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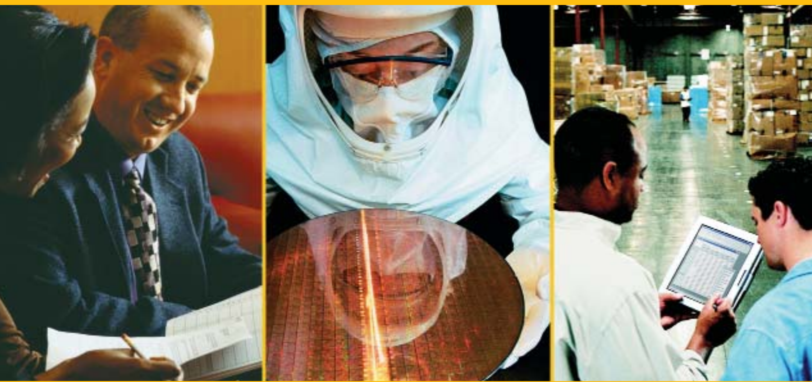

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Managing International Supply and Demand at Intel

Inventory Modeling

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ABSTRACT

Original Equipment Manufacturer (OEM) customers and distributors across the electronics industry are pursuing all available means to reduce their materials costs while maintaining high service levels to their end customers. The OEMs have asked their suppliers to implement various programs to minimize their (OEMs) risk to excessive inventory. In 2002, inventory across Intel was $2.3B or 8.5% of sales, including $0.7B of FG inventory. If the approach of these OEMs and distributors were to be adopted, we could expect the FG inventory to increase by >20%, resulting in higher levels of inventory risk to Intel.

This paper describes a new way of optimizing Intel Corporation's supply chain, from factories to customers. The methodology that will be discussed uses statistical methods to characterize the order distributions of customers and the distribution of times to ship products from different points in the supply chain (factories to customers). These results are then used to build a stochastic simulation model that can be experimented on to gather data that contain information on interaction effects and inventory pooling effects. Response Surface Modeling (RSM) methods are used to set up the experimental design and to analyze the results. This allows a statistical model to be developed that allows the user to explore the effects of varying inventory levels at different locations on customer-service levels. By using this methodology, optimal placement of inventory (minimizing the inventory while providing the desired service level) can be achieved.

INTRODUCTION

As the Intel distribution network continues to expand in order to reach new markets, the complexity and impact of the management of the network has grown. With this growing complexity the need to optimize distribution network processes that affect Order Fulfillment Quality (OFQ) is critical to avoid lines being down at customer manufacturing sites. OFQ is made up of four key elements:

1. The right product was delivered to the right customer.
2. The product arrived undamaged to the customer.
3. The correct amount of product was received by the customer.
4. The product arrived at the customer site at the agreed-upon time.

The last of these elements, the product arrived at the customer site at the agreed-upon time, is highly impacted by the availability of product and the placement or staging of product in the distribution network. A typical representation of the distribution network structure for a given geography is shown in Figure 1. It shows that product can be held in inventory at warehouses or distribution centers.

