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SIMULATING THE EFFECTS OF WORK-IN-PROCESS ON CUSTOMER SATISFACTION IN A MANUFACTURING ENVIRONMENT

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ABSTRACT

This paper addresses the effects of varying levels of Work-In-Process (WIP) on product turntime, delivery time, and customer satisfaction. By analyzing a static manufacturing process with known demand, a company can determine the optimum level of Work-In-Process, meet customer demand, and ensure customer satisfaction. Determining the optimum level of Work-In-Process through actual changes in the manufacturing process can negatively affect customer satisfaction. Attempting to find the optimum level via a spreadsheet model will not take into account the interdependency of resources. Development of a simulation model allows for off-line analysis without any physical changes to the process and will provide better results than a standard spreadsheet model.

1 INTRODUCTION

This paper presents a model to evaluate the effects of various Work-In-Process levels in a static manufacturing process. With the optimum level of Work-In-Process, a company meets customer demand at a minimal cost. Work-In-Process directly affects product turntime through queue size. The greater the amount of Work-In-Process, the larger the queues, and therefore longer product turntime. Conversely, a low Work-In-Process level can lengthen delivery time through a lack of available parts. This problem, common to many manufacturing firms, can be solved through the use of simulation. A simulation model can determine the equilibrium point of Work-In-Process versus product turntime and delivery time for the best level of customer satisfaction.

This paper is organized as follows: Section 2 provides an overview of the business process illustrating the interdependent relationship of Work-In-Process, product turntime, inventory, delivery time, and customer satisfaction. Section 3 describes the model used to evaluate the system. Section 4 summarizes and discusses the results of our model. Finally, Section 5 presents the conclusions.

2 THE BUSINESS PROCESS

2.1 Customer Satisfaction and Delivery Time

In increasingly competitive markets, customer satisfaction determines a company's survival. A company must know the customer and what he/she expects. To make money, the company must consistently meet or exceed customer expectations. Reducing product delivery time increases customer satisfaction. The faster a company delivers a product which meets or exceeds customer expectations, the more satisfied the customer. Figure 1 illustrates the relationship of faster delivery time with increasing customer satisfaction. As delivery time is reduced, customer satisfaction increases.

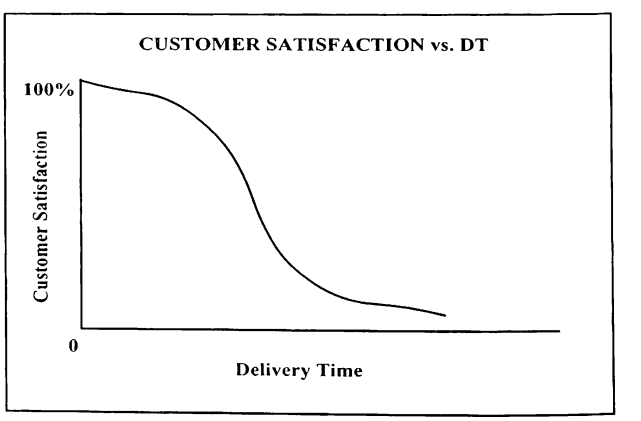

Figure 1: Customer Satisfaction vs. Delivery Time (DT)

2.2 Product Turntime

Product turntime and inventory level establish delivery time. Product turntime is the amount of time it takes to

complete all processes needed in the creation of a product. If product turntime is long, it will delay delivery of the product and negatively affect customer satisfaction. Figure 2 illustrates a delivery time and product turntime relationship. As product turntime increases, delivery time increases, thereby reducing customer satisfaction.

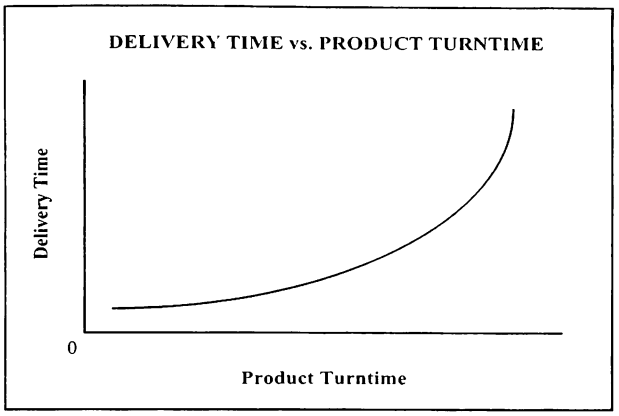

Figure 2: Delivery Time (DT) vs. Product Turntime (TT)

2.3 Inventory

An inventory level of finished products can be established to offset a long product turntime. However, if the inventory level is not adequate to meet customer demand, delivery time is adversely affected. A company must find the level of inventory that provides a satisfactory delivery time to its customers.

