The Encyclopedia of Operations Management

by

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This encyclopedia includes definitions and discussion of a wide range of operations management terms. Extensive explanations are provided for many terms and concepts. Many new service management, strategic management, manufacturing management, and e-business terms are included here that are not found in other dictionaries and encyclopedia.

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Essential terms for business and engineering students are marked with an asterisk (*) in front of the term.

ABC classification – A method for prioritizing items based on the product of the annual demand and the unit cost. The high "annual dollar volume" items are classified as "A" item. The low annual dollar volume items are classified as "C" items. Based on Pareto's Law, the ABC classification system drives us to manage "A" items more carefully. This means that these item should be ordered more often, counted more often, located closer to the door, and be forecasted more carefully. Conversely, "C" items are not very important from an investment point of view, and therefore should be ordered rarely and not counted often. Some firms use other methods for defining the ABC classification -- such as the stockout cost or the medical criticality of the item. This has nothing to do with Activity Based Costing. See Pareto's Law.

acceptance sampling –** Acceptance sampling plans are used to make accept/reject decisions for each lot. With ***attribute sampling plans, these decisions are based on a count of the number of defects and defectives; with ***variable*** sampling plans these decisions are based on measurements. Plans requiring only a single sample set are known as single sampling plans; double and multiple sampling plans may require additional samples sets. For example, an attribute single sampling plan with a sample size n=50 and an accept number a=1 requires that a sample of 50 units be inspected. If the number of defectives in that sample is one or zero, the lot is accepted. Otherwise it is rejected. Ideally, when a sampling plan is used, all bad lots will be rejected and all good lots accepted. However, because accept/reject decisions are based on a sample of the lot, there is always a chance of making an incorrect decision. So what protection does a sampling plan offer? The behavior of a sampling plan can be described by its operating characteristic (OC) curve, which plots percent defectives versus the corresponding probabilities of acceptance. Excerpted from Dr. Wayne Taylor, http://www.variation.com/techlib/as-9.html. See inspection.

Activity Based Cost (ABC) – Activity-based costing (ABC) is an information system that maintains and processes data on a firm's activities and products. It identifies the activities performed, traces cost to these activities, and then uses various cost drivers to trace the cost of activities to products. These cost drivers, such as the number of persons performing work or the number of setups required per product reflect the consumption of activities by the products. By costing the various activities performed, it is easy to see how you might easily pinpoint changes in resource requirements for each activity if you changed your process or procedure. If you operated under a traditional costing system, pinpointing changes in resource requirements would be virtually impossible because it accumulated cost under budgetary line items (such as salaries) or functions (such as engineering). Activity-base management (ABM) is merely the use of the activity-based costing tool by process owners to control and improve their operations. Because process analysis is conducted in the building of an activity-based cost model, management knows its business much better and can consequently evaluate value added and non-value added activities. Because all of the costs for processes are known, outsourcing and privatization questions can easily be evaluated. Because a certain volume of work produces a certain outcome, "what if" analysis can be conducted to determine what resources are required if operations are scaled back or expanded. The potential of the activity-based costing tool to assist management in daily operational decisions is powerful. (Source: http://www.acq-ref.navy.mil/wcp/abc.html)

active item – Any inventory item that has been used or sold within a given period (say last year). It is common for some retailers to have 200,000 items in their item master, but only 20,000 "active" items.

A-plant – In this type of manufacturing process, we have many components that are "assembled" into just a few end items. We master schedule this plant at the finished products level. (The term "A-plant" is probably not the best term. This is more of a description of the bill-of-material than it is of the plant.)

Advanced Planning and Scheduling (APS) – A manufacturing planning and scheduling system that is often used to supplement "infinite planning" systems based on MRP (ERP) logic. An APS can create detailed schedules for orders, whereas traditional MRP systems create very crude plans based on fixed planned leadtimes. Currently, the two best known APS software vendors include i2 Technologies and Manugistics. See MRP, ERP, finite scheduling.

affinity diagram – A group decision-making technique designed to sort a large number of ideas, process variables, concepts, and opinions into naturally related groups. These groups are connected by a simple concept. Groups use Affinity Diagrams to clarify complex issues and reach a consensus on the definition of a problem. It answers a "What" question; for example, it might be used to clarify the question, "What are the root causes of events that determined or impacted the quality of our product?"

aggregate inventory management – Inventories with thousands or even hundreds of thousands of items are difficult to manage at an item level. Aggregate inventory management tools allow managers to group items and manage each group with policies, key performance indicators, targets and reports. For example, a particular group of items might share carrying charge parameters, turnover goals, and have a fixed space allocation.

aggregate planning (aggregate plan) – The process of translating the annual business and marketing plans into a production plan. In academic circles, the result of the aggregate planning process is called the "aggregate plan," whereas in APICS circles it is known as the "production plan." Aggregate planning is particularly difficult for firms with seasonal products -- firms such as Polaris (snowmobiles and personal watercraft) and Toro (snow blowers and lawnmowers). Whereas the business plan is usually defined in dollars (profit, revenue, and cost), the production plan is defined by units produced or by an aggregate output (or input) measure, such as shop hours worked, gallons produced, etc. An aggregate measure is particularly useful if the production plan includes many dissimilar products. Costs relevant to the aggregate planning decisions include: inventory carrying costs, capacity change costs (hiring, training, firing, facility expansion or contraction, equipment expansion or reduction), and possibly the opportunity costs of lost sales.

agile manufacturing – Agility is an integrated set of business strategies for competitiveness in a turbulent business environment, based on four cardinal principles: (1) Enrich the customer, (2) Master change and uncertainty, (3) Leverage resources, and (4) Co-operate to compete. Companies that successfully embrace Agility profit from:

- New markets for niche, customized products and services
- Long-term relationships with customers
- Faster concept to cash time
- Turning change into market opportunity
- Greater bottom-line impact of people, information and technology
- Multiple win/win partnerships

A company that knows how to be Agile …

- Strategizes to fragment mass markets into niche markets
- Competes on the basis of customer-perceived value
- Produces multiple products and services in market-determined quantities
- Designs solutions interactively with customers
- Organizes for proficiency at change and rapid response
- Manages through leadership, motivation, support and trust
- Exploits information and communication technologies to the full
- Leverages all its capabilities, resources and assets regardless of location
- Works in entrepreneurial and empowered teams
- Partners with other companies as a strategy of choice, not of last resort
- Thrives and is widely imitated

Sources: http://www.agility.co.uk/ai.html

Agile Competitors and Virtual Organizations by S.L. Goldman, R.N. Nagel and K. Preiss; New York, Van Nostrand Reinhold, 1995.

Agile Networking: Competing Through the Internet and Intranets by G. Metes, J. Gundry and P. Bradish; Upper Saddle River New Jersey, Prentice-Hall PTR, 1997.

See agile work force.

all-time order – The last order for a particular product in the last phase of its life cycle. This order should be large enough that the stock provided will satisfy all expected future demand for the product concerned.

all-time demand – The total future requirements for an item. This is the sum of the demand until the product termination date or until the end of the world. This is used to determine the requirements for the final purchase or production run. This is sometimes called the "all-time" or the "lifetime" requirement. See geometric decay.

allocated stock – A quantity of an item that has been reserved, but not yet withdrawn or issued from stock. Allocated inventory is not available for other purposes

anticipation stock – Inventory held in order to (a) satisfy seasonal demand; (b) cope with expected reduced capacity due to maintenance or anticipated strike; or (c) store seasonal supply for a level demand throughout the year (for example, a crop that is harvested only once per year).

****Assemble-to-Order (ATO)*** – A customer interface strategy that responds to a customer order by putting together standard components and modules for the customer. Customer leadtime is sum of the assembly, packing, and shipping time. This approach allows for a large variety of final products within a relatively short customer lead-time. Examples include Burger King, which assembles hamburgers with many options while the customer waits, and Dell Computer, which assembles and ships a wide variety of computers on short notice. ATO systems have no finished goods inventory, but usually stock major components. Pack-to-Order and Configure-to-Order systems are special cases of ATO. See make-to-order and make-to-stock.

autonomation – Stopping a line automatically when a defective part is detected. See Jidoka.

autonomous maintenance – A TPM principle of having each worker responsible for both maintaining and operating a machine. Maintenance activities include cleaning, lubricating, adjusting, inspecting, and repair. See Total Productive Maintenance.

Available-to-Promise (ATP) – Uncommitted inventory and planned production in master scheduling to support customer order promises. (Source: http://gartner4.gartnerweb.com/public/static/hotc/hc00088697.html, updated October 27, 2000) The uncommitted portion of a company's inventory and planned production, maintained in the master schedule to support customer order promising. The ATP quantity is the uncommitted inventory balance in the first period and is normally calculated for each period in which an MPS receipt is scheduled. In the first period, ATP includes on-hand inventory less customer orders that are due and overdue. (http://www.iolt.org.uk/sig/scimglossary.htm, January 26, 2001)

****B2B*** – Business-to-business. A business selling to other businesses.

****B2C*** – Business-to-consumer. A business selling directly to consumers.

backflushing – A means of reducing the number of inventory transactions by relieving (reducing) the inventory count for parts only when the final product is shipped. For example, instead of counting the number of letter "A"s that issued to assembly, we simply count the number of keyboards that we ship and reduce the letter "A" inventory count accordingly. Backflushing gives us an imprecise inventory count because of the delay -- but it can reduce the transaction cost significantly. A concept of measurement used to periodically explode an end item's BOM to calculate how many of each part went into the final product(s). This eliminates much of the shop-floor data collection activity, which is required if each part must be tracked and accounted for during production.

***backorder** – A customer demand for which no stock is available and where the customer is prepared to wait for the item to arrive in stock. If a firm cannot immediately satisfy a customer order, the customer is asked to wait. This order is called a "backorder," and is usually filled as soon as the items become available. If a product is not available, it is said to be "on backorder." In a sense, when we "backorder" demand, we are "inventorying" the demand. The set of backorders for a firm is often called the "order backlog."

backward loading (backloading) – A planning method that plans backwards from the due date to determine the start date. The word "loading" implies that we are not creating a detailed schedule; backward loading might fill up a time "bucket" (say a half-day) until the capacity is fully utilized. See backward scheduling.

backward scheduling – A scheduling method that plans backwards from the due date (or time) to determine the start date (or time). Unlike backward loading, backward scheduling creates a detailed schedule for each operation based on the planned available capacity.

***balanced scorecard** – A reporting tools that shows senior management key performance metrics so that they can assess how well the firm is achieving the strategy. Typical "boxes" include owners (financial metrics), operations (internal non-financial metrics such as cycle time and quality), customers (customer satisfaction/loyalty), employees (employee satisfaction), and suppliers (on-time delivery, quality, etc.). (Source: Art Hill)

A balanced scorecard is a framework that translates a company's vision and strategy into a coherent set of performance measures. Developed by Robert Kaplan and David Norton (published in the ***Harvard Business Review*** in 1993), a balanced business scorecard helps businesses evaluate how well they meet their strategic objectives. It typically has four to six components, each with a series of sub-measures. Each component highlights one aspect of the business. The balanced scorecard includes measures of performance that are lagging (return on capital, profit), medium-term indicators (like customer satisfaction indices) and leading indicators (such as adoption rates for, or revenue from, new products).

(Source: http://www.adamssixsigma.com/Glossary_of_terms/six%20sigma%20glossary%20B.htm

Professor Hill has written a two-page technical note on Strategy Maps, which is closely related to the balanced scorecard concept.

***bar code –** Information encoded into a pattern of parallel bars and spaces that can be read by a scanner.

***benchmarking** – Comparing products and/or processes to a standard in order to evaluate and improve performance. Benchmarking can be done for either product or process performance. Internal process benchmarking sets the standard by comparing processes in the same firm (e.g., another department, region, machine, worker, etc.). External process benchmarking sets the standard based on a process from another firm. Competitive benchmarking sets the standard based on a competitor's product or process. Several quality awards such as the Deming Award in Japan, The European Quality Award in Europe, and The Malcolm Baldrige Award in the U.S.A. provide benchmarks for quality performance. Many professional trade organizations provide benchmarking standards. Having a numerical standard is only part of the benchmarking process -- real improvement only comes when a "best in class" process or product is understood in detail and when the technology is transferred. Some firms foolishly "benchmark" against another firm that is convenient, easy to find, close by, etc. Clearly, it is better to benchmark the best in the world. Benchmarking can be informal or formal -- informal benchmarking involves going to a warm climate in the winter, having some good food, and making some new friends. Formal benchmarking involves mapping processes, sharing process maps, comparing numbers, etc. We want to measure not only the current status of the variable but also the rate of change. For example, if we benchmark a "world class" firm and find that they have a cycle time of 10 weeks. We work really hard over the next year and get our cycle time down to 10 weeks. Does that mean that we now have world class cycle time? The answer, of course, is that we might not because the "world class" firm will likely be improving its cycle time during the year and might be doing so at a very rapid rate. Calculus teaches us that we need to know $s(t)$, the position of the metric at time t and $v(t)=ds(t)/dt$, the velocity (first derivative) at time t.

***best practices** – This term is typically used in the context of a multi-divisional or multi-location firm that has similar processes in many locations. For example, Wells-Fargo buys banks, which all have similar teller policies. Clearly, it is in the best interest of the firm to find out which of the many banking subsidiaries has the "best practice" for this process, document the process with process maps and other documentation, and then implement that process throughout the system. This is really just an application and extension of internal benchmarking.

***Bill of Lading (BOL)* –** Bill of Lading. A document used to acknowledge the receipt of products.

***Bill of Material (BOM)** – A listing of components, parts, and other items needed to manufacture a product, showing the quantity of each required for each intermediate item. The BOM is usually drawn as a "tree structure" with the end items at the top. A bill of material is similar to a parts list except that it usually shows how the product is fabricated and assembled. The BOM is organized in "levels" where each level is an "inventoriable" item. Also called a product structure, formula, recipe, or ingredients list. See commonality and routing.

***blanket purchase order –** An agreement with a supplier that specifies the price, minimum quantity, and maximum quantity purchased over a defined time period (usually a year). Purchase orders are placed "against" the blanket order to define the quantity and due date for the specific order. The advantage of blanket purchase orders for both parties is that they lock in the price and the parties only have to negotiate once every year or so. The supplier usually gives the customer a quantity discount for the blanket order.

blocking (a process, not football) – Production is said to be "blocked" when a process is not allowed to produce when the output storage area (container, kanban square) is full. Blocking is good for non-bottleneck processes because it keeps them from producing before the output is needed. Blocking avoids "over-production" and keeps the total work-in-process inventory down to a reasonable level. See JIT, kanban, CONWIP.

bottleneck – A resource that constrains a system from improving its performance. Goldratt expands this definition to include any philosophy, assumptions, mindsets, etc. that limit a system from performing better.

Box-Jenkins forecasting – This is a mathematically sophisticated time-series extrapolation forecasting method. The method was originally developed in the 1930s, but not widely known until Box and Jenkins published a detailed explanation in 1970. Contrary to early expectations, empirical studies have shown that it does not consistently perform better than much simpler exponential smoothing methods. BJ methods develop forecasts as a function of the actual demands and the forecast errors at lagged time intervals (say one week back). The approach iteratively follows three steps (1) specification (choose which lagged terms to include in the model), estimation (find the best weights for these terms), and diagnostic checking (see if any terms should be added or deleted from the model).

buffer stock – See safety stock.

bullwhip effect (in supply chains) – A pattern of increasing variability in the demand from the customer to the retailer to the distributor to the manufacturer, to the supplier to the manufacturer, etc. The four causes of the bullwhip effect include (1) forecast updating, (2) periodic ordering/order batching, (3) price fluctuations, and (4) shortage gaming. Even if the customer is consuming at a constant rate, the supplier to the manufacturer will often see high variability in the demand as variations in the demand are amplified along the supply chain. The primary solution to this problem is for the retailer to regularly share actual and projected demand information. Other solutions include vendor-managed inventories, reducing order sizes by reduced ordering costs, everyday low prices (instead of promotional prices), and avoiding allocation based on orders placed. The following is a more complete explanation of the subject excerpted from "The Bullwhip Effect in Supply Chains," by Hau L. Lee, V. Padmanabhan, and Seungjin Whang (***Sloan Management Review***, Spring 1997, pp. 93-102):

Demand forecast updating. Ordinarily, every company in a supply chain forecasts its demand myopically--that is by looking at the past demands they have faced from their own direct customers. Since each upstream chain member sees fluctuations in demand caused by the bullwhip effect from downstream, that member orders accordingly, creating further swings for the upstream suppliers. This occurs even when the ultimate demand is relatively stable. One obvious way to counteract this forecast effect is for all members of a supply chain to use the same basic demand data coming from the furthest downstream points. Technologies such as point-of-sale (POS) data collection, electronic data interchange (EDI), vendor-managed inventories (VMI), as well as lead-time reduction can all help to reduce the problem.

Order batching. Companies placing orders on upstream suppliers usually do so periodically, ordering a batch of an item to last several days or weeks, thus reducing transportation costs or transaction costs or both. These tactics contribute to larger demand fluctuations further up the chain. Here the authors suggest reducing transaction costs through various forms of electronic ordering, offering discounts for mixed-load ordering (to reduce the demand for solid loads of one product), and the use of third party logistics providers to economically combine many small replenishments for/to many suppliers/customers.

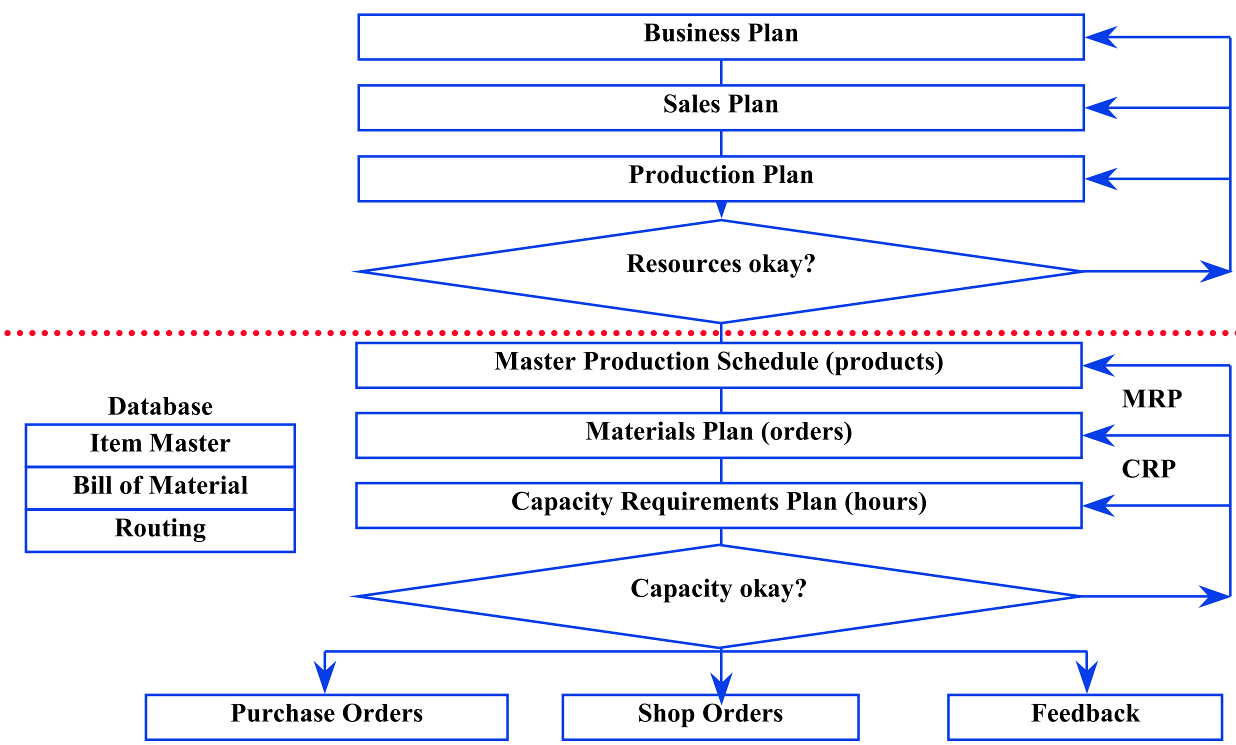
Price fluctuation. Frequent price changes--both up and down--lead buyers to purchase large quantities when prices are low, and avoid buying when prices are high. A common practice in the grocery industry, this forward buying creates havoc upstream in the supply chain. The answer here is for sellers to stabilize prices (e.g. "every day low prices"). Activity-based costing systems that highlight the excessive costs in the supply chain caused by price fluctuations and forward buying also can help provide the incentive for the entire chain to operate with relatively stable prices.