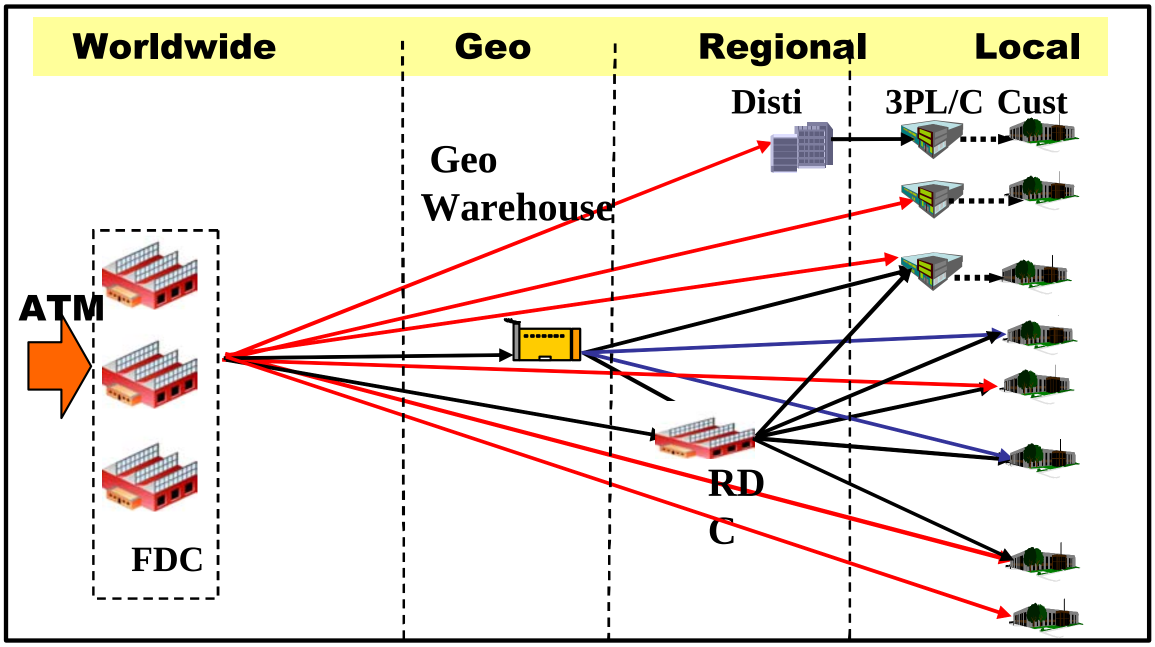

Figure 1: Typical distribution network

In this paper we discuss an alternative methodology that was successfully used to optimize inventory placement within the distribution network. The methodology includes developing a stochastic simulation model and then running experiments on that simulation model to develop a Response Surface Model (RSM) to characterize the effects of different allocations of inventory across the distribution network. This approach to experimenting on a simulation model was used because experimentation on the physical distribution network would have these undesirable consequences:

1. The customer may have lines down because of lack of product.
2. The time to get results could run into years.
3. The cost and difficulty of managing these experiments would be high.

In this paper we focus on statistical methods used to build a stochastic simulation model of the distribution network. This model takes into account the variables in the delivery process that are uncontrollable, called noise variables (i.e., shipping times from one location to another and product order patterns). It then addresses the use of RSM to explore and optimize the effects of variables that can be controlled, called controlled variables (i.e., amount of inventory to be placed at different locations and the replenishment periods) on the service level (i.e., did the product arrive when it was supposed to). Optimization in this sense is defined as meeting service-level goals with minimal costs to the distribution network.

DISTRIBUTION NETWORK MODELING

The methodology used to optimize inventory placement within the distribution network consisted of two modeling phases (stochastic simulation of the distribution network and statistical modeling using RSM) as well as a financial analysis. The stochastic simulation models were developed to create virtual models of the distribution network that could be experimented on without impacting our customers and were run in a relatively short period of time. The statistical models, RSMs, were based on data from experimental runs of the simulation models and provided information on service levels vs. amount of inventory placed at various points in the distribution network. Since it is possible to have a variety of inventory configurations that yield a particular service level to a customer, a financial analysis was done to optimize the specific configuration to minimize cost while providing the desired service level. This methodology was repeated for each major geography (Asia, Europe, and the Americas), and by each product type (tray and boxed CPUs, and motherboards).

Stochastic Simulation Modeling

The stochastic simulation model was built using a software package called e-SCOR*. To achieve the stochastic nature of the model, estimates of the variability for the noise factors had to be quantified and built into the model. These noise factors are uncontrollable, and where historical data were not available, were assumed to be random. They include order patterns, shipping or transit times, and throughput times through the warehouses and distribution centers.

For order pattern variability, historical data were available and used in the simulation model. Historical order pattern data of the same product type (i.e., CPU order pattern history for CPU products) were used in the simulation model to represent that source of variation. The use of historical data is the ideal method for representing variability of noise factors.

When historical data do not exist for noise factors, then other methods for representing those sources of variation are used. Some of these methods include using a triangular distribution, a uniform distribution, or some assumed distribution, such as a normal distribution. The parameters of those distributions can be estimated by individuals considered knowledgeable in these areas.

For transit times and throughput times no historical data were available, and a triangular distribution was used. Individuals knowledgeable in shipping and customs were asked what the minimum, typical, and maximum transit times are for given shipping lanes. These were used as the estimates of a triangular distribution. The same process was used with experts in the warehouse and distribution centers to get triangular distributions for throughput times.

Once the simulation model was developed in e-SCOR by geography and product type, this model was used to represent the physical distribution network. The model in e-SCOR also required that the controlled factors of amount of inventory in each location and rules for replenishment were to be entered into the model. In order to generalize the simulation results to multiple products, the volumes of inventory were normalized to Days of Inventory (DOI).

A single experimental run of the simulation in e-SCOR was run to investigate a particular configuration of the distribution network. Each configuration was an investigation of how the distribution network behaves under a given set of conditions. These conditions are comprised of the days of inventory to be targeted at each warehouse and distribution center along with replenishment rules. The output of each experimental run is the service level attained for the customers in a region for a given configuration of the distribution network.

The investigation of all possible configurations was not feasible as the time to run the simulation for a given configuration was approximately one hour.

