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SIMULATION-BASED SUPPLY-CHAIN OPTIMIZATION FOR CONSUMER PRODUCTS

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ABSTRACT

This paper presents an application of discrete-event simulation in modeling a supply-chain for consumer products. Optimization of the simulation model provides an efficient way to produce operating recommendations from the model. The use of ProModel and SimRunner in this application describes a modeling and optimization software suite which can be used for supply-chain planning and operation.

1 SUPPLY-CHAIN MODELING

The concept of supply-chain management has become a complex and important facet of manufacturing and delivery systems. Companies desire supply-chains that are lean on inventory, responsive to customer demands with global markets and suppliers. These three seemingly contradictory goals need to be monitored and input factors managed to anticipate and plan for any uncertainty in supply, demand and costs. Through observational data and simulation, companies have identified "bull whip" effects in supply-chains where small movements in any key link in the chain cause dramatic negative consequences rippling throughout the chain.

In this application, a linear program had been employed to provide cost models for supply-chain management which attempt to satisfy the three objectives of low cost, high service and inventory control. The company sited that the LP models did not account for variability and must be maintained and analyzed as input data changed. While simulation is a proven tool to account for variability and data fluctuations, the iterative nature of simulation experimentation has been a shortcoming which has limited the use of simulation for supply-chain modeling due to the number of possible combinations and permutations.

2 THE SUPPLY-CHAIN DESCRIPTION & GOALS

An international consumer product company was agreeable to developing the application and testing the suitability of simulating and optimizing their supply-chain. The model consisted of two factories, two distribution centers, four products and four shipment routes. Each factory was simplified into capacity constrained workcenters with two workcenters for products A & B and three workcenters for products C & D. Each workcenter had production rates (cases/shift) and schedules (shifts/day and days/month) which provided the plant-level simulation input data.

The company provided forecasted monthly production requirements for each distribution center. Due to market competition, the commodity nature of the products and the management policies of the company, the supply-chain had to provide 100% of the forecasted requirements. Service levels below 100% were not acceptable.

The company's goals in this effort were to:

- Build a model which accurately represents the data
- To run the model through a forecast year
- To derive production costs by factory
- To derive delivered costs by product/factory/distribution center and route
- To identify the least-cost sourcing solution (capacity constrained)

At this point in the project, sufficient information was available to build the ProModel simulation model of the plant operations. This first model provided an easy way to verify and validate the modeled plant operations. The model was used to evaluate the aggregate production requirements (for both distribution centers) before adding further detail to insure sufficient plant capacity. Another finding from the initial model was that both plants were required since neither plant had capacity to provide a single source of supply for any of the four products.

Confident that the model was performing correctly with sufficient supply capability, the two distribution centers, shipping delays and costing information were added to the model. This step-wise approach to incremental model building is recommended to provide rapid modeling, accurate results and customer-approved simulation models. Adding two distribution centers increased the complexity of the model and defined the number of variables to be used in the optimization. Production demands (N) ranged from 48K to 60K cases per month for each product. With four products (i), two plants (j) and two distribution centers (k) the number of ways to schedule this system was:

$$Nijk = 50K(4)(2)(2) = 800{,}000 \qquad (1)$$

The capacity of the distribution centers was considered as infinite and therefore did not enter into the capacity constraints. Also, there were no plant-to-distribution center rules other than varying shipping delays based on which plant was supplying which distribution center.

Costs were entered to produce each product at each manufacturing plant (dollars per case) for both fixed and variable costs. Freight costs including applicable taxes were also entered into the model. The animation layout is shown in Figure 1.

