CHAPTER 6: DISCRETE-EVENT SIMULATION MODEL

The discrete event simulation was developed, using Promodel software, for a manufacturer of defense products that had to reduce costs through improved efficiency and process control and invest in new infrastructure to effectively compete for future contracts. The simulation models a production line that produces solvent-based propellants for use in military applications. The model was originally designed for the production of a single product; therefore, changeover and machine times for other products were not included. Also, the model was not designed to read-in production schedules. Hence, these aspects were incorporated into the existing simulation model prior to using it to compare the production schedules.

6.1 Existing Simulation Model

The simulation model was developed based on a generalized chemical production line. With the help of the line engineers, the various work areas were modeled. The production process consists of five operations: dehydration (dehy) press, mixing, blocking, extrusion press and cutting. Raw material arrives at the dehy press in large barrels. The material is put in the press and placed under pressure. The water in the material is then removed and replaced with alcohol. The process produces a 100-pound block of material. After five blocks have been produced, they are tested and transported to the Mixer where they are split and loaded along with dry chemicals and liquid solvents. Mixing produces a dough-like material that is placed into six tubs and taken to the Blocker where the contents of each tub are pressed into a block. These blocks are transported in pairs to the Extrusion Press where they are loaded and pressed through dies to produce 16 to 25 parallel strands that are fed into a "hen's nest" for transport to the Cutter. In this area, the strands are fed, in parallel, into machines that cut the material into pellets that are then stored in large wheeled containers to wait for transport to the "Water-Dry Process."

The model was developed for ideal operational conditions. All machines are fully operational, i.e., wear and tear and breakdowns are not considered. Also, all workers work continuously without fatiguing, i.e., time for shift changes, safety meetings, lunches/dinners, breaks, etc. are not considered. The simulated production line continuously produces propellant, i.e., shift changes and breaks are not considered, and raw material is always available.

6.1.1 Simulation Parameters

The parameters used in the model can be found in Table 10. The production line has the following characteristics:

- an open flowshop with a generalized serial network;
- a multi-product batch plant with fixed transport vehicle size (hence batch sizes vary with size of transport vehicles);
- 5 multiple processing stages with several out-of-phase parallel machines in each stage;
- the production line operates in a non-preemptive mode;
- there is finite intermediate storage between each of the production stages; and
- stochastic machine and LUT times for one product.

❖ Number of Machines in Operation
- 1 NIR Testing Machine
- 2 Dehy Presses
- 3 Mixers
- 2 Blockers
- 3 Extruders
- 4 Cutters

❖ Number of Transport Mechanisms
- 12 Dehy Buggies
- 3 Mix Flats
- 4 Block Buggies
- 8 Hen's Nests
- 5 Can Flats

❖ Number of Workers Working
- 1 NIR Worker
- 2 Dehy Workers
- 4 Mixer Workers
- 1 Mixer Transporter
- 2 Blocker Workers
- 2 Upstairs' Extruder Workers
- 3 Downstairs' Extruder Workers
- 4 Cutter Workers
- 1 SPC/Cutter Worker (spends half the time cutting and the other half doing paperwork)

