Proceedings of the 1997 Winter Simulation Conference
ed. S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson

SIMULATION BASED APPROACH TO STUDY THE INTERACTION OF SCHEDULING AND ROUTING ON A LOGISTIC NETWORK

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ABSTRACT

This research investigates the interaction of production scheduling and routing/transportation on a logistic network. Basic scheduling rules and existing routing/transportation alternatives were studied using a simulation model, with cost and customer service levels as measures of performance. The simulation model, including network configuration, orders, service times, etc., was based on a “real world” electronic manufacturer, where the production process requires components to flow through three facilities. The two existing routing/transportation alternatives are ocean and air freight. The analysis of the results indicated that certain combinations of scheduling and routing rules result in low manufacturing-logistic costs while maintain high levels of customer service.

1 INTRODUCTION

Companies continue to expand into the global marketplace and into global manufacturing. A growing number of products, from toys to automobiles, are manufactured in multiple plants scattered around the world. Products that were previously manufactured in a single location, are now manufactured on a complex network of facilities separated by thousands of miles. Efficient coordination of this network is essential to the success of many of today’s global corporations.

Companies divide manufacturing operations in order to move production activities to the various regions of the world (or within a country) where they add the most value to a product (Fawcett 1992). In the last 30 years, labor intensive manufacturers have moved a large percentage of their operations to Third World countries to exploit low wages and growing markets. Other reasons used to move manufacturing operations include the tax incentives in free-trade zones, the abundance of raw material, an unlimited workforce, and the availability of technological expertise. The most important driving force to divide and relocate manufacturing operations is the reduction of production costs from a low-wage, or non-unionized, workforce.

Most companies, however, do not foresee increases in other costs—especially, logistic and customer service costs—when analyzing the division of manufacturing operations (Turnquist 1992). Costs overruns in transportation and inventories have caused the reduction or elimination of a number of multi-plant manufacturing networks. One of the major reasons behind these failures is the focus on partial optimizations, away from a systems view. To be successful, organizations must realize the existence of manufacturing-logistic tradeoffs (Fawcett 1992). The production planning function must consider all of the required manufacturing-logistic resources and constraints in order to ‘optimize’ the performance of the whole system. Simulation has been used for manufacturing and logistic planning for more than twenty years (Ballou 1992). The use of simulation modeling in logistic systems is the result of high complexity and variability. As additional control and policy functions are added to the model in order to include both logistic and scheduling control, the need for a simulation approach increases.

This paper describes an extension of an existing project that addresses the use of simulation modeling in manufacturing-logistic systems. This paper focuses on the interaction of routing/transportation and scheduling on logistic networks. The first objective of this paper is to show the importance of considering the interaction between production and transportation decision making on logistics networks. The second objective is to demonstrate how a study of the processes can lead to better overall performance. By using simulation models that include basic scheduling rules, and existing transportation options, an organization could analyze multiple scenarios and determine the best manufacturing-logistic tradeoffs in terms of cost and customer service levels.

2 THE INTERACTION OF SCHEDULING AND LOGISTICS DECISION MAKING

The process of manufacturing products becomes increasingly complex as manufacturing is divided into multi-location chains. An important component in the process of manufacturing goods is the allocation of resources over time (e.g., production cells) to perform a series of tasks (Baker 1974). Scheduling is the application of models and methods to allocate these resources over time to optimize one or more objectives. Most of the current scheduling applications focuses in production systems, but increasingly they have been applied to information processing, distribution, and human resource management (Pinedo 1995).

A logistics system includes the procedures to move and store parts, both inside and outside the factory (Miller 1994). Logistics decision making has concentrated in developing models and policies to plan and control inventory, facilities, and transportation elements. The models developed in the past have addressed four logistic systems sub problems: facility location, network flows, transport modeling, and inventory modeling (Ballou 1992).

The integration of resource allocation over time (scheduling) and inventory/transportation policy making is receiving increasing attention by both academia and industry. However, most ‘real’ production planning functions are still concerned with scheduling at the factory floor level, while most logistics planning functions are concerned with the availability of raw materials and finished product distribution. Several authors have recognized the importance of integrating these two areas as Hameri and Paatela (1995).

