Lecture Plan

1. Syllabus
2. Motivation
3. History of Production and Operations Management
4. Recent trends in Production and Operation Management
5. Types of Manufacturing Operations
6. Strategy and Hierarchical Planning
7. Inventory Systems

1 Syllabus

Course:	Production Management
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Text Book:	*Silver, E. Pike, D. and Peterson, R.* Inventory Management and Production Planning and Scheduling Third Edition, Wiley 1998.
References:	*Nahmias, S.* Production and Operations Analysis, Third Edition, Irwin, 1997.
	Pinedo, M. Scheduling, Theory, Algorithms and Systems, Prentice Hall, 1995.
Evaluation:	Assignments 20 %
	In-class closed-book 1.25 hour midterm 35%.
	In-class closed-book three hour final 45%.

Software Requirements

Around the middle of the semester we will deal with aggregate production planning, and for this topic we will need to solve linear programs. The linear capabilities of Excel would suffice, but you may want to use alternative solvers. We will also study forecasting and inventory management under uncertainty. A recent version of Excel should be enough to solve most of the problems assigned in class. Some exercises use of Crystal Ball which is an add-in to Excel. You do not need to purchase Crystal Ball as it is available at the IEOR lab.

Level of the course:

The course requires a working knowledge of calculus, probability and statistics, and linear programming.

2 Motivation

Operations is concerned with the transformation of inputs into goods and services. Operations is a primary business function along with marketing and finance, which plays a vital role in achieving a company's strategic plans. Operations typically involve the greatest portion of the company's employees and is responsible for a large portion of the firm's capital assets. The operation function is performed by the group of people who are responsible for producing the goods or providing the services that the business offers to the public. These activities include

plant management,
product development,
process engineering,
facility layout,
production and capacity planning,
quality control,
inventory control,
product distribution, etc.

An effective management of the operation function should provide desirable products in the appropriate quantities, at the appropriate times, of the required quality and at a reasonable cost.

Advances in information system, telecommunications, and the liberalization of trade has heightened global competition. Companies are seeking new insights into customer needs, developing new products, and improving old ones. Many are working to target smaller-volume niche markets. Companies are downsizing to reduce levels of bureaucracy, reorganizing and empowering employees and teams of employees to pursue new levels of performance.

U.S. firms have responded to international competition by working to improve both their operating efficiencies and the quality of their goods and services. With this renewed emphasis on operations, it has become increasingly important that students have an understanding of operations management's significance to the success of the companies where they will work.

Companies must work to improve the "value ratio," i.e., the desirability of a good or service to the customer divided by the cost of the good or service. This ratio can be improved by improving the company's performance in regards to these measures:

1. Cost
2. Quality (meet the needs for which products or services are intended)
3. Flexibility (quick response to customer needs: volume, new product, and product mix)
4. Delivery (standard goods must be readily available, others should have low leadtimes. Speed and reliability)

3 History of Operations Management

Imagine life without organized groups to produce goods and services. Most of our time would be consumed providing the necessities of life. Two centuries ago most households were rural and had to be more self-sufficient. Products were produced in low volume by craftsman with customized designs. Parts were not standardized so they were not interchangeable. The evolution of production from the small workshops of the era to the vast factories of today is often referred to as the Industrial Revolution. It was this movement that brought about the need for more formal and sophisticated methods of management.

3.1 The Industrial Revolution

The industrial revolution began in England in the late eighteenth century with the development of the steam engine designed by James Watts. The steam engine made it possible to replace human labor by powered machines. Steam powered trains increased transportation speed and the telegraph provided the means to instantly transport information. The industrial revolution spread to Europe and the United States.[1] Adam Smith praised the advantages of the division or specialization of labor which allowed workers to develop dexterity quickly and because specialists were more likely to develop specialized mechanical devices to assist their operations. Consider a pin factory. Smith observed that specialized workers, each performing a single step in the manufacturing of a pin, could make far more pins in a day than the same number of generalist, each engaged in making whole pins. One man draws out the wire, another straightens it, a third cuts it, a fourth points it, a fifth grinds it at the top. To make the head requires two or three operations, to put on the head is another operation, etc. Together ten persons could make 48,000 pins in a day. By themselves, each could not each made twenty pins a day. Specialization of labor brought about new requirements for management since coordination was more crucial and more difficult to achieve. Adam Smith's division of labor and functional specialization often results in significant cost reductions and better quality but lower flexibility.