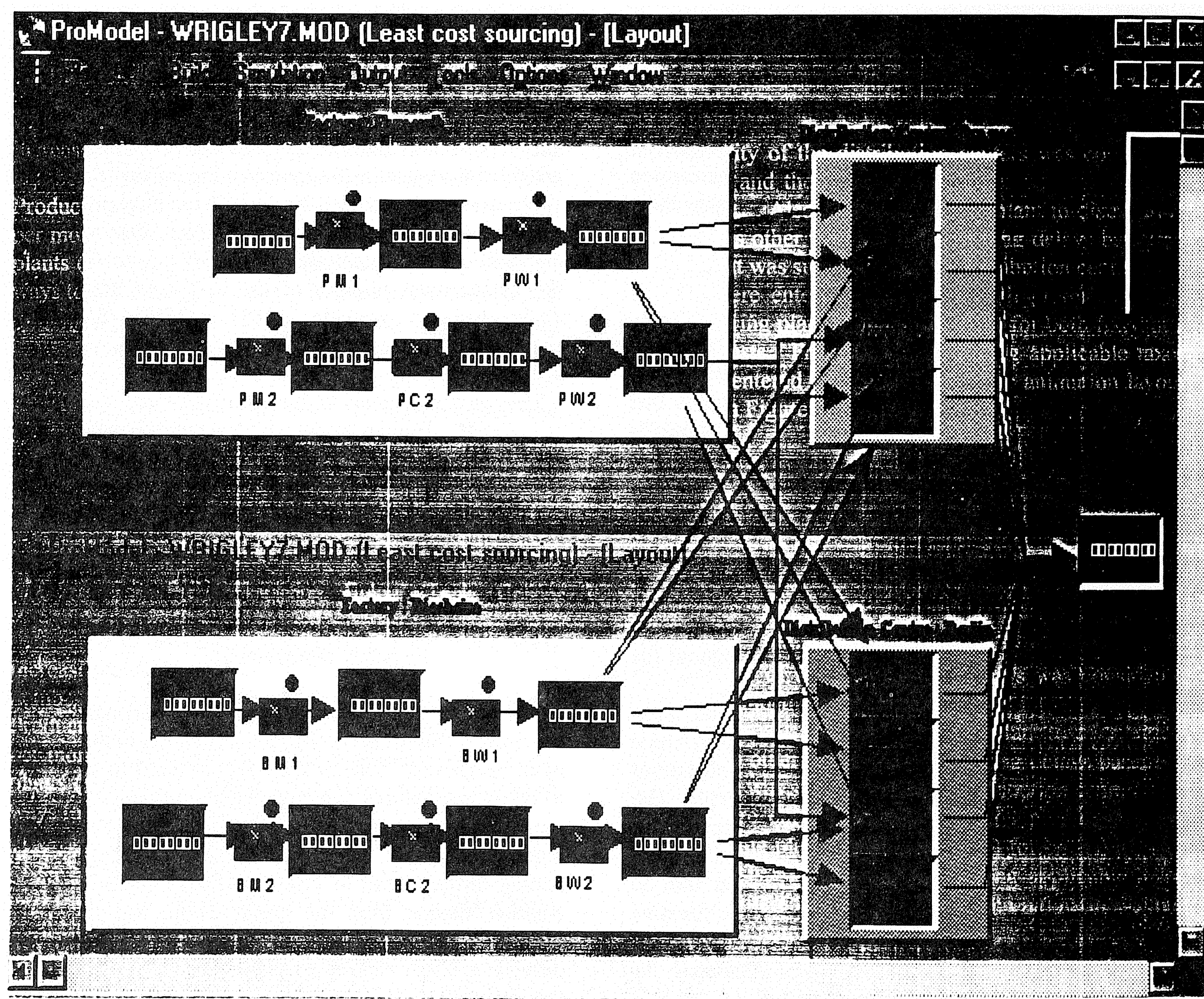


Figure 1: Layout of Supply-Chain Model

3 MODELING CONSIDERATIONS

The ProModel for Windows package provides many convenient features for modeling constrained supply chains. Also, the optimization capabilities and seamless linkage with SimRunner makes for easy, yet complex analysis to be performed. The model was designed to generate product demand with an attribute to designate the final distribution center location. Macros were established in the model to vary the amount of each product produced at each factory. By using macros, SimRunner was then able to run experiments on the supply-chain model, varying and eventually optimizing the four key variables.

Capacity was modeled using finite queues for each production line. Each of these queues had overflow capacity at the other factory. During the optimization, SimRunner could generate a schedule which exceeded the capacity of a particular production line. However, the alternate routing capability in ProModel allowed the model to maintain capacity constraints. Following production, the product was routed to the appropriate distribution center based on the predetermined attribute. Therefore, plant capacity and distribution center requirements were maintained.

As each case of product was produced, costs based on factory and product were assigned to the product category and the factory. Based on the routing chosen, transportation costs and taxes were calculated and summed as product was delivered to the distribution centers. Upon completion of each simulation experiment, a variable (TOTAL_COST) was calculated in the termination logic of the model. This was a sum of all the four (4) product category costs and represented the objective function for SimRunner to optimize (minimize).

4 OPTIMIZATION OF THE SUPPLY-CHAIN MODEL

Figure 2 shows the input for the SimRunner optimizer. The four (4) factors listed are ProModel macros which are varied during SimRunner's DOE and optimization. In this application, the objective function includes only one (1) term, TOTAL_COST as described above. It is possible to construct a multi-variable, weighted objective function.

In the scenario presented in Figure 2, one month's production was analyzed. SimRunner ran 246 experiments in optimizing the schedule. The results of the SimRunner optimization are shown in Figure 3.