Response Surface Modeling

Experiments were run on the virtual model of the distribution network built in e-SCOR. These experiments had the purpose of quantifying the effects of the amount of inventory placed at various locations within the distribution network on the service level (measured as the percentage of time that product arrived to the customer at the agreed-upon time). Since volumes of products vary for different stages in a product's life cycle, inventory levels were measured as DOI, where a DOI is the average daily volume of product that passes through a location in the distribution network.

Central Composite Designs (CCD) were the family of experimental designs that were run. In a CCD, the factors under investigation (in this case DOI) are set to have the points of a typical full-factorial design (all combinations of low and high values) along with augmented axial and center points. Multiple runs of the center points are run to get an estimate of the error in the model. Figure 2 shows a graphical representation of a CCD.

* Other brands and names are the property of their respective owners.

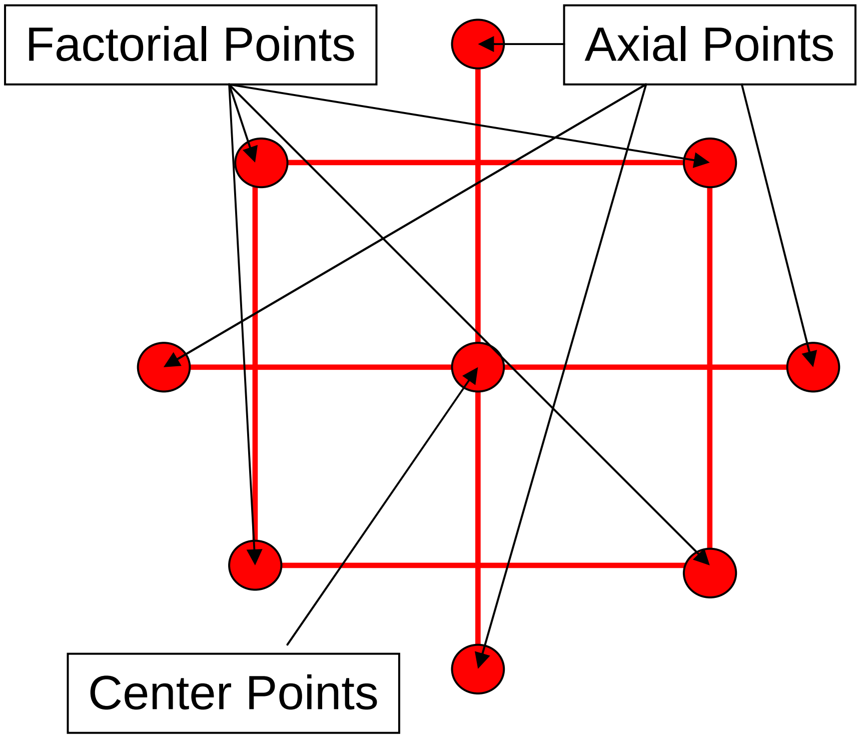

Figure 2: Central composite design

The factor settings in a CCD were chosen so a quadratic model with interactions could be estimated. The mathematical form is

$$y = b_o + b_1x_1 + b_2x_2 + \ldots + b_nx_n + b_{12}x_1x_2 + \ldots$$
$$+ b_{(n-1)n}x_{(n-1)}x_n + b_{11}x_1^2 + \ldots + b_{nn}x_n^2, \text{ where}$$

y = estimate of the service level.

Only those terms of this model that are statistically significant (p-value <= .05) were included in the model.

From this mathematical model a graphical response surface was made to visualize the effects of different levels of DOI on the service level. Figure 3 shows an example of the graphical output that was obtained.

As can be seen in Figure 3, many different possible combinations of inventory levels yield the same estimated service level. For a desired service level the optimal settings are determined by a financial analysis that finds the minimum cost of inventory in the network. A more simplistic method would be to minimize the overall DOI in the distribution network. Another consideration in choosing inventories is the sensitivity of the service level to changes or departures from the targeted DOI at the various locations.

