Elements of Manufacturing, Distribution and Logistics

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Quantitative Methods for Planning and Control

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For my wife, my children, and
my grandchildren

Preface

I was fortunate to have a rich and diverse career in industry and academia as it unfolded. This included working at International Harvester as supervisor of operations research in the corporate headquarters, at IIT Research Institute (IITRI) as a senior scientist with worldwide applications, and as a professor in the Industrial Engineering Department and in the Stuart School of Business at the Illinois Institute of Technology (Illinois Tech) and the many years of consulting assignments with industry and government throughout the world. At Illinois Tech, I was lucky to be assigned a broad array of courses, gaining a wide breadth of analytical knowledge with the variety of topics, and with the added knowledge I acquired with every repeat of the course. I also was privileged to serve as the advisor to 36 bright Ph.D. students as they carried on their dissertation research. Bits of knowledge from the various courses I taught and continual research helped me in the classroom and also in my consulting assignments. I used my industry knowledge in classroom lectures so the students could see how some of the textbook methodologies are actually applied in industry. At the same time, the knowledge I gained from the classroom helped me to formulate and develop solutions to industry applications as they unfolded. This variety of experience allowed me to view the quantitative tools that are doable and useful in industry, and this book is based on this total experience.

Thanks especially to my wife, Elaine Thomopoulos, who encouraged me to write this book and who gave consultation whenever needed. Thanks also to the many people who have helped and inspired me over the years. I can name only a few here. These are:

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Chicago, IL Nick T. Thomopoulos

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Chapter Summaries

Chapter 1. Forecasting: The forecast is perhaps the most important function in controlling the inventory. In a typical inventory entity, forecasts are needed for each of the future months up to the planning horizon, typically 12 months. Data from the past demands is needed to generate the forecasts.

Assuming monthly time buckets, the demand for a fixed number of history months (usually 12, 24, or 36) is saved in the database. The monthly demands represent the number of pieces ordered on an item for each month. Many entities also save the lines per month. These are the number of customer orders that arrive during a month. The history months are mostly saved in calendar months, but some entities use fiscal months of the 4, 4, 5 type. It behooves the entity to process the demand history prior to forecasting, by running a routine to seek if any outlier demands are found, and, if so, to adjust them prior to forecasting. Another useful routine would seek to adjust the demand history if any demands are returned due to a ship-in-error by quantity or by part.

To control the inventory, the total requirement of the part is needed for each future month. The total requirement is the sum of the forecast plus any other requirements that may occur. The other requirements are any demands outside of the normal customer base, like foreign country or military. Also, the forecast of a future month may need to be adjusted when a customer brings in an order for a quantity of an item, but not to be delivered until a future month. In inventory systems, four methods of generating the forecasts are generally in use: moving average, regression, discounting, and smoothing. The three basic forecast models are horizontal, trend, and smoothing. The smoothing model is of two types: seasonal multiplicative and seasonal additive. In most situations, the forecasts are converted from fractions to integers for ease of use by the management. Finally, a way to convert the monthly forecasts to weekly forecasts is developed for entities that require weekly forecasts.

Chapter 2. Forecast Error: The standard deviation of the 1-month-ahead forecast error is used to determine how much safety stock to have available to satisfy the level of service to customers. An exact measure of the standard deviation is not easy to generate; however, estimates are sometimes used in its place. The way to estimate the standard deviation varies depending on the forecasting method in use (moving average, regression, discounting, smoothing). This chapter describes how to estimate the standard deviation for each of the forecast models presented in Chap. 1.

Another important statistic for each forecast model is the coefficient of variation (cov). The closer the cov is to zero, the better. When cov is near 0.30, the distribution of the forecast errors is similar to normal distribution. When the cov is closer to 1.00, the distribution of the forecast errors is not like a normal distribution. In Chap. 4, the concept of the truncated normal is presented. The cov is used to estimate the parameter to use for the truncated normal. When the distribution of the forecast errors is not normally distributed, the truncated normal distribution should be applied to determine how much safety stock is needed. In determining the safety stock, the standard deviation and cov of the lead-time demand are used in the computations. The methods to generate these statistics are included in the chapter.

When the forecast and its standard deviation are generated for a total collection of SKUs, estimates are needed for each SKU. A way to measure the standard deviation for each SKU is presented. As an example, this need occurs for a style shoe where the forecast is based on all sizes combined, and estimates for inventory control are needed for each size of the style.