Table 10: Model Parameters

Figure 3 is a screen shot of the simulation model of the production line under study. Section 6.1.2 provides a description of each work area on the production line and Section 6.1.3 discusses the verification and validation of the simulation model.
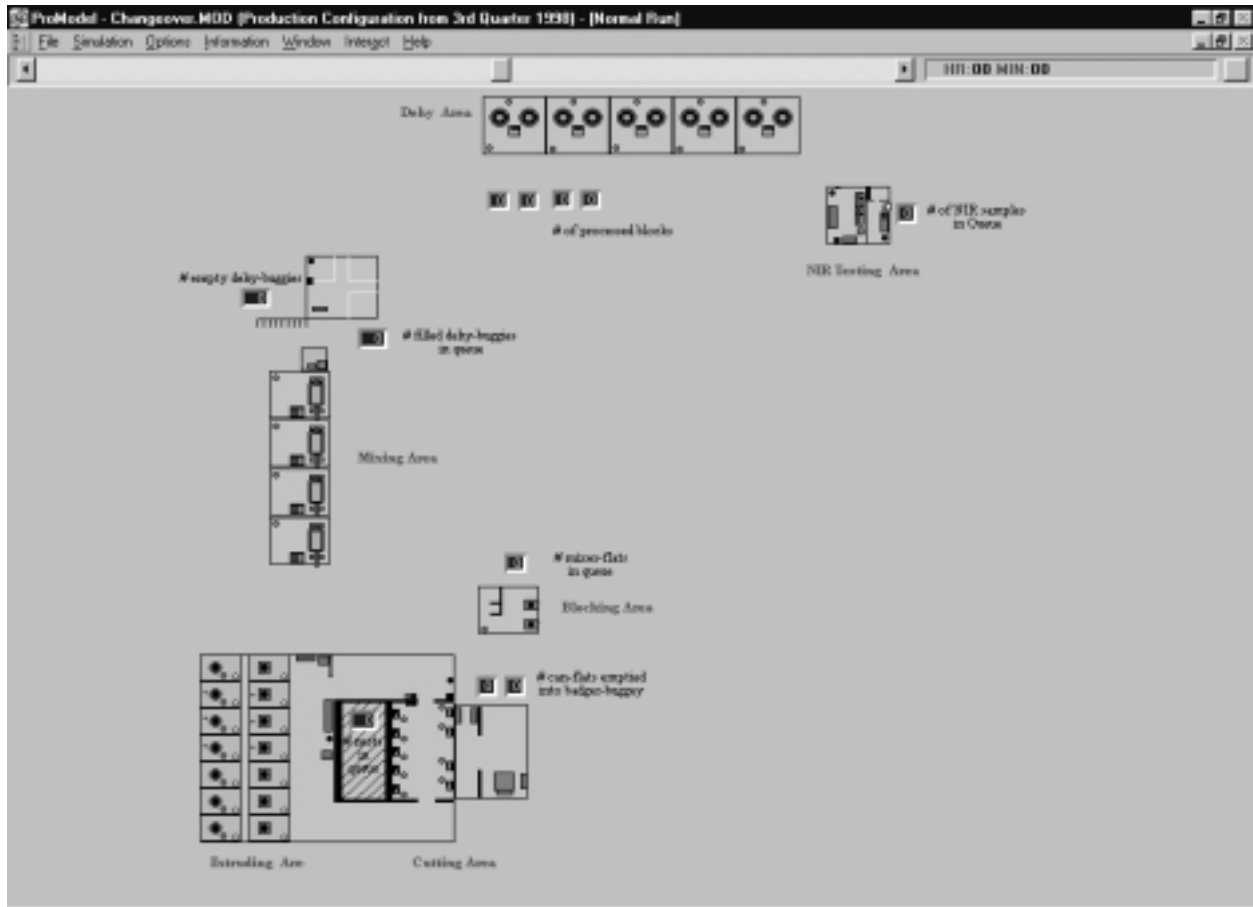
Figure 3: Simulation Model of Production Line

6.1.2 Work Area Description

This section provides detailed descriptions of the events that take place in each of the work areas.

6.1.2.1 NIR Testing Area

When a set of NIR test samples arrives at the Testing Area, the NIR worker walks over to the packing room, packs the samples into two NIR dishes and returns to the testing room with the sample dishes. Next, the worker tests the samples and enters the data into a computer. When testing and data-entry are finished, the worker walks back to the packing area, empties the dishes and cleans up the area. If there is another set of samples waiting to be tested, the same steps are repeated, otherwise the worker returns to the testing area and waits for the next sample to arrive.

6.1.2.2 Dehy Area

It is assumed that broken blocks of nitrocellulose cotton are always available whenever needed by the Dehy worker. First, the Dehy worker pulls two cotton barrels into the bay area. He/she waits until the presses stop, then unloads them. Then the worker loads the dehy press, starts the machine and repeats the procedure for the other press. Once both machines have been started, the worker weighs the cotton blocks that were unloaded and places them into their respective dehy buggies. After each press produces five blocks, NIR samples (one from each press) are collected and taken to the NIR Testing Area for a quality check.