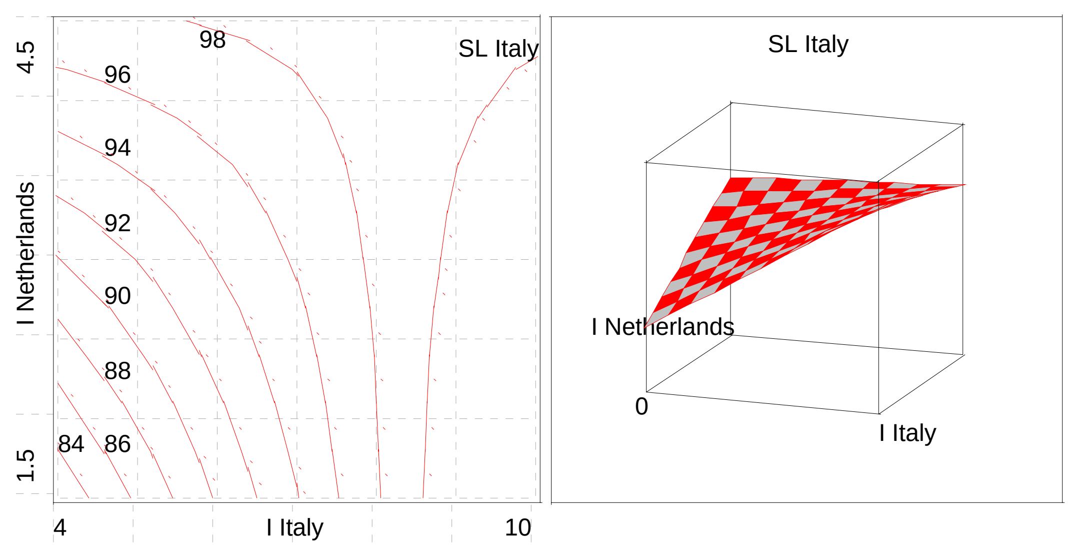

Figure 3: Response surface output

RESULTS

The results of these efforts were originally reported in a paper by Michael Waithe, et al. at the 2004 Intel Manufacturing for Excellence Conference (IMEC) titled "Use of Simulation Modeling to Reduce Product Distribution Costs and Develop Rules for Supply Chain planning." Results for our top four OEM customers include a drop in average days of inventory from a high of 11.8 in Q3'01 to 8 days by Q3'03, a $145M reduction in working capital.

These solutions have enabled Intel to successfully win or retain business at a lower cost. The lower cost alternative offered to one customer avoided a loss of motherboard business and enabled a significant growth in annual revenue.

The modeling output data were validated by actual operational results by a second customer. This customer realized an inventory reduction of 10 days.

The Supply Network modeling data also demonstrated that pooling geographic supply would decrease overall network inventory and not just shift customer inventory to Intel's shelves. Scenario analysis around key variables such as demand variability, forecast error, frequency of delivery, TPT improvements, and inventory placement identified additional opportunities.

The data from the models were instrumental in the decision to expand the JMI program to the distributor channel for Boxed CPUs. The data indicated an opportunity to reduce channel inventories by ~21% and have been validated by pilots in the European and Asia Pacific geographies.

DISCUSSION

The modeling, both stochastic and statistical, yielded results that did not contradict the general results that would be seen if only the impact of variation from a strictly theoretical perspective was studied. That is to say that one would expect a benefit (reduction in inventory) to be seen by pooling inventory upstream from the end customer. The rationale is that if each of "n" customers has an average demand D_k and the sum of the average total demand of those "n" customers is D_{total}. That is:

D_k : average demand of customer k

σ_k : standard deviation of demand of customer k

For the "n" customers with independent demands D_1, D_2, … D_n which are met from a single pooled inventory location, the total average demand at the pooled location is

$$D_{total} = D_1 + D_2 + \ldots + D_n$$

and the standard deviation of total demand is

$$\sigma_{total} = \text{Square Root } (\sigma_1^2 + \sigma_2^2 + \ldots + \sigma_n^2)$$

This indicates that the overall variability of an upstream location is less than the sum of the variability of the end customers. This result was confirmed by the modeling. The additional question answered by the modeling was how much pooling could be utilized while still meeting the end customer service level.

In the response surface modeling a quadratic model was fit to the data. Since service level is monotonically increasing with respect to increasing inventory, this assumption does not hold true. However, in the area of investigation where service level is between 80% and 95%, the quadratic model holds up. If one was interested in the 95% to 100% region for service level, different mathematical forms would need to be investigated.

This approach to building a stochastic simulation model and then running experiments on those simulation models is a viable approach to improving processes that might otherwise be difficult to run experimentally.

CONCLUSION

Through the use of stochastic simulation models and traditional ways of running experiments (i.e., RSM), it was possible to make improvements on the strategies of placing inventory throughout the distribution network. This was accomplished first by quantifying the sources of variability to emulate the physical distribution network through a simulation model, and secondly by varying controllable factors (DOI) in a structured manner to characterize how these factors affect the service level that regional resellers and OEMs receive.

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AUTHOR'S BIOGRAPHY

Kurt Johnson currently works as a quality engineer in the Information Services and Technology Group at Intel Corporation. His professional interests include applying statistical methods to improve business processes and systems. Mr. Johnson has a B.S. degree in Mathematics from the University of Utah and an M.S. degree in Statistics from Brigham Young University. His e-mail is kurt.l.johnson at intel.com.

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