Chapter 3. Order Quantity: The order quantity, Q, is a planned amount of stock to replenish the inventory from the supplier when new stock is needed. In the ideal situation, Q is calculated to give the minimum cost of holding and ordering the stock, called the economic order quantity, EOQ. The EOQ is obtained from several factors: A is the annual forecast of the item, Co is the cost per order, c is the cost per unit, and h is the annual holding rate. Note, A comes from the forecast, c from the supplier, and Co and h are parameters from the stocking facility. In some facilities, the order quantity is restricted to fall in monthly buckets, but in most situations it is not limited in that way. A related cost measure is the stocking rate denoted as s, which measures the rate of added cost on the item due to stocking the item via hold plus order. The stocking rate yields another measure labeled the stocking cost per unit denoted as $(c \times s)$ which is a hidden added cost due to hold plus order. The effective cost per unit becomes $c' = c(1 + s)$. It is sometimes useful for the inventory management to realize the sensitivity between the four ingredients and the order quantity. When A changes, how does this affect Q? The same queries can be made with changes in Co, c, and h. Another measure of interest is the change in the hold plus order cost when using an order quantity different from the EOQ. Note also, as the order quantity changes, the on-hand inventory also changes.

Oftentimes, the simple economic order quantity is restricted due to a series of constraints. The more typical type are described below:

- Price breaks are when the supplier offers discounts on the cost per unit or cost per order as the buy quantity increases. The more you buy, the less you pay.
- Min and max constraints are when the supplier specifies that the buy quantity cannot be higher than a max constraint and cannot be lower than a min constraint.

- Multiple quantity constraints occur when the supplier specifies a multiple number for which the buy amount must conform.
- Bin max constraint is when the stock holding entity has limited space to stock the item. The on-hand plus on-order quantity cannot exceed this bin max quantity for the item.
- Job quantity constraint is when the stock holding entity typically sells the units in multiples of a fixed number, like four tires on an auto vehicle. The order quantity to buy is restricted to conform to the job quantity and the current on-hand for the item.

In service parts, two important order quantities are the initial buy quantity and the final buy quantity.

- The initial buy quantity occurs when a new part is introduced and there is no demand history to base a forecast. The service facility is obliged to carry stock on this item and must generate a first time buy.
- The final buy quantity occurs when the supplier notifies the stocking facility they will stop supplying the item, and the facility is obliged to have the item available for a prolonged obligation period. A last time buy is needed.

Chapter 4. Safety Stock: Safety stock is needed to attain a desired level of service when the demands exceed the forecasts over the lead-time duration. Four popular methods to generate the safety stock are in use: month's supply, service level, percent fill, and Lagrange. For each method, a safety stock parameter is assigned by the management to specify how to compute the safety stock. The month's supply method is based on a specified number of future forecasts. The service level method is set so the probability of not having an out-of-stock condition during the lead-time is satisfied. The percent fill method seeks to accommodate the ratio of (demand fill)/(total demand) over the lead-time. The Lagrange method is a cost-benefit way to set the safety stock. The latter three methods are based on the distribution of forecast for the lead-time demand. The distribution for the lead-time demand can be normally distributed or not normally distributed. When normally distributed, the standard normal distribution is applied to set the safety stock. When not normally distributed, the truncated normal distribution is used to set the safety stock. The coefficient of variation for the lead-time demand is used to identify which of the two distributions to use.

The Lagrange method works well when the safety stock for a group of items is controlled simultaneously. The goal is to have a desired service level for the entire group at the total minimum cost. The safety stock depends on the lead-time provided by the supplier; but for suppliers who are late in the delivery of the replenish stock, adjustments to the safety stock are needed. Each supplier is measured as to its delivery score, and the safety stock adjustment for the supplier is based on his score. Sometimes loss sales occur when stock is not available to complete a customer demand. A way to measure and control the amount of loss sales is developed.

