A DETERMINISTIC SPREADSHEET SIMULATION MODEL FOR PRODUCTION SCHEDULING IN A LUMPY DEMAND ENVIRONMENT

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This article provides an effective solution to the common problem of managing inventory levels and production scheduling when demand is very lumpy. This problem existed at Welch's, the producer of several product lines of fruit juices, drinks, and spreads in a make-to-stock operation. Welch's produces and distributes three basic product lines: bottled juice, frozen juice concentrates, and spreads. Raw material consists primarily of grapes but many other fruits are used as well. Product lines have diversified away from grape to include juice blends of apple, cherry, orange, pineapple, passion fruit, banana, etc. Welch's is owned by the National Grape Cooperative Association, Inc. As a cooperative, it purchases all of the grapes harvested by its grower/owners. Welch's has three plants (Pennsylvania, Michigan, and Washington), each supplying approximately one third of the United States with products.

Welch's was confronted with two problems, both directly resulting from lumpy demand for their products. Demand for Welch's products is not typically seasonal, but has very pronounced peaks resulting from product promotions which must be planned for in the same way one would plan for seasonal demand peaks. Product demand during a promotion period can be several times greater than nonpromotional demand. Complicating matters, there is also a "post-promotion lag" resulting from the tendency of retailers to stock up on product during a promotion. This lumpy demand resulted in two problems: it was difficult for Welch's (1) to determine desired inventory levels and (2) to schedule production.

MANAGING INVENTORY LEVELS AND SAFETY STOCKS WITH LUMPY DEMAND

Prior to developing a more effective approach, a very simple method was used to determine inventory levels. A items were targeted at 2.5 wk of average inventory, B items at 4 wk average inventory, and C items at 6 wk average inventory. This method was common in the consumer goods industry during the 1970s and 1980s and is often termed "weeks of supply" coverage. The number was calculated from the monthly demand forecast. For each week of the month inventory was recorded and, at the end of the month, each week's inventory was averaged and compared to the target (2.5 wk for A items, etc.). The average inventory for each item was determined using heuristics. Generally, if inventory averaged 2.5 wk supply on A items, 3–4 wk on B items, and 4–6 wk on C items, packed product turned 12 times per year with a relatively high service level. The problem with this method is that it did not account for forecast bias or lumpy demand within a month, nor provide any method for scheduling production. The main purpose of the heuristic was as an aggregate inventory control tool.

Several alternatives were considered to improve the situation. A simple reorder-point system with a safety stock based on the forecast mean absolute deviation (MAD) was considered for inventory planning, but weaknesses were identified. The classic reorder-point model presented several problems for Welch's. The first problem, specifically related to the lumpy demand, is obvious when the model is examined. In a lumpy demand environment, the average of past demands during lead time is not a good predictor of the demand during a lead time in the immediate future. After all, it is the demand during this lead time in the immediate future that will result in a stockout or an excess of inventory, not the average demand of past lead times. This problem was easily solved by using the actual forecast for demand during the lead time in the reorder-point calculation rather than the average of past demands.

When using this method of calculating the reorder point, the occurrence of a stockout is the result of forecast error. If one could forecast without error, no safety stock would be required. The MAD, therefore, is typically used as the basis for calculating safety stock. The greater the MAD, the larger the safety stock needed. This provides an acceptable approach to determine safety stock, but only in a situation where the forecasts are unbiased. Welch's, like many demand forecasts based on sales forecasts, were often biased negatively. (A negative bias means that actual demand minus forecast demand was negative, i.e., the *forecast was too high.*)

In the unbiased situation, high forecasts will occur as frequently as low forecasts. When the forecast is too high, no stockout occurs. However, when the forecast is low, the safety stock serves to prevent a stockout from occurring. A large MAD can be the result of large errors in an unbiased or biased forecast. When forecasts are too high, the MAD results in an increase in safety stock. Increasing the safety stock when forecasts are too high is counterintuitive. The reorder-point calculation is based on a forecast for demand during the lead time plus a safety stock. If the forecast was always high, a stockout would be impossible and a safety stock would be unnecessary. Thus, if the forecast has a negative bias, using the MAD in the safety stock calculation results in excess inventory.

This problem was addressed by the application of Krupp's approach [1] to computing safety stock. Krupp's technique utilizes a suppression factor to link the quantity of safety stock to forecast bias in recent time periods. With this approach, if forecasts are higher than demand, safety stock is reduced. For a complete description of this technique see [1]. The combination of using actual forecast and Krupp's technique resulted in successfully planned inventory levels and replenishments in the lumpy demand environment.

SCHEDULING PRODUCTION WITH LUMPY DEMAND

Planning for production in a lumpy demand environment can be difficult. Projecting production orders requires a projection of when the reorder point will be reached and of how many shifts of production will be required. Had a classic reorder-point system been used to manage inventories, replenishment orders going to production would not have taken into account the lumpy demand, and production planners would have had to continue to plan production manually. This was not acceptable. Another alternative was to build large stocks of packed product inventory. This was a poor alternative given the high carrying costs and large amount of product overage that would be required.