Interchangeable parts were introduced in 1810 at the national armory at Springfield, Massachusetts. Interchangeable parts eliminated the need of the specialized skills need to custom-fit parts into assembly. The era of mass production started with Henry Ford's moving assembly line in 1913. This allowed Ford to reduce the time to assemble a car from 12.5 hours to just 1.5 hours. Ford was then able to produce cars in high volume at a low cost. His vertically integrated factory, however, was not flexible, and it took Ford many years to make the necessary changes to produce the Model A in 1927. Alfred Sloan of General Motors introduced product variety by "offering a car for every purpose and every price." Offering variety requires costly changeovers that reduce production efficiency. This tradeoff gives rise to the productivity dilemma. Toyota has been very successful in reducing changeover times and thereby mitigating the effects of the productivity dilemma.

3.2 The Scientific Method

Frederick Taylor used the **scientific method** to experiment with work methods in search for the best way to perform a job. He published a book called "The Principles of Scientific Management," where he synthesized the ideas that came to be known collectively as scientific management. He believed that management and laborers could work as a team to improve efficiency, and that improved efficiency would result in higher wages for the work force, lower cost to companies, and better and less expensive products for the consumer. Management's function was to develop the most effective methods to perform operations. The role of labor was to learn and apply the work methods.

The goal of finding the most efficient way to perform operations is still being relentlessly pursued by many companies such as the Mazda Motor Company. What has changed is the emphasis. During Talylor's time the workforce was uneducated, and he believed that it was the responsibility of management to find and teach the most efficient method of performing a task. Now that the workforce is better educated, the burden of finding the most efficient method to perform a task is shared with management.

3.3 Management Science

Management Science, also known as Operations Research, is concerned with the development and application of mathematical and statistical theory to business situations. It involves the use of models to describe and provide an understanding of a problem and its alternative solutions. People who study management science and operations research have developed a wide body of models for production planning and inventory control. The development of decision support systems based on this body of models was slow at first, due to lack of data and to managerial skepticism, but this has changed dramatically with the widespread deployment of Enterprise Resource Planning (ERP) systems, the training of managers in the use of sophisticated models, and the need to stay

[1] By 1870, the U.K. produced more goods than France, Germany, and the U.S. combined.

competitive. An important aim of this course is to familiarize the student with some of the models that management scientists have developed in the areas of production planning and inventory control.

4 Recent Trends in Production Operation Management

4.1 Information Technology

Advances in information and communications technology have had a major impact on the way business is done and on the management process. These developments, coupled with reduced trade barriers have made possible competition from all parts of the globe so that management must deal with new challenges. The improved ability to record, summarize, analyze, and communicate data has reduced the need for so many layers of management, and organizations have become flatter, more flexible, and more responsive to the changing environment. Enterprise Resource Planning (ERP) systems help provide a unified database for a corporation. Many additional capabilities, such as forecasting, demand planning, inventory planning, and supply chain integration software, can be bolted-on to an ERP system.

4.2 Plant Automation

Automation has had a large impact on the way things are produced. Machines were initially man-powered and controlled. Now most machines are powered by electricity and some are controlled by computers. Automated manufacturing continues to become more flexible and versatile.

4.3 Just-in-Time

New management practices and operating methods such as the concepts of *just-in-time* production are employed in repetitive manufacturing environments. These concepts rely on employing only a minimum of inventories or other resources to make products. Companies coordinate their operations so that one work center produces only what is required by subsequent work centers, and this production occurs just when the necessary components are needed. Successful implementation of JIT requires that companies develop reliable supplier networks, sound preventive maintenance programs, and excellent quality control programs.