Chapter 5. Replenishments: Replenishing the stock is one of the most important functions in the control of the inventory. The goal is to replenish the stock that properly covers the customer demands at minimum cost in inventory. To accomplish, two measures are regularly computed: the order point and order level. Each day, these are compared to the current on-hand plus on-order inventory to determine if a new replenishment is needed now and, if so, how much. Each replenishment must conform with any constraints provided by the supplier, as minimum buy quantity and multiple buy quantity. For analysis sake, the inventory is partitioned into cycle stock and safety stock, where the sum is the total stock. The ingredients that affect the stock levels are the percent fill, lead-time, coefficient of variation, and month-in-buy. The sensitivity of each with the stock levels and with the turnover is described. In many retail entities, the demand for each item is low, and thereby the Poisson distribution is used to determine the order point and order level. For entities with low demand items, table entries are provided to guide the management on how to set the order point and order level.

Chapter 6. Distribution Control: For convenience here, a network (NW) is defined when two or more stock holding facilities are connected with one entity. This is a distribution system with two or more locations, could be a system with distribution centers (DC) or two or more retail outlets. The individual stocking locations are here referred as locations. The goal is to control the inventory for the NW and for each location. Typically, once a month at the NW, forecasts, standard deviation of the forecast error, and the planned order quantity are generated. Also, at each location, the forecast, standard deviation, and order quantity are also needed to compute the order point and order level. At each location, the on-hand and on-order are observed and compared to the order point and order level to determine if a location needs a replenishment buy, and if so, how much. Sometimes the location buys directly with the supplier, and other times, the NW buys for the total system

When the NW buys the stock and the replenish quantity arrives from the supplier, a way to distribute the stock to the locations is needed. This process is called allocation, with a goal to allot the stock to the locations in a fair-share manner. Another important process at the NW is called transfer. Transfer occurs periodically, perhaps weekly, where the stock status of each location is measured, and if a location is low and another is high, a transfer quantity is computed. Share is another process that takes place on occasion. One location is selected as the source, and each of the parts at the location is analyzed in a share manner as follows: if the inventory status of a part is high at the share location, and it is low at another location, a share quantity is computed, whereby the quantity is transferred accordingly. Limit buy is another process that sometimes occurs in the NW. The total buy for a supplier cannot exceed a given limit, could be in dollars, pieces, and so forth. Discount buy is when the total buy, all parts, must reach a goal to qualify for a discount, could be for a supplier discount, for a truckload min limit, and so forth.

Chapter 7. Manufacturing Control: The manufacturing plant consists of an assortment of raw materials, components, machines of various types, and a variety of skilled workers, with the goal to produce goods to a higher level and some to finished-good-items. The management's task of coordinating all this activity is difficult indeed. A first concern of the management is to periodically generate a production plan for the coming planning horizon. This plan pertains to the aggregate of all items in the plant and yields the volume of production for all. The plan depends on the type of items to produce: make-to-stock, make-to-order, or a combination of make-to-stock and make-to-order. For each finished-good-item, a master production plan is generated to coordinate the schedule that satisfies the inventory status and customer demands. This schedule also yields the available-to-promise quantity that is a vital tool to the sales force. The concept of raw load and level load by future time periods for various production centers in the plant is described. To ensure the schedule of all items is doable, a rough-cut capacity planning analysis is calculated for each of the production centers in the plant. When the capacity does not meet the load, adjustments are required. For every item to be produced, a bill-of-material is used to identify each of the parts and components that are required in the build. From here, a material requirement planning set of computations determines the build schedule for every item.

Chapter 8. Just-in-Time: Just-in-time (JIT) is a philosophy of production based on the concept of adding value and eliminating waste. JIT and lean manufacturing have very similar goals. Value is added only by work performed on the product, and waste is anything other than a minimal amount of necessary resources—material, manpower, and the capital equipment—that is required for production and does not add value to the product. The process called Kanban is a system where cards are used between send and receive stations in a way so that the stations produce only the necessary quantity of goods at the necessary time. JIT examples are presented where the components to a product are received from a supplier shortly after the customer order arrives. The relation between lean manufacturing and JIT is described. Smaller batch sizes are preferred in production, and this is accomplished as the setup time at a production process is reduced. The smaller the setup time, the lower the economic batch size. The safety stock to achieve a service level to the customer depends largely on the lead-time of replenish time from the supplier. As the lead-time becomes smaller, the amount of safety stock needed is lowered accordingly. The management should also seek to level the week-to-week aggregate production loads to avoid excess cost of overtime, backorders, and outsourcing. When the finished-good-items are on a make-to-order basis, the strategy of postponement reduces the lead-time to the customers and also eliminates much of the complication in the assembly.

