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IMPACT OF PRODUCTION RUN LENGTH ON SUPPLY CHAIN PERFORMANCE

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ABSTRACT

This paper documents an experiment designed to show the value of simulation in understanding the relationship between production run lengths and overall supply chain performance. Current production practices and supply chain policies of an existing company provided the starting point for the experiment. The experiment consisted of two deployment scenarios and a range of run length multipliers that vary the company's actual run length rules. Minimum cost run lengths were determined for twelve combinations of cost assumptions for changeovers and inventories.

1 THE VALUE OF FOCUSING ON RUN LENGTH

It is difficult for production schedulers to take into account all of the cost and customer service consequences of production run lengths. It is human nature for production planners to place a high value on the easily quantifiable benefits of longer run lengths but the costs resulting from longer runs are more difficult to quantify.

A better understanding of the full impact of production run lengths on overall supply chain performance may result in recalibration of run length rules. It may also bring focus on the value of reducing the fixed costs of production changeovers. Reducing the time and labor required to change over a production system from one product to the next may have greater value than currently recognized. Even rationalizing production schedules to more carefully control the sequence of runs may have a significant impact on supply chain performance. However, the practice of controlling production sequence to minimize changeover times may have hidden costs of its own.

For a given run length, the higher the rate of demand, the more frequently runs will be made and therefore the lower the holding period and the consequent holding cost. This weighs on the side of consolidating production at single production sites, as opposed to producing a product regionally. Of course regional production may reduce overall transportation cost.

2 FRAMING THE PROBLEM AS EOQ

Production runs have fixed costs, which are amortized over the number of units produced in a run. The cost per unit of fixed costs goes down as the number of units in a run goes up. Counteracting the economy of scale are the costs that result from longer runs. The most quantifiable costs resulting from long runs are inventory-carrying costs. Longer runs will result in higher average inventories as long as the rate of consumption is less that the rate of production. So far, the question of the most economic run length is framed as a traditional supply chain economic order quantity (EOQ) problem. EOQ problems are solved by equations that capture the relationships shown in Figure 1 below. A minimum overall cost is found at the low point of the total cost curve.

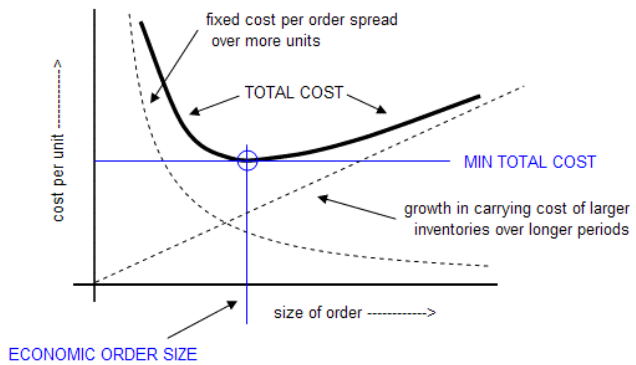

Figure 1: EOC Relationships

3 FULL BREADTH OF SC IMPACT

Cycle stock is that part of a production run that is not consumed downstream during the production run. The amount of cycle stock generated each run is the product of the length of the run and the difference between the production rate and the consumption rate.

3.1 Deployment of Cycle Stock

Companies with multiple supply chain echelons must decide where to deploy cycle stock. For example, if cycle stock of an intermediate product is produced at a plant there may be three options:

- Hold cycle stock in bulk at the plant and package as needed
- Package cycle stock into finished goods and store at plant
- Ship cycle stock downstream to company distribution centers.

The choice among these options is often driven by the availability of storage space at the plant. If storage space is scarce, cycle stock will be shipped to company distribution centers (DC's).

3.2 Allocation of Deployed Cycle Stock

In the above example, in order to package cycle stock, an allocation must be made among the SKU's that can be produced from the bulk material. Depending on the production cycle, this allocation may require a forecast of demand weeks or months in advance. A consequence of less accurate allocation is that one of the SKU's made from the bulk material will run out sooner. This, in turn will result in a shorter production cycle, and higher overall average inventory levels.

In order to ship cycle stock of finished goods downstream, it must be allocated to DC's. Misallocation to DC's may result in the need for redeployment as some DC's run out of the product while others have excess amounts.

3.3 Impact of Forecast Error

Greater forecast error increases the cost of downstream allocation of cycle stock. Unfortunately, the very products likely to have a high ratio of cycle stock to throughput are the ones with relatively low demand. These SKU's also tend to have highly variable and unpredictable demand.