The Dehy worker continues to process the nitrocellulose cotton while the test is conducted. When the test is completed the buggies are individually transported to the Mixing Area. On the return trip the worker brings back an empty buggy, if one is available. If no buggies are available and there are no more buggies in the bay area, the Dehy worker waits in the Mixing Area until two buggies are available to take back to the Dehy Area.

6.1.2.3 Mixing Area

In the Mixing Area, DNT and a mixture of alcohol is added to the blocks in the mixers. The DNT tubs are located in the mixer queue housing area. When a Dehy Buggy arrives in the Mixing Area, it is placed in the mixer queue until there is a free mixer available for loading. One Mixer worker splits the blocks, loads a DNT tub onto the Dehy Buggy, then moves the buggy from the mixer queue to the mixer. Two workers load the mixer with the blocks and the DNT powder, then one worker takes the empty buggy to the Empty Buggy waiting area for the Dehy worker to take back to the Dehy Area. The workers then wait until the mixer is done processing the blocks. When the machine stops, one worker moves a mix flat next to the mixer. Another worker then joins him/her to unload half the mix from the mixer into the mix flat. The filled flat is then moved back outside by one Mixer worker, where it is handed off to the Mixer transporter. Another empty mix flat is then moved into position by one worker; and then two workers unload the remaining mix from the mixer.   Once again the filled flat is moved outside for the transporter.

The Mixer transporter moves the filled mix flat down to the Blocking Area and returns with an empty mix flat. If one is not immediately available, the worker waits at the Blocking Area until one becomes available.

6.1.2.4 Blocking Area

Blocker workers wait for mix to arrive from the Mixing Area, then one Blocker worker moves the mix flat in between the two blockers. Each blocker is loaded by an available worker and then started only when both machines have been loaded. When the machines stop, the blocks are unloaded into the block buggy. When the 6th tub from the mix flat has been loaded into the blocker, the mix flat is moved to the Empty Flat waiting area for the Mixer transporter to take back to the Mixing Area. After six blocks have been produced, one Blocker worker transports the block buggy to the elevator by the Extruding Area and returns to the Blocking area with an empty block buggy.

6.1.2.5 Extruding Area

The block buggies are brought up to the extruding area via the elevator and wait for the extruders to become available for loading. The first Upstairs Extruder worker pushes the buggy to an empty extruder. The second Upstairs Extruder worker then removes two blocks from the buggy, loads them into the extruder, continues to prepare the extruder for the run and then starts the machine. Once the two blocks have been removed from the block buggy, the first worker moves the buggy to the next available extruder, loads two blocks from the buggy into the extruder and finishes preparing the extruder for the run. The next available worker then transports the buggy to the last extruder, loads the machine and starts it. When the last two blocks have been unloaded from the buggy, it is returned to the elevator and lowered to the bottom for the Blocker worker to transport back to the Blocking Area. The workers then wait for the Downstairs Extruder workers to return, stop the extruders and return them to the starting position. Once the extruder presses are back upstairs, the Upstairs Extruder workers clean them in preparation for the next loading cycle.

The Downstairs Extruder workers load empty hen's nests under each extruder in preparation to start the pressure for the extruders once the Upstairs workers start the presses. The Downstairs worker turns on the pressure when the extruders are ready, then they wait. When the extruding is completed, the worker turns the pressure off, returns the press back upstairs and transports the filled hen's nest to the cutting area. Another hen's nest is then placed under the extruder for the next extruding cycle.

6.1.2.6 Cutting Area

When a hen's nest arrives, a Cutter worker moves it to one of the available cutters, loads the propellant strands into the cutter, and cuts them into a can that is then loaded onto a can flat. Once all the strands in the nest have been cut, the nest is returned to the Cutting Area entrance. The filled can flat is transported to the first available badger buggy for emptying. The empty can flat is then returned to either the empty can flat area or to a cutter without a can flat. When nine can flats have been unloaded into a badger buggy, two Cutter workers move the buggy to the scale, weigh it, record necessary data, and then move the buggy out to the Loading Area. One worker then replaces the filled badger with an empty badger buggy.