4.4 Reengineering

Reengineering, is another idea that has caught the attention of people involved in operations. The core message is that it is no longer necessary or desirable for companies to organize their work around Adam Smith's Division of labor. Task-oriented jobs in today's world of informed customers, heightened competition and constant change, are obsolete. Today's fragmented organizations display appalling diseconomies of scale, the opposite of Adam's Smith's goal. The diseconomies show up not in direct labor but in overhead. Reengineering is the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed. In essence reengineering calls for an effort to reunite disparate tasks into coherent business processes, to start over an examine work with a clean slate approach. The underlying problem, to which bureaucracy has been and remains a solution, is that of fragmented processes. The way to eliminate bureaucracy and flatten the organization is to reengineer the process so that they are no longer fragmented. Only then can a company manage without its bureaucracy. Examples of reengineering include IBM's credit approval process that was simplified by eliminating specialists in each step of the process and replacing them by generalists aided by computer systems and databases to carry out the whole process. Ford improved its procurement procedure by eliminating invoice, purchase order and proof of delivery conciliation. Now each time a shipment arrives, the employee verifies in a computer database that it matches an existing purchase order and generates a check. Kodak's product development was slow because it was sequential. Each step had to be completed before the next one could be started. Now, many tasks in design can be carried out simultaneously using CAD/CAM, and production engineers can participate since the very early stages to design a product that is cheaper to produce.

4.5 Supply Chain Initiatives

Advances in information technology allow manufacturers to track orders and match production to changes in demand. The game plan is to use information to better coordinate inventory replenishment with upstream and downstream supply chain partners. Supply chain initiatives include Electronic Data Interchange (EDI), Efficient Consumer Response (ECR), and Vendor Managed Inventory (VMI).

EDI is the direct computerized transmission of orders, invoices and payments. ECR comprises marked oriented logistics strategies that link suppliers and distributors to efficiently introduce new products, promote them, and replenish them using point of sale information. VMI gives suppliers the responsibility to managing the inventories on its customer's shelves. Other variants of VMI include retail managed inventories (RMI), jointly managed inventories (JMI), and consignment selling.

4.6 Changing the Givens

Most models assume *given* data parameters, decision variables, and an objective function. One important source of competitive advantage is to not only focus on optimizing a system given the data parameters, but to also explore the benefits of changing them. Changing the *givens*, for example reducing lead times, setup times, setup costs, and yield variability can have a large impact on system performance. In fact, sensitivity analysis is often used to identify high impact *givens* that, if changed, can significantly improve system performance.

4.7 Sharing Demand Information

A new literature stream is emerging pointing to the benefits of demand information sharing in supply networks as well as within different plants in a vertically integrated firm. A supplier is usually able to reduce his costs if his customers (e.g., retailers) share demand information. This is so, in part, because it reduces the variance of the supplier's lead time demand. Retailers, however, do not always benefit from sharing demand information. For this reason it is important for retailers to determine when sharing demand information is beneficial to them. If not, retailers must insist on a monetary compensation (information trading) or on higher service levels.

4.8 Demand Lead Times

Different customers often have different willingness to pay for the speed with which their orders are filled. A build-to-order company may be able to improve its profits by shifting its production strategy to satisfy customers willing to pay higher prices for shorter demand leadtimes[2] This requires a mixed strategy where part of the production is build-to-order and part is build in anticipation of orders. Similarly, a build-to-stock company may be able to increase its profits by offering price discounts to customers willing to accept longer demand leadtimes. This shifts the production strategy from build-to-stock to build-to-order. There is a growing consensus that manufacturers can benefit from a hybrid strategy of having a portfolio of customers with different demand leadtimes, see Appell et al. (2000). The hope is that such portfolios will lead to higher, more regular, revenues and better capacity utilization.

Customers with positive demand leadtimes place orders in advance of their needs resulting in what we call *advance demand information.* Finding optimal production/ordering policies under advance demand information is a challenge that needs to be solved in order to design effective

[2] A customer who places an order l units of time ahead of his needs is said to have demand leadtime l.

strategies to induce advance demand information and achieve a portfolio of clients with different demand lead times.