Rationing and shortage gaming. Cyclical industries face alternating periods of oversupply and undersupply. When buyers know that a shortage is imminent and rationing will occur, they will often increase the size of their orders to insure they get the amounts they really need. To counteract this behavior, Lee and his colleagues advocate allocation of demand among customers based on past usage, not on present orders. Furthermore, they encourage more open sharing of sales, capacity, and inventory data so that buyers are not surprised by shortages.

***Business Process Re-engineering (BPR) –** A radical change in the way that an organization operates. Business Process Re-engineering involves a fundamental re-thinking of the business systems. BPR typically includes eliminating non-value added steps, automating some steps, changing organization charts, and restructuring reward systems. It often includes job enlargement, which reduces the number of queues, and gives the customer a single point of contact. In many firms, BPR has a bad reputation because it is associated with downsizing (firing people).

Business Requirements Planning (BRP) **–** BPR is a conceptual model showing how business planning, master planning, materials planning, and capacity planning processes should work together. The BRP model (Figure 1) starts the business plan (profits), sales plan (revenues), and production plan (costs and aggregate units). Once the production plan has been checked to make sure that the resources and available and that the top level plans are consistent, it is used as input to the master production schedule, which is a plan (in units) for the firm's end products (or major subassemblies). The Materials Requirements Planning (MRP) module translates the MPS into a materials plan (orders defined by quantities and due dates). CRP translates the materials plan into a capacity plan (defined in terms of shop hours). (Note that not very firms use CRP.) Ultimately, the system creates both purchase orders for suppliers and shop orders for the firm's own factories. Orders in the action bucket (the first period) are released and become scheduled receipts. This planning process is supported by the ERP database, which provides information on items (the item master), the bill of material (the linked list of items required for each item), and the routings (the sequence of steps required to make an item). Source: Adapted from ***Business Requirements Planning*** by Terry Schultz. See aggregate production planning, master scheduling.

Figure 1. Business Requirements Planning



c-charts – Quality control charts that display the number of defects per sample.

call center – An organization that provides remote customer contact. This might be in the form of (a) a help desk operation that provides technical support for software or hardware, (b) a reservations center for a hotel, airline, or other service, (c) dispatch operation that is sends technicians or other servers on a "service call." A well-managed call center can have a major impact on customer relationships and on firm profitability. Call center management software monitors system status (number in queue, average talk time, etc.) and measuring their customer representative productivity. Advanced systems also provide forecasting and scheduling assistance. Well-managed call centers receive customer requests for help through phone calls, faxes, emails, regular mail, and information coming in through the web. Well-managed call centers respond via interpersonal conversations on the phone, phone messages sent automatically, fax-on-demand, interactive voice response, and e-mail. Web-based information can provide help by dealing with a large percentage of common problems that customers might have and providing downloadable files for customer use. By taking advantage of integrated voice, video, and data, information can be delivered in a variety of compelling ways that enhance the user experience, encourage customer self-service and dramatically reduce the cost of providing customer support.

capability – See process capability.

****capacity*** – The maximum rate of output for a process, measured in units of output per unit of time. The unit of time may be of any length, a day, a shift, or a minute. Note that it is redundant (and ignorant) to use the phrase "maximum capacity" because a capacity is a maximum – just say "capacity." Some people make a distinction between nominal capacity, demonstrated capacity, and theoretical capacity. This author finds these distinctions of little value. Demonstrated capacity is the capacity that the process has actually been able to sustain over a long period. However, in the long run, the demonstrated capacity will never exceed the market demand. The theoretical capacity is the maximum production rate based on mathematical or engineering calculations, which sometimes do not consider all relevant variables; therefore, it is quite possible that the capacity can be greater than or less than the theoretical value. (It is not uncommon for factories to work at 110% of their theoretical capacity.) Do not confuse capacity with load. If an elevator has three people on it, what is its capacity? The answer is "you don't know." The capacity might be 2, 3, 20, etc. If it has three people on it, the elevator has a current load of three and probably has a capacity of at least three.

The optimal capacity is that which minimizes the total relevant cost, which is the sum of the capacity and waiting cost. All systems have a tradeoff between capacity utilization and waiting time. These two variables have a non-linear relationship. As utilization goes to 100%, the waiting time tends to go to infinity. Maximizing utilization is NOT the goal of the organization. The goal in this case is to minimize the sum of two relevant costs – the cost of the capacity and the cost of waiting. For example, the optimal utilization for a fire engine is not 100% – it is closer to 1%. The OMS Department copy machine is sitting idle right now, should we go make some copies to keep it utilized? Of course, we should not. The goal is to find the optimal balance between the cost of the machine and the cost of professors and staff members waiting. In this case, the U. of M. has decided to have utilization less than 5% for the machine. In contrast, some very expensive machines such as a bottling system are run three shifts per day 365 days per year. The cost of downtime is the lost profit from the system and is quite expensive. See Little's Law, safety capacity.

carrying charge – A rate parameter that is used in applying managerial economics for operations decision making with respect to inventory. The rate should be the sum of (1) the weighted average cost of capital, (2) a risk premium for obsolete inventory, and (3) a storage cost. Reasonable values are in the range of 15-40%. This rate should only reflect costs that vary with the size of the inventory – and should ***not*** include costs that vary with the number of inventory transactions. See setup cost. Professor Hill has written a technical note on this subject.

carrying cost – The carrying cost is the average inventory investment times the carrying charge. See carrying charge.

category management **–** The management of groups of products that are interchangeable, or substitutable, in meeting consumer needs as opposed to the traditional focus on individual products and/or brands.

cause & effect diagram – See Ishikawa diagram.

certification **–** See supplier certification.

channel conflict – Contention between players trying to sell to the same customers. A current example of this is a manufacturer (such as Compaq) begins competing with its own distributors (such as Sears) for customers by selling directly to customers. Channel conflict is not a new phenomenon with the Internet – but has become more obvious with the disruptions caused by the Internet.

channel partner **–** A firm that works with another firm to provide products and services to customers. 3M often calls its distributors its "channel partners."

chase strategy – Businesses that have seasonal demand can take two extreme approaches in meeting the demand. The chase approach keeps finished goods inventory quite low – and matches the production rate to the seasonal demand. The level approach maintains a constant production rate and builds inventory in the off-season to meet the demand in the peak season. Many firms are able to economically implement a "chase" strategy by offering counter-seasonal products such as snow skies and water skis to maintain a constant workforce but not build large inventories in the off-season.

check digit – Check digits are used to quickly validate part numbers, bank account numbers, credit card numbers, and other types of identifying numbers. The check digit is the last digit in the number and is computed from the base number, which is the number without the check digit. By comparing the check digit computed from the base number with the check digit, incorrect numbers can be found very quickly without accessing a database of valid numbers. This is particularly powerful for remote data entry of credit card numbers and part numbers. These applications typically have enormous databases that make number validation relatively expensive. The simplest approach for checking the validity of a number is to multiply the last digit (the check digit) by one, the second to last digit by two, the third to last digit by one, etc. We then sum all of the ***digits*** in these products, divide by 10, and find the remainder. The number is proven invalid if the remainder is not zero. For example, the account number 5249 has the check digit 9. The products are 1x9=9, 2x4=8, 1x2=2, and 2x5=10. The sum of the digits is 9+8+2+1+0=20, which is divisible by 10 and therefore is a valid check digit. (Because we add the ***digits***, the "10" is treated as 1+0=1; not as 10.) Numbers with valid check digits are not necessarily valid numbers; we are only checking if the number is clearly invalid. Check your credit card number and your bank account number – it works! A good check digit website is http://www.beachnet.com/~hstiles/cardtype.html. A VBA algorithm for this is available from Professor Hill.

click-and-mortar **–** What dot-coms are attempting to become; a hybrid between a dot-com and a "brick-and-mortar" (viz. profitable) operation. See dot-com.

Collaborative Planning Forecasting and Replenishment (CPFR) – Data and process model standards developed for collaboration between suppliers and an enterprise with proscribed methods for planning (agreement between the trading partners to conduct business in a certain way); forecasting (agreed-to methods, technology and timing for sales, promotions, and order forecasting); and replenishment (order generation and order fulfillment). The Voluntary Inter-Industry Commerce Standards (VICS) committee, a group dedicated to the adoption of bar-coding and EDI in the department store/mass merchandise industries, has established CPFR standards for the consumer goods industry that are published by the Uniform Code Council (UCC). (Source: http://gartner4.gartnerweb.com/public/static/hotc/hc00088697.html, updated October 27, 2000)

commonality – The degree to which parts are used in many products. For example, if a firm uses a standard screw size that is used in many components and products, we say that the bill of material has a high degree of commonality for that screw. Increasing commonality often has many benefits such as:

- Reduced setup (ordering) cost – Because the robust component has a higher demand rate, its economic order quantity is larger and it does not have to be ordered as many times as the current components. This saves on ordering cost.
- Potential quantity discounts – In general, robust components will cost more because they have a wider range of uses. However, robust components will have higher demand and therefore might qualify for a quantity discount on the price.
- Reduced cycle (lotsize) inventory – The economic order quantity logic suggests that the robust component will have a larger order size than either one of the current components, but that the total cycle stock for the robust component will be less than the sum of the cycle stock for the two current components. This will result in lower carrying cost.
- Reduced safety stock inventory and/or improved service levels – The variance of the demand during leadtime for the robust component will likely be about equal to the sum of the variance of the demand for the two current components. When this is true, the safety stock inventory for the robust component will be better. Conversely, the firm can keep the same safety stock level and improve the service level -- or make improvements in both. This can result in lower carrying cost, lower stockout cost, or both.
- Reduced forecasting error – Based on the same logic as above, the robust component will have a lower forecast error variance than the sum of the variances of the two current components. This again can reduce safety stock inventory, improve service levels, or both.
- Reduce product design cost – If the firm is using truly robust components, it can use these components in many different products and not have to "re-invent the wheel" with each new product design. (Note that cost component is not included in the economic model developed in this paper.)
- Reduced purchasing and manufacturing overhead – As the number of components are reduced, overhead needed to maintain the engineering drawings, tooling, etc. can also be reduced. (Note that this type overhead is not included in the economic model developed in this paper.)
- Reduced transportation cost – HP was able to standardize all of its printers and put all of the country-specific power management technology in the cord. This allowed for lower inventory and faster deliveries.
- Increased reliability – In some cases, a more robust part is also more reliable and easier to maintain.

A technical note and a companion Excel workbook on this subject are available from Professor Hill.

Computer Aided Design (CAD) – A CAD system is a combination of hardware and software that enables engineers and architects to design everything from furniture to airplanes. In addition to the software, CAD systems usually require a high-quality graphics monitor, a mouse, light pen, or digitizing tablet for drawing, and a special printer or plotter for printing design specifications. CAD systems allow an engineer to view a design from any angle and to zoom in or out for close-ups and long-distance views. In addition, the computer keeps track of design dependencies so that when the engineer changes one value, all other values that depend on it are automatically changed. Until the mid 1980s, CAD systems were specially constructed computers. Today, CAD software runs on general-purpose workstations and personal computers.

Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) – CAD/CAM computer systems are used to design and manufacture products. An engineer can use the system for both designing a product and for generating the instructions that can be used to control a manufacturing process.

Computer Aided Manufacturing (CAM) – See CAD/CAM and CAD.

Computer Integrated Manufacturing (CIM) – See CAD, CAD/CAM, and CNC.

Computer Numerical Control (CNC) – A computer controlled machine.

concurrent engineering – Concurrent Engineering (CE) is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developer, from the outset, to consider all elements of the product lifecycle from concept through disposal, including quality control, cost, scheduling, and user requirements. As far as I can tell, CE is synonymous with simultaneous engineering and integrated product development. (Source: Institute for Defense Analyses, with minor edits by Professor Art Hill, updated October 5, 2000.) See also QFD, waterfall.

configurator – A configurator is tool (usually a software tool with web-based human interface) that allows customers, order entry, or sales people to create a customized order by selecting various product features from menus. Ideally, a configurator will (a) encourage customers to select standard, high-margin combinations of features, (b) prevent customers from selecting prohibitive combinations of features, (c) discourage customers from selecting low margin (or negative margin) combinations, and (d) create a manufacturing order that can be sent electronically to manufacturing. In some cases, the configurator creates instructions for automated equipment. Configurators might contain many expert rules and might draw heavily on science, engineering, and manufacturing expertise. In conclusion, the ideal configurator is easy for the customer to use, creates product configurations that customers want, and guides customers to product configurations that the firm can make and sell profitably. For example, mycereal.com, General Mills custom blended breakfast cereal, has a configurator that includes tremendous amounts of food science so that customers get healthy food and tasty portions. Lifetouch provides software to high schools so that they can configure their own student ID cards, populate a database with student photos, and then send a file to the firm's ID card manufacturing facility. See configure-to-order, mass customization.

configure-to-order – In a configure-to-order system, a firm sells standard products that require that certain parameters be set, adjustments be made, or certain modules be added in response to a customer order. Examples include setting the height of a seat for a riding mower, selecting the language option for a software package, or setting some customer-specific parameters for a medical device.

****conformance quality*** – The degree to which the product or service design specifications (standards) are met. Conformance quality is generally measured by the yield rate (the percentage of units started that are not defective) or the scrap rate (the percentage of units started that have to discarded because they are defective). For example, the marketing and R&D people have decided that a watch should be able to survive in 100 meters of water. However, the manufacturing process is not very careful in applying glue around the back of the watch, which results in about 10% of all watches failing to meet this standard. In this example, the yield rate is 90% and the percent defective is 10%. See performance quality.

****consignment stock*** – An inventory held by a customer that is owned by the supplier. Payment is made only when stock is sold or used by the customer. For example, Medtronic has many pacemakers in hospital inventories that are still owned by Medtronic. They are not sold until a doctor needs a device.

consumable – A type of item or products that is used up (consumed) in the process (e.g. paper, oil, grease, etc.). Many firms make more money selling consumable products than they do in selling capital goods or other products. The most famous example of this is Gillette almost giving away the razor in order to sell the razor blades.

****continuous review*** – A policy for managing independent demand inventory systems. With a continuous review system, we compare the inventory position with the reorder point with every transaction and place an order when the position is less than the reorder point. See periodic review system, inventory position, and reorder point system.

****control chart –*** A graphical tool used to plot the statistics from samples of a process over time. If all points are within the upper and lower statistical control limits, variation may be ascribed to "common causes" and the process is said to be "in control." If points fall outside the limits, it is an indication that "special causes" of variation are occurring and the process is said to be "out of control." Eliminating the special causes first and then reducing common causes can improve quality. Control charts are based on the work of Shewhart and Deming.

CONWIP – An approach for manufacturing planning and control that maintains "constant WIP" (work in process) in the system. The process is really quite simple – every time that the line (factory, process) completes one unit, the first step in the process is given permission to start one unit. This is similar to the theory of constraints concept of "drum buffer rope." Some research suggests that CONWIP is superior in terms of system performance. It is clearly easier to operate that many other systems. Unlike JIT, CONWIP does not need to have buffers (kanbans) between each pair of workcenters. Unlike DBR, CONWIP does not need to send a signal from the bottleneck. CONWIP was development by Professors Mark Spearman and Wally Hopp. See JIT, TOC.

core capabilities – See core competence.

****core competence*** – (a) Skills that differentiate a firm from its competitors. (b) A set of organizational skills and systems that is perceived by customers as providing exceptional value in the marketplace. A true core competence is unique, hard to copy, and can lead the firm into new products and markets. Some authors make a distinction between core competencies and distinctive competence. They define core competence as the basic product and process technologies and skills that all firms need to compete in an industry and distinctive competence as the set of technologies and skills that a firm uses to differentiate itself in the market. However, it appears that most authors now use the terms synonymously. Knowledge of a firm's core competence can lead its management team to finding new products and guide its thinking about outsourcing. A firm should never outsource its core competence. According to the web page (http://www.aavantguard.com/marktip5.html) three requirements for a valid distinctive competence are:

1. A unique competence must really exist.
2. The unique competence must offer value to the marketplace. Something merely unique without offering value is not a Distinctive Competence.
3. The unique competence must be credible in the marketplace. Its existence and value have to be accepted and believed in the marketplace.

****cost of quality*** – A framework used to attempt to measure all of the quality-related costs. (It probably should be called the cost of bad quality.) This framework includes:

(1) Prevention – Cost of designing quality into the product and process. This includes product design, process design, work selection and worker training.

(2) Appraisal – Cost of inspection and testing.

(3) Internal failure – Cost of rework, scrap, wasted labor cost, wasted lost machine capacity, and poor morale. Lost capacity for a bottleneck process can result in lost gross margin as well.

(4) External failure – Warranty, repair, lost gross margin, lost customer good will, damage to the brand, damage to channel partnerships, law suits.

Phil Crosby, a well-known author and consultant, encourages firms to attempt to measure all of these costs. In my experience, prevention cost is too hard to measure.

coverage – See inventory turnover.

critical chain – The set of tasks that determines the overall duration of a project, talking into account both precedence and resource dependencies. As I understand it, the mechanics of this work as follows: (1) compute the early start, early finish, late start, late finish, and slack times just as we normally would with the critical path method. The path through the network with the longest total time is called the critical path. The critical path is also the path (or paths) with the shortest slack. (2) Create a detailed schedule starting from the current date and moving forward in time. Each time we schedule an activity, we assign the necessary resources (people, machines, etc.). When we move to the next activity and find that a resource is already being used, we have to wait until the resource becomes available. When a resource becomes available we assign it to the task that has the least amount of slack time as computed in step (1). We continue this process until we have a complete schedule for all activities. This new schedule is called the critical chain and will be longer than the critical path, which only considers the precedence constraints. The critical chain will still follow the precedence constraints, but will never have any resource used more than its capacity. (3) Strategically add time buffers to protect activities on the critical chain from starting late. Non-critical chain activities that precede the critical chain should be planned to be done early so that we avoid harming the critical chain. See project planning, critical path, CPM, PERT.

critical incidents technique – A method for identifying the underlying dimensions of customer satisfaction. The method involves collecting a large number of customer complaints and complements and analyzing each one to identify the underlying quality dimension (timeliness, friendliness, etc.). We can use this method to identify the key dimensions of service quality for use on a customer satisfaction survey.

The technique is used a variety of contexts other than quality improvement. For example, the web page http://www.hr-guide.com/data/G022.htm offered the following definition of December 26, 2000:

"The Critical Incident Technique is a method of Job Analysis that focuses on identifying the critical incidents that distinguish satisfactory workers from unsatisfactory workers. This is based on the theory that certain tasks are crucial to satisfactory job performance, while others are not. In this method, the job analyst interviews incumbents and/or supervisors to identify a list of critical incidents. The identification of required Knowledge, Skills, and Abilities (KSAs) is made by examining the incidents—their causes and solutions. This technique is useful for developing work sample tests."

****critical path*** – The critical path is the longest path through a project-planning network. Note it is possible to have two or more critical paths. The big idea here is that management should focus its attention only on critical path activities. The only way to speed up a project is to "crash" activities along the critical path; crashing other activities will not speed up the project. See the Critical Path Method, critical chain.