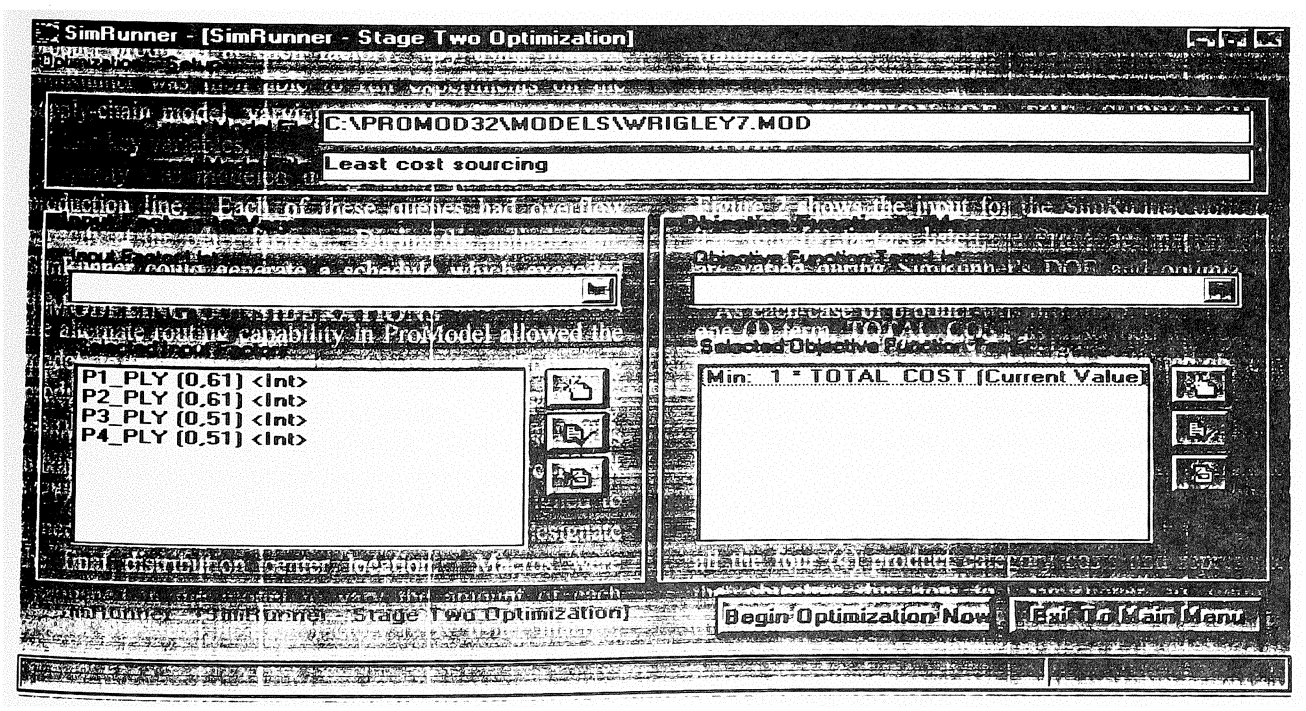
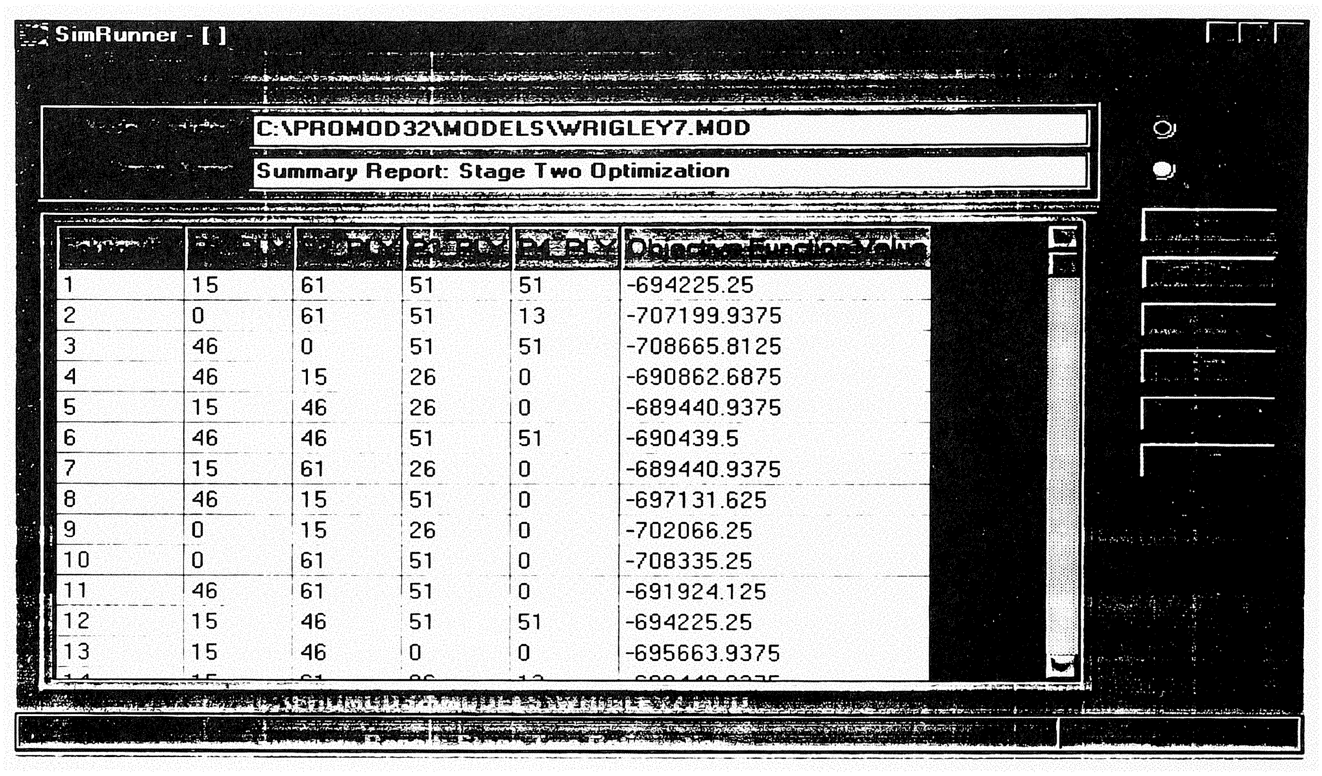