Chapter 9. Assembly: A variety of assembly lines are applied in industry. For the smaller type of products, the assembly lines are often of the single model type, where one model of the product is produced on the line. The work elements to assemble one unit are gathered and set in a precedence diagram showing the feasible work relations between the elements. The number of operators needed is computed, and the work elements are assigned to each operator in a fair-share way. This latter function is called line balancing.

For larger products that are stocked in a warehouse or distribution center waiting for subsequent customer demands (washing machines, refrigerators, and so forth), the assembly is called a mixed model make-to-stock line. Two or more models of the product are assembled on the line at the same time. The plan schedule to produce the units is stated by the management, and the total time to complete all the work elements is tallied. The number of operators needed to conform to the schedule is computed, and the work elements are then assigned to the operators, via line balancing. Because two or more models are mixed on the line, another task of the management is to determine the sequencing of the models down the line.

On the higher price items (trucks, tractors, and so on), the units produced on the line each have a variety of features and options assigned by the customers. This is a make-to-order line. Because of this, each unit going down the line is unique. Each day, a different schedule of units, called jobs, is registered to be produced. The work elements are assigned (via line balancing) to the operators in a way to satisfy an average day of production. The sequencing of the units down the line is arranged so the operator times are efficient as the units roll down the line from one unit in the sequence to the next unit.

In the latter two assembly lines described, robots are often scattered on the line and perform major tasks of the units, like in the paint booth or in lifting of heavy components as what takes place in the body shop of the assembly line. The line balancing and sequencing tasks are still in need to accommodate the robots.

Chapter 10. Statistical Process Control: A process can be defined as a combination of components, tools, people, and machines that together produce an item, like a part that subsequently is inserted into a finished-good-item. Although, the output of the process may vary, the final customer requires the product to satisfy the standards specified by the engineers. Management's goal is to control the output units of a process so that it conforms to the standards set by the engineers. The output measures are of two types: attribute or variable. Attribute is when the output measure is defective or not defective. Variable is when some measure is taken from each sampled unit.

Four attribute type control methods are described and labeled as the following: p-chart, np-chart, c-chart, and u-chart. A pre-study is set up for each of the methods. N subgroups are studied at intermittent time intervals with a number of samples taken from each subgroup and the number of defectives tallied, if any. Statistics on the capability of the process is measured after the pre-study, and if acceptable, lower and upper control limits are computed. The process is monitored in the same way for the future subgroups to ensure the process is performing with high standards.

Four variable type control methods are described and labeled as the following: x-bar and R-chart, median and R-chart, individual-chart, and x-bar and s-chart. A pre-study is arranged with N subgroups at systematic time intervals, where sample data is taken. Specification limits are provided from the engineers, and these are compared with the sample output data from the samples. The goal is for the output to be well within the specification limits and ideally within six-sigma limits. Measures of process potential and process capability are computed using the results gathered in the pre-study. If these are acceptable, a set of statistical coefficients is used to compute control limits for the particular testing method. Thereupon, the process is monitored over future subgroups to ensure the output measures remain within the control limits.

Chapter 11. Distribution Network: In a typical original equipment manufacturing (OEM) system, the suppliers ship stock to one or more distribution centers that serve as the source to a series of retailers (dealers, stores), and the retailers sell the products to the customers. This could be a network that holds service parts for an automotive corporation. The dealers sell the autos to the customers, and when repair or maintenance is needed, the customer seeks service from the dealer. The dealer carries a limited supply of parts for this purpose and relies on the DC to have a full set of parts as needed. The OEM is faced with holding the minimal amount of stock needed to properly service the demands from the dealers. In the ideal situation, the DC system consists of a network of locations that are strategically near the dealers and to some extent near to the suppliers. One location is the master stock location that serves as the headquarters for the entire system. The other locations are branch locations. The master location is often a much larger location and holds more variety of stock. Sometimes a small location is provided and is called a 2-level-service location. This location holds minimal stock and is supplied by the master stock location. The parts that have a high amount of demand are stocked in most locations and are called distributed parts. The low demand parts are labeled as non-distributed and are mostly stocked only from the master stock location.

Periodically, the management runs an analysis to seek what is the best arrangement of the DC network. The analysis seeks answers to: how many locations, where should the locations be sited, and how to allot the stock by locations. A series of parameters are provided in a "what if" arrangement. The management can run a variety of options with various settings of the parameters, and the system provides summary results for each option.

