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APPLICATION OF SIMULATION TO SCHEDULING, SEQUENCING, AND MATERIAL HANDLING

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ABSTRACT

We describe the application of simulation analysis to a complex operational problem involving scheduling, sequencing, and material-handling decisions. The manufacturing process under study required close attention to correct mix and sequencing of raw materials, reduction of material-handling costs, high utilization of a resource having significant purchase and operational expense, and a steady, low-variance throughput.

1 INTRODUCTION

The manufacturing process under study comprised scheduling, sequencing, and material-handling considerations interacting with high complexity. Analytical and "closed-form," or heuristic, results are available for the optimization of scheduling policy in the absence of stochastic variation and potential conflict with competing objectives (Pinedo 1995), (Morton and Pentico 1993). However, the combination of other competing objectives (e.g., reduction of material-handling costs, high resource utilization, and low variance of output production) and stochastic variation required the analytical power of simulation. Simulation has a long and strong track record in analysis of manufacturing systems whose complexity and interaction of components defy closed-form methods (Clark 1996). Further, recent advances in techniques of analysis and computer software enable simulation to provide excellent support to real-time, hence dynamic and adaptable, scheduling (Harmonosky 1995).

In this paper, we first describe the operation of the process under study and describe the performance metrics whose improvement was sought via analysis. Then we describe the development of the simulation model, stressing important steps such as establishment of objectives, choice of software tools, and determination of input data, problem assumptions, and output data necessary to meet the objectives. Each of these steps is a prerequisite for success of simulation analyses (Banks and Gibson 1996). We next present our results and conclusions, and indicate expectations for further analyses.

2 DESCRIPTION OF PROCESS OPERATION

In this process, five distinct raw materials first arrive at a railroad yard owned and operated by a common carrier, via freight trains of seventy to eighty cars. These freight trains are not unit trains; i.e., their cars carry loads whose recipients are customers other than the company whose operations were being analyzed (Sillcox 1967). Therefore, managers of this company must specify the extraction of freight cars from the public railyard and their placement and sequencing within their corporation's private railyard.

From the private railyard, these freight cars, each hauling one of the five raw materials, must be moved to one of three sidings, each capable of accommodating ten freight cars. From these sidings, the cargoes are used to supply two kilns of capacity one hundred tons each. Each kiln is capable of making any of six output products, and each product has a different "recipe" of types and amounts of raw materials required. Two automatic guided vehicles (AGVs), each carrying a 100-ton bucket, move along the three sidings. A bridge crane astride the three sidings moves raw materials from the freight cars to the buckets, and an AGV carries the bucket alongside the appropriate freight cars. When the bucket is fully loaded, the AGV moves it to a kiln; the bucket's "charge" is then emptied into the kiln. A typical output-product recipe specifies that raw materials be emptied into the kiln in a certain order. Therefore, those raw materials must be loaded into the bucket in the opposite order: the bucket inherently uses a "last in first out" [LIFO] discipline. A schematic of these operations appears in Figure 1, next page.

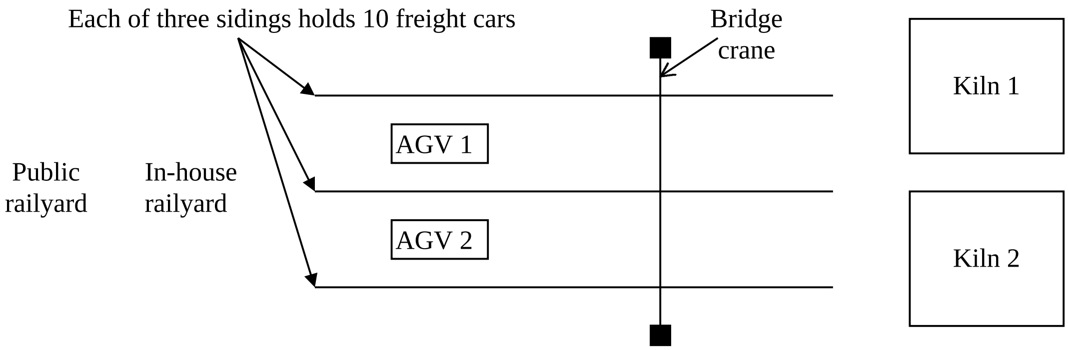

Figure 1: Schematic of Operations

3 DEVELOPMENT OF THE SIMULATION MODEL

Development of the simulation model proceeded through various stages, such as setting of scope and objectives, gathering of data, building, verifying, and validating the model, and analyzing its output. Each of these steps is essential to simulation project success (Robinson and Bhatia 1995).

3.1 Setting of Scope and Objectives

The modeling team and the engineering users agreed to restrict the scope of this model to the sidings, material-handling equipment (crane and AGVs) and kilns; intuition and experience strongly suggested that the most rapid, cost-effective efficiency gains lay there. Additionally, negotiations with railroad managers concerning freight train compositions and movements would have a firm basis only after all endogenous improvement opportunities were identified and acted upon. This conservative and explicit restriction of study domain at the beginning of a simulation study is a key step toward subsequent project success (Ülgen et al. 1994). For an example of the importance of such restriction in practice, see (Jayaraman and Agarwal 1996).