In this situation, a forecast of customer demand must be translated into the timing and size of orders coming from the reorder-point system. This was accomplished by developing a spreadsheet simulation model called the Inventory Planning Model [IPM]. It is a spreadsheet-based time-phased order point (TPOP) system.

A DETERMINISTIC SPREADSHEET SIMULATION: THE INVENTORY PLANNING MODEL

The IPM projects future production and inventory levels based on several user-defined parameters: customer service level, queue time, hold time, and cases of finished product produced per shift. Future demand is incorporated into the simulation model by using the actual demand forecast in the reorder point (RP) calculation. This is a deterministic input for the simulation model. The forecast's performance (using a 24-week rolling history) is used as an additional criterion for determining future production levels, since the reorder-point calculation takes forecast bias into account.

The IPM incorporates the runout of current inventory and the scheduling of future production for replenishment of each individual SKU. Figure 1 graphically represents the runout and replenishment cycles for a theoretical SKU. As the inventory is depleted, the reorder point is reached. Beyond the reorder point,

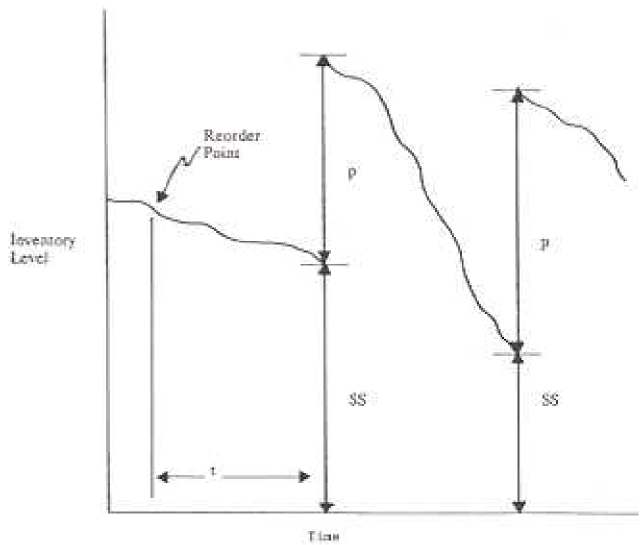

FIGURE 1: Inventory cycle for a theoretical SKU

the inventory continues to be depleted until reaching the end of the replenishment lead time. The cycle is completed as available product enters the inventory. This inventory cycle of depletion and replenishment continues indefinitely.

Since changeover time in bottling lines is long, the production lot size is a multiple of the amount of production that can take place in a single shift. If the inventory level projected by ordering one shift of product still remains below the reorder point, the production lot size is incremented by one shift of production. This logic is continued until the production lot size results in the projected inventory level being above the reorder point.

As a result of several factors, such as lack of materials, the need to finish current production runs, etc., production cannot take place at the precise instant the inventory level reaches the reorder point. A time interval, designated as queue time, passes before any production can take place. The queue time value is a deterministic parameter selected by the user. Production takes place as soon as queue time has elapsed, but the product remains on hold for quality control evaluation. Items are placed on hold for one to six days, depending on the product. Finished product is stored in inventory until it is shipped to the customer, completing the manufacturing cycle.

The manufacturing cycle begins with the inventory reaching the reorder point, goes through queue time, process time, hold time, and inventory time, and ends when product is shipped to the plant warehouse. The manufacturing cycle, in its many variations, is the basis of the planning model. It should be noted that the cycle is not constant in time span, but varies. Since the hold time is constant for every product class, the primary changes in the length of the manufacturing cycle result from fluctuation in queue time and the amount of time the product remains in inventory (determined by the rate of demand).

Table 1 presents the basic simulation output which was described graphically in Figure 1. The inventory (INV), listed by day, represents the available inventory at the beginning of each day, Day 1 being the beginning of the period (Monday's beginning inventory level). The second column (DEM) is the forecast demand for Day 1. DEM is deducted from Day 1 INV to arrive at a balance (BAL) for the end of Day 1. The BAL for the end of the day, plus any previously scheduled production, is equal to the queue (QUE) (all numbers in thousands, rounded to the nearest 10). If the queue is less than the RP, as is the case in Day 1 of the example, production is indicated by a 1 in the PROD column.

TABLE 1: Simulation Output Sample of Manufacturing and Inventory Cycles

Day	*Inv*	*Dem*	*Bal*	*Que*	*RP*	*Prod*	*Lot*
1	4.00	0.99	3.02	3.02	5.54	1	7
2	3.02	0.99	2.03	9.03	5.54	0	0
3	2.03	0.99	1.05	8.05	5.54	0	0
4	1.05	0.99	1.05	8.05	3.70	0	0
5	7.06	0.99	6.08	6.08	1.85	0	0

Once the decision has been made to produce, the next question is "How much?" Under the last column (LOT) in the example a 7 appears, indicating that, based on projected future volumes, 7,000 cases (1 shift) need to be produced. Keeping in mind that the combination of the hold time and queue time is three days, production indicated on Day 1 actually comes into available inventory on Day 5. (Notice the increase in INV from Day 4 to Day 5.) This cycle can be repeated indefinitely into the future and an estimation of the production timing and inventory levels can be obtained for future months. The model employed at Welch Foods projects a nine-week production schedule, as shown in the simulation output presented in Table 2.