3.4 Resource Utilization

It is common for the systems where run length is of greatest concern to also be the capacity limiting echelon of the supply chain. Longer runs provide less scheduling flexibility and therefore lead to the need for additional safety stock to protect downstream inventories from the fact that the start of a production run may be delayed in order to complete a prior run.

4 EXPERIMENT

To test the sensitivity of supply chain performance and costs to production run length, we designed an experiment based on the practices of a consumer products company.

4.1 Test Case

Company X has four plants producing 14 brands on five mixing systems. These systems feed packaging lines that produce 18 SKU's. Customers are supplied from seven company-owned DC's; although a few customers are supplied directly from the plants. Each DC is assigned to a primary plant. During times of demand over capacity, plants can shift demand to other plants that make the same product. When demand is over capacity system wide, product is pre-built to meet the anticipated excess demand.

4.1.1 Deployment of Cycle Stock

Two deployment scenarios are included in the experiment. In the upstream scenario, all cycle stock and pre-builds are held at the plants until downstream inventory ordering policies request re-supply. In the downstream scenario, cycle stock and pre-builds are pushed downstream as they are produced. Allocation of these stocks to DC's is based on a demand forecast.

4.1.2 Demand Forecast and Forecast Error

Allocation decisions and downstream order points were based on a demand forecast. The look ahead period of the forecast varied with SKU categorization. Forecast error was applied by A, B, and C SKU class based on historical forecast accuracies. All forecast, forecast error and ordering parameters were held constant across all scenarios in the experiment. Precise details on forecasting and ordering policies are beyond the scope of this paper.

4.1.3 Production Parameters

Of the 14 brands, only two are compatible with more than one production system. The others run on only one system. Target run lengths between 2 and 5 days were specified for each allowable brand/system combination, based on current Company X practices. Minimum run lengths were specified both for brands in unit loads and for systems in days.

Changeovers were specified in hours for all combinations of brands for each system.

4.1.4 Production Scheduling

A Most Urgent Order scheduling system was used. Under this scheme, each time a system becomes available after completion of a run, the most urgently needed brand is run without considering the resulting changeover times. Urgency was computed as the number of days of unfilled orders.

4.2 Experiment Methodology

The goal of the experiment was to establish the relationship between run length and key supply chain performance measures under two alternative deployment strategies.

4.2.1 Run Length Multiplier

Alternative run length scenarios were generated by introducing a run length multiplier. Each run length parameter – target run length, minimum quantity for brands, and minimum days for systems – was multiplied by the run length multiplier. The value of the multiplier was varied from 0.05 to 1.50 in increments of 0.05, resulting in 30 scenarios for each deployment strategy.

4.2.2 Deployment Strategies

Upstream and downstream deployment strategies were run, resulting in a total of 60 scenarios combining deployment and run length.

4.2.3 Changeover Cost

In each scenario, the number and total duration of changeovers was measured. Three alternative changeover costs were analyzed: \$40, \$80, and \$160 per hour. These values were intended to cover a range of possible labor and materials costs. No separate cost was included for potential indirect costs of the loss of productivity as total changeover hours increase. Lower productivity potentially increases the amount of production that must be transferred to other plants during peak demand periods.

4.2.4 Inventory Carrying Cost

In each scenario, total unit loads in system were averaged over a period of one year. Four alternative carrying cost rates were analyzed: \$10, \$20, \$50, and \$100 per unit load per year. These costs include the cost of capital, insurance, warehouse space, and handling.

4.2.5 Customer Demand Met

In each scenario, average percent of customer orders filled was measured. Preliminary experiment results are given showing the variation in demand met performance across deployment and run length scenarios.

Note: Company X has a goal of 98% customer demand met. Typically, safety stock parameters will be adjusted from scenario to scenario to achieve this goal. This normalization of customer demand met eliminates the need to convert variations in demand met to a dollar value. In the preliminary experiment, demand was not normalized in order to simplify the experiment, and to see the relationship between run length and demand met.

4.2.6 Replications

Each scenario in the experiment was replicated ten times and the results were averaged. One of the compelling features of simulation is that random fluctuations, which actually occur in real systems, can be used to capture different interactions between systems represented in the model. Averaging the results from ten trials of the same scenario captures the generalized behavior we are interested in quantifying.

5 RESULTS

5.1 Downstream Deployment

Figure 2 shows changeover hours, average unit loads in system, and percent customer demand met for the 30 run length scenarios. Each data point on the chart is an average of 10 replications with random variation from run to run. Above the run length multiplier of 0.50, percent demand met is relatively level. In all cases, percent demand met was below the customer goal of 98%. Unsurprisingly, the changeover hours vary with 1/run length.