Concurrently, the project objectives were established. A key decision variable was “which cars (cargoes of the various raw materials) should be placed in which order on which of the three sidings?” That is, how should freight cargoes be sequenced on these sidings? Client production engineers and managers were also eager to assess the adequacy of one bridge crane and two AGVs relative to the performance metrics of high, steady throughput and high utilizations of the kilns. Since the kilns are costly to purchase, maintain, and keep hot, their high utilization is important to economic efficiency of this production system. Client engineers and managers specified desired time intervals at which the kilns were to be emptied (“tapped”). Thereupon, three scenarios of material-handling equipment and policies (the current situation and two proposals for altering the operational specifications of the bridge crane) were evaluated for their ability to support the kilns. Relative to the current system, the second proposal would significantly lower acceleration rates of the crane to reduce operational and maintenance costs; conversely, the third proposal would increase crane acceleration.

3.2 Gathering of Data

Data was supplied by the client’s engineering design team. Key data items used in the development of the simulation model were crane movement times (in all three dimensions), crane pick-up and drop-off times, bucket loading and unloading times, capacity and movement rates of rail cars, demand mix for the five raw materials as driven by demand for the six output products fused in the kilns, and equipment breakdown frequencies and repair times. When explicit data was initially unavailable, industry experience and standards supplied values which allowed model build, verification, and validation to proceed concurrently with ongoing data collection. Exploitation of this concurrency opportunity shortened project time to delivery of useful results to the client (Nordgren 1995).

3.3 Building, Verifying, and Validating the Model

The simulation tool AutoMod™ was chosen for this study in view of its high capability to model material-handling systems (for example, inclusion of AGV and bridge-crane constructs), availability of an underlying language in which the modeler could define various scheduling and sequencing proposals, ability to import CAD drawings, and three-dimensional animations built concurrently with model definition (Rohrer 1996). Further, AutoMod™ is accompanied by AutoStat™, a post-processor providing significant statistical-analysis capabilities (Rohrer 1994). These statistical capabilities include several anticipated by (Schmeiser 1992) as highly valuable to simulation practitioners.

The production system, which operates seven days a week, was modeled as a steady-state, not a terminating, system. The analysts avoided initial (warm-up period) bias by initializing system conditions to typical values (e.g., relative to freight cars and their contents available on the three sidings) and by running the model for a one-day warm-up time prior to collection of output statistics (Banks, Carson, and Nelson 1996). To reduce variance, common random numbers (CRNs) were used when comparing alternative scenarios (Kelton 1996).

Model verification and validation were achieved by structured walkthroughs of model logic, extensive use of execution traces, comparison of the first scenario to observed current conditions (Turing tests) (Porcaro 1996), and by soliciting the client's comments on the reasonableness of the animation.

4 OUTPUT ANALYSES AND RESULTS

Once steady state was reached, the model for each scenario was run for ninety days of simulated time. Ten replications with respect to each scenario were used (thirty runs in all) to build confidence intervals (typically at $\alpha = 0.05$) describing the predicted performance characteristics of each scenario. Early results showed that either the existing crane (scenario 1) or the more expensive crane proposed in scenario 3 could meet the current interval between kiln tap time, but that the less expensive crane proposed in scenario 2 could not. Therefore, analysis of scenario 1 was expanded to assess its ability to support more frequent tapping of the kilns. Results were highly sensitive to the interval between taps, as shown in the following table:

Table 1: Ability of Scenario 1 to Support Kilns

Tap Interval Time	Batches	Kiln Utilization
20 minutes	38	90%
21 minutes	37	93%
22 minutes	36	98%
23 minutes	36	100%
24 minutes	35	100%

Hence this simulation study provided valuable guidance in scheduling the taps from the kilns. Crane utilization was inevitably lower than kiln utilization; typically use of cranes for material handling forgoes high utilization in return for ability to carry heavy loads with small "footprint" (Gould 1994). The crane statistics are shown in Table 2.

Table 2: Crane Statistics

Tap Interval Time	Delivery Percent	Retrieval Percent	Parking Percent	Util-ization Percent
20 min	41.2	42.9	15.9	68.2
21 min	40.3	40.8	18.9	66.1
22 min	38.3	38.1	23.6	64.8
23 min	37.2	36.8	26.0	61.4
24 min	36.5	36.2	27.3	59.8

Overall, the following conclusions were drawn:

- the crane is capable of delivering raw material to the kilns at the current tap interval of 24 minutes
- the crane will remain capable of supplying the kilns if the tap interval is reduced to 23 minutes, but would become incapable of maintaining 100% kiln utilization at 22 minutes and lower
- train cargoes must be brought into the private railyard sidings in an explicitly specified order to support tap intervals shorter than 24 minutes
- train switching must occur when, and only when, all freight cars in a particular siding have been emptied.

5 CONCLUSIONS AND DIRECTION OF FUTURE WORK

Simulation had already become an accepted tool for improvement of manufacturing productivity in this context through documentation of previous successes and availability of training, as advocated by (Williams 1997). Furthermore, simulation is most profitably used not as a "one-shot" technology for addressing questions during process design, but as a continuous improvement tool throughout the lifetime of the manufacturing process (Nelson 1994). The clients and analysis team have identified several promising expansions of this simulation study.

One natural extension of this simulation study is examination of long-term raw-material requirements and assurance of delivery under uncertainty. The simulation may be extended for use in driving material-requirements planning [MRP] using methods described in (Dittrich and Mertens 1995). Such extension invites the expansion of model scope to include services provided by the common-carrier railroad; simulation is highly capable of such rail-capacity planning (Greasley 1996).

Additionally, the simulation will be extended to assess the comparative merits of various scheduling policies when reacting to unexpected equipment downtimes; an example of such simulation usage appears in (Kutanoglu and Sabuncuoglu 1995).

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APPENDIX: TRADEMARKS

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