Several performance measures are included with the simulation output. In addition to the time increment contingency factor (TICF) value (used in Krupp's calculation) and the forecast error tracking signal (FETS) used in determining the reorder point, 6-month error, 24-week oversell, and 12-week oversell figures are provided. The 6-month error is the percentage of the forecast sold over the past six months. In Table 2 this value is 0.71, meaning that over the past 6 months 71% of the forecast demand has actually been sold. The 37.5% figure for the 24-week oversell means that during the last 24 weeks sales have exceeded the forecast quantity 37.5% of the time. However, the 12-week oversell figure shows that during the last 12 weeks the forecast was oversold 75% of the time. These figures demonstrate how deceiving a long term measure of bias can be.

The complete model provided benefits (1) obtained from Krupp's method, (2) from enhancements to Krupp's method, and (3) obtained from the simulation model. Krupp's method provides a mechanism to include forecast bias in the safety-stock calculation, which reduces total inventory when forecasting bias is negative. Another advantage of this approach to determining reorder point is the use of an actual forecast in the reorder-point calculation. Classic reorder-point calculations have used the average of past de-

TABLE 2: Simulation Output Sample of a Production Schedule

	Wk 1	*Wk 2*	*Wk 3*	*Wk 4*	*Wk 5*	*Wk 6*	*Wk 7*	*Wk 8*	*Wk 9*
Planned prod.	0	7	7	0	7	0	0	7	0
Inventory	9.50	3.02	5.38	8.79	5.21	8.54	5.11	1.77	5.43
Shifts/wk	0	1	1	0	1	0	0	1	0
Demand/wk	5.50	4.93	3.58	3.58	3.58	3.58	3.34	3.34	3.34

TICF	*FETS*	*6-month Error*	*24-week Oversell*	*12-week Oversell*
0.58	0.36	0.71	37.5%	75%

mands during lead time as the "forecast" for demand during replenishment lead time. This is quite obviously not a very good forecast, especially in instances where seasonality or lumpiness caused by promotions is expected.

The remaining advantages relate directly to the deterministic simulation. First, it allows the user to test different service levels and immediately see the resulting effects on inventory levels. This makes it possible to see a direct cost / benefit relationship between holding costs and service levels. Target service levels can be constructed for A, B, and C inventory items, aiding the development of service-level policies for different inventory classifications. Second, in instances where lumpy demand is caused by promotions, various forecasts (minimum and maximum, for example) can be used to help ensure enough production to meet the promotion. Third, production-line load profiles can be constructed from the expected production quantities provided by the simulation. This provides capacity requirements resulting from reorder points which are directly linked to forecast demand. The lumpy demand is directly converted into lumpy production requirements, based on service level, queue time, hold time, etc. At Welch's, this serves as the master production schedule to feed an MRP system which determines order releases for packaging materials.

The IPM at Welch's is operated by clerical personnel using Symphony software. The computer used is an IBM PC/AT 286, 10 megahertz computer with 1 megabyte of RAM. The model consists of one main spreadsheet (about 200 K) and numerous other small files of data. Approximately 300 products are modeled. The model is done centrally for the three plants, modeling about 100 SKUs per plant. The entire model takes 4 to 6 hr to run. An individual SKU can be modeled in about 20 sec. The model is run weekly on Monday nights and the output is distributed to the three plants by electronic mail. Copies of the software are available through the first author.

SUMMARY

The IPM presented describes the techniques currently used at Welch Foods.* It provides two enhancements to the classic reorder-point system and uses a deterministic simulation to test the effects of various parameters on production requirements. The simulation model is built on microcomputer-spreadsheet software. Microcomputer-based modeling is a low-cost alternative to mainframe-system modeling efforts. Required investment is reduced significantly. High availability of microcomputers and spreadsheet software is making simulation techniques much more accessible to the average user.

REFERENCE

1. Krupp, James A. G., "Effective Safety Stock Planning," *Production and Inventory Management*, 3rd Quarter (1982), pp. 35–47.

* EDITOR'S NOTE: Welch's Director of Logistics, Donald F. Biggs, has written to me verifying that the application mentioned in this paper is "valid and currently being used for planning at Welch's Corporate Logistics Department . . ." (since 1984). He further reported that "the Welch experience with the production planning model has been very positive . . . the model predicts production as good, or better, than manual calculations performed by plant production schedulers in much less time . . . serves as the master schedule for three Welch production facilities, and drives the central MRP System."

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