Newhart et. al. (1993) investigated the design of a system integrating batch size and inventory level decision making. These researchers illustrated how measures related to cost and customer service changed depending on different combinations of strategies to select batch sizes and inventory levels at each point of the supply chain. Related research at the production floor level by Tu and Sorgen (1991) describes a tool that integrates scheduling and routing control.

3 SYSTEM DESCRIPTION

Figure 1 shows an organization with three factories in separate countries which manufactures electronic components. Products are made to customer order and to stock, and production flows among locations in *A*-*B*-*C* order. The products are sub-assembled in facility *A*, and then transported to facility *B* for final assembly and inspection. Finally, all parts are transported to facility *C* for labeling and packaging. For the purpose of this study, all parts depart the system when they are finished in facility *C* and ready to be sent to the finished products warehouse or to the customer. A single product line with annual volumes of about two million units is considered. There are three major versions of the product and a set-up process is required in all plants for product type changes.

3.1 Current Production Scheduling

The production planning function controls the release of all orders into each of the manufacturing centers. Production planning is based on a MRP system and a completion date is assigned to all orders. Completion times for orders to stock is based on the order’s production

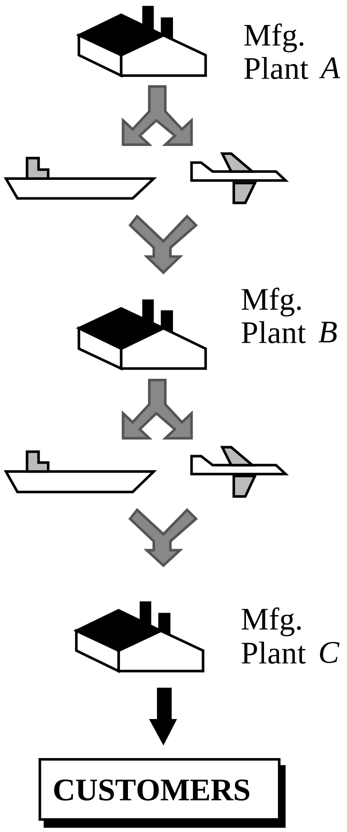

Figure 1: Description of a multi-location manufacturing chain

time plus a 26 working day slack allotment, while customer orders have a 15 working day slack allotment. The company used experience and previous performance to estimate the slack time. At the floor level, orders are scheduled on a FIFO basis. To give priority to customer or late orders, however, expediting and other system disruptions, such as batch preemption, are very common.

3.2 Current Logistics Planning

The materials planning function oversees raw and work in process (WIP) inventories, and transportation mode selection. Raw material orders are determined by the MRP system, which includes forecasts for customer orders. WIP inventories are not planned, but are the result of blockages or transportation time. All orders are shipped as soon as they are ready. The transportation policy at both locations focuses on the use of consolidated ocean freight to keep the use of air cargo shipments to a minimum. However, there is a tendency to use air cargo at the end of the month to expedite late customer orders and maintain on-time performance levels for the monthly review.

The performance (reliability) and availability of the two transportation modes is controlled by several factors including weather conditions and customs. The air cargo mode is available everyday, while ships are available four times per week. Customs (inspection) plays an important role in the movement of goods across locations, as it is a highly political and uncontrollable matter. One year of transportation data from several carriers was used to create a general distribution for the transportation lead-time for the two possible modes.

4 THE EXPERIMENTAL FRAMEWORK

This section presents the three major components of this investigation: the cost model, the production scheduling rules, and the routing/transportation alternatives. The simulation model of the system described in Section 3.0, and the cost model (described next) provide a constant framework to investigate the effect of changes in performance caused by changes in the scheduling and transportation policies. The simulation model was developed in the Extend simulation software, and validated. The model validation consisted in comparing the simulation's output to actual performance for one year of actual orders (input).

4.1 Cost Model

The logistic-manufacturing cost model is illustrated in Table 1. These costs include set-up, inventory, transportation, and finally customer discount costs due to late orders. Some of the cost were obtained directly from the organizations records, while others were estimated given average product cost (Note: average daily production for both production centers is 8,000 units).