****Critical Path Method (CPM)*** – CPM is a popular approach for project planning and scheduling. The approach starts with the beginning time for the project and plans forward in time to find the earliest start time and easiest finish time for each task. It then works backward from the desired project completion time for the project to determine the latest start and finish time for each task. The slack for any task is the difference between the early start and the late start (which is always the same as the difference between the late start and the late finish). The critical path is the path (or paths) with the smallest slack. Management should prioritize the critical path with respect to resource allocation and attention. In order to reduce the total project time, we find the task on the critical path that can be reduced (crashed) at the lowest cost per unit time – and then repeat the crashing process until we have achieved the desired project completion time. See PERT, Gantt chart, work breakdown structure, slack time.

****cross-docking –*** (1) A warehouse management strategy where product is moved directly from incoming shipping trucks to outgoing trucks to be shipped to stores. Cross-docking can save money by avoiding costly moves to and from shelves in the warehouse. (2) The planning of warehouse "put away" assignments so that inventory can be moved from one shipment to another on a dock without movement to a rack or warehouse location. Although this type of inventory movement may violate lot and code date movement parameters, cross-dock planning is used frequently to minimize labor costs and handling in warehouses and distribution centers. (Source: http://gartner4.gartnerweb.com/public/static/hotc/hc00088697.html, updated October 27, 2000) (3) Cross-docking is a logistics technique that eliminates the storage and order picking functions of a warehouse while still allowing it to serve its receiving and shipping functions. The idea is to transfer shipments directly from incoming to outgoing trailers without storage in between. Shipments typically spend less than 24 hours in a crossdock, sometimes less than an hour. Crossdocking is attractive for two main reasons. First, crossdocking is a way to reduce inventory holding costs. The retailer essentially replaces inventory with information and coordination. Second, for less-than-truckload (LTL) and small package carriers, crossdocking is a way to reduce transportation costs. Crossdocking is a way to consolidate those shipments to achieve truckload quantities. (Adapted from: http://web.nps.navy.mil/~krgue/Teaching/teaching.html)

Napolitano (2000) proposes the following classification scheme:

Manufacturing crossdocking -- receiving and consolidating inbound supplies to support Just-In-Time manufacturing. For example, a manufacturer might lease a warehouse close to its plant, and use it to prep subassemblies or consolidate kits of parts. Because demand for the parts is known, say from the output of an MRP system, there is no need to maintain stock.

Distributor crossdocking -- consolidating inbound products from different vendors into a multi-SKU pallet, which is delivered as soon as the last product is received. For example, computer distributors often source components from different manufacturers and consolidate them into one shipment in merge-in-transit centers, before delivering them to the customer.

Transportation crossdocking -- consolidating shipments from different shippers in the LTL and small package industries to gain economies of scale. For small package carriers, material movement in the crossdock is by a network of conveyors and sorters; for LTL carriers it is mostly by manual handling and forklifts.

Retail crossdocking -- receiving product from multiple vendors and sorting onto outbound trucks for different stores. Crossdocking has been cited as a major reason Wal-Mart surpassed Kmart in retail sales in the 1980's (Stalk et al., 1992).

Opportunistic crossdocking -- in any warehouse, transferring an item directly from the receiving dock to the shipping dock to meet a known demand.

The common elements to all of these operations are consolidation and extremely short cycle times, usually less than a day. The short cycle time is possible because the destination for an item is known before or determined upon receipt. (Adapted from: http://web.nps.navy.mil/~krgue/Teaching/teaching.html)

***Customer Relationship Management (CRM)* –** CRM software manages a number of activities including call center management, sales force automation, and direct selling. A good CRM system will provide the following benefits:

(a) Provide timely and complete information on customers.
(b) Reduce the transaction cost for buying products and services.
(c) Provide immediate access to order status.
(d) Provide support that will reduce the costs of using products and services.

***customer satisfaction* –** See service quality.

cycle counting – An effective means of prioritizing the counting of items in an inventory. Instead of counting all items with a year-end physical inventory count, with cycle counting we count the "important" items much more often than other items. Cycle counting is an application of Pareto's Law – we count the important few quite often and count the trivial many infrequently. Both cycle counting and the "annual inventory" will result in accurate inventory balances (at least once per year). However, cycle counting does a much better job of identifying problems that cause inaccurate inventory balances; therefore, cycle counting does a much better job of improving inventory accuracy. Some rules for determining how often to count an item include: (a) count items with higher annual usage more often (the ABC system), (b) count just before an order is placed, (c) count just before a new order is placed on the shelf, (d) count when the physical inventory balance is zero, (d) count when the physical inventory balance is negative, (f) count after a specified number of transactions. Systems (b) and (c) are really just ways of implementing (a) because "A" items will be ordered more often. System (c) minimizes the number of units that need to be counted because the shelf is nearly empty when an order arrives.

cycle stock – The inventory that exists because we order in quantities more than one at a time. Cycle stock generally follows a "saw tooth" pattern. For "instantaneous" replenishment and constant average demand, the average cycle stock is Q/2, where Q is the fixed order quantity. We can reduce cycle stock economically only by reducing the ordering (setup) cost. See safety stock.

cycle time – Historically, cycle time was defined as the time between completions of a process step. For example, you could look at the end of manufacturing process and time how look it took from the completion time of one part to the completion time of the next part. However, it is now common to talk about the "cycle time" for a factory as the cumulative time required for a product from start to end, which can be measured as the completion time minus the start time. In other words, it is now common to use the terms manufacturing throughput time and cycle time synonymously. Assuming we define cycle time as the throughput time, it is often difficult to figure out the starting time for complex assemblies. This is because each component has a different starting time. The longest time might be for a $0.20 assembly. A simple approach for estimating the cycle time (manufacturing leadtime) is simply taking the inverse of the inventory turnover ratio. Therefore, if inventory turnover is four turns per year, the "dollar weighted cycle time" is 3 months. See manufacturing lead time.

Delphi forecasting – Named after the Greek oracle at Delphi to whom the Greeks visited for information about their future, the Delphi technique is the best-known qualitative forecasting method today. Delphi is a set of procedures for eliciting and refining the opinions of a panel of experts. This collective judgment of experts is considered more reliable than individual statements and is thus more objective in its outcomes. Delphi methods overcome many problems with face-to-face meetings –

being dominated by a few individuals, falling into a rut of pursuing a single train of thought for long periods of time, exerting considerable pressure on participants to conform, and regularly becoming overburdened with periphery information. Delphi forecasting is usually applied to estimate unknown parameters, typically forecasting dates for long-term change in the fields of science and technology. A survey instrument is used over several iterations. Both statistical and commentary feedback are provided with each iteration. After two or three iterations, opinions converge and a final report is made. (Adapted from http://www.soc.hawaii.edu/future/j7/LANG.html by Professor Arthur V. Hill, updated November 11, 2000)

demand chain management **–** Supply chain management that focuses on using signals from the customer to trigger production. See supply chain management.

****demand filter*** – A control tool for time series forecasting. When the forecast error is very large or small, an exception report is generated to warn the user. The simplest rule is to test if the forecast error is larger than plus or minus three standard deviations of the forecast error. See tracking signal, forecast bias, exponential smoothing.

****demand management*** – The practice of affecting demand to better meet the supply. This can be done through pricing, advertising, promotions, replacing unscheduled arrivals with scheduled arrivals (e.g., appointments), and with customer communications.

Deming's 14 points

1. Create constancy of purpose toward improvement of product and service, with the aim to become competitive and to stay in business, and to provide jobs.
2. Adopt the new philosophy. We are in a new economic age. Western management must awaken to the challenge, must learn their responsibilities, and take on leadership for change.
3. Cease dependence on inspection to achieve quality. Eliminate the need for inspection on a mass basis by building quality into the product in the first place.
4. End the practice of awarding business on the basis of price tag. Instead, minimize total cost. Move toward a single supplier for any one item, on a long-term relationship of loyalty and trust.
5. Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs.
6. Institute training on the job.
7. Institute leadership. The aim of supervision should be to help people, machines, and gadgets to do a better job. Supervision of management is in need of overhaul, as well as supervision of production workers.
8. Drive out fear, so that everyone may work effectively for the company.
9. Break down barriers between departments. People in research, design, sales, and production must work as a team, to foresee problems of production and in use that may be encountered with the product or service.
10. Eliminate slogans, exhortations, and targets for the work force asking for zero defects and new levels of productivity. Such exhortations only create adversarial relationships, as the bulk of the causes of low quality and low productivity belong to the system and thus lie beyond the power of the work force.
    a. Eliminate work standards (quotas) on the factory floor.
    b. Substitute leadership.
    c. Eliminate management by objective. Eliminate management by numbers, numerical goals. Substitute leadership.
11. Remove barriers that rob the hourly worker of his right to pride of workmanship. The responsibility of supervisors must be changed from sheer numbers to quality.
12. Remove barriers that rob people in management and in engineering of their right to pride of workmanship. This means abolishment of the annual or merit rating and of management by objective.
13. Institute a vigorous program of education and self-improvement.
14. Put everybody in the company to work to accomplish the transformation. The transformation is everybody's job.

(Source: www.deming.org/deminghtml/wedi.html, updated October 27, 2000)

****dependent demand inventory*** – This term has two meanings. (1) Demand from internal customers, rather than external customers. (2) Demand that should be planned rather than forecasted. In other words, the demand for a dependent demand item can be *calculated* from the production plan of a higher-level item under the firm's control. Demand for a component that goes into an end-item is considered dependent demand, because this demand is planned based on the production plan for the end-item. This dependent demand should not be forecasted. Dependent demand has to do with boundaries of the firm – demand for items under the firm's control is dependent; whereas, demand for items outside of the firm's control is considered independent demand. Given that many firms can now get detailed long-range demand information from their customers, this term may now be less meaningful now than it used to be. (See independent demand.)

****design for assembly (DFA)*** – A set of methodologies and principles that can be used to guide the design process so that product assembly will have low cost, low assembly time, high labor productivity, low manufacturing cycle time, and high conformance quality.

design for disassembly (DFD) – DFD is a set of principles used to guide designers in designing products that are easy to disassemble for re-manufacturing and/or repair operations. DFD enables a product and its parts to be easily reused, re-manufactured, refurbished, or recycled at end of life. In the long run, DFD could make it possible to eliminate the need for landfills and incineration of mixed waste. Products would be designed so as never to become waste, but instead inputs into new products at the end of their useful lives. DFD is a key strategy within the larger area of Sustainable Product Design, which is concerned with a more proactive approach to environmentally responsible design. This approach has been most widely and successfully adopted by the product design industry. As environmental concerns grow in North America, we will be increasingly concerned about "re-manufacturing" – which is disassembling products and reusing what we can. In Europe, this is already a big deal with manufacturers such as VW being forced to design products that can be disassembled very easily. See remanufacturing.

design for environment – See Design for Disassembly (DFD) and remanufacturing.

****design for manufacturing (DFM)*** – See Design for Assembly.

design for manufacturing and assembly (DFMA) – See Design for Assembly.

design for quality – See Design for Assembly.

design of experiments (DOE) – The objective of DOE is to build quality into the product and process designs so that the need for inspection is reduced. DOE achieves this by optimizing product and process designs and by making product and process designs robust against manufacturing variability. Experimental Designs are used to identify or screen important factors affecting a process, and to develop empirical models of processes. Design of Experiment techniques enable teams to learn about process behavior by running a series of experiments, where a maximum amount of information will be learned, in a minimum number of runs. Tradeoffs as to amount of information gained for number of runs, are known before running the experiments. See Taguchi methods.

digital convergence – The combining of a number of technologies such as entertainment (movies, videos, music, TV), printing (books, newspapers, magazines), news (TV, newspapers, radio), communications (phone, mobile phone, data communications), computing (personal computers, mainframe computers), and many other important technologies that we touch everyday. The term "convergence" implies that these technologies will become standardized and will tend to radically change each other. For example, many people now get their news over the web and no longer read newspapers.

****diseconomies of scale*** – An economics term that suggests that as the volume produced increases, the cost per unit also increases. For example, it is said that the optimal hospital size is about 400 beds and that larger hospitals tend to become less personal and less efficient due to complexity of the operation (which is a function of the number of employees) and the distance that people have to travel. This is also said to be true to high schools – the optimal student body size is probably between 400-600 students.

The point at which a plant becomes too large and, as volume continues to increase, the average cost per unit of output increases rather than drops. Increase in long-run average costs, which may set in as the scale of production increases. Although the unit cost of production may fall as plant size increases (see economies of scale), there are several reasons why this process is eventually reversed: (a) the different processes within a plant will probably not have the same optimum scale. For example, a car-body press might be at its most efficient at 150,000 units a year, while an engine transfer machining line may be optimal at 100,000 units a year. When 150,000 cars are produced, it will be necessary either to have a sub optimal engine line with a capacity of 50,000 in addition or to run a second line at 50 per cent capacity. (b) As firm size increases, problems of administration and coordination increase and there is a growth of bureaucracy. (c) If output for a national or international market is concentrated at one large plant in a single location, transport costs of raw materials and finished goods to and from distant markets may offset scale economies of production at the large plant. These are internal diseconomies. External diseconomies are said to arise as a geographic region sees larger-scale production - these might include traffic congestion or pollution, for example.

****disintermediation*** – Displacing a distributor in the channel. For example, a manufacturing firm replaces its distributors with a web site to sell directly to its customers has "disintermediated" its distributors. A wholesale distributor is an intermediary between manufacturers and customers. If you remove an intermediary, you have disintermediation.

****dispatching*** **–** The process of determining the next job (order) to be processed in a factory (or job shop). See job shop, job shop scheduling. Typical rules include earliest due date, shortest processing time, short slack time, and critical ratio.

distinctive competence – See core competence.

Distribution Requirement Planning (DRP) **–** The function of determining the need to replenish inventory at branch warehouses over a forward time period. A time-phased order point approach is used where planned orders at branch warehouse level are exploded via MRP logic to become gross requirements on the supplying source enabling the translation of inventory plans into material flows. In the case of multi-level distribution networks, this explosion process can continue down through the various levels of regional warehouses, master warehouse, factory warehouse etc and become input to the master production schedule. Distribution Resource Planning (DRP II) is an extension of MRP into the planning of the key resources contained in a distribution system.

DC – A distribution center. This is a location that is used to warehouse and ship products.

dot-com – A startup-firm in the late 1990's selling products through its web site, often having only two "managers," two computers, and a dream. Dot-coms often have no products to sell, have no warehouses, and little experience with operations. Amazon.com is probably the more famous of these firms.

drop ship – When a distributor (or retailer) has a supplier send an order directly to a customer, it is said to be "drop-shipped" to the customer. This reduces the customer's lead time, but usually increases the distribution cost for the system.

****drum-buffer-rope (DBR)*** – A theory of constraints concept that creates a signal every time that the bottleneck completes one unit. (This is the "drum.") The signal authorizes all upstream work centers that they have authority to produce. (This is the "rope" that "pulls" production from these non-bottleneck resources to produce for the bottleneck.) The buffer describes the queue in front of the bottleneck to keep it busy. (This is Art Hill's rough definition of this concept.)

DBR is a newer system of production control that follows the TOC philosophy. In doing so, it concentrates on managing the flow of products to meet the bottleneck constraint's needs. Since the bottleneck acts as a valve controlling the system's throughput, managing the bottleneck's throughput manages the system's throughput. To maximize the system's throughput, the bottleneck must utilize all of its available capacity. Similar to MRP, the DBR system uses a scheduled release of products to control the production rate, and a safety stock or buffer at the bottleneck to guard against stoppages from the upstream workstations. Although the DBR control system provides improvement over MRP, it is not immune from shortcomings, which include: (a) Failure to locate the bottleneck of the system will result in lost throughput, or increased WIP and cycle time depending on the false bottlenecks' location relative to the real bottleneck. (b) The use of fixed lead times to schedule the bottleneck can lead to increased WIP much as in MRP / MRPII systems. (c) Incorrect bottleneck buffer size can result in bottleneck starvation; thus, system throughput is lost. (Source: http://gurgun.ise.ufl.edu/dbr.htm, adapted by Professor Art Hill) See CONWIP, JIT, TOC.

Dupont Analysis – An economic analysis that can be used to show the return on investment as a function of many other variables. Operations managers sometimes use this analysis to show that a small reduction in inventory can reduce cost, increase sales, and reduce investment – and if you increase the numerator and decrease denominator of ratio at the same time, the ratio gets much larger. An Excel workbook (dupont.xls) is available from Professor Hill for this analysis.

Early Supplier Involvement (ESI) – The practice of getting suppliers involved early in the product design process. Your suppliers have core competence for their product – or they would not be your supplier. For example, Seagate (the computer hard drive manufacturer) buys power supplies from Zytec. Zytec is a world-class expert in power supplies. It is to the advantage of both firms to get Zytec involved in the product design process early on – so that Zytec can improve the design and reduce product cost for both firms. Companies that involve their suppliers at an early stage in the design of new products reap financial and competitive rewards. Companies that involve suppliers early substantially reduce product development time, improve quality and features and significantly reduce product or service costs. Companies do best when they gave suppliers the leeway to come up with their own designs rather than simply manufacturing parts to OEM's specifications. The supplier may have better information or greater expertise regarding these technologies than the buying company design personnel.

****Economic Order Quantity (EOQ)*** – The optimal order quantity (batch size) that minimizes the sum of the carrying and ordering cost. The equation for the total incremental cost is $TIC=(D/Q)S+(Q/2)ic$, where D is the annual demand, Q is the order quantity, S is the order cost, i is the carrying charge, and c is the unit cost. Taking the first derivative of this function and setting it to zero, we find that the optimal order quantity (the *EOQ)* is given by $EOQ=\sqrt{\frac{2DS}{ic}}$. The *EOQ* model is considered to be of little practical value for three reasons. First, it is very difficult to estimate the parameters of the model. As a joke, the equation is often rewritten $EOQ=\sqrt{\frac{2??}{??}}$. Second, even with perfect estimates of the parameters, the total incremental cost function is very flat near the optimal solution, which means that the total incremental cost is not sensitive to errors in the *EOQ*. Third, managerial intuition is usually good at finding the *EOQ* without the equation. It is obvious to most managers that costly items should be ordered more often and in smaller quantities. In other words, the *EOQ* really does not matter very much -- except on the exams in all major business schools. On the positive side (1) the *EOQ* model does help people get a better understanding of lotsizing issues, (2) in some cases the tradeoffs do have a significant economic impact, and (3) the *EOQ* model is the foundation for other models such as the quantity discount model. An Excel workbook for this calculation is available from Professor Hill. See carrying charge, carrying cost, ordering cost, quantity discount, periodic order quantity.

****economy of scale*** – A concept from economics that states that the cost per unit will decline as the volume produced increases. See diseconomies of scale, economy of scope.

****economy of scope*** – A concept from economics that states that the cost per unit will decline as the variety of products increases. In other words, economies of scope arise from synergies in the production of similar goods. A firm with economics of scope can reduce its cost per unit by having a wide variety of products that share resources. According the following website (http://www.csuchico.edu/mgmt/strategy/module7/tsld031.htm), the following is true about economies of scope:

- Economies of scope arise from the ability to eliminate costs by operating two or more businesses under the same corporate umbrella.
- These economies exist whenever it is less costly for two or more businesses to operate under centralized management than to function independently.

- Cost savings opportunities can stem from interrelationships anywhere along a business' value chain.

See commonality, mass customization.

efficiency – Ratio of average processing time to some standard processing time. For example, if a process has a standard time of 100 minutes per unit and the operator can do the process in 90 minutes per unit, the operator is said to have an efficiency of 100/90 = 111%. An efficient process is one that can perform at a very low cost compared to some standard.