Many companies attempt to solve the problem of high product turntime by increasing inventory level to improve customer satisfaction. However, this may tie up manufacturing resources and waste valuable facility space that could be used in more productive ways.

Likewise, to lower product turntime and inventory level simultaneously, companies often mistakenly "throw" capacity at a problem by adding manpower or equipment. However, too much capacity decreases the profit margin by increasing production cost.

2.4 Work-In-Process

The amount of WIP in the manufacturing process influences product turntime and inventory. Too much WIP increases turntime. Larger queues form at each station, and a general confusion develops of what process to perform, on what product, at what time. Too little WIP increases product turntime by not having the needed product at the right place at the right time in the manufacturing process. Generally, a U-curve illustrates the association for WIP levels (see Figure 3).

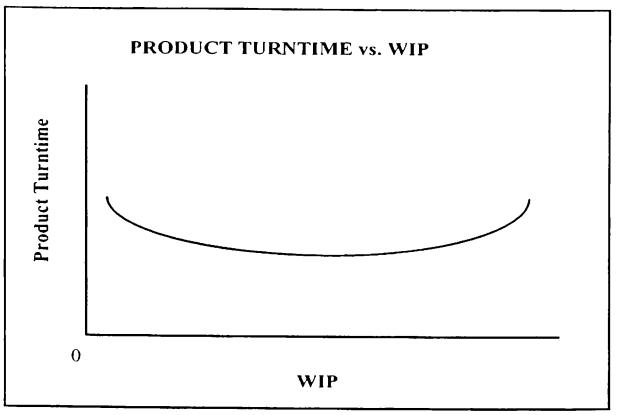

Figure 3: Product Turntime (TT) vs. WIP

At the equilibrium point, a specific amount of WIP produces the shortest product turntime with the best customer service. As WIP increases, queue time increases, driving up product turntime. Companies gain only minimal benefits by pushing employees to work faster. In some instances, as WIP decreases below the equilibrium point, workers hold work and cause product turntime to increase. The effect on the left side of the equilibrium point is usually less drastic than on the right. Finding the equilibrium point by varying actual WIP is costly to customer service. Determining the level through a simulation model however, allows the company to test different scenarios without harming the working environment.

3 DEVELOPING THE MODEL DEFINITION

3.1 Model Definition

This model shows the effects of WIP on customer satisfaction. Therefore, the only variable modified between runs in the test simulation will be WIP. Resources, processes, routings, and demand remain constant. Although modifying these factors may impact customer satisfaction, they will remain unchanged throughout all simulation runs to isolate the effects of WIP level changes. Two scenarios will be tested: (1) resource capacity derived using mode process time and (2) resource capacity derived using maximum process time.

To determine the proper amount of WIP, we established measures for average turntime, average delivery time, and average customer satisfaction. While the goal of this simulation is to achieve the best customer satisfaction, this may not apply to every situation. Some businesses may trade reduced service level for reduced cost to provide a higher profit margin. Each situation differs and therefore must be modeled differently.

3.2 Building the Model

3.2.1 General Plant Description

The plant produces three products: A, B, and C. Each of the three products has its own unique routing encompassing some of the eight resources within the plant. The process time on each resource varies by product. In the model, each product will seize, delay, and release each resource in its routing. Generic equipment is used with no conflicts for personnel and no downtime. Their respective capacities are derived by multiplying the average demand per product over a time period and their respective process times. Figure 4 illustrates the general philosophy used when building the model. Raw material waits to seize WIP capacity. Once produced, the final product enters inventory until ordered.

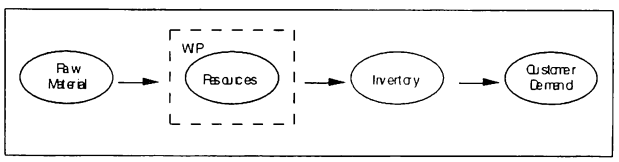

Figure 4: Process Flow

3.2.2 Raw Material and Final Product Generation

The model creates raw material on a percentage basis based on the average demand of the three products. However, it creates the raw material at a faster rate than demand to ensure availability of WIP at the determined level. To offset orders during the initial loading of the plant, finished product is added to inventory for each product based on the demand during the mode process time.

3.2.3 WIP Level Control

The WIP level is controlled through a false resource called WIP_Level, which raw material seizes as it enters the cycle and releases when the final product is complete. The WIP_Level capacity is the only variable changed during all simulation runs.