Table 1: Cost Model

$TC = LC + MC + CSC$

$LC = 4{,}500(C_T) + 375\,(T_{AC}) + 67(T_S)$
$MC = 25{,}000(St_A) + 20{,}000(St_B) + 5{,}000(St_C)$
$CSC = 125(L_{CU}) + 435(L_{SU})$

Where

TC = Total Cost ($)
LC = Logistic Cost ($)
MC = Manufacturing Cost ($)
CSC = Customer Service Cost ($)
St_A = Total Set-up time (days), Location A
St_B = Total Set-up time (days), Location B
St_C = Total Set-up time (days), Location C
C_T = Average Cycle Time
T_{AC} = Total number of units transported by Air (000)
T_S = Total number of units transported by Ship (000)
L_{CU} = Total number of late Customer Units (000)
L_{SU} = Total number of late Stock Units (000)

25,000 = Cost of lost production ($/day), location *A*
20,000 = Cost of lost production ($/day), location *B*
5,000 = Cost of lost production ($/day), location *C*
4,500 = Inventory Cost
375 = Air Cargo cost ($/1,000 units)
67 = Ocean Freight cost ($/1,000 units)
435 = Discount for late customer orders [cost] ($/1,000 units)
125 = Discount for late stock orders [cost] ($/1,000 units)

In addition to the total cost (TC), several measures related to customer service are considered in the company's review system. These measures include the number of units late (made to stock, customer orders, total), the number of orders late (customer orders) and the number of days late. Especially important are service measures related to customer orders.

4.2 Scheduling Rules

At each manufacturing location, five scheduling rules are experimentally used to determine which order "enters" the production center next. Selection of orders is determined from among all the orders that are waiting in the staging area at the time the current order is completed. On average, only a few orders are waiting on the staging area (< 7). Finally, orders cannot be preempted (an occurrence in the actual system) as a simplification of the simulation model, and to follow the company's official procedures.

The five scheduling rules are presented in Table 2. FIFO, or first-in first-out, organizes waiting orders in order of arrival. The earliest due date rule, EDD, organizes waiting orders by their assigned due date. The TYPE rule separates all waiting orders into two groups, the customer orders first, then stock orders. If there are more than one of any type, it organizes them by their due date. Note that this rule always schedules first all customer order, regardless of the number and arrival time of made-to-stock orders in the queue. The SPT rule organizes orders by the batch size (number of units). If there are ties, orders are organized by their due date. Finally, in the SET_UP rule, an order is selected from the queue if it is of the same product type as the current order in the production floor. If there is more than one order of the current type in the queue, of those, the order with the smallest due date is selected. If there is no order in the queue of the same type, the order with the lowest due date is selected.

Table 2: Scheduling Rules

Name	**Attribute**	**Objective**
FIFO	Arrival Time	To maintain orders waiting the minimum possible.
EDD	Promised Date	Minimize the difference between an order's due date and its completion time.
TYPE	Order Type	To serve customer orders first.
SPT	Batch Size	Minimize the average cycle time.
SET_UP	Product Type	Minimize the total set-up time.

4.3 Transportation Rules

After each manufacturing stage, each order is routed to the next manufacturing plant by one of two carrier modes. Company tractor-trailers are used to move parts from the factories to the airport or dock. Although there are only two possible modes, three rules on how to assign orders to a mode are investigated and presented in Table 3. The SHIP rule assigns all orders to be transported by ocean freight. The AIR rule assigns air cargo to all customer orders, and ocean freight to all stock orders. Finally, the AIR_DD rule assigns to air cargo only those customer orders that are close of being late.

Table 3: Transportation Rules

Name	**Objective**
SHIP	To minimize transportation cost.
AIR	To speed up all customer orders to their next production stage.
AIR_DD	To speed up all customer orders that are close to their due date.

5 RESULTS

Table 4 presents the performance of the five production scheduling rules combined with the three transportation rules. The table presents logistic, manufacturing, customer service, and total costs. The table also presents two measures of performance related to customer order on time performance: the percentage of customer orders late CO-Late(%) and the average number of days late for those orders, CO-Late(d). Several relevant results in relation to our cost model include:

1. When the total cost, TC, and the percentage of customer orders late are considered, the number of Pareto Efficient solutions is small (only 4). The SET_UP-SHIP combination provides the lowest cost solution (TC = \$947K, CO-Late(%) = 55.3%), while the SPT-AIR combination provides the lowest number of customer orders late (TC = \$1212K, CO-Late(%) = 1.1%). Two other combinations, SPT-AIR_DD and SET_UP-AIR_DD, provide alternative efficient solutions. This result shows the applicability of this analysis on a periodic decision making system that determines scheduling and transportation policies. As the number of efficient solution is small, decision-makers can choose from among the few efficient choices for the best tradeoff solution.