Efficient Consumer Response (ECR) – A consumer goods (primarily grocery) initiative aimed at reducing inefficient practices and waste in the supply chain. This is an application of JIT to retail distribution. See quick response.
(Source: http://gartner4.gartnerweb.com/public/static/hotc/hc00088697.html, October 27, 2000, adapted by Art Hill)

Electronic Data Interchange (EDI) – Electronic Data Interchange (EDI) is a system (and a related set of standards) that firms can use to communicate routine business transactions between computers without human intervention. EDI transactions can include information for inquiries, planning, purchasing, acknowledgments, pricing, order status, scheduling, test results, shipping and receiving, invoices, payments, and financial reporting. The simplest form of EDI is to send purchase orders to suppliers. More advanced forms of EDI include sending invoices, electronic payments, and planned orders (requirements). The advantages of EDI include:

- Reduced transaction cost – electronic transactions are cheaper than manual/paper ones.
- Reduced transaction time – electronic ordering is nearly simultaneous, versus days or weeks for a manual/paper transaction send via mail.
- Improved forecast accuracy – forward visibility of your customer's requirements can dramatically improve forecast accuracy. For many firms, this is the most important benefit.
- Improved data quality – sending information via electronic means can improve quality because it eliminates almost all the human data entry from the process.

With the rapid growth of e-commerce, many expect that the phrase "EDI" will soon die. E-commerce will, of course, serve the same purposes as EDI and will have to include all of the same functionality.
The web page http://www.etechnologycorp.com/edi_e-commerce.htm has an excellent summary of the subject.

emergency maintenance – An unplanned maintenance problem that usually results in the disruption of the schedule. See preventive and predictive maintenance.

Engineer-to-Order (ETO) – An environment in which the engineering is done in response to a customer order.
-Products are designed to the customer's specifications,
-Quoted leadtimes equal engineering, procurement, fabrication, assembly, pack, and shipping time,
-Components can be stock items or designed specifically to the order,
-Supply orders are typically pegged directly to the customer order,
-Common parts may not be stocked unless their procurement time is less than that of the engineered parts,
-Engineering may be treated as a workcenter with its backlog scheduled as if it were part of the factory, and
-Actual costing is favored because many items are purchased/manufactured only one time.

Space shuttles, stamping dies, plastic molds, and specialized capital equipment are examples of products manufactured in an engineer-to-order environment. In these factories, engineering must be integrated into the factory functions in order to serve the customer. In an engineer-to-order environment, improvement comes from…
-Reducing the engineering time,
-On line engineering change order control with electronic approval process,
-Automatic sensing, notification of pending ECO's during purchase order creation,
-Reducing thru-put time for components and finished goods to improve inventory turns and lower cost,
-Reducing the number of SKUs without limiting customer selection, and
-Lowering labor and procurement costs.
(Source: www.magimfg.com/engineer_to_order.htm, updated October 27, 2000)

engineering change order (ECO) – A change made in the product design (or process). The timing for an ECO can be dependent on the current inventory. This is a major opportunity for improvement for many firms, given that ECOs tend to be error-prone and the timing is complicated by current inventories, documentation, training, etc.

Enterprise Resources Planning (ERP) – Integrated applications software that manufacturing corporations can run to run their business. ERP systems typically include accounts payable, accounts receivable, general ledger, payroll, MRP (Manufacturing Resources Planning), and many other interrelated systems. SAP, J.D. Edwards, Oracle, PeopleSoft, and Fourth-Shift are some of the better-known ERP systems currently on the market. See manufacturing resources planning.

ergonomics – The science of designing work to be consistent with the capabilities (and limitations) of the human body. This science is usually taught in an industrial engineering department. It is concerned with minimizing the cumulative trauma disorders related to motions and forces applied to the body in the workplace.

exponential smoothing – Exponential smoothing is probably the most popular time-series extrapolation forecasting technique. It can also be used as a data smoothing technique. An "exponentially smoothed" average puts much more weight on recent demand (sales) data. An exponentially smoothed average is a weighted average with weights declining geometrically back in time.

(Note: it really should have been called geometric smoothing.) The basic idea of the exponential smoothing forecasting technique is that we use the average at the end of a period as the forecast for every period into the future. Expressed mathematically, F_{t+1}, the forecast for the demand in period t+1 is A_t, the exponentially smoothed average at the end of period t. In other words, $F_{t+1}=A_t$. The exponentially smoothed average at the end of period t is the previous exponentially smoothed average plus some fraction (alpha, α) times the forecast error. The exponentially smoothed average at the end of period t is $A_t=A_{t-1}+\alpha E_t$, where the forecast error is $E_t=D_t-F_t$, and D_t is the actual demand (or sales) in period t. Alpha (α), the smoothing constant, is in the range (0, 1). The Winters' model takes exponential smoothing a step further by also smoothing trend and seasonal factors. The forecast equation for this is $F_{t+n}=(A_t+nT_t)R_{t+n-m}$, where F_{t+n} is the forecast of demand n period ahead, T_t is the exponentially smoothed trend at the end of period t, and R_{t+n-m} is the exponentially smoothed multiplicative seasonal factor at the end of period t+1, lagged by one year (m periods). In this model, A_t is the underlying deseasonalized average and the multiplicative seasonal factors (R_t) inflates or deflates this average to adjust for seasonality. The complete set of equations for the Winters' model is as follows:

$$A_t = \alpha D_t / R_{t-m} + (1-\alpha)(A_{t-1} + T_{t-1})$$

$$T_t = \beta(A_t - A_{t-1}) + (1-\beta)T_{t-1}$$

$$R_t = \gamma D_t / A_t + (1-\gamma)R_{t-m}$$

$$F_{t+n} = (A_t + nT_t)R_{t+n-m}$$

See forecasting, time-series forecasting, demand filter, tracking signal, moving average.

extranet **–** The use of Internet/intranet technology to serve an extended enterprise, including defined sets of customers or suppliers or other partners. It is typically behind a firewall, just as an intranet usually is, and closed to the public (a "closed user group"), but is open to the selected partners, unlike a pure intranet. More loosely, the term may apply to mixtures of open and closed networks. See intranet.

failure mode and effects analysis (FMEA) – Failure Mode Effect Analysis was invented by NASA early in the US Apollo space program. NASA created the tool to alleviate the stress between two conflicting mottos; "failure is not an option" and "perfect is the enemy of good." The first meant successfully completing the mission and returning the crew. The second meant that failure of at least some components was unavoidable, the job was to predict them, prevent them when possible, plan for them, and build in the ability to overcome failures. Failure Mode Effect Analysis was a tool for facilitating the process of predicting failures, planning preventive measures, estimating the cost of the failure, and planning redundant systems or system responses to failures. (Source: www.robertluttman.com/Week4/page6.htm October 1, 2001)

A FMEA is an inductive bottoms-up method of analyzing a system design or manufacturing process in order to evaluate the potential for failures. It involves identifying all potential failure modes, determining the end effect of each potential failure mode, and determining the criticality of these failure effects. FMEAs are sometimes referred to as FMECAs (Failure Mode, Effects and Criticality Analyses). FMEAs are based on standards (both military and commercial) in the reliability engineering industry. These analyses can take many forms, but they are all used to study a particular system and determine how that system can be modified to improve overall reliability and avoid failures. Once this is completed, a FMEA or FMECA can be used to determine the most critical failure modes, and then determine how these critical failures can be minimized or eliminated. (Source: www.fmea.net October 1, 2001.)

For example, perhaps you are performing a piece part FMEA on a computer monitor. One component in that computer monitor might be a capacitor. You have determined that there are 2 potential failure modes for the capacitor, and they are that the capacitor could fail "open" or it could fail "shorted." If the capacitor fails open, the effect might be that the monitor appears with wavy lines. However, if the capacitor fails shorted, the effect might be that the monitor goes completely blank. In the case above, if the capacitor fails shorted and the monitor goes blank, that failure mode could be considered more severe or critical than if the capacitor fails open and wavy lines appear. In this case, you would attempt to find ways to prevent these failures from happening or lessen their criticality. (Source: www.relexsoftware.com/reliability/fmea.asp October 1, 2001)

As far as I can tell DFMEA (Design Failure Mode and Effects Analysis) is just another term for FMEA.

See poka yoke.

faxban **–** A modification of a kanban system that faxes forms to signal demand. It is identical to any other kanban system except that it uses faxes rather than kanban cards or squares. See kanban.

****fill rate (unit, line, order)*** – The unit fill rate is the percent of the units filled immediately from stock. The line fill rate is the percent of lines on purchase orders filled immediately from stock. (A purchase order might request five different items; each of item ordered on the purchased order is a "line.") An order fill rate is the percent of orders filled immediately from stock. The order fill rate is generally a lower number than the others and therefore is a more difficult fill rate to satisfy. The terms "fill rate" and "service level" are often used synonymously in many make-to-stock firms. See perfect order, service level.

Final Assembly Schedule (FAS) – The final assembly schedule is a schedule for the assemble-to-order portion of a manufacturing process. The firm will use MRP to plan the production of all major components, and then use the FAS to schedule the final assembly for specific customer orders after those orders arrive.

finite loading – See finite scheduling.

finite scheduling – Creating a sequence of activities with associated times so that no resource (person, machine, tool, etc.) is assigned to work more than the time available. A "due-date feasible" finite schedule will satisfy all due date requirements for all tasks (orders). A start-date feasible schedule will start after the current time -- as opposed to the situation where you should have started 2 weeks in order to get done on time. The opposite of finite scheduling is infinite planning that ignores capacity constraints when a schedule is created. (The words finite loading and infinite loading are sometimes used.) While many ERP systems and project management tools have finite scheduling capabilities, nearly firms use infinite planning for both ERP and project management – and then resolve resource contention after the plan (schedule) has been created. See Advanced Planning and Scheduling systems, MRP, project management.

****First-in, First-out (FIFO)*** – (1) Stock Valuation - The method of valuing stocks which assumes that the oldest stock is consumed first and thus issues are valued at the oldest price. (2) Stock Rotation - The method whereby the goods which have been longest in stock are delivered (sold) and/or consumed first.

first pick ratio – During order picking, the percentage of orders or lines for which 100% completion was achieved from the primary location or picking face.

fixed-order quantity – The policy of using a constant (fixed) order quantity. One special case of this is the economic order quantity (the EOQ).

fixed storage location systems – The practice of labeling the shelf in a storage area with the item ID. In other words, each item has a home location with the item ID on the shelf. See random storage location.

Flexible Manufacturing System (FMS) – An FMS is an integrated set of machines that have automated materials handling between them and an integrated information system. Often oversold by vendors in this author's opinion.

****flexibility –*** The ability to change. From a strategic point of view, only four kinds of flexibility exist. These are:

- **volume flexibility** – The ability to increase or decrease the production rate and be profitable. See aggregate production planning.
- **mix flexibility** – The ability to increase the number of products in one facility and be profitable. (This is sometimes called product range.)
- **customization flexibility** – The ability to provide a wider range of "respond to order" products and still be profitable. This is sometimes called mass customization. See mass customization.
- **new product development flexibility** – The ability to quickly bring new products to market.

****focused factory*** – A focused factory is a process that is "aligned with its market" and therefore requires a limited range of operations objectives. A factory focused on making high volumes of standard products at low cost will likely have minimum wage workers, fairly automated processes, MRP systems, and JIT delivery of supplies. A focused factory reduces the "variability" of the requirements in the process and therefore can help the process achieve its stated operations objectives. "You can't be everything to everyone" is an old phrase which suggests that you cannot do everything well – at least not in one process. A focused factory is a means of implementing a strategic direction in your operations. A firm might have many "focused factories" in any one factory.

forecast bias – The average forecast error over time. Forecast bias can be defined mathematically as $\sum_{i=1}^{T} E_i / T$, where E_t is the forecast error in period t and T periods of data have been collected so far. A simple recursive approach for handling this is to define $R_t = R_{t-1} + E_t$. The ideal forecast has a zero forecast bias. An exception report called a tracking signal is used to signal that the forecast bias is large and requires an intervention. See forecast error, tracking signal, demand filter.

forecast error – The demand minus the forecast in a period. Using standard mathematical notation, $E_t = D_t - F_t$, where E_t is the forecast error in period t, D_t is the demand in period t, and F_t is the forecast made for period t. See forecast bias.

forecast horizon – The number of time periods ahead that a firm forecasts. For example, if a firm has a 6-month manufacturing leadtime, it should clearly forecast at least six months into the future. The forecast error increases quickly with the forecast horizon. It is often more practical to reduce the manufacturing leadtime (and the corresponding forecast horizon) than it is to improve the forecast error.

****forecasting*** – Predicting the future of a variable. Many firms confuse the planning and the forecasting process. In a typical business context, the firm needs a forecast of the demand for its product without consideration of the firm's capacity or supply. In response to this "unfettered" (unconstrained) demand forecast, the firm makes production and inventory plans. In some periods, the firm might plan to have inventory greater than the demand; in other periods the firm might plan to have inventory well short of the demand. In many firms they use the term "forecast" for what is essentially their production plan and therefore lose important stockout (opportunity cost) information from the rest of the firm. See Box-Jenkins, exponential smoothing, Delphi forecasting, CPFR, demand filter, tracking signal, geometric decay, time-series forecasting.

forward loading (forward scheduling) – A finite scheduling method that begins with the start date (which could be the current time) and plans forward in time, never violating the capacity constraints. The complete date is an output of the process. (See back scheduling, finite planning systems).

forward buy – The practice of purchasing raw materials, components, etc. ahead of the need, usually in anticipation of a price increase. See bullwhip effect.

gate **–** In project management, a gate (or stage-gate) is a step (sometimes called a milestone) where the merits and progress of the project are evaluated before further progress is allowed. A gate involves a review that often results in a “go/no go” decision for the project. Examples include freezing product designs, updating projected costs to completion, and gaining customer acceptance prior to funding full tooling or scaleup. See project management.

****Gantt chart*** – A graphical project planning tool that shows horizontal bars that depict the beginning and ending time for each task. While a Gantt chart is powerful tool for communicating a project plan, it does not clearly show the precedence relationships and therefore is not a particularly helpful tool for project planning.

geometric decay – A geometric series is defined as $d_{t+1}=rd_t$, where r is the common ratio. For example, if the demand in period 1 is 100 and r=.8, then the demand in period 2 is .8(100)=80. The demand in period T is $d_{t+T}=r^T d_t$. Professor Hill has a technical note and an Excel workbook that explains how to use this concept for forecasting the end of life demand. The geometric time series model can be used to forecast demand for either a finite or an infinite number of periods into the future. See “all time demand.” A technical note and a companion Excel workbook on forecasting lifetime demand are available from Professor Hill.

Goldratt **–** See Theory of Constraints.

gravity model **–** The gravity model for retail store location can a retailer locate one or more new retail stores given that they know some basic information about your competitors in the area -- which might include some of your own stores. The basic concept of the model is that large stores that are close to a set of customers have a high “gravitational pull” on the customers -- and that stores that are smaller or farther away have less “gravitational pull” on the customers. This is really an application of Newton’s Law, which states that the gravitational pull between two heavenly bodies is directly proportional to the mass of the bodies and inversely proportional to the square of the distance between them. Professor Hill has an Excel workbook called gravity.xls that implements the gravity model.

green manufacturing **–** Manufacturing that is environmentally conscious.

groupware **–** Groupware is a class of software that provides functions to aid workgroups. These include “the three C's” of communications, collaboration, and coordination. Emphasis is on computer-based augmentation of human communications and information sharing, and support of generic workgroup tasks like scheduling and routing of message-based workflow tasks.

half-life curve – A mathematical model that relates a performance metric such as defects, costs, percent tardy, or cycle time to time. The half-life concept suggests that the performance metric will be cut in half every so many periods. For example, if the half-life is 6 months, and the defect rate is 10% at time zero, at month six, the defect rate should be 5%, and at month twelve the defect rate should be 2.5%. The basic equation for the half-life curve is $y(t)=\exp(a+bt)=e^{a+bt}$, where $\exp(x)$ is the function that takes e to the x power and $e \approx 2.718281$. $y(t)$ is the value (cost, labor time per unit, etc.) at time t. The constants are $a=-\ln(y(0))$ and $b=-\ln(2)/h$, where the half-life (in periods) is $h=-b/\ln(2)$. The value for b can be estimated with regression using historical data. A technical note and a companion Excel workbook on this subject are available from Professor Hill.

heijunka **–** Keeping the total production rate as constant as possible. Defined as “production levelization” by Taiichi Ohno. Similar to production smoothing.
Heijunka is the foundation for the pillars of the Toyota Production System (or TPS). A corporation's objectives should be to deliver products of a quality, price, and within a timeframe defined by the customer. Heijunka, or Production Smoothing, is a technique used to adapt production to naturally fluctuating customer demand. The Japanese word “heijunka” (pronounced hey June kah), means literally “make flat and level.” Customer demand must be met with the customer's preferred delivery times, but customer demand is “bumpy,” while factories prefer “level,” or stable production. Therefore, a manufacturer needs to try and smooth out these bumps in production. The main tool for smoothing production is frequent changing of the model mix to be run on a given line. Instead of running large batches of one model after another, TPS advocates small batches of many models over short periods of time. This requires faster changeovers, but results in smaller lots of finished goods that are shipped frequently. (Source: www.fredharriman.com/services/glossary/heijunka.html)

hockey-stick phenomenon – A pattern of sales or shipments that increase dramatically at the end of the week, month, or quarter. This pattern looks a like a hockey stick because it is low at the beginning of the period and high at the end. The hockey stick phenomenon is nearly always a logical result of reward systems based on sales or shipments. The large changes causes “variance” in the system, which often results in increased inventories, stockouts, overtime, idle capacity, frustrated workers, and other significant problems. Clearly, the solution is the change reward systems to motivate workers to produce and sell at the market demand rate.

holding cost – See carrying cost.

House of Quality – See Quality Function Deployment.

****independent demand inventory*** – This term that has two meanings. (1) Demand from external customers, rather than a higher-level assembly or warehouse. (2) Demand that must be forecasted rather than planned. This concept is no longer very helpful given that many firms can now get detailed long-range demand information from their customers. Typical examples of independent demand include retail inventory demand, demand for an item sold from a distributor's warehouse, and demand for an end-item for a manufacturing firm. Demand for a component that goes into an end-item would be considered dependent demand, because this demand is planned based on the plan for the end-item. (See dependent demand.)

infinite loading **–** See finite loading, APS, MRP, project management.

****inspection*** **–** The process of checking parts that have already been completed to make sure that they were done correctly. Inspection can be done for either (1) an accept/reject decision for a batch of parts (batch control), or (2) to check to see if a process is still in control (process control). Inspection can be done by (1) the operator (self-check, source inspection), (2) the next person in the process (successive check), (3) the last step (final inspection), or some combination of the above. Ideally, inspection is done at the source (quality at the source) so that the process has immediate feedback and has a sense of ownership of quality. Most firms conduct final inspection before a product is delivered to a customer. Inspection should be done just ***before*** a bottleneck so that valuable bottleneck time is not wasted on a bad part. (Attention to parts that have gone through the bottleneck because valuable bottleneck capacity has been invested in these parts.) Many firms are eliminating incoming inspection by having the supplier certify that the parts meet certain quality standards. This saves money and time for both parties. An ideal process has no inspection – the product and process are carefully designed so that inspection, which is fundamentally a non-value adding activity, is not needed. See supplier qualification and certification, Total Quality Management, Deming's 14 points (point 3), cost of quality, acceptance sampling.

integrated product development (IPD) – Integrated Product Development (IPD) is a philosophy that systematically employs a teaming of functional disciplines to integrate and concurrently apply all necessary processes to produce an effective and efficient product that satisfies the customer's needs. There is no checklist for implementing IPD because there is no one solution...each application will be unique. As far as I can tell, IPD is synonymous with simultaneous engineering and concurrent engineering. Benefits of CE and IPD include 30% to 70% less development time, 65% to 90% fewer engineering changes, 20% to 90% less time to market, 200% to 600% higher quality, and 20% to 110% higher white collar productivity. [As reported by the National Institute of Standards & Technology, Thomas Group Inc., and Institute for Defense Analyses in Business Week April 30, 1990] (Sources: Society of Concurrent Engineering web page http://www.soce.org/ and USAFMC Guide on IPD, 1993, with minor edits by Professor Arthur V. Hill, updated October 5, 2000)

intranet **–** A private application of the same internetworking technology, software, and applications within a private network, for use within an enterprise. It may be entirely disconnected from the public Internet, but is usually linked to it and protected from unauthorized access by security firewall systems. More loosely, the term may include extranets, as well. See extranet.