3.2.4 Product Demand and Delivery Time

Orders are placed every day for product A, every five days for product B, and every 10 days for product C. If the product is available from inventory, the order is satisfied with instantaneous delivery (no delay). If unavailable from inventory, time accrues daily until the order is satisfied.

3.2.5 Measures

Turntime equals the time when raw material enters the process until the product is complete. Delivery time is the sum of days the product is unavailable for delivery after an order. The number of orders equals the number of initial orders (each subsequent backorder is not counted). Customer satisfaction is a calculation based on average delivery time. The test model assumes customer satisfaction is 100 percent when the product is available from inventory. Any delivery time over 14 days is considered unacceptable. Refer to Table 1 for customer satisfaction index.

Table 1: Customer Satisfaction Index

DELIVERY TIME	CUSTOMER SATISFACTION
Delivery When Ordered	100%
Within 7 days	95%
Within 14 days	85%
Within 21 days	15%
Within 28 days	5%
Within 35 days	5%

3.3 Performing "What-If" Analyses

This simulation model isolates the effects of WIP levels on the desired level of customer satisfaction. Delivery time of the product to the customer determines customer satisfaction. The longer the delivery time, the less satisfied the customer (See Figure 5 for details). To study these effects different levels of WIP are simulated. Performance measures are captured for average turntime, average delivery time, and customer satisfaction. The WIP level is modified based on results from previous runs to highlight the equilibrium point which produces the best customer satisfaction with the best turntime. In addition, outer limits on both sides of the equilibrium point are tested to ensure accuracy.

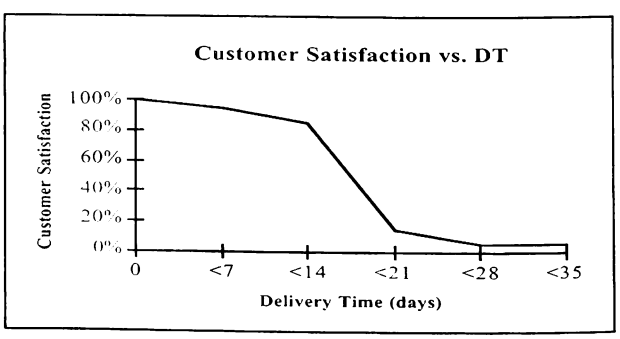

Figure 5: Customer Satisfaction vs. Delivery Time (DT)

4 RESULTS

We ran the simulation model for two scenarios: (1) resource capacity using mode process time and (2) resource capacity using maximum process time. In scenario 1, starting WIP level is 50. For each subsequent run the WIP level is increased in increments of 25. Initial runs show delivery time decreasing as WIP level approaches 100 and increasing as WIP level is increased past 100. Additional runs are made using values of WIP less than and greater than 100 until the best delivery time and customer satisfaction is determined within a WIP range of 100 to 106. Table 2 displays the data captured from these simulation runs for scenario 1.

Table 2: Scenario 1 (Mode Capacity) Results

WIP	Avg. Turntime	Avg. Delivery Time	Customer Service
50	45.76	15.52	15%
75	65.57	15.28	15%
90	76.19	14.59	15%
95	79.81	14.48	15%
100	82.65	13.79	85%
103	84.70	13.79	85%
106	86.73	13.79	85%
110	90.02	14.48	15%
125	99.60	14.48	15%
150	114.08	14.48	15%
250	153.75	14.48	15%
500	163.35	14.48	15%

In scenario 2, the same WIP levels derived from scenario 1 are used. All runs under this scenario produce a 100 percent service level. Table 3 displays the data captured from these simulation runs for scenario 2.

Table 3: Scenario 2 (Maximum Capacity) Results

WIP	Avg. Turntime	Avg. Delivery Time	Customer Service
50	35.07	0	100%
75	50.79	0	100%
90	59.81	0	100%
95	62.59	0	100%
100	65.93	0	100%
103	67.79	0	100%
106	68.99	0	100%
110	71.55	0	100%
125	79.19	0	100%
150	92.06	0	100%
250	133.05	0	100%
500	164.13	0	100%

A comparison of average turntime versus WIP for each scenario shows a fairly constant gap between the two. Average turntime increases as WIP level increases, as shown in Figure 6.