Figure 2: Data Entry Screen for the SimRunner Optimizer



[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	15	61	51	51	-694225.25
2	0	61	51	13	-707199.9375
3	46	0	51	51	-708665.8125
4	46	15	26	0	-690862.6875
5	15	46	26	0	-689440.9375
6	46	46	51	51	-690439.5
7	15	61	26	0	-689440.9375
8	46	15	51	0	-697131.625
9	0	15	26	0	-702066.25
10	0	61	51	0	-708335.25
11	46	61	51	0	-691924.125
12	15	46	51	51	-694225.25
13	15	46	0	0	-695663.9375

Model Optimized: C:\PROMOD32\MODELS\WRIGLEY7.MOD

Input Factors that were optimized:
  P1_PLY (0 to 61)
  P2_PLY (0 to 61)
  P3_PLY (0 to 51)
  P4_PLY (0 to 51)

Objective Function Terms that were measured:
  1 * TOTAL_COST (Current Value)

246 experiments were run.

The best solution found:
  P1_PLY = 27
  P2_PLY = 52
  P3_PLY = 28
  P4_PLY = 42

The best objective function value is -678544.5

Figure 3: Results of the SimRunner Optimizer

The recommended (optimal) schedule for the first factory is as shown below:

- 27 units of product A
- 52 units of product B
- 28 units of product C
- 42 units of product D

Products A & B are produced on the same line in each factory. Products C & D are produced on the same line in each factory. Both of these combined production requirements exceeds the capacity of the lines at factory 1. Therefore, we must look to the ProModel output report to see how alternate capacity at factory 2 was allocated. In section 3 we explained this anticipated capacity issue and used the modeling and optimization features of the products to minimize modeling effort and optimization run-time.

5 VALIDATION AND OUTPUT ANALYSIS

The optimized model recommended that all of the capacity from factory 1, the low cost provider, be used to supply distribution center 1 for all four products. Additional supply from factory 1, up to its capacity, was used to supply products 2 and 4 to the second distribution center. The capacity from the second factory was used to supply the second distribution center for all products where the cost differences were minimal between the two sources. This recommendation matched the expected results, when calculated manually and noting that the factory capacity and distribution center requirements were met.

6 CONCLUSIONS AND OBSERVATIONS

This application of discrete event simulation and optimization proved that the combined technologies are a viable and useful tool for planning and operation of supply-chains. This approach allows for an accurate model with variability to be constructed and then optimized in an efficient algorithm. SimRunner establishes a designed experiment (DOE) to begin convergence on the optimal answer from the ProModel simulation model. The algorithm is adaptive in that the results from the DOE direct the final local optimization search.

While the example problem was small, it was a real problem with a fair degree of complexity (800,000 possible solutions) and was executed in a matter of minutes on a personal computer. The effort did require a competency in the use of the simulation package as well as familiarity with the optimizer to insure valid results. Akbay (1996) has a good description of other uses of optimizing discrete-event simulations in the areas of manpower planning, line balancing and scheduling. As computing power becomes more available and affordable, further uses of these technologies will be developed and existing static and deterministic methods will be displaced.

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