****inventory position*** – The on-hand plus on-order minus allocated inventory quantities. Allocated inventory is that which has been promised to customers or other orders.

****inventory turnover*** – This is the cost of goods sold divided by the average inventory investment (in dollars). The inverse of the inventory turnover ratio is an estimate of the cycle time. It can be proven mathematically that inventory turnover should increase as the demand increases. If sales double, the turnover ratio should increase by roughly $\sqrt{2} \approx 1.414$ or 41%. Therefore, caution should be used in benchmarking inventory turnover ratios between firms (or divisions) that have differing demand rates -- or within a firm if the demand rate is changing drastically over time. Technically, sales divided by the average inventory investment is "coverage" but many managers mistakenly call this "turnover." Note that in Europe, the word "turnover" is often used for sales or revenue. See cycle time.

****Ishikawa diagram (fishbone diagram)*** – A graph tool often used as a brainstorming approach for identifying the root causes of a problem. Also called a Cause-and-Effect or Fishbone Diagram. The diagram illustrates the relationships among the wide variety of possible contributors to the effect. Note that this tool is referred to by several different names: Ishikawa diagram, Cause-and-Effect diagram, Fishbone diagram, and Root Cause Analysis. The first name is after the inventor of the tool, Kaoru Ishikawa (1969) who first used the technique in the 1960s. The basic concept in the Cause-and-Effect diagram is that the name of a basic problem of interest is entered at the right of the diagram at the end of the main "bone." The main possible causes of the problem (the effect) are drawn as bones off the main backbone. The "Four-M" categories are typically used as a starting point: "Materials," "Machines," "Manpower," and "Methods." Different names can be chosen to suit the problem at hand, or these general categories can be revised. The key is to have three to six main categories that encompass all possible influences. Brainstorming is typically done to add possible causes to the main "bones" and more specific causes to the "bones" on the main "bones." This subdivision into ever increasing specificity continues as long as the problem areas can be further subdivided. The practical maximum depth of this tree is usually about four or five levels. When the fishbone is complete, one has a rather complete picture of all the possibilities about what could be the root cause for the designated problem. Sources: (mot.vuse.vanderbilt.edu/mt322/Ishikawa.htm adapted by Professor Arthur Hill, updated October 27, 2000)

ISO9000 – Certification Standards created by the International Organization for Standardizations in 1987 that now play a major role in setting process documentation standards for global manufacturers. These standards are recognized in over 100 countries. Some people summarize ISO as an external motivation to "document what you do – and do what you document." ISO is criticized by some as a non-value added activity. Others argue that ISO was created by Europeans as a barrier to entry – and that its primary value for North American firms is to help them sell their products in Europe. (Source: Chase, Aquilano, and Jacobs text, 2002 adapted by Professor Arthur V. Hill, updated October 27, 2000)

ISO14000 – Certification Standards created by the International Organization for Standardizations related to environmental impact.

Jidoka – A Japanese practice of designing processes and empowering workers to shut down the process when abnormal conditions occur. The translation of the Japanese word "is automation with a human touch (or human mind)." The philosophy is that the production process itself should ensure quality and that defective parts should never be allowed to move from one workstation to the next. Production should stop when a problem occurs – the goal is quality, not quantity. Ideally, the machine (or production line) is able to stop automatically, which reduces the burden of workers to monitor the process. (Many sources define Jidoka as stopping production ***automatically*** when a problem occurs. See autonomation.) automatic Jidoka is also used when workers encounter a problem at their workstation. They are responsible for correcting the problem and stopping the line if they cannot. Jidoka is often implemented with a signal to communicate the status of a machine. For example, a production line might have a green light if everything is okay, a yellow light in an abnormal condition, and a red light if stopped. According to the Nummi web site (http://www.nummi.com/prodsyst.htm), the objectives of jidoka can be summed up as (1) ensuring quality 100% of the time, (2) preventing equipment breakdowns, and (3) using manpower efficiently. (Source: Professor Arthur Hill with help from Eishi Kimijima, CSOM MBA 2002, updated October 4, 2000) See autonomation.

JIT II – A practice of having supplier representatives work at a customer location in order to better facilitate product design and/or production coordination activities. The term and concept were developed by Lance Dixon at Bose Corporation. JIT II is essentially vendor managed inventory, early supplier involvement, and co-location of personnel. See Just-in-Time (JIT).

job enlargement – Adding tasks to a job to make it more interesting for the worker and/or to eliminate queues between workers. Some authors define both "vertical job large enlargement" (which might add panning, organizing, and inspecting his or her own work) and "horizontal job enlargement" (which might add similar tasks). Some authors define the job enlargement as horizontal in nature – you get more of your co-workers job. These same authors define job enrichment as vertical job enlargement – you get more of your boss' job and get to decide which jobs you do first. See job enrichment.

job enrichment – Adding more responsibility to a job. Job enlargement gives you more of your co-worker's job – job enrichment gives you some of your boss's job. Note that the management literature does not have consistent definitions of the terms "job enlargement and job enrichment." See job enlargement.

***job shop –** A factory (or department in a factory) that has a number of general-purpose machine and processes orders for customers. A pure job shop is always a "make-to-order" process. Job shops typically offer fixed planned customer leadtimes, have long queues, and employ highly skilled workers.

***job shop scheduling –** The process of creating a schedule (a sequence with associated times) for jobs (orders) being processed in a job shop. See job shop, dispatching.

Just-in-Time system (JIT) – A philosophy developed by Toyoda in Japan that emphasizes delivery when needed of small lotsizes. The philosophy includes an emphasis on setup cost reduction, small lotsizes, pull systems, level production, and elimination of waste (muda).

An integrated set of activities designed to achieve high volume production using minimal inventories of raw materials, work-in-process, and finished goods. Parts arrive at the next workstation "just-in-time" and are completed and move through the operation quickly. JIT is a management philosophy that strives to eliminate sources of manufacturing waste by producing the right part in the right place at the right time. Waste results from any activity that adds cost without adding value, such as moving and storing. JIT (also known as lean production or stockless production) should improve profits and return on investment by reducing inventory levels (increasing the inventory turnover rate), improving product quality, reducing production and delivery lead times, and reducing other costs (such as those associated with machine setup and equipment breakdown). In a JIT system, underutilized (excess) capacity is used instead of buffer inventories to hedge against problems that may arise. JIT applies primarily to repetitive manufacturing processes in which the same products and components are produced in high volumes. The general idea is to establish flow processes (even when the facility uses a jobbing or batch process layout) by linking work centers so that there is an even, balanced flow of materials throughout the entire production process, similar to that found in an assembly line. To accomplish this, an attempt is made to reach the goals of driving all queues toward zero and achieving the ideal lot size of one unit. http://www.ashland.edu/~rjacobs/m503jit.html. See JIT II.

kaizen – A Japanese word meaning gradual and orderly continuous improvement. The kaizen business strategy involves everyone in an organization working together to make improvements without large capital investments. It is a culture of sustained continuous improvement focusing on eliminating waste in all systems and processes of an organization. The kaizen strategy begins and ends with people. (Sources: www.kaizen-institute.com/kzn.htm, adapted by Professor Arthur V. Hill, updated October 27, 2000)

kanban system – A simple device that sends a pull signal. "Kanban" is the Japanese word for sign. In the US, a kanban might be a card, a container, or a square on a table or floor. An empty container gives a factory worker permission to work to fill the box. If a worker does not have an empty box to fill, the worker is "blocked" from doing any more work and should be re-assigned somewhere else where their work is needed. See blocking and starving.

A Kanban control system uses a signaling device to regulate JIT flows. Kanban means "sign" or "instruction card" in Japanese. The cards or containers make up the kanban pull system. The authority to produce or supply additional parts comes from downstream operations. A kanban is a card that is attached to a storage and transport container. It identifies the part number and container capacity, along with other information. A kanban system is a pull-system, in which the kanban is used to pull parts to the next production stage when they are needed; a MRP system (or any schedule-based system) is a push system, in which a detailed production schedule for each part is used to push parts to the next production stage when scheduled. The weakness of a push system (MRP) is that customer demand must be forecast and production lead times must be estimated. Bad guesses (forecasts or estimates) result in excess inventory, and the longer the lead time, the more room for error. The weakness of a pull system (kanban) is that following the JIT production philosophy is essential, especially concerning the elements of short setup times and small lot sizes. See http://www.ashland.edu/~rjacobs/m503jit.html. See faxban.

Keiretsu **–** A Keiretsu is a uniquely Japanese form of corporate organization. A keiretsu is a grouping or "family" of affiliated transnationals with broad power and reach. Operating globally, integrated both vertically and horizontally, and organized around their own trading companies and banks, each major keiretsu is capable of controlling nearly every step of the economic chain in a variety of industrial, resource and service sectors. A Keiretsu can research and develop a technology, plan its production, finance and insure the project, extract resources from virtually anywhere in the world, transport them back to Japan or elsewhere, process them, produce the item, package it, promote it, and then distribute and sell it globally. While Japanese corporate and government leaders deny or play down the existence or relevance of the keiretsu, their existence and vitality have been well documented by Japanese and Western scholars alike. (Source: http://www.corpwatch.org/trac/feature/planet/japan_k.html, November 1, 2000)

In terms of supply chain management and Just in Time, the characteristics of Keiretsu in Toyota are:

- Pressure on suppliers to reduce price.
- Compensation to suppliers for the suggestions (or kaizen).
- Early involvement of suppliers in design – drawings approved as opposed to drawings supplied.
- Commitment of suppliers to supply high quality parts.
- Evaluation and competition of suppliers: Two-vendor policy
- Propagation of Just In Time to suppliers
- Sustainable monthly master schedule with kanban as a signal for the adjustment
- Leveled production

(Source: The mechanism of innovative adaptation by Japanese enterprise organization, the function and structure of longstanding transaction relationship, Asanuma, Banri. Toyo-Keizai Publishing, 1977.)

kits, kitting – Grouping individual items together for future use. In a manufacturing context, "kits" of parts are often put together in boxes and given to workers to assemble. In a distribution context, kits of parts are prepared to be packed and shipped. Kits have their own part numbers.

knowledge management – There are two key strategies for managing knowledge. In some entities, knowledge management centers on the computer. Knowledge is carefully codified and stored in databases, where it can be accessed and used easily by anyone in the company. This is called codification strategy. For other entities, knowledge is closed tied to the person who developed it and is shared mainly through direct person-to-person contacts. The purpose of the computer for these companies is to help people communicate knowledge, not to store it. This is called the personalization strategy. (Source: Hansen, *et al*., "What's your strategy for managing knowledge?" ***HBR***, March-April 1999.

Last-In, First-Out (LIFO) – (1) Stock Valuation. The method of valuing stocks that assumes that all issues or sales are charged at the most current cost but stocks are valued at the oldest cost available. (2) Stock Rotation. The method whereby the goods which the newest goods in stock are delivered (sold) and/or consumed first.

leadtime **–** The term has many meanings related to the time to produce something. The ***planned leadtime*** is a time parameter used in a planning and control system to determine the release date (start date) for an order. For example, if a student always plans to start homework assignments two days before the assignment is due, the student's planned leadtime is two days. The planned leadtime for a manufacturing order is the sum of the planned leadtimes for all of the steps in the routing for the order. For a single operational step, this typically includes (a) queue time before the operation begins, (b) setup time to get the machine ready for production, (c) run time to process the order, (d) post-operation time to wait for the order to picked up and moved to the next workcenter. The ***actual leadtime*** is the time actually required to produce the order. The ***promised customer***

leadtime is the promised customer wait time for an order – the planned difference between order placement and order receipt. The ***actual customer leadtime*** is the actual wait time experienced by the customer. The planned leadtime, actual leadtime, promised customer leadtime, and actual customer leadtime might all be different. These are all random variables and have means, modes, medians, standard deviations, minimums, maximums, etc. Therefore, it is important that managers (and students of management) be clear when they use the word "leadtime." When a manager tells you that the factory has a leadtime of two-weeks, this could mean a two-week planned leadtime, average leadtime, minimum leadtime, modal leadtime, promised customer leadtime … you get the idea. See cycle time, purchasing leadtime.

leadtime syndrome – A perverse cycle whereby a supplier's planned leadtimes gets longer and longer. The cycle is as follows:

(a) A manufacture increases planned leadtime (this could for almost any reason – a vacation, a machine problem, a slight increase in demand, etc.)

(b) The customer learned about the increased leadtime and immediately increases the order quantity to cover the demand. (Note that the customer's real demand has not changed.)

(c) The manufacturer sees the larger order quantity, assumes that demand is up, and further increases planned leadtimes. This gets us back to step (a).

The solution to the leadtime syndrome is for customers to communicate their true demand to their suppliers – to give their suppliers forward visibility of their true demand – and for suppliers to work very hard to never increase their quoted leadtimes, even when the demand increases. See the "bullwhip" effect.

lean manufacturing –Lean Manufacturing is an approach to organizing manufacturing activities that focuses on five key concepts:

1. Value centered on customer needs.
2. Value creation occurring along a series of steps - the value stream.
3. Value creation along the value stream is achieved through a closely synchronized flow of activities.
4. Value creating activity only occurs when a customer pulls or demands it.
5. Continuous improvements to the process move towards perfection.

Central to the lean manufacturing approach is a focus on waste reduction and a high level of engagement of all company personnel in implementing and improving the manufacturing process. One lean manufacturing website states that "typical" firms are able to achieve benefits of (a) 80% reduction in cycle time, (b) 50% reduction in lead times, (c) 50% reductions in inventory, and (d) other improvements in quality and customer responsiveness. Lean manufacturing is based on the Toyota Production System. The term "lean" and the most widely known discussion of lean manufacturing can be found in ***Lean Thinking*** by Womack and Jones. (Adapted by Professor Art Hill from www.valuedge.com/valuedge/value2/index.html)

****learning curve (experience curve)*** – A mathematical model that relates the cost per unit (or labor time per unit) to the cumulative number of units produced. The learning curve equation is given by $y_n = y_1 n^b$, where y_1 is the cost/unit for the first unit produced, y_n is the cost/unit for the n-th unit produced, and b is the model parameter. The b parameter should be set to $\ln(k)/\ln(2)$ for a "k-percent learning curve." Note that b is always negative. For example, an 80% learning has k=0.8 and b=ln(.8) /ln(2)=−0.32193. If y_1=100, the cost for the first 8 units is given by 100, 80, 70, 64, 60, 56, 53, and 51. (Note these values are rounded to the nearest integer.) A technical note and a companion Excel workbook on this subject are available from Professor Hill.

****learning organization* –** An organization that has the ability to learn from its environment and becomes (or at least maintains) its ability to compete over time. Most organizations today find that their current products and processes will become obsolete in a fairly short period of time. It is necessary, therefore, for managers to lead their organizations in such a way that the organization has built-in systems for improving over time. Specifically, organizations needs to learn from many sources:

customers – to learn about customer's needs and desires as they change over time,

suppliers – to learn about new materials, technologies, and processes.

research labs/technology suppliers – to learn about product and process technologies as they are developed by research labs universities, and suppliers

workers – to learn about and document new processes as they are developed by workers (to make implicit knowledge explicit)

Approaches for accelerating learning include:

service guarantees – to reward customers for sharing their complaint information.

early supplier involvement – to get suppliers more involved in product design.

benchmarking – to capture standards *and* processes to use a basis of comparison.

cross-training/job rotation/job enrichment – to disseminate learning within the firm.

line balancing – When we design an assembly line, we have many tasks (elements) that need to be assigned to workers. These assignments are constrained by a cycle time for each worker and precedence relationships between the tasks (e.g., some tasks need to be done before others). The line balancing problem is to solve this problem so that we need the minimum number of workers and still satisfy the cycle time and precedence constraints. Some practitioners argue that the line balancing problem has become less important when we can use cross-trained workers who can move between stations.

linear programming (LP) – A mathematical approach for finding the optimal value of a linear function constrained by a set of linear equations. LP has been applied to many operations problems such as (a) finding the optimal blend of ingredients for animal feed to minimize the cost while still meeting the nutritional requirements, (b) finding the optimal product mix to maximize contribution to profit while still meeting the capacity constraints, and (c) finding the assignments of products to factories to minimize the total system distribution cost while still meeting the marketing demand and factory capacity constraints. Related techniques include integer programming, mixed integer linear programming, and many others. Mathematically, a linear program is expressed as: Minimize $\sum_{j=1}^{N} c_j x_j$ ***;*** Subject to: $\sum_{j=1}^{N} a_{ij} x_j \le b_i$ for constraints i=1,2,…, M. The x_j are the decision variables, the c_j are the coefficients of the objective function, and the b_i are the "right hand side" constraint coefficients. Very efficient code is available to solve very large linear programs with tens of thousands of variables. Closely related tools include integer program (IP), with all variables restricted to integers, mixed-integer programming (MIP), with a mixture of integer and continuous variables, zero-one programming, with all variables restricted to either zero or one, network optimization, stochastic programming, chance constrained programming, and goal programming.

linear regression – A statistical method that fits a line to a set of historical data points in order to minimize the sum of the squared errors. This method is commonly used to find an approximate linear relationship between two or more variables.

****Little's Law –*** In 1961, MIT Professor John D.C. Little proved that for a queuing system in steady state, the relationship between the average time in system (W_s), the average arrival rate (λ), and the average number in system (L_s) is given by $L_s = \lambda W_s$. Similarly, the relationship between the average time in queue, average arrival rate, and average number in queue is given by $L_q = \lambda W_q$. The average time in system can be defined as $W_s = W_q + 1/\mu$, where μ is the mean service rate, which means that $1/\mu$ is the mean service time. For example, if a factory has a demand rate (λ) of 10 orders per day, and work in process plus order backlog (L_s) of 100 orders, the average time in system (W_s) for an order will be about $W_s = L_s / \lambda$ =100/10 = 10 days. See capacity.

load leveling – In both project planning and manufacturing contexts, we often want to have a level (even) workload for resources (machines, people, etc.) over time. Some finite planning systems attempt to create schedules that require about the same amount of a resource in every period. This is called level loading. See finite scheduling.

****lotsize (order size, batchsize)*** – The quantity that is ordered. When we are dealing with suppliers, we typically call this the order size; when dealing with manufacturing orders placed on our own factory, we call this the lotsize or batchsize. See lotsizing methods.

lotsizing methods – See EOQ, Period Order Quantity, Wagner-Whitin, time-varying demand lotsizing. An Excel workbook is available from Professor Hill that illustrates all of these (and other) lotsizing methods for production planning with time-varying demand.

LTL – Less-than-truckload. A small shipment that does not fill the truck or a shipment of insufficient weight to qualify for a truckload quantity discount.

****Material Requirements Planning (MRP) –*** A system to support manufacturing and fabrication organizations by the timely release of production and purchase orders using the production plan for finished goods to determine the materials required to make the product. Orders for dependent demand items are phased over time to ensure that the flow of raw materials and in-process inventories matches the production schedules for finished products. The three key inputs are (1) the master production schedule, (2) inventory status records, and (3) product structure records. See MRP II, ERP.