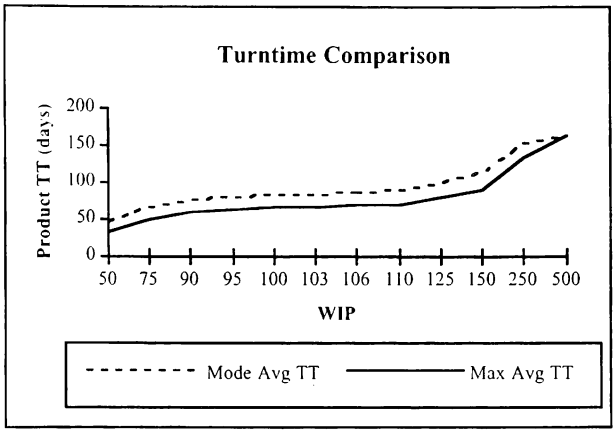

Figure 6: Mode vs. Maximum Capacity Turntime (TT) Comparison

Product Turntime is a component of delivery time. In the model, a low WIP level produces a low product turntime. Unfortunately, too few parts are in the system and delivery time is adversely affected. With a high WIP level, the product turntime is too long, adversely affecting delivery time. The best solution minimized both delivery time and product turntime. Figure 7 illustrates that a WIP level between 100 and 106 produces the best product turntime/delivery time combination.

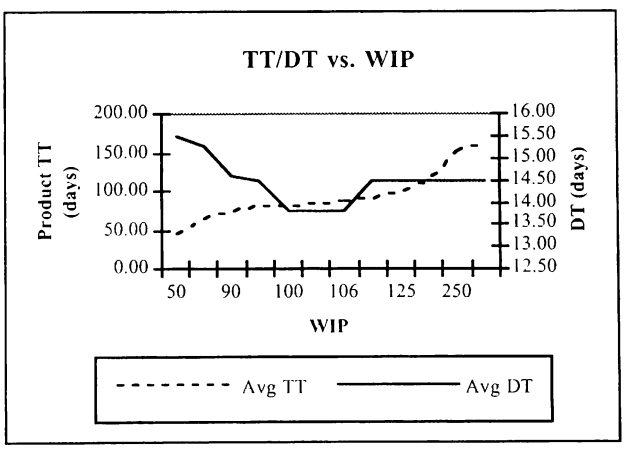

Figure 7: Mode Capacity Turntime (TT) and Delivery Time (DT) vs. WIP

The plant must provide the final product within 14 days. Customer satisfaction suffers greatly with a delivery time over 14 days. The results from scenario 1 and scenario 2,

when combined with the customer satisfaction index, produce the following graph (see Figure 8). As this graph illustrates, for scenario 1 only the WIP levels between 100 and 106 produce the required customer satisfaction. For scenario 2 all tested levels of WIP produce 100 percent customer satisfaction.

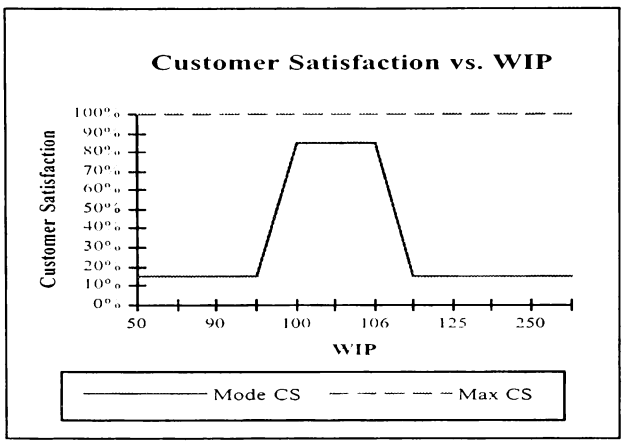

Figure 8: WIP vs. Customer Satisfaction

From these results, scenario 1 suggests an inventory level of 100. This WIP level meets the required 85 percent customer satisfaction and produces the least product turntime, which will allow the plant to be as reactive as possible to demand changes. Because all WIP levels in scenario 2 produce 100 percent customer satisfaction, the best WIP level is 50. Scenarios 1 and 2 cannot be compared against each other without more information on the costs of resources versus the money earned through greater sales.

5 CONCLUSION

While simulation will not produce an exact replica of the environment, simulation will allow for "off-line" analysis of process changes without affecting actual production. By isolating WIP in the system, a simulation model can closely map out the equilibrium point of WIP versus product turntime and delivery time for the best level of customer satisfaction. Simulation produces better results than standard spreadsheet methods because interdependencies between resources are addressed. Further, as more products and resources are modeled, the combinations of interdependencies grow and become impossible to accurately predict using a spreadsheet.

While this test simulation does not make any allowances for the cost of inventory in process or potential lost sales from delivery delays, it demonstrates the effects of WIP on customer satisfaction. By adding a resource that controls the WIP level of the plant, any simulation can be modified to model the effects of WIP level changes.

AUTHOR BIOGRAPHIES

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