Sometimes the parts supplier does not package the parts as needed by the DC system and thereby sends the units produced to a packager who places the parts in containers with appropriate labeling. The packager then ships the packaged parts to the DC network. Cross-docking is also a strategy where the suppliers ship in large vehicles to a cross-dock facility and the goods are taken off the larger vehicles, sorted, and placed in smaller vehicles for transport directly to the stocking facility (DC or dealer). Back at the DC network, the integrity of the inventory count is vital to the efficiency of the service to customers. It behooves the DC network to have a continual cycle counting system in place to maintain the count of the amount of units in stock for each part. Three cycle counting methods are popular: random, ABC, and Pareto. Queuing theory is introduced showing how it has a wide variety of applications in the operation of a network.

Chapter 12. Supply Chain Management: The supply chain management team in a manufacturing firm is concerned with the flow of raw materials, basic goods, components, work-in-process, and finished goods from suppliers to warehouses, plants, distribution centers, retailers, and finally to the customers. The goal is to minimize throughput times and expenditure costs while achieving a high level of service to the customers with a clean environment. To accomplish, the team remains vigilant on the use of all technology available to them. Data sharing with the customers and throughout the operation is needed so all can work efficiently. The team applies the technology of scan-based tracking, electronic data interchange, bar codes, data matrix bar codes, quick response codes, and radio frequency identification where and when appropriate. In the inventory operations, vendor managed inventory and continuous replenishments are applied when suitable. In transportation, incoterms are applied along with tracing and tracking of the shipments; and whenever feasible, outsourcing and third-party providers are employed. Five examples are sited: a heavy-duty make-to-order manufacturer, a network of men's shoe stores, an offshore automotive dealership, a replenishment of inventory at retail stores for seasonal style good, and a delivery system to stores for a popular bakery item.

Chapter 13. Transportation: Transportation pertains to the movement of items from one location to another, could be from a plant to a distribution center to a retailer. A way to classify the type of goods is by shipping categories: household, express, parcel, or freight. Transport modes are the access ways to transport: rail, road, air, water, or pipes. Transport vehicles are the trucks, trailers, barges, aircraft, and cargo ships. Cargo handling is by ports, container terminals, shipping containers, forklift trucks, cranes, pallets, and dunnage. The shipment of goods also concern dispatchers, bill of lading, manifest, truckload shipping, less than truckload shipping, parcel carriers, bulk cargo, and break bulk cargo. Some industrial trading terms are free on board, carriage and freight, carriage, insurance and freight, and best way.

Chapter 14. Reverse Logistics: Reverse logistics is the process of managing the operations concerned with any returned goods to the manufacturer. On average, near 5 % of the goods sold are returned to the original manufacturer for a variety of reasons as: worn out goods, damaged goods, unsold goods, recall goods, and so forth. The manufacturer is obliged to receive and process the returned goods seeking any revenue that can be gained or arranging for proper disposal. The role of processing returned goods has expanded ever more as the environmental mandate of industrial growing green has gained strength. In the typical forward logistic way, the goods' final destination is with the customer. As the goods become old, they may be replaced and returned to the manufacturer to begin the reverse logistics cycle. The returned goods are mostly one-model-at-a-time occurring in a disjointed manner. The return process is costly, perhaps 10 % of the total cost of the original sales price, requiring the manufacturer to seek as much value from the item as possible. In the typical situation, the returned goods are cleaned, tested for worthiness, and, if accepted, are repaired and refurbished for resale. When not accepted, they are disposed in the proper manner.

The returned goods are often from various reasons: worn out and no longer usable goods, damaged goods from shipment or use, new goods that are unsold at the retailer, goods ordered on the internet with cash-on-delivery terms and payment refusal when delivered, recalled goods, discontinued goods, and so forth. The returned items are also from warrantee claims, some from fraudulent claims, and some are stolen goods. Other returned goods are of the reusable type whereby they are recycled after cleaning and repair. These include pallets, containers, packages, bottles, cans, cylinders, and the like.

Two examples are described. The first concerns appliances where a customer purchases an appliance, and later in time, the unit does not operate properly, and the defective product is sent back to a return facility that refurbishes the product as new for future use. The second pertains to the automotive industry from the truck industry where worn out and discarded engines, brakes, or transmissions are removed from the vehicle and are remanufactured to like-new status.