****Manufacturing Resource Planning (MRP II) –*** A method for the effective planning of all the resources of a manufacturing company. Ideally it addresses operational planning in units, financial planning in money, and has a simulation capability to answer what if questions. It is made up of a variety of functions, each linked together: business planning, master (or production) planning, master production scheduling, material requirements planning, capacity requirements planning and the execution systems for capacity and priority. Outputs from these systems would be integrated with financial reports such as the business plan, purchase commitment report, shipping budget, stock projections in money etc. Manufacturing resource planning is a direct outgrowth and extension of material requirements planning (MRP). For all practical purposes, ERP is just a new name for MRP II. See MRP, ERP.

mean absolute deviation (MAD) – A measure of forecast error. $MAD = \sum_{t=1}^{T} |E_t| / T$, where E_t is the forecast error in period t and we have T observed values. See forecast error.

mean absolute percent deviation (MAPD) – A measure of forecast error. $MAPD = 100\sum_{t=1}^{T} |E_t / D_t| / T$, where E_t is the forecast error in period t, D_t is the actual demand in period t, and we have T observed values. See MAD, forecast error.

MRO (Maintenance, Repair, Operations) – Items that are purchased for a firm that are not used directly in the product. Examples include office supplies, cutting oil for machines, 3M sandpaper, etc. These items are generally not handled by the firm's ERP system, but are often significant expense items for many manufacturing firms.

****make versus buy decision*** – Managers in manufacturing firms often have decide between making a part (or product) and buying it from a supplier. These decisions require careful analysis of accounting data and often have strategic implications. One of the most difficult aspects of this decision is how to handle overhead. If you completely ignore overhead, the decisions will generally go in the direction of "in-sourcing" – if you fully allocate overhead, decisions will generally go in the direction of "out-sourcing" and can lead the firm into the "death-spiral" where the more you outsource, the more overhead you have, which leads you to more outsourcing. A company should never outsource a core competence.

****Make-to-Order (MTO)*** – A process that produces products in response to a customer order. In other words, the firm does not keep any finished goods inventory. MTO processes typically produce products that are unique to the customers' requirements, but this is not always the case – it is possible to use a MTO process for standard products. A special case of MTO is "print-to-order." See also assemble to order, make to stock, engineer to order, and print to order.

****Make-to-Stock (MTS)*** – A process that produces standard products to be stored in inventory. These can be delivered quickly to the customer. The performance metric for MTS is the fill rate (unit, line, or order fill rate).

****Malcolm Baldrige National Quality Award* –** In 1987 this annual award was established to recognize total quality management in American industry. It represents the US Government's endorsement of quality as an essential part of successful business strategy. Quality is improved by: (a) Helping to stimulate American companies to improve quality and productivity, (b) Establishing guidelines and criteria in evaluating quality improvement efforts, (c) Recognizing quality improvement achievements of companies, (d) Making information available on how winning companies improved quality.

****manufacturing cell* –** A manufacturing cell can be defined as a mini production line dedicated to processing similar parts or products that require similar or identical operations. While a cell does not necessarily make the same parts repeatedly, it does make the same family of parts or products. The machines and fixtures within the cell are typically arranged so close to each other that there is no need to allow for storage between the operations or handling with hand trucks or pallet jacks. Cells offer a way to simplify production control and scheduling and shorten the manufacturing cycle time required to complete the product. They also reduce inventories and, therefore, manufacturing space required to satisfy production requirements.

Manufacturing Execution System (MES) – A Manufacturing Execution System (MES) provides real-time information on manufacturing operations from the time an order is started until it is completed in a factory. Unlike ERP and MRP systems, manufacturing execution systems do not plan order launch dates or order sizes; instead they focus on collecting data and planning the detailed operations after an order has been started. Functions include resource allocation and status, dispatching production orders, data collection/acquisition, quality management, maintenance management, performance analysis, operations/detail scheduling, document control, labor management, process management, and product tracking and genealogy. In many systems, document control includes systems for providing work instructions, videos, and drawings to operators on the shop floor at the time of need. A well-developed MES allows production planners to create work instructions that contain appropriate buyoffs and data collection forms embedded in the work instructions. Some of the benefits claimed for an MES include (1) reduces manufacturing cycle time, (2) reduces data entry time, (3) reduces work in process (and increases inventory turns), (4) reduces paper between shifts, (5) reduces lead times, (6) improves product quality (reduced defects), (7) eliminates lost paperwork and blueprints, (8) improves on-time delivery and customer service, (9) reduces training and changeover time, and, as a result, (10) improves gross margin and cash flow performance. The related concept of a shop floor control system has been around for many years; the term "MES" was first used in 1990. An MES has features that go well beyond the traditional shop floor control system. The MES Association website http://www.mesa.org has lots of useful information on this subject. See shop floor control.

***Manufacturing Resources Planning* –** See ERP.

****mass customization*** – Producing customized products at nearly the same cost as mass-produced (standard) products. This is a strategy for producing products that are customized for a channel partner, a customer segment, or an individual customer (personalization) without sacrificing margin. See postponement.

****Master Production Schedule (MPS)*** – MPS is a time-phased plan specifying how many and when the firm plans to build each end item. Example, the aggregate plan for a furniture company may specify the total volume of mattresses it plans to produce over the next month or next quarter. The MPS goes the next step down and identifies the exact size mattresses and their qualities and also states period by period (usually weekly) how many and when each of these mattresses types is needed. Further down this process is the MRP program which calculates all raw materials, parts, and supplies needed to make the mattress specified by the MPS. (p554, Chase, Aquilano, and Jacobs) See Business Requirements Planning, Aggregate Planning.

***Material Review Board (MRB)* –** A standing committee that determines the disposition of items that have questionable quality.

****Materials Requirements Planning (MRP)*** – MRP is a comprehensive system for planning both factory and purchase orders based on a master production schedule of end items (or major subassemblies). MRP logic "backschedules" from the order due date using fixed planned leadtimes to get start dates. Lotsizing rules are applied to determine order quantities. These rules are often defined in terms of the number of periods (days) of net requirements. Planning is done level by level down the bill of materials. MRP systems generally apply fixed planned leadtimes when creating schedules – they do NOT consider factory capacity. Therefore, MRP systems are called "infinite" loading systems rather than "finite loading systems." MRP was originally called materials requirements planning and only planned purchase orders to outside suppliers. When MRP was applied to also planning factory orders, the name was changed to Manufacturing Resources Planning. MRP systems are the heart of Enterprise Requirements Planning systems – in fact, ERP is really just a new "buzzword" for what MRP systems have been for many years. See ERP.

Derived from a master schedule, a MRP system creates schedules identifying the specific parts and materials required to produce end items, the exact number needed, and the dates when orders for these materials should be released and received or completed with the production cycle. MRP systems use a computer program to carry out these operations. The main purpose of a basic MRP system is to control inventory levels, assign operation priorities for items, and plan capacity to load the production system. Getting the right materials to the right place at the right time. (p555, Chase, Aquilano, and Jacobs)

The president of a medium-sized manufacturing firm wrote the following complaints on why ERP systems inevitably do not produce the benefits expected …

Time – ERP systems are huge and are not able to keep up with the speed of modern production processes. For example, in our factory we receive orders in the morning and ship in the early afternoon. We use pull systems to empower line workers and the systems get in the way. MRP runs once per day and therefore cannot provide visibility into the true nature of our business. ERP systems have been structured to reduce costs and improve managerial control. However, managerial "control" is the enemy of speed inside a factory. I suspect that as "time based competition" becomes more important, ERP systems will have to change substantially.

Investments in ERP systems – The developers and sellers of software usually believe they know more than you do about your business and most managers are too quick to concede that the experts are right. Most companies simply do not know what they want to achieve even with the software and are hoping for the "immaculate conception" once the software is implemented. Several millions of dollars later, no one has the stomach for do a post-mortem to assess the success of the project and the contribution to the bottom line. Generally, there are no improvements to the bottom line – only penalties. The lack of measurable benefits (or penalties) is a result of applying a solution without having first defined the problem. It is not the software vendors and ERP that should get a "bad rap" (the software almost always does what it is advertised to do) – it is the management teams that deserve the bad rap.

Cross-departmental visibility – The ironic part is we have stifled the things that our ERP system is good at doing, which is cross-departmental visibility. Our corporate MIS controls the security profiles and for users based on their departmental affiliation. The profile ONLY allows access to areas traditionally accessed by that department. Getting access into other areas requires a written request from corporate. I am not making this up … honest.

Mean Time Between Failure (MTBF) – The average time that a component is expected to work without failing. The MTBF is a good measure of the reliability of a product. The MTBF is often described as a "bath-tub" curve, which suggests that most components fail either right away at the beginning of the product life, or towards the end of the expected product life.

Mean Time To Repair (MTTR) – Measure of the average time required to fix something such as a machine. This is a measure of the complexity of a repair job.

****min/max inventory system*** – The min/max system (also known as an R,T system or S,s system) triggers an order when the inventory position falls below the reorder point (the "min" or minimum). The order size is defined as the "max" (maximum, or target inventory) less the current inventory position. In other words, when you hit the minimum, you order enough to bring the inventory position up to the maximum. A special case of this is the S,S-1 system where orders are placed on a "one-for-one" basis – every time a unit is consumed, another is ordered. The S,S-1 policy is very practical for low demand items such as repair parts.

mixed model assembly – The practice of assembling more than one product during any period of time. For example, an assembly worker might see three units of product A, then two units of product B, then four units of product A, etc. The alternative to this policy is to make large batches of each product and then switch over to the other product. The advantage of mixed model assembly is that it reduces inventory and improves service levels; the disadvantage is that it requires frequent changeovers from one product to another and adds complexity to the manufacturing task.

****modular design*** – The basic idea underlying modular design is to organize a complex system (such as a large program, an electronic circuit, or a mechanical device) as a set of distinct components that can be developed independently and then plugged together. Although this may appear a simple idea, experience shows that the effectiveness of the technique depends critically on the manner in which systems are divided into components and the mechanisms used to plug components together. (Source: www-unix.mcs.anl.gov/dbpp/text/node40.html, updated October 27, 2000)

****moment-of-truth*** – A moment of truth is the time that a firm "touches" its customers. This is an opportunity for the firm's customers to find out the truth about the firm's employees and its character – to find out "who they really are." This is a chance for the employees to show the customers that they really care about them. These are special moments and should be managed very carefully. When creating a process map, it is important to highlight the process steps that include the customer. A careful analysis of a typical service process often uncovers many more moments of truth than management truly appreciates – a call for a quick question, a question posed to a salesperson, a contact regarding a billing problem, etc.

***moving average** – The average of the last *N* periods of data is said to be an "*N*-period moving average." This is sometimes used to make forecasts based on the most recent data. Exponential smoothing is a similar approach that applies weights to historical data with the weights declining geometrically with the age of the data. An *N*-period moving average is equivalent to simple exponential smoothed average with smoothing constant $\alpha = 2/(N+1)$. See exponential smoothing.

***muda** – Japanese word for "waste." Any activity that does not add value, i.e. that which the customer is not prepared to pay for. Originally part of a trilogy of Mura (Imbalance), Muri (Overload), and Muda (Non-value-added). In more popular terminology, Muda is used for any type of waste. (Source: www.tpi-europe.ltd.uk/nowaste.htm, and Professor Art Hill, updated August 29, 2000)

In everyday Japanese, muda means useless, futile, and waste (source: MS/Shogakkan Bookshelf Basic). The word's meaning for production management is essentially the same, but another, simpler definition of muda is non-value-adding. A good example of muda that relates to the value placed on just-in-time supply, might be a yard filled with raw materials bought for projected orders that have not been received yet. Under conventional accounting practices, these materials are assets, even though the manufacturer does not know when they will be turned into product. JIT views these materials as muda, essentially useless, a waste of purchasing resources because they add no value to products known to be sold. The following areas are often the source of muda: over-production, waiting, conveyance, processing, inventory, motion, and correction. Muda can be found everywhere in an organization or system. The definition is uncompromising, and some non-value-adding activities that cannot be eliminated are still defined as muda. This insistence on viewing them in a negative light drives kaizen (continuous Improvement) activities in a relentless pursuit of better methods by all members of an organization. (Source: www.fredharriman.com/services/glossary/muda.html)

***Murphy's Law –** If it can go wrong, it will.

***newsvendor problem** – A decision maker must decide how much to purchase, given the distribution of demand, the cost of under buying per unit (c_u), and the cost of over buying per unit (c_o). The optimal order quantity is the demand associated with the critical ratio, which is defined as $R=c_u/(c_u + c_o)$. In more mathematical terms, $Q^*=F^{-1}(R)$, where $F^{-1}(R)$ is the inverse of the cumulative distribution function. In a retail environment, c_u is the sales price minus the unit cost (the gross margin) and c_o is the unit cost minus the salvage value. Solving the problem for a discrete distribution requires a simple search procedure. The newsvendor problem used to be called the "newsboy" problem. Professor Hill has written a technical note and an Excel workbook "newsvendor.xls" on this subject.

normal time – An industrial engineering term for the time observed from a time study. Step 1. The average time from a time study is collected. Step 2. Each person's average time is adjusted by the subjectively determined performance rating. The average of these times is called the normal time for the operation. Step 3. The normal time is adjusted for allowances to compute the standard time. See standard time.

numerically controlled (NC) machine – A machine that is under control of a computer, typically these are machines that cut and form metal. Comprised of (1) a typical machine tool used to turn, drill or grind different types of parts; and (2) a computer that controls the sequence of processes performed by the machine.

***operations strategy** – Policies for using the firm's resources to support the business unit's strategy for gaining competitive advantage. These policies are usually defined in terms of the operations objectives of cost, quality, flexibility, and service. Often firms can gain competitive strategic advantage by avoiding tradeoffs between these objectives. For example, Dell Computer was able to "change the rules of game" and gain significant competitive advantage by being the first to successfully offer low cost assemble to order computer through direct mail. Similarly, Fed Ex was one of the first to order reliable overnight package delivery.

***order picking* –** Collecting items from storage locations to satisfy a shop or customer order.

order point system – See "reorder point" system.

order qualifier, order winner – An order qualifier is a screening criterion that permits a firm's products to be considered as possible candidates for purchase. An order winner is a screening criterion that differentiates the products or service of one firm from another and often makes a critical difference in the buyer decision process.

Overall Equipment Effectiveness (OEE)* –** OEE is a key metric for lean operations and is used extensively in TPM applications. OEE = (Availability rate) x (Performance rate) x (Yield rate). ***Availability rate is (Operating time less downtime)/(Total operating time) and reflects downtime losses due to changeovers, equipment failures, and startup losses. ***Performance rate*** is (Total output)/(Potential output a rated speed) and reflects speed loses due to idling and minor stoppages or reduced speed operation. ***Quality rate*** is (Good output)/(Total output) and is a function of defects and rework. The six big losses are:

Breakdown losses: These are losses of quantity via defective products and losses of time due to decreased productivity from equipment breakdowns. (Affects the Availability rate.)

Set-up and adjustment losses: These losses stem from defective units and downtime that may be incurred when equipment is adjusted to shift from producing one kind of product to another. (Affects the Availability rate.)

Idling and minor stoppage losses: Typically, these kinds of losses are relatively frequent. They result from brief periods of idleness when between units in a job or when easy-to-clear jams occur. (Affects the Performance rate.)

Reduced speed losses: These losses occur when equipment is run at less than the design speed. Design speed may not be known. Materials or tooling may be off spec and require special treatment. There may be fear of running equipment if it is run too fast. (Affects the Performance rate.)

Quality defects and rework: These are product related defects and corrections necessitated by malfunctioning equipment. (Affects the quality rate.)

Start-up losses: These are yield losses incurred during early production, i.e. from machine start-up to steady state. (Affects the quality rate.)

Reasonable target values are Availability greater than 90%, Performance greater than 95%, and Quality greater than 99%. The goal of measuring OEE is to improve the effectiveness of your equipment. Since equipment effectiveness affects shopfloor employees more than any other group, it is appropriate for them to be involved in tracking OEE and in planning and implementing equipment improvements to reduce lost effectiveness. It is recommended that the operator collect the daily data about the equipment for use in the OEE calculation. Collecting this data will:

- Teach the operator about the equipment
- Focus the operator's attention on the losses
- Grow a feeling of ownership of the equipment

The shift leader or line manager is often the one who will receive the daily operating data from the operator and process it to develop information about the OEE. Working hands on with the data will:

- Give the leader/manager basic facts and figures on the equipment
- Help the leader/manager give appropriate feedback to the operators and others involved in equipment improvement
- Allow the leader to keep management informed about equipment status and improvement results

Source: http://www.oeetoolkit.nl/OEEAlgemeen/what_is_oee.htm, November 9, 2001. See TPM, utilization.

***outsourcing** – Buying raw materials and components from a supplier rather than making it yourself. Many firms find that they can improve both cost and quality if they can find a supplier that has a core competence in a particular area. A good example is Guidant's clean room gowns. Guidant's core competence is designing and making implantable medical devices – not managing gowns. However, their supplier has a clear focus on clean room gowns and is "world class" at this business. Therefore, Guidant outsources its gown management to this firm.

p-chart – A quality control chart that monitors the percent defective of the process. A sample of *n* parts is collected from the process every so many parts or time periods. The percent defective in the sample is plotted on the control chart and a determination is made if the process is "under control" or not.

***pack-to-order* –** A customer's order is collected from standard components and packed into a box or some other shipping container. This is a very similar to "assemble to order" except that no product assembly is required. Guidant Corporation calls this "pack to demand." At Guidant, they put a country and language specific label on the box and ship it to the distributor in the country. See assemble to order, make to order.

***Pareto's Law** – Alfredo Pareto was an Italian economist who lived in France in the early 1900's. In studying the distribution of wealth in Milan, he found that 20% of the people controlled 80% of the wealth. Pareto's Law is also known as the "80-20 rule," which states that 80% of the value (or problems or whatever) is in the top 20% of the causes (items, people, etc). Note that it may not be 80-20 ... it might be 80-10 or 90-20, etc. Pareto's Law can be observed in many, many situations such as inventory/value distribution (most of the value in an inventory is in just a few items), customer sales distributions (just a few customers give you most of your sales), quality control (most of the defects can be attributed to just a few problems), human relations (most of the problems in your life are caused by just a few people), etc. Pareto's Law can best be remembered by the following phrase "The trivial many and the important few." The implication of Pareto's Law is that as a manager you need to find and manage the important few and ignore the trivial many that don't mean that much. As my roommate at West Point used to say, "Don't sweat the small stuff." and as my Tactical Officer used to say, "Major on the majors." See ABC classification.

***Parkinson's Law** – Work expands to fill the time allotted to it. (Work expands to fill the time allowed.)

part number – See stock keeping unit (SKU).

perfect order fill rate – The percent of orders that are perfect in every way – this could include on time or filled from stock, quality, packaging, information, billing, etc. See fill rate.

***performance quality* –** The product design standard (specifications) set for the product and service attributes. For example, the marketing and R&D people in a firm decide that a watch should be able to survive in 100 meters of water – probably based on focus groups with customers, salesforce feedback, etc. See conformance quality.

***picking* –** The process of selecting items from a warehouse.

***planogram* –** A plan for retail space allocation designed to maximize the return on investment for the retail space. A good planogram allows inexperienced employees to properly maintain shelf stock and appearance. The benefits of a planogram system include

(a) better control of inventory investments, (b) improved inventory turnover, (c) reduction in labor cost, (d) more satisfied customers, (e) increased sales, and (f) increased profit.

product structure **–** See bill of material.