The SPC/Cutter worker spends half their time filling out quality-control forms and the other half helping the other Cutter workers process the hen's nests.

6.1.3. Model Verification and Validation

The model verification process determines whether or not the model was built correctly. This process compares the modeler's system conceptualization with the computer simulation developed. Whereas the model validation process determines whether the conceptual model is an accurate representation of the real world system. It checks to insure that the modeler's system conceptualization properly represents the actual system to be modeled.

6.1.3.1 Verification Techniques Used

- Assertion checking compares the model's execution with the real system's behavior [Balci et al. 1996].
- Debugging is done by analyzing the code by stepping through the logic and altering parameters to check all logic loops.
- Visualization/Animation (Visually review logic.)
- Desk Checking thoroughly examines the model for correctness, completeness, consistency and no ambiguity. This involves line by line inspection of the code for syntax errors, convention violations, specification deviation, and path sensitizing [Beizer 1990].
- Execution Monitoring requires inserting print statements in the model logic to gather information about its behavior [Glasow et al. 1996]. By examining the data it is possible to analyze the activities and events that take place during the model execution.
- Trace output compares model output with sample data.
- Track the line-by-line execution of the simulation.

6.1.3.2 Validation Techniques Used

- Face Validation consists of discussing the conceptual model and logic with domain experts to determine if model behaviors are reasonable [Whitner and Balci 1989].
- Animation Validation compares animations with the operation of the real system.

6.2 Additions to the Simulation Model

In order to use the simulation model as a production schedule comparison tool, a few additions were implemented. New code was added to the existing simulation model to account for product-dependent changeover times and product-dependent machine times and schedule input. Once all the code was added, process data, such as product type and related machine and changeover times, were gathered from the production plant and used as input parameters for the model. Finally, the model was tested to ensure that the new code was functioning properly.

CHAPTER 7: PERFORMANCE EVALUATION

The deterministic and stochastic objective function values (minimal tardiness), the schedules' robustness (precision of schedule) and performance (accuracy of schedule), the computing and simulation CPU time required, the schedule throughput, and the required simulated time to process all the jobs were compared to determine the best scheduling algorithm. Mignon, Honkomp, and Reklaitis' (1995) evaluation technique was used to determine the robustness and performance of the schedule. The Multiple-Comparison with the Best (Swisher and Jacobson 1999a) method was used to identify the differences between each of the schedule's performance.

7.1 Mignon, Honkomp, and Reklaitis' Evaluation Technique (1995)

Mignon, Honkomp, and Reklaitis measure the "robustness" of a schedule as a function of the variability of the objective function. The lower the variability the more robust the schedule is said to be. They weight the standard deviation of the objective function with the absolute deterministic objective function value "to reduce the impact of different orders of magnitude of the objective function values." In other words, the robustness measures the precision of the schedule. The robustness of a schedule is calculated as follows:

$$Robustness = 100 - \left(\frac{OF_{sto}}{|OF_{\det}|} * 100 \right) \% \,,$$

where: $OF_{\det}$ = deterministic objective function value,

OF_{sto} = standard deviation of the objective function.

The higher the percentage the more robust the schedule.

The schedule's "performance" is a "percentage of the deterministic objective function value," i.e., it measures the schedule's accuracy. Similar to the measure of robustness, the higher the performance percentage the better the schedule is

$$Performance = \left(\frac{\overline{OF_{sto}}}{|OF_{\det}|} * 100 \right) \% \,,$$

where: $OF_{\det}$ = deterministic objective function value,

$\overline{OF_{sto}}$ = average value of the objective function for the replicate runs with
stochastic variability.

7.2 Multiple Comparison with the Best

Multiple Comparison with the Best (MCB) uses pair-wise comparisons to make deductions in the form of confidence intervals about relationships among all designs (Swisher and Jacobson 1999a). The goal of MCB is to identify the differences between systems' performance; it does not guarantee a decision. This technique will determine the best system from a set of alternatives and can only be applied to independently seeded simulation runs and the results must be normally distributed (Swisher and Jacobson 1999b). MCB may only be used for models with discrete input parameters and the number of designs to be compared is both discrete and small (between 2 and 20).