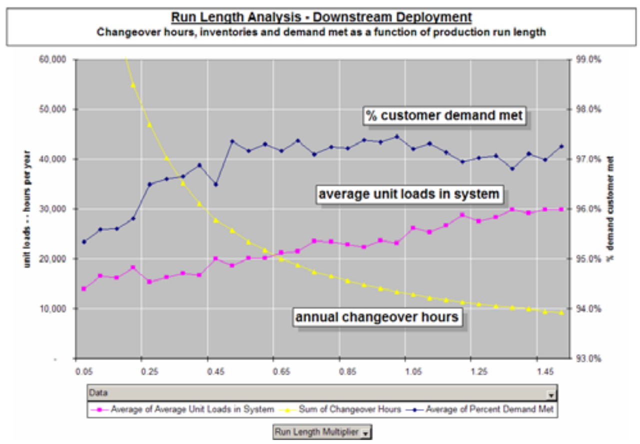

Figure 2: Run Length Analysis – Downstream Deployment, Chart 1

Chart 2 (Figure 3) shows the costs of changeovers and inventories for the upstream scenario at the range of rates being evaluated in the experiment. The next chart, Figure 4 plots the total cost for all twelve combinations of changeover and inventory cost assumptions. The low point of each total cost curve has been estimated. Table 1 summarizes these results. Note that these results do not incorporate the drop off in customer performance at the 0.50 level.

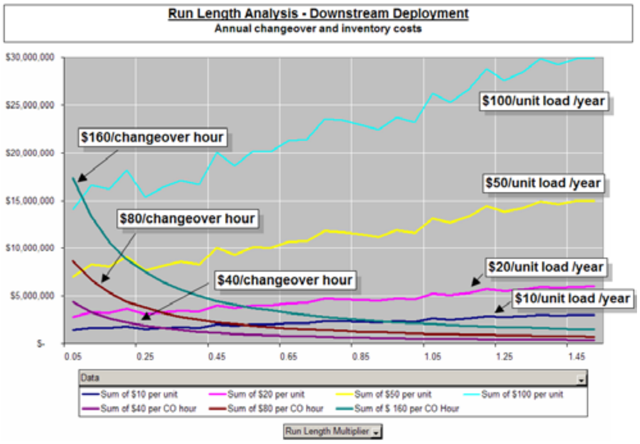

Figure 3: Run Length Analysis – Downstream Deployment, Chart 2

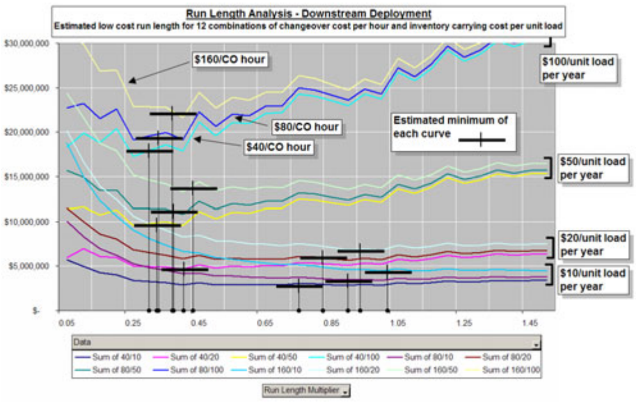

Figure 4: Run Length Analysis – Downstream Deployment, Chart 3

Table 1: Estimated Low Cost Production Run Multipliers – Downstream Deployment

Cost per hour of changeover	**Annual cost to carry one unit load of inventory**			
	$10	$20	$50	$100
$40	0.78	0.42	0.34	0.32
$80	0.92	0.85	0.40	0.35
$160	1.03	0.96	0.46	0.39

Among the twelve cost combinations, only the combination of highest changeover cost and lowest inventory cost are consistent with current run length practices of Company X (multiplier of 1.0). All other combinations would indicate that run lengths should be shorter.

5.2 Upstream Deployment

The three results charts displayed below in Figure 5, Figure 6, and Figure 7 are for upstream deployment with all other parameters set the same as for the downstream deployment reported above.