****Project Evaluation and Review Technique (PERT)*** – PERT is an approach for project planning originally developed by the U.S. Navy for the Polaris project. PERT and CPM are essentially the same methods now. Originally, PERT required that each task have three task times estimates – the optimistic task time (a), most likely task time (m), and the pessimistic task time (b). The technique estimates the mean task time using the equation $(a+4m+b)/6$ and the variance of the task time as $(b-a)^2/36$. These equations were supposedly based on the beta distribution, but an article in ***Management Science*** many years ago (reference?) noted that these equations have little or no scientific basis. The mean of the critical path time is estimated by adding the means of the tasks along the critical path; similarly, the variance of the critical path time is estimated by adding the variances along the critical path. The confidence interval for the project completion time is then estimated as the mean plus or minus z standard deviations, where the standard deviation of the project time is the square root of the variance of the project time. This approach assumes that (a) the distribution of the project completion time is determined ***only*** by the critical path time (*i.e.*, that no other path could become critical), (b) the project completion time is normally distributed, and (c) the equations for the mean and variance are correct. In reality, none of these assumptions is correct. Few organizations find that the three task time approach is worth the time, confusion, and cost. See CPM, work breakdown structure, slack time.

Period Order Quantity (POQ) – A simple lotsizing rule that defines the order quantity in terms of the periods' supply. (See periods' supply.) POQ is implemented in MRP system simply by adding up the next POQ periods' of net requirements. The mathematically correct way to define the POQ is as the EOQ divided by the average demand per period.

****periods' supply*** – The concept of expressing an inventory quantity in terms of the periods of demand. For example, if I have 100 pounds of candy in my office, and I am using 20 pounds per day, then I have 5 days' supply. Some firms plan their inventories so that all items have equal periods' supply. This is generally a very bad idea because not all items have the same unit cost, the same standard deviation of demand, and the same replenishment leadtime. Note for English purists: According to my writing consultant, this is a plural possessive word. See Periodic Order Quantity.

****periodic review system*** – An order-timing rule used for planning independent inventories. Every "P" time periods, we place an order. Also known as a fixed-time period model, periodic system, fixed-order interval system, or P-model. See p.515 of the Chase, Aquilano, and Jacobs text. The system is "time-triggered" rather than "event-triggered" as the case of the order point model. The system is limited to placing orders at the end of a predetermined time period; only the passage of time triggers the model. The system requires a larger average inventory than the order point system because it must also protect against stockouts during the review period. It is appropriate for less expensive, non-critical items and/or items that are delivered on a regular scheduled basis. See continuous review system.

****perpetual inventory system*** **–** An inventory control system where a "real-time" record is kept of the amount of inventory for each item.

pick face **–** The primary location in a warehouse at which order picking, of less than pallet loads, is undertaken.

picking list **–** An output from an inventory control system designating those items, by part number, description and quantity, to be picked from stock to satisfy customer demand.

pipeline inventory **–** The products, which are currently being moved from one location to another.

planning versus forecasting – See forecasting demand.

****Point of Sale (POS)*** – A data collection device where the product are sold, usually a scanning and cash register device in a retail store. POS data is a rich source of data that can be used to inform the entire supply chain.

****poka-yoke*** – A Japanese word for a "foolproof device" or "avoid mistakes." Poka-yoke principles teach us to design products that cannot be assembled in the incorrect way and processes that are easy to do in the correct way and hard to do in the wrong way. We want products and processes that are "failsafe." See Failure Model Effects Analysis (FMEA).

****postponement principle*** – It is best to keep products standardized as long as you can in the process to minimize complexity and inventories. The advantage is that standardized products can be made a lower cost and that you do not want to inventory an enormous variety of products. This is foundational principle for mass customization. This is sometimes called the "maximum delay" principle. See mass customization.

****predictive maintenance*** – Predictive maintenance is the practice of monitoring a machine with a measuring device that can anticipate and predict when it is likely to fail. This is often based on vibration. Maintenance is then scheduled based on feedback from this measuring device. See preventive maintenance.

****preventive maintenance*** **–** Preventive (or preventative maintenance) is the practice of checking and repairing a machine on a scheduled basis before it fails. The schedule is usually based on some historical information on the time between failures for the population of machines. The machine operators often perform it. The opposite of preventive maintenance is emergency maintenance, where the maintenance is done after the machine fails. In the practice of dentistry, preventive maintenance is your annual checkup and cleaning and emergency maintenance is the emergency trip to the dentist when you have a toothache. See emergency maintenance and predictive maintenance.

print-to-order – A printing process that has very small printing batch sizes, typically equal to a customer order size. Print to order is made possible by new printing technologies. See Make-to-order.

process capability – This is the total range of inherent variation in a stable process. It is determined using data from control charts. The control charts shall indicate stability before capability calculations can be made. Histograms are to be used to examine the distribution pattern of individual values and verify a normal distribution. When analysis indicates a stable process and a normal distribution, the indices Cp and Cpk can be calculated. If analysis indicates a non-normal distribution, advanced statistical tools such as PPM analysis, will be required to determine capability. If control charts show the process to be non stable, the index Ppk can be calculated.
(Source: http://www.adamssixsigma.com/Glossary_of_terms/six%20sigma%20glossary%20C.htm)

process control – See Statistical Process Control (SPC).

****process flow chart (process map)*** – A diagram showing the logical flow of entities through a process. Ideally, the process map should show the queues and delays because these often represent 80% of the total process flow time. Process maps should also highlight handoffs (because this is where information is likely to be lost), moments of truth (this is where the process touches the customer), and failure points (this is where the process is likely to fail).

****process layout*** – An approach to organizing the physical configuration of a facility so that workcenters are grouped by process, rather than organized to match the requirements of a particular product. A process layout will have all of the grinding machines together, all of the lathes together, etc. A process layout is appropriate for a "job shop" where the routing sequence for products is almost completely unpredictable. See product layout.

product design quality – The degree to which the product design contributes to the creation of a high quality product. Product design quality is the output of the knowledge workers who generally work in marketing, design, development, quality assurance, and operations. Quality historically originated in a task-oriented manufacturing environment. The challenge is how to integrate a quality philosophy into the knowledge work areas of marketing, design and development. Existing quality tools traditionally used in production settings may not work in this environment or may require serious adaptation. The approach to quality must adapt to be successful in the knowledge/professional environment. The approach to communication is a vital element in this environment. The knowledge workers' manager needs to have sufficient technical expertise to be seen as competent by the knowledge worker in their area of expertise. The manager manages outcomes, not the process details. A design engineer is already trained how to analyze designs by various boundary conditions, hand calculations, FEA or other means. The outcome should be a design report (folder) with drawings, technical specifications, producability requirements and supporting analysis reports. In order to assure the quality of the creative process, the manager assures that the systems that communicate information to the design engineer are functioning properly. Thus, systems not part of the knowledge workers' area of expertise are audited. These are the systems put into place to manage communication flow that directly impact results. Moral: Audit systems and results, not knowledge or thought process. (Source: Rick Christensen, MOT Class of 2001) This is not the same as either performance or conformance quality. See conformance quality, performance quality.

product layout – An approach to organized the physical configuration of a facility that is driven by the steps required to build a particular product. See process layout.

production planning (production plan) – See aggregate planning.

****productivity*** – A ratio of an output measure divided by an input measure (e.g., hamburgers created per hour). Is a measure of how well a country, industry, business unit, person, or machine is using its resources. It is a relative measure. Productivity can be compared to another company or to itself over time. Total factor productivity is measured in monetary units. Partial factor productivity is measured in individual inputs, with labor being the most common.

project management – See CPM, PERT, slack time, work breakdown structure, critical path, critical chain, load leveling, gate.

purchasing lead-time – The time between the release and receipt of a purchase order from a supplier. This is also known as the replenishment lead-time. See leadtime.

****push versus pull systems*** – All production and inventory control systems deal with fundamentally only two decision variables – when to order and how much to order. It is easiest to understand "push" and "pull" systems for managing these two variables in a logistics context. Suppose, for example that we have a factory supplying two regional warehouses. With a push system, the people (and the computer) at the factory decide when and how much to ship to each of the two warehouses based of forecasted demand and inventory position information. With a pull system, we disaggregate the problem so that people (and the computer) at each warehouse decide when and how much to order from the factory based on their need. (Of course, the factory might not have the inventory, so some of these orders might not be filled.) See CONWIP, JIT.

Push versus pull systems

	Push	Pull
Signal to produce more	Schedule or plan	Customer signal
Timing of signal	Advance of the need	At the time of the need
Type of signal	Paper or computer	Container, square, cart, or paper
Information scope	Global	Local only

Planning horizon	Fairly long	Very short
Level demand needed	No	Generally yes
Standard parts/products	Not necessary	Generally necessary
Large queues possible	Yes	No
Negatives	Too much inventory Not visual. Requires more information. Long planned lead times	Does not plan ahead. Missed customer demand at the beginning of the product lifecycle and too much inventory at the end.
Best for	Non-repetitive, batch. Seasonal demand, short product lifecycles. Long leadtime purchasing.	Repetitive, high-volume manufacturing. Stable demand.
Problem visibility	Not visible	Visible
Stress to improve	Little	Much
Problems found from	Computer reports	Shop floor

Source: Professor Arthur V. Hill

qualification **–** See supplier certification and qualification.

quality at the source – The philosophy that we do not try to inspect quality into the system – we ensure that perfect conformance quality happens at every step of the process. The person who does the work is responsible for ensuring a quality output. For example, a data entry process should ensure that every number is entered properly. Data accuracy should not have to be checked at a later step.

Quality Function Deployment (QFD) – A method for ensuring that the customer has a voice in the design specification of a product. QFD uses interfunctional teams from manufacturing, engineering, and marketing. The process begins with market research, studying and listening to customers to define their needs and then breaking these needs down into categories called customer requirements. Requirements are then weighted based on their importance to the customer. Customers are asked to rate the firm's products against competitor's products. This process assists the firm in determining what the customer values and how the customer rates the product compared to a competitor's product. QFD results in a better focus on customer's needs and product characteristics in need of improvement. (Source: student homework assignment, updated August 29, 2000)

Quality Function Deployment (QFD) is the only comprehensive quality system aimed specifically at satisfying the customer. It concentrates on maximizing customer satisfaction (positive quality) - measured by metrics, such as repeat business and market share. QFD focuses on delivering value by seeking out both spoken and unspoken needs, translating these into design targets, and communicating this throughout the organization. Further, QFD allows customers to prioritize their requirements, tells us how we are doing compared to our competitors, and then directs us to optimize those features that will bring the greatest competitive advantage. (Source: http://www-personal.engin.umich.edu/~gmazur/tqm/voc.htm, December 10, 2000)

****quantity discount*** – Sellers often offer a lower price to customers when they order in larger quantities. The difference between the normal price and the reduced price is called a discount. Two policies are common in practice. The "incremental units" discount gives the customer a lower price on the units ordered above a breakpoint. (For example, if you order more than 100 units, then the price for the units over 100 is lowered from $10 to $9.) The "all-units" discount policy offers a lower price on all units ordered. (For example, if you order more than 100 units, the price for all units ordered will be lowered from $10 to $9.) The optimal order quantity will always be either at a "breakpoint" where the price changes or at a feasible EOQ. See EOQ.

****queuing theory*** – A branch of mathematics that deals with understanding systems with customers (orders, calls, etc.) arriving and being served by one or more servers. The time between arrivals and/or the service times could be random variables. Queuing theory models are usually concerned with estimating the steady state performance of the system such as the utilization, the mean time in queue, the mean time in system, the mean number in queue, and the mean number in system. Queuing theory is sometimes called "stochastic processes." Queuing theory models are sometimes good tools for understanding capacity issues, but are limited by the assumption that the mean arrival rate and the mean service rate do not change over time. See Little's law, utilization.

Quick Response (QR) – See efficient consumer response.

r-chart – A quality control chart that monitors the range (variability) of the process. A sample of *n* parts is collected from the process every so many parts or time periods. The range (maximum minus minimum) of the sample is plotted on the control chart and a determination is made if the process is "under control" or not.

Radio Frequency Identification **–** The attachment of transponders (which may be read only or read/write) to products, as an alternative to linear bar codes, to enable product identification some distance from the scanner or when out of line of sight.

random storage system – Storage locations in a warehouse can be either fixed or random. Fixed storage locations do not work very over time because (1) new items are added to inventory, (2) old items are removed from inventory, (3) the demand rate for some products decreases, and (4) the demand for other products increase. All four of these issues create problems because the firm will need to reallocate space to "fixed" storage locations with each change. A random storage location allocates inventories to the first available location that has enough (but not too much) space. This approach will end up with most items stored in more than one location. Random storage makes much better use of the space and does not require that the fixed storage locations be changed, but requires much more information to make the system work. See fixed storage location system.

****reorder point (order point) system*** – An approach for managing independent demand items that releases an order when the inventory position hits a certain level called the reorder point. An order point system is generally a continuous review system based on perpetual inventory records. The equation for the reorder point is $R=dL+SS$, where d is the average demand per period, L is the planned leadtime, and SS is the safety stock in units. The safety stock should be set to $SS=kL^{0.7}\sigma_d$, where σ_d is the standard deviation of the demand per period and k is the safety factor. The safety factor should be either based on a target service level or on the economics of a stockout. The determination of the proper safety factor is beyond the scope of this document.

re-engineering **–** See business process re-engineering.

remanufacturing **–** Remanufacturing is the process of repairing, refurbishing, and/or disassembling products into reusable components. Remanufacturing is being driven by both economic and environmental rational. In some countries, remanufacturing is required by law. See reverse logistics.

replenishment lead-time **–** See purchasing leadtime, leadtime.

response time – The time between a request for service and the time the service actually begins. In the field service context, the travel time is not considered a part of the response time.

reverse logistics **–** The management of the return flow for products, salvage, and or waste from the customer to either safe disposal or reuse, often via the manufacturer or distributor. The materials could be either hazardous or non-hazardous. Examples include: 3M has its field service technicians manage the return flow of hazardous circuit boards for refurbishing or proper disposal. Volkswagen takes back old Volkswagen cars to recycle and reuse some seat materials. Interest in reverse logistics is driven by both environmental concerns and cost saving opportunities. See remanufacturing. Similar terms include "return logistics."

****robust*** **–** The dictionary definition for "robust" is "full of health and strength, vigorous, sturdy." Robust in an operations an engineering context means "hard to break" or "applicable in a wide variety of situations." For example, if a component can be used in a wide variety of products, it is said to be "robust." (See commonality.) If a part is very sturdy and almost never breaks, it too is said to be robust.

Sales & Operations Planning (S&OP) **–** S&OP is a horizontal communications process in which key managers from sales and operations meet frequently to develop realistic plans and promise dates for new orders.

salvage value **–** The value of an item when it is scrapped instead of sold. Both retailers and manufacturers can usually find a salvage firm or discounter to buy obsolete inventory. 3M uses a salvage firm to buy used electronic components, which buys them for a very low value (such as $0.01 per pound) and then keeps them in inventory available for sale in the rare instance that someone might need a replacement part. The salvage firm sells the parts at the normal book value (say $250).

****safety capacity*** – Capacity that is available in case of an emergency. Examples include a medical doctor "on call," a supervisor who can help in time of need, or capacity for overtime. Note that safety capacity is very different from safety stock.

****safety lead-time*** – "Extra" planned lead-time used in the materials requirements planning process. Time above the average used in planning. For example, if it takes me 30 minutes to get to work on average, and I plan to leave 40 minutes before my work begins, then I have a safety leadtime of 10 minutes. Safety leadtime should absorb the variability in the actual leadtimes; safety stock should absorb the variability in the demand or yield. Most experts agree that safety leadtime (rather than safety stock) is the right approach to use to protect against uncertainty in leadtimes.

****safety stock*** – The average inventory on hand when an order is received. In an independent demand inventory system, the safety stock should be a function of the standard deviation of the demand during the replenishment leadtime. See reorder point.

satisfice – To obtain an outcome that is good enough. Satisficing action can be contrasted with maximizing action, which seeks the biggest, or with optimizing action, which seeks the best. In recent decades doubts have arisen about the view that in all rational decision-making the agent seeks the best result. Instead, it is argued, it is often rational to seek to satisfice (i.e. to get a good result that is good enough although not necessarily the best). The term was introduced by Herbert A. Simon in his Models of Man 1957. Source: The Penguin Dictionary of Philosophy ed. Thomas Mautner, ISBN 0-14-051250-0, http://www.utilitarianism.com/satisfice.htm.

scope creep **–** The tendency for project requirements to grow over time, usually resulting in huge, unmanageable projects.

scrap – The number units that are defective and cannot be reworked.

search cost – The cost of finding a supplier that can provide a satisfactory product at an acceptable price.

seasonal factor – Many forecasting models apply a multiplicative seasonal factor. The forecast, therefore, is equal to the underlying average times the seasonal factor. For example, a retailer might have a seasonal factor for the month of December (Christmas season) that is 4.0, whereas for the month of January, the factor might be 0.6.

sequence-dependent setup time – The time to changeover from producing one product to another is dependent upon the order in which the products are produced. For example, a paint manufacturing process might be easy to changeover from white to yellow, but very difficult to changeover from black to white. The optimal sequence to the sequence-dependent setup problem can be found by solving the famous "traveling salesperson problem." See traveling salesperson problem.

****service failure*** – When a service provider (such a barber) does not provide satisfactory service (e.g., a very bad haircut), the service episode is considered a "service failure." The best service organizations pay a great deal of attention to these and try very hard to recover the customers before they become "terrorists" and give a bad report to large number of potential customers. See service recovery.

****service guarantee*** – A set of two promises offered to customers before they buy a service. The first promise is the level of service provided. The second promise is what the provider will do if the first promise is not kept. Advantages include (1) helping to retain customers who are about to defect (and give bad reports about the firm), (2) helps the organization to learn from its mistakes and to improve its service offerings, (3) provides some opportunity to advertise service quality. Professor Hill's research has found that a service guarantee often has more impact on the operations of a firm than it does for advertising. A service guarantee is a promise relating to the intangible attributes of the service (e.g., timeliness, results, satisfaction, etc.), whereas a product warranty is on the physical attributes of the product (durability, physical performance, etc.). However, from a legal standpoint, they are both considered warranties. See service recovery and service quality.

****service level*** – For a make to stock (MTS) process, the service level is the percent of the units (or lines or orders) that are immediately available from stock. Some firms (and textbooks) mistakenly define the service level as the probably that the firm will not run out of stock on a single order cycle. This definition is hard to understand – and even when it is understood, it has little relevance to any business decision. Many retail firms use a measure of the time that the inventory is stock (or out of stock). See fill rate and perfect order. For assemble to order (ATO), make to order (MTO), and engineer to order (ETO) systems, service level is measured in terms of on-time delivery (OTD). OTD is measured as the percent of orders that are received within either the promise date or the requested date. OTD can be improved by either (1) making safer promises (e.g., 20 weeks instead of 2 weeks), or (2) reducing the manufacturing leadtime. See fill rate.

service parts **–** Components, parts, or supplies used to maintain or repair machinery or equipment. Sometimes called "spare parts." The term "spare" implies that they are not needed, which is often not the case.

****service quality*** **–** This author defines service quality as a customer's long-term overall evaluation of a service provider. This author defines customer satisfaction as the customer's evaluation of a specific service episode (a service event). However, some authors reverse these definitions. Many authors define the service quality "gap" as the difference between the expectations and the delivery for a particular service episode. However, this model suggests that service quality (or customer satisfaction) is high when customers expect bad service and get it is high. In response to this problem, this author has created the "FED up" model, where F equals E minus D and F=Frustration, E=Expectation, and D=Delivery. When F=0 the customer is not satisfied -- just not frustrated. For example, when I tell my wife that I will be home by 5:30 pm and then don't get home until 6:30 pm, she is quite frustrated. See critical incidents method, service guarantee, service quality, SERVQUAL, single point of contact, and triage.

****service recovery*** – Resorting customers to a strong positive relationship with the firm after they have been experienced a service failure. The six steps to service recovery are (1) Listen, (2) Apologize and show empathy, (3) Ask the "recovery" question "What can we do to completely satisfy you?" (4) Fix the problem quickly - prioritize customers and escalate if needed, (5) Offer symbolic atonement, (6) Follow-up to make sure that the relationship is fixed. The slogan here is that "it is much easier to keep an existing customer than it is to find a new one." The "three fixes of service quality" include (1) make sure that the ***customer's problem*** is fixed, (2) make sure that the ***customer relationship*** is fixed – so that they will come back next time, and (3) make sure that the ***system problem*** is fixed so that this customer (and all future customers) doesn't have the same problem ever again.

