systems is not a new concept. We use a discrete-event model to simulate continuous-time process. The purpose of the study was to develop a detailed simulation model of a logistics system to determine the minimum requirement to allow a continuous production outflow. Statistics are collected from various frames and analyzed for their impacts. Examination of the results reveals that the current logistics design can provide a continuous production flow.

The model is extremely flexible in terms of the user's ability to make changes for scenarios and is easily understood. The model generates several reports automatically. Any future assessments of this logistics system can be aided by analysis within the model. This model takes guesswork out of the determination of the best configuration for the logistics system.

APPENDIX : TRADEMARKS

eM-Plant is a registered trademark of Tecnomatix, Inc.

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