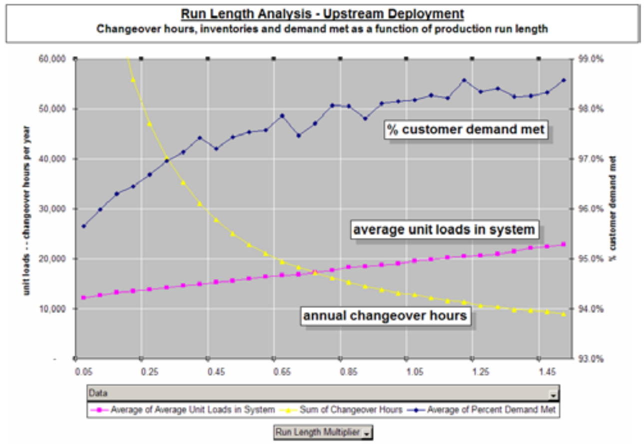

Figure 5: Run Length Analysis – Upstream Deployment, Chart 4

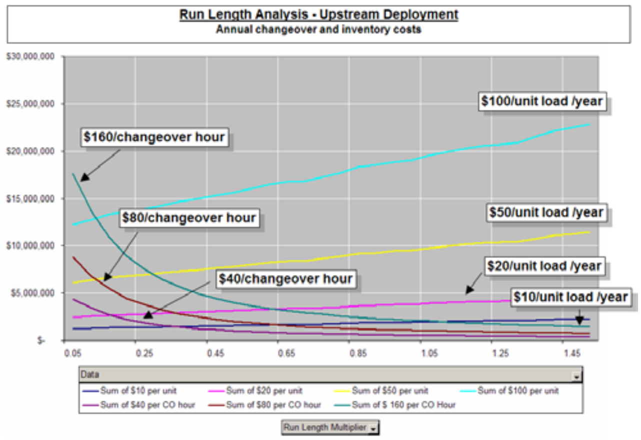

Figure 6: Run Length Analysis – Upstream Deployment, Chart 5

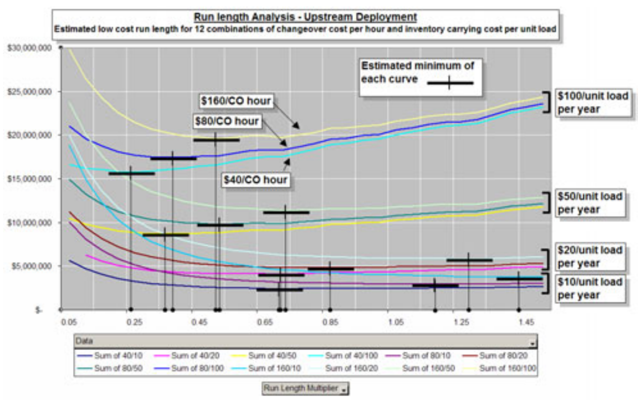

Figure 7: Run Length Analysis – Upstream Deployment, Chart 6

Chart 4 (Figure 5) indicates that upstream deployment is significantly superior to downstream deployment in both customer demand met and average inventories. Unlike the results with upstream deployment, customer demand met continues to increase as run lengths increase. Table 2 summarizes the cost results for the upstream scenarios.

Table 2: Estimated Low Cost Production Run Multipliers – Upstream Deployment

Cost per hour of changeover	**Annual cost to carry one unit load of inventory**			
	$10	$20	$50	$100
$40	0.72	0.72	0.37	0.27
$80	1.20	0.88	0.53	0.39
$160	1.45	1.30	0.73	0.52

6 CONCLUSIONS

We can draw conclusions from this experiment at three levels. First, regardless of run length, for Company X upstream deployment is superior to downstream deployment assuming that storage space is available and inventory-carrying costs are equal. Second, upstream deployment tends to support longer run lengths than downstream deployment. Third, since Company X currently deploys cycle stock downstream, their current run length practices are probably not cost effective.

In spite of the rather interesting results for Company X, we would not suggest that these conclusions could be generalized, even to similar companies within the consumer products sector. These results are likely to be sensitive to numerous factors captured in the simulation of Company X that may be quite different for Company Y or Company Z. To name a few such factors: demand variability, forecast error and forecast bias; sourcing policies, including redeployment and alternative plant sources; integration of segregation of production; ratio of cycle stock to safety stock system wide; and capacity utilization over time. In fact, this model could be used to quantify the effects of the aforementioned factors, too. The purpose of this experiment is not to draw general conclusions about appropriate production run lengths, but rather to show the usefulness of simulation in assessing their system-wide effects.

AUTHOR BIOGRAPHIES

DAVID J. PARSONS is a principal of Simulation Dynamics. He is responsible for development of SDI's Supply Chain Builder, a supply chain simulation and analysis tool. His experience with simulation began in 1965 with experiments in the use of natural selection algorithms to evolve architectural designs. During the 1980's, he designed, built, and operated several dairy-processing plants using simulation of key systems as an integral tool for design, value engineering, and trouble-shooting. Mr. Parsons received a B.A. from Harvard College and a Master of Architecture degree from the Harvard School of Design. His e-mail and web addresses are: <Parsons@SimulationDynamics.com> and <www.SimulationDynamics.com>.

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