5 Types of Manufacturing Operations

Manufacturing operations generally transform some tangible input or raw materials into some tangible output. Manufacturing operations perform some chemical or physical processes such as weaving, sewing, sawing, welding, grinding, blending, refining, or assembling to transform their raw materials into tangible products.

The facility, equipment, and operating methods (the production system) that a company uses depend on the type of product that it offers and the strategy that it employs to serve its customers. Some companies are make-to-stock producers, while others are make-to-order or assemble-to-order producers.

Flexibility is one characteristic often used to distinguish among types of factories. At one extreme is a factory that makes custom products in low volume or in single units. At the other extreme is a factory that makes only one standard product in very high volume.

5.0.1 Job Shops

A job shop manufacturing business contracts to make-to-order custom products, typically in low volumes, so these companies must contract to make a wide variety of products in order to achieve a sufficient level of sales. These factories need general-purpose production equipment and employees who have a broad range of skills. Job shops are generally classified as high-variety, low-volume manufacturers. These companies face a big challenge in planning, scheduling, and coordinating the production of numerous components of a wide variety of unfamiliar products. Examples: Drapery, woodworking, and metal fabrication shops that make custom made goods.

5.0.2 Repetitive Manufacturing

Repetitive manufacturing, repetitive production, flow shop, and production lines are terms used for mass production facilities that produce a high volume of the same or similar units of product that follow the same path through the production steps. The products are normally made to stock. The production equipment may be specifically design to do a particular operation rapidly and reliably with little variation in its results from cycle to cycle. Typical products of this type of production might be televisions, telephones, refrigerators, microwave ovens and roller skates.

5.0.3 Batch Manufacturing

Many manufacturing operations fall somewhere in between job shops and repetitive manufacturing in terms of variety and volume. A batch manufacturing facility makes some intermediate variety of products and produces an intermediate volume of each. The volume of any one item is not sufficient to justify dedicating a set of equipment to its production, so a few of several products share the production resources. The production equipment in batch manufacturing must be capable of performing some variety of tasks, but the range of possible operations is much narrower than in a job shop. Attachment and tooling may be installed to run one type of item. After a batch is completed, the equipment may be set up anew to run some other item. The ability to change back and forth quickly is important in this type of production system. An example of a batch manufacturer might be a company that makes small hand tools, such as drills of different sizes, electric screw drivers hand mixers, etc.

Process and projects are two other terms that are sometimes used to describe types of manufacturing operations. Some repetitive production operations produce a product that blends together in bulk rather than in discrete units. These industries that produce these types of products are sometimes called process industries, particularly if some physical or chemical reaction is used. Examples include petroleum refineries, flour mills, cement factories, and chemical processing plants. Lying at the high-flexibility end of the continuum is the low-volume type of operation often referred as a project.

It is important that the type of factory we use is well aligned with the need for product variety. It would not make sense, for example, to have a job shop that produces only one product because we will be underutilizing the inherent flexibility of the job shop. On the other hand, it would not make sense to use flow shop to produce a variety of products in low volumes because of the high cost of changeovers.

5.1 Types of Nonmanufacturing Operations

Customers deal with nonmanufacturing companies to obtain purely intangible services, such as advice or instruction, or to obtain goods not manufactured by these companies. They service their customers by transporting, packaging, storing, and so on.

Nonmanufacturing operations–also known as service operations–are operations that do not produce tangible outputs. They can be subdivided according to the degree of standardization of their outputs, i.e., standard versus custom services and/or the processes they perform.

Another way to classify nonmanufacturing operations is whether or not they provide a tangible product. Among those nonmanufacturing operations that provide a tangible product are mail service, library service, wholesalers, retailers, and distributors. Among those who do not are health care, legal and financial advice, travel, etc.

Four differences between manufacturing and service operations:

1. Productivity is easier to measure in manufacturing operations.
2. Quality standards are more difficult to establish and evaluate in service operations.
3. Persons who provide services generally have more contact with customers.
4. Manufacturing operations can accumulate or decrease inventory of finished products.