Specifically, Rinott's MCB Procedure was selected because it "assumes independent samples across systems" (Nelson 1995). This means that it does not require all the scenarios to use the same common random numbers; hence, enabling us to use the data already collected. The following variables will be used in the procedure description.

k total number of scenarios,
h Rinott's integral,
w whisker length (indifference zone),
μ_i unknown average system processing time for scenario i,
n_0 initial number of replications,
N_i calculated total number of replications for scenario i,
$1 - \alpha$ confidence level,
S_i^2 marginal sample variance for scenario i,
Y_{ij} system processing time for scenario i in batch j,
$\overline{Y}_{ij}$ sample average (for n_0 data points),
$\overline{\overline{Y}}_{ij}$ overall sample average (for N_i data points).

Rinott's MCB procedure is as follows (Nelson 1995):

1. Specify w, α, and n_0. Let h solve Rinott's integral for n_0, k, and α (see the tables in Wilcox 1984).
2. Take independent and identically distributed (i.i.d.) samples $Y_{i1}, Y_{i2}, ..., Y_{in_0}$ from each of the k systems (simulated independently).
3. Compute the marginal sample variances

$$S_i^2 = \frac{\sum_{j=1}^{n_0} \left(Y_{ij} - \overline{Y}_{i.}\right)^2}{n_0 - 1} \qquad for\ i = 1,2,...,k.$$

4. Compute the final sample sizes

$$N_i = \max\ \{n_0, \lceil (hS_i/w)^2 \rceil\} \qquad for\ i = 1,2,...,k.$$

5. Take $N_i - n_0$ additional i.i.d. replications from system i, independently of the first stage sample and the other systems.

6. Compute the overall sample means

$$\overline{\overline{Y}}_i. = \frac{1}{N_i}\sum_{j=1}^{N_i} Y_{ij} \qquad for\ i = 1,2,...,k.$$

7. Select the system with the largest $\overline{\overline{Y}}_i.$ as best.

8. Simultaneously form the MCB confidence intervals

$$\mu_i - \max_{j\neq i}\mu_j \in \left[-\left(\overline{\overline{Y}}_i. - \max_{j\neq i}\overline{\overline{Y}}_j. - w\right)^-,\ \left(\overline{\overline{Y}}_i. - \max_{j\neq i}\overline{\overline{Y}}_j. - w\right)^+\right] \qquad for\ i = 1,2,...,k.$$

The following is an example of how Rinott's MCB is applied. The parameters used in the Rinott's Procedure are as follows: $k = 6$; $w = 1$ hour; confidence level = 95% ($\alpha = 0.05$), and $n_0 = 50$ replications. From Wilcox's table, h = 3.367 (Wilcox 1984). The calculations for the Musier and Evans Algorithm using the Set 2: Customer Orders (using the data shown in Table 11 in Chapter 8) are as follows:

$$S_{ME20}{}^2 = \frac{\sum_{j=1}^{n_0}\left(Y_{ij} - \overline{Y}_i.\right)^2}{n_0 - 1} = \frac{274.63}{50 - 1} = 5.60,$$

$$N_{ME20} = \max\left\{n_0, \lceil (hS_i/w)^2 \rceil\right\} = \max\left\{50, \lceil (3.367*\sqrt{5.60}/1)^2 \rceil\right\} = 64,$$

Since 50 replications have already been made and a total of 64 replications are needed, 14 additional replications were collected and the overall total tardiness sample mean is:

$$\overline{\overline{Y}}_{ME20}. = \frac{1}{N_i}\sum_{j=1}^{N_i} Y_{ij} = \frac{13402.91}{64} = 209.42.$$

Assume this is the best of the six solutions and assume the max overall sample mean is 259.25, then

$$\overline{\overline{Y}}_i - \max_{j\neq i}\overline{\overline{Y}}_j - w = 209.42 - 2059.25 - 1 = \pm53.83.$$