2. In terms of costs, each of the three primary costs (LC, CSC, MC) was affected differently by transportation and scheduling rules. Logistic costs were minimized by the SPT rule (minimizes inventory costs), while the SET_UP rule minimized manufacturing costs (less set-ups). Customer service costs were minimized by the SPT rule, a result that can be explained by a larger total number of on-time stock orders. In terms of the three transportation options, the SHIP transportation rule was the most cost-effective choice, as logistics cost skyrocket as air-freight is used to move products.
3. In terms of the customer service measures, late orders are minimized by the SPT and EDD scheduling rules, and by the AIR transportation rule. In all cases the EDD scheduling rule minimized the average number of days late.
4. A statistical analysis of the results demonstrated that both the scheduling and transportation rules had a large effect on both TC and CO-Late(%). The analysis also showed that there are strong interaction effects between several of the scheduling and transportation rules: The FIFO rule, and the interactions FIFO-SHIP, FIFO-AIR, and FIFO-AIR_DD had a strong effect on the CO-Late(%) result (higher). Similarly, the interaction terms TYPE-AIR, SPT-AIR and SPT-AIR_DD had a strong effect on CO-Late(%) (lower). In terms of total cost, the FIFO-AIR, TYPE-AIR, EDD-AIR, FIFO-AIR_DD, and SET_UP-SHIP interactions were the most significant, with SET_UP-SHIP the only combination with a reducing effect on TC.

In general these results support the idea that a combination of scheduling and transportation rules has an effect on total network costs and customer service performance. A change in either the scheduling or routing/transportation policy affects both manufacturing and logistics costs, and the service provided to the customers. This study not only shows that the scheduling-routing interaction affects the performance of the system, but that there are combinations that can reduce total costs, and simultaneously maintain high levels of customer service. In terms of the company being studied, it was shown that changing from FIFO scheduling to SPT, and utilizing air only on those orders that were close to their due dates (SPT-AIR_DD), could reduce total costs and improve customer service levels. Two areas of future work include due date assignment and the selection of the cutoff point for orders that are close to their due dates based on shop conditions, routing options and inventory levels.

Table 4: Summary of the Results

		FIFO	EDD	TYPE	SPT	SET_UP
SHIP	CSC	*137,000*	*131,000*	*125,500*	*120,000*	*118,000*
	MC	*604,500*	*565,500*	*567,800*	*587,300*	*473,200*
	LC	*365,360*	*358,205*	*358,295*	*350,645*	*356,630*
	TC	1,106,860	1,054,705	1,051,595	1,057,945	947,830
	CO-Late(%)	72.3 %	47.8 %	53.2 %	51.1 %	55.3 %
	CO-Late (days)	9.2	4.0	5.8	4.2	12.1
AIR	CSC	*109,500*	*73,000*	*57,000*	*36,000*	*67,500*
	MC	*582,100*	*577,500*	*559,000*	*587,300*	*461,800*
	LC	*594,145*	*593,155*	*593,695*	*588,700*	*585,415*
	TC	1,285,745	1,243,655	1,209,695	1,212,000	1,114,715
	CO-Late(%)	57.4 %	14.9 %	10.6 %	1.1 %	23.4 %
	CO-Late (days)	5.9	4.1	5.8	5.3	14.5
AIR_DD	CSC	*109,500*	*65,500*	*53,500*	*53,000*	*88,500*
	MC	*578,500*	*568,100*	*564,600*	*578,500*	*468,000*
	LC	*527,855*	*465,680*	*460,750*	*445,995*	*490,880*
	TC	1,215,855	1,099,280	1,078,850	1,077,495	1,047,380
	CO-Late(%)	61.4 %	17.0 %	12.8 %	8.5 %	36.2 %
	CO-Late (days)	4.9	2.3	2.3	2.4	6.5

6 CONCLUSIONS

The globalization of manufacturing requires that companies recognize the existence of manufacturing-logistic tradeoffs. This study demonstrated the importance of considering the interaction between scheduling and routing/transportation rules. This study also demonstrated that certain combinations of scheduling and routing rules result in low manufacturing-logistic costs while maintain high levels of customer service.

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