6 Strategy and Hierarchical Planning

We can classify decisions into three categories:

Type	Time horizon	Example
Strategic planning	Long range	product line, location of plants
Tactical planning	Intermediate range	size of work force, production rates.
Operational Control	Short range	work assignment, scheduling

Strategic planning is concerned with the definition of the **product line**, the determination of the **location, size, and number of plants and warehouses** that the firm needs in order to serve its market. It is also concerned with the acquisition of new production equipment, and the design of working centers within each plant. An essential characteristic of these strategic decisions is that they have **long lasting effects** thus forcing long planning horizons in the analysis. This in turn requires considerations of uncertainties in the decision making process.

Tactical Planning is done within the framework of the long range planning process. The basic problem to be resolved is the effective allocation of resources to satisfy the demand and the technological constraints. Typical decisions to be made are the **size of regular work-force, the rate of production, the distribution of goods** in existing distribution channels, and setting company targets for inventory levels.

Operational Control is the process of assuring that specific tasks are carried out effectively and efficiently. Typical decisions are: assignment of work to work stations or to machines, sequencing of these works on a given machine, short-term inventory control issues.

Notice that all these decision levels are strongly connected. For example, the size of a warehouse is influenced by the inventory policy in use, which itself is influenced by demand and production rates.

Hierarchical planning recognizes the time nature of these decisions and provides a framework to build strategic, tactical and operational control models.

In addition to classifying strategy as it relates to time, people think of strategy as it relates to the **focus** of the factory. A focused factory has a process technology that is adequate for its product mix and volume, has reliable, high quality products in tune with the market.

A company's overall strategy defines the major products and services and the market segments that represent appealing opportunities to profitably use the company's resources. A logical recommendation is that planning be market driven and focused on the true needs of the customer. The underlying philosophy is that it is better to work at trying to provide what the customer truly wants to buy than it is to work at trying to get the customer to buy whatever the company wishes to provide.

7 Inventory Systems

Inventories are produced, used or distributed, by most organizations. Moreover, inventories account for a significant part, about 34%, of the current assets of a typical firm, and for 10% to 15% of annual sales. The average manufacturing companies has 2.5 years worth of after-tax profits tied up in inventories.[3]

The impact of adequate production and inventory management on the operating profit of a firm (revenue minus operating expenses) can be seen by noting that

> (i) sales revenue can be increased by an appropriate allocation of inventories among specific items and locations, (ii) operating expenses can be reduced by reducing aggregate inventory levels and by more effective scheduling and control of inventories of individual items.

Inventories are also important at a macroeconomic level in that their aggregate levels fluctuate in a more or less predictable way during the business cycles. Indeed, at the peak of the cycle because of over-optimistic expectations too many products are produced by the economy and they cannot be sold. At this point aggregate inventories are so high that producers start to downscale their production rates and to slash prices to reduce their inventories. The effect of reducing the production rate results in layoffs. In addition some firms cannot survive at lower price levels. This causes additional unemployment. At the trough aggregate inventories are low, prices start to recover, and managers start to expand their operations by purchasing raw materials and hiring additional labor. The cycle repeats when aggregate inventories peak and sales flatten.

The above indicates that adequate production and inventory management can have a significant effect both at the firm an at a national level. People who study management science and operations research have developed a wide body of models for production planning and inventory control. Some of these models have been developed by a procedure that consists of reducing a decision problem to a key set of causal variables, with an explicit mathematical objective criterion. These models are build in an attempt to gain a deeper qualitative and quantitative understanding of the problems they address. An important goal of this course is to introduce students to some of these models, and more importantly to develop the students' ability to model complex manufacturing systems.

Inventory management is a problem of managing large numbers of items of a diverse nature. For each item, one must answer three basic questions:

[3] U.S. Department of Commerce, July 1990.

(i) How to monitor the inventory (periodically or continuously)?
(ii) When to order?
(iii) How much to order?

The above decisions must be consistent with the overall objective of the firm. In order to answer some of the above questions, it is important to classify inventories by type, function, and dollar value, and to be cognizant of some cost factors related to inventories.

7.1 Functional Classification of Inventories.

1. *Cycle stock*: batch production to achieve economies of scale.
2. *Congestion stock*: are inventories due to items competing for limited capacity.
3. *Safety stock inventories:* cope with uncertainties in supply/demand.
4. *Anticipation inventories*: cope with peak seasonal demand.
5. *Pipeline inventories (or Work-in-Process)*: goods in transit between levels of a multi-echelon system.
6. *Decoupling stock*: used to decentralize control in multi-echelon systems.

Some authors classify inventories with respect to their time flow as input inventory, work-in process inventory, in-transit inventory, and output inventory.

7.2 Classification by Value.

A stock keeping unit (sku) is a basic item which has its own unique characteristics such as function, shape, size, color, and location. Many existing inventory systems may be improved by simply adopting rules that do not treat all sku equivalently. A useful classification, called the ABC classification, starts by sorting the sku in descending order of their annual dollar volume of sales also called *dollar usage* value. The dollar usage value of an sku is simply the product of its annual usage (demand) by its variable cost. Sku that are near the top of the sorted list have a relatively high dollar usage value; sku that are near the bottom of the sorted list have a relatively low dollar usage value. By plotting the cumulative percentage dollar usage value against the cumulative percentage of the sku, we obtain what it is called the *distribution by value* (DBV) of the sku. Most firms have a skewed DBV in that about 20% of the sku account for about 80% of the dollar usage value. The DBV gives a relative ranking of the economic importance of the sku. Generally speaking an sku with a high dollar usage value deserves more managerial attention. The ABC classification assigns a priority rating for each and every sku according to its dollar usage value: A (most important), B (intermediate importance), C (least important). Typically the top 20 percent of the sku are classified as A items, the next 30% are classified as B items, and the rest as C items. While A items should be given careful managerial attention, B items can be monitored and control by a computer based system, with management by exception routines appended. For C items decision systems must be kept as simple as possible.

Other bases of an ABC type classification are sometimes used. For example profit or volume may be used instead of variable cost to identify those items that generate more profit, or those items that require more warehouse capacity.

7.3 Relevant Costs

1. *Procurement or ordering costs*: Fixed and variable.
2. *Holding cost*: Warehousing, insurance, opportunity cost of tying up inventory.
3. *Stockout or penalty costs*: lost sales, expediting, keeping track of backorders, goodwill.

4. *Cost of changing the production rate*: includes the cost of hiring, overtime, expediting, downsizing, etc..

5. *System control costs*

7.4 Characteristics of Inventory Systems.

1. *Demand.* Constant versus Variable, Known versus Random, Internal versus External.

2. *Lead Times.* The amount of time that elapses from the instant that an order is placed until it arrives. Deterministic or stochastic.

3. *Review Time* Continuous review versus periodic review

4. *Excess Demand* Lost or backordered

5. *Changing Inventory* Perishability, obsolescence.

6. *Structure.* Central Warehouse, regional warehouses, retailers.

7.5 Performance Measures.

1. Probability of not stocking out during the lead time. (Appropriate when a shortage occurrence has the same consequence independent of its time or amount.)

2. Fill rate: Proportion of demands that are met immediately from stock.

3. Average number of backorders.

4. Turnover ratio defined as the ratio of throughput to average inventory measured in terms of costs.

7.6 Motives for Holding Inventories.

Most authors list three motives for holding inventories:

1. Economies of scale

2. Speculation

3. Uncertainties

Economies of scale make it economical to produce in batches which result in the holding of cycle stocks. Speculation may lead to holding inventories in anticipation of price increases e.g., real estate, stocks. Uncertainty of external demand, coupled with production or ordering lead times, create the need to carry inventories (just-in-case) to be responsive to customer needs.

Other authors list additional motives such as transportation, production smoothing, logistics (e.g., minimum order quantities), and control costs (it may be cheaper to carry large inventories of inexpensive items than the cost of maintaining a tight control).