SERVQUAL **–** A service quality instrument that measures the gap between customer expectations and perceptions after a service encounter. The instrument was created by Parasuraman, Zeithaml, and Berry (1988) and has been used in numerous service industries. The SERVQUAL instrument is organized around five dimensions of customer service:

Tangibles - physical facilities, equipment, and appearance of personnel
Reliability - ability to perform the promised service dependably and accurately
Responsiveness - willingness to help customers and provide prompt service
Assurance - competence, courtesy, credibility and security
Empathy - access, communication, and understanding

The instrument has been criticized in a number of different research papers for a number of different reason, but continues to be popular in many industries. One of the main criticisms is that service quality may ***not*** be a function of the gap between expectation and service – but is a function of the value that is delivered to the customer. For example, my wife hates White Castle hamburgers. If she goes to White Castle and gets what she expects, she still does not perceive this as good quality.

***setup cost (changeover cost, order cost)** – The marginal cost of a setup. This generally includes the labor and the materials cost associated with the scrap generated by the setup. Allocated overhead (fixed costs) should not be included as a part of the setup cost. The cost of a setup at a bottleneck (constrained) resource should include the opportunity cost of entire system. The cost of a setup at a non-bottleneck resource should be only the marginal cost of the labor and materials. (Goldratt would argue that the labor cost is fixed, but that might not be true in North America where we are fairly free to hire and fire workers.) Professor Hill has written a technical note on this subject. See setup time, theory of constraints.

setup reduction methods – For many processes, the key to process improvement is to reduce the setup time and cost. One of the key methods for doing this is to move the setup time to "external" setup time. (I like to call it a "running setup.") An external setup is done to prepare a job for a machine while the machine is still running. For example at the Indianapolis 500 race, the crew will prepare the tires, fuel, and water for the race car while the car is still going around the track. When the racecar arrives in the pit area, the crew changes all four tires, adds fuel, and gives the driver water – all in 18 seconds or less. Setup teams can also reduce setup times. When a setup is needed, a signal (such a light) indicates that all members of the setup team should converge on the machine. The setup team then quickly does its job. Some people who do not understand managerial accounting might challenge the economics of using a team. However, for a bottleneck process the labor cost for the setup team is justified by the increased capacity for the bottleneck and the plant. See SMED.

***setup time (changeover time)** – The time required to prepare a machine for the next job. See setup cost, sequence-dependent setup time, setup reduction methods.

***seven tools of quality* –** Quality improvement tools that include the histogram, Pareto chart, check sheet, control chart, cause-and-effect diagram, flowchart, and scatter diagram.

***shop floor control** – Shop floor control (also known as production activity control) involves all of the activities required to monitor the process of moving an order through a factory, from order release to order completion. SFC systems often involve information systems to communicate the status of shop orders and workcenters. Major functions of shop-floor control include:

1. Assigning priority of each shop order
2. Maintaining WIP quantity information
3. Conveying shop-order status information to the office
4. Providing actual output data for capacity control purposes
5. Providing quantity by location by shop order for WIP inventory and accounting purposes
6. Measuring efficiency, utilization, and productivity of manpower and machines.

See Manufacturing Execution System (MES).

***shrinkage* –** Losses resulting from scrap, deterioration, pilferage, etc

***simulation –** A representation of reality, often used for experimentation. In operations management, we sometimes need to create computer simulations of complex systems such as factories or service processes in to order experiment with changes. Experimenting with the simulation model can help us to find problems and opportunities without having to actually build (or change) the physical system. Computer simulations of this type are generally "discrete event" simulation models, as opposed to continuous simulations models which are used to represent the movement of rockets over continuous time.

***simultaneous engineering** – Simultaneous Engineering is a systematic approach to the integrated concurrent design of products and their related processes including manufacturing and support. Benefits include reduced time to market, increased product quality, and lower product cost. Simultaneous engineering is very closely related to DFM (Design for Manufacturing). As far as I can tell, simultaneous engineering is synonymous with concurrent engineering and integrated product development. (Source: www.ckgp.com/ckgp/simultaneous_eng.html adapted by Professor Art Hill)

***single point of contact –** A service quality principle that suggests that a customer should have to talk to only one person for the delivery of a service. The opposite of this happens in many service organizations when a customer waits a long time in queue only to be told by the unfriendly service worker that they have to go see someone else – and never builds any relationship with any service worker – and no service worker ever takes any "ownership" of the customer's needs. Advantages of the single point of contact principle include (1) the firm builds a closer relationship with the customer, (2) the customer does have to wait in multiple queues, (3) much less information is lost in the "hand-offs" between multiple service workers, (4) the job design is more satisfying for the service worker because they get to "own" the entire set of the customer's needs.

***single source and sole source supplier** – With a single source supplier the firm is has only one supplier for a part, but has other suppliers who are qualified to provide the part. With a sole source supplier, the firm has one and only one source capable of supplying the part. A sole source supply is basically a monopoly situation and can be very dangerous for the customer. However, in some situations a sole source relationship is unavoidable.

***Six Sigma** – Six sigma has at least three different meanings depending upon the context. (1) Six Sigma is the structured application of the tools and techniques of Total Quality Management on a Project Basis to achieve strategic business results. (2) Six sigma is a management philosophy. Six sigma is a customer based approach realizing that defects are expensive. Fewer defects mean lower costs and improved customer loyalty. The lowest cost, high value producer is the most competitive provider of goods and services. Six sigma is a way to achieve strategic business results. (2) Six sigma is six sigma is a statistic. Six sigma processes produce less than 3.4 defects or mistakes per million opportunities. Many successful six sigma projects do not achieve a 3.4 ppm (parts per million) or less defect rate (or 99.99966% good). That just indicates that there is still opportunity. (4) Six sigma is that six sigma is a process. To implement the six sigma management philosophy and achieve the six sigma level of 3.4 defects per million opportunities or less there is a process that is used. The six sigma process includes five steps (a) define, (b) measure, (c) analyze, (d) improve, and (e) control. Note that six sigma is not a set of new or unknown tools. Six sigma tools and techniques all are found in total quality management. Six sigma is the application of the tools on selected important projects at the appropriate time.

Six Sigma training programs develop leaders in the following three categories: (a) ***master blackbelts*** who have completed numerous projects and train other blackbelts; (b) ***blackbelts*** who are team leaders with between four to eight weeks of training; and (c) ***greenbelts*** who are team members with between two and four weeks of training. Certification programs for these roles are now available.
(Sources: www.adamssixsigma.com/Glossary_of_terms/what_is_six_sigma.htm
www.adamssixsigma.com/Glossary_of_terms/six%20sigma%20glossary%20S.htm)

slack time – See critical path method.

***Single Minute Exchange of Dies (SMED)* –** The reduction in die set-up time to less than one minute. This is the time from the last good part for one order to the first good part of the next order. A single minute is not required, but is used as a reference. This term was coined by Shigeo Shingo. See setup reduction methods, setup time, setup cost.

***special cause* –** The cause(s) of variation in a process that have a source that is identified, and can be eventually eliminated. (also known as "assignable cause"). Causes of variation in a process that are not inherent in the process itself but originate from circumstances that are out of the ordinary. Special causes are indicated by points that fall outside the limits of a control chart.

***statistical process control (SPC)* –** The application of statistical methods and procedures relative to a process and a given set of standards. Analysis and control of a process through the use of statistical techniques, particularly control charts. (Source: http://www.adamssixsigma.com/Glossary_of_terms/six%20sigma%20glossary%20S.htm) See acceptance sampling.

statistical quality control (SQC) – Analysis and control of quality through the use of statistical techniques with a focus on the product rather than the process.
(Source: http://www.adamssixsigma.com/Glossary_of_terms/six%20sigma%20glossary%20S.htm)

standard deviation – A measure of the variability of a random variable. The sample standard deviation is the square root of the variance and is defined by:

$$\hat{\sigma} = \sqrt{\sum_{i=1}^{n} (x_i - \overline{x})^2 /(n-1)} = \sqrt{\left(\sum_{i=1}^{n} x_i^2 - n\overline{x}^2\right)/(n-1)}$$

The first expression is known as the definitional form; the second expression is known as the "computational form" because it is easier for computing purposes. The population standard deviation should have "/n" instead of "/(n-1)."

standard time – An industrial engineering term that is the process time per part used for planning purposes. The standard time is the normal time adjusted for "allowances," which is time for bathroom breaks, rest, etc. See normal time.

starving (a process, not students) – A process is "starved" if it runs out of input materials to process. This is very bad for the bottleneck process because it will reduce the output of the entire process. Setup times are often too long because the process does not have all of the materials needed for the setup. Starving a non-bottleneck process may have no consequences for the overall output of a process. Starving at a non-bottleneck process signals that we should use that worker somewhere else in the process.

strategy map – Kaplan and Norton proposed a "strategy map" as a tool for communicating the critical relationships and metrics needed to understand and implement the strategy. Strategy maps show cause and effect relationships in the business system such as the relationships between:

- The firm's value proposition, target markets, and business performance.
- Investments in people, systems, R&D, capacity, and process technology and the value proposition as defined by operational excellence (price, conformance quality, reliability), customer intimacy (service, customization), and product leadership (performance quality, time to market).
- Employee recognition programs, employee reward systems, employee motivation, service quality, customer satisfaction, and customer loyalty.
- Sales force size, incentives, and sales.
- Advertising investment, message, and media selection.

Strategy maps should also depict the key metrics that will be used to motivate and monitor the execution of the strategy. Kaplan and Norton argue that the strategy map should focus on the few "balanced scorecard" metrics that drive the strategy to success. These metrics should be reported at a very high level in the firm. Goldratt emphasizes that systems have only one bottleneck that is keeping them from improving the performance and that this should be the focus for the strategy and the metrics. The strategy map and balanced scorecard articles are as follows:

Kaplan, Robert S., and David P. Norton, "Having trouble with your strategy? Then map it." ***Harvard Business Review***, September-October 2000.

Kaplan, Robert S., and David P. Norton, ***The Balanced Scorecard: Translating Strategy into Action***, Harvard Business Press, 1996.

Professor Hill has a two-page summary of this concept with a nice example.

***stickiness* –** The amount of time a visitor stays on a website and the ability of the website to hold the attention of the visitor.

****stock keeping unit (SKU)*** – A unique identification number (or alphanumeric string) that defines an item for inventory purposes. For example, in retail applications, an SKU may designate style, size and color. A more detailed identifier for a specific item is called a serial number or unique identifier. In a manufacturing process, some items might exist for a short period of time in the assembly process; however, if these items are not inventoried, they should not be given a SKU identifier. Sometimes called a "part number" or an "item number." Sometimes a part number is used to identify the item, but the SKU is used for recording the inventory count at a specific location. It is wise to use only numerical values (0-9) and not mix alpha (letters A-Z) and numerics. The rational for this is that many numbers and letters appear the same. For example, the number 1 and the letter l, the number 5 and the letter S, and the number 0 and the letter O. Also, many letters sound the same. For example, K and A, M and N, and Y and I. If SKUs are restricted to only numerics, the probability of a data entry error is reduced significantly. It is also considered good practice to use short numbers, say 7 digits or less. Long part numbers have more meaning for the users (location, commodity type, etc.), but require more work for data entry and can be more error prone. The widespread use of bar coding has made these issues less important. See check digit.

supplier qualification and certification – A customer "qualifies" a supplier when it has been determined that the supplier is capable of providing a part. A supplier becomes "certified" when it has delivered parts with perfect quality over a pre-specified time period (say six months). At that point, inspection is no longer needed. In some cases, the two firms share the savings.

****supply chain management*** – The central idea of supply chain management is to apply total system approach to managing the flow of information, materials, and services from raw material suppliers through factories and warehouses to the end customers. The result of this should be lower total system cost (lower inventory, higher quality) and higher service levels. However, the benefits of such changes need to be shared between the players in the supply chain. See value chain, bullwhip effect.

****switching cost*** – The customer's cost of switching from one supplier to another. It is often in the supplier's best interests to increase the customer's switching costs so that the customer does not defect to the competition the first time that the competition offers a small price decrease. Some suppliers have been successful in increasing switching costs through frequent purchase reward programs. Others have increased switching costs by helping customers reduce transaction costs through information systems. See transaction cost.

synchronous manufacturing – Refers to the entire production process working in harmony to achieve the profit goal of the firm. When manufacturing is truly synchronized, its emphasis is on total system performance, not on localized measures such as labor or machine utilization. See Theory of Constraints.

***Taguchi methods* –** Taguchi methods were developed by Genichi Taguchi to improve the implementation of total quality control in Japan. They are based on the design of experiments to provide near optimal quality characteristics for a specific objective. They are often demeaned by academia for technical deficiencies, which can be improved by using response surface methodology. Unfortunately, most of those who demean Taguchi methods have missed the whole point. Taguchi methods are not just a statistical application of design of experiments. Taguchi methods include the integration of statistical design of experiments into a powerful engineering process. The true power of Taguchi methods comes from their simplicity of implementation. They are often applied on the Japanese manufacturing floor by the technicians to improve their product and their processes. The goal is not just to optimize an arbitrary objective function, as they are so often used in the USA. The goal is to reduce the sensitivity of engineering designs to uncontrollable factors or noise. The objective function used is the signal to noise ratio, which is maximized. This moves design targets toward the middle of the design space so that external variation affects the behavior of the design as little as possible. This permits large reductions in both part and assembly tolerances, which are major drivers of manufacturing, cost. Linking quality characteristics to cost through the Taguchi loss function was a major advance in quality engineering, as well as in the ability to design for cost. Taguchi methods are claimed to have provided as much as 80% of Japanese quality gains. This is no small feat considering that Japanese quality gains have brought a large number of industries in the USA to their knees. Taguchi methods are also called robust design in the U.S.A.. (Source: http://mijuno.larc.nasa.gov/dfc/tm.html, November 1, 2000). See also http://www.dnh.mv.net/ipusers/rm/loss.htm for more information.

A methodology developed by Dr. Genichi Taguchi for designing quality into product and process. This methodology makes quality decisions based on cost effectiveness by:

- Recognizing the importance of associating quality with the financial loss imparted by poor quality. (The loss function)
- Designing efficient experiments and analyzing experimental data. (Orthogonal arrays with the linear graphs)

- Specifying the cost-effective combination of factors, which affect variation of quality and are feasible and practical to control, and minimizing the influence of the incontrollable factors. (Robustness)

In the traditional methodology of design, the assurance of relationship between input and output precedes the adjustment to factors, or noise, which affect the variation of quality. This adjustment process might result in infinite trial-and-error and increase the cost of development. In Taguchi Method, the robustness precedes the adjustment to the design for the assurance of input-output relationship. In terms of precedence, universality and recurrence, research should be done with a test piece in the upstream rather than in the downstream with a finished product. The accumulated know-how about the proper combination of factors would give a maker a competitive edge.
Precedence: Research that precedes product planning
Universality: Technology applicable to a variety of products
Recurrence: Recurrence of the results of experiment in the development, mass-production, and actual use.
(Source: ***Taguchi-Methods: A hands-on approach***, Glen Stuart Peace. 1993 Addison-Wesley Publishing.)

takt time – Daily demand rate divided by the number of working hours in the day. This is really just the cycle time required to meet the demand rate.

****tardiness*** – An order is said to be "tardy" if it is past the due date (or due time). Tardiness is zero if the order is on-time or is early. Average tardiness is a common measure, but should be used with caution because it only considers orders that are tardy. For example, a firm has hundreds of orders that are tardy with an average of 2 days. The firm dramatically improves its on-time performance for nearly all orders. However, it now has two orders that are tardy with an average tardiness of 4 days. The average has gotten worse, but has tardiness gotten worse?

****Theory of Constraints*** – The Theory of Constraints (TOC) is a management philosophy developed by Dr. Eliyahu M. Goldratt, an Israeli physicist. TOC recognizes that there are very few critical areas, resources or policies that truly block the organization from moving forward. As Goldratt states, "a chain is only as strong as its weakest link." This is really an application of Pareto's Law to process management and process improvement. The concepts are consistent with managerial economics that teach that the setup cost for a bottleneck resource is the opportunity cost of the lost gross margin and that the opportunity cost for a non-bottleneck resource is nearly zero. See throughput accounting, drum-buffer-rope.

According to TOC, if performance is to be improved, an organization must identify its constraints, exploit the constraints in the short run, and in the longer term, find ways to overcome the constraints (limited resources.) Developed by Goldratt (wrote the book ***The Goal***, which later became a movie with Herbie as the "bottleneck"). His theory of constraints is composed of the following:

1) Identify the system constrains -- No improvement is possible unless the constraint or weakest link is found.
2) Decide how to exploit the system constraints -- Make the constraints as effective as possible.
3) Subordinate everything else to that decision -- Align every other part of the system to support the constraints, even if this reduces the efficiency of non-constraint resources.
4) Elevate the system constraints. (If output is still inadequate, acquire more of this resource so it no longer is a constraint.)
5) If, in the previous steps, the constraints have been broken, go back to Step 1, but do not let inertia become the system constraint. (After this constraint problem is solved, go back to the beginning and start over. This is a continuous process of improvement: identifying constraints, breaking them, and then identifying the new ones that result.)

Underlying Goldratt's work is the notion of synchronous manufacturing, which refers to the entire production process working in harmony to achieve the profit goal of the firm. When manufacturing is truly synchronized, its emphasis is on total system performance, not on localized measures such as labor or machine utilization.
This leads to the whole goal of the firm, which is to make money. In operations terms, this is accomplished through (1) increasing throughput, (2) reducing inventory, and (3) maintaining or reducing operating expenses.
The "constraint" is the bottleneck, which is any resource that has capacity less than the market demand. Alternatively, the process that has the lowest average processing rate for producing end products. (Remember a constraint, or bottleneck, can be a machine, a process, a regulation, a person, etc.)
Ways to manage the constraint: in Art's words from his presentation
-Identify the constraint (where is the largest queue? What process has the least idle time?)
-Manage the constraint to protect it from being idle or wasting capacity. (Reduce setup times, increase lotsizes, inspect before the constraint)
-Manage other processes so the constraint is never starved (everything else has small lotsizes, do not overproduce, move people to balance the flow)
-Find additional capacity (work more hrs, use alternative routings, buy more capacity, subcontract)

throughput accounting – Accounting principles based on the Theory of Constraints. See Theory of Constraints. The following is a book on the subject. Noreen, Eric, Debra Smith, and James T. Mackey, ***TOC and Its Implications for Management Accounting***. Publisher?

Throughput is the rate at which an organization generates money through sales. Goldratt defines throughput as the difference between sales revenue and unit-level variable costs such as materials and power. Cost is the most important driver

for our operations decisions, yet costs are unreliable due to arbitrary allocation of overhead, even with Activity Based Costing. Since the goal of the firm is to make money, operations can help this through three items of throughput accounting: Inventory (I), operating expenses (OE), and throughput (T)
Inventory = materials cost and other truly variable costs with no overhead
Operating expenses = overhead and labor cost (the things that turn "I" into "T")
Throughput rate = revenue – materials cost
When we apply throughput accounting to the bottleneck (constraint), we must look at key performance measurements: output, setup time (average setup time by product and total setup time per period), downtime (planned and emergency), and yield rate. We focus on the constraint because it can have the biggest impact on our throughput accounting measures (I, T, OE), which in turn affect the goal, which is making money for the firm.

time-based competition – A strategy to shorten customer leadtimes in order to (1) segment the demand to target the time-sensitive (and price-insensitive) customers, (2) reduce finished goods inventory cost, (3) drive out non-value activities (e.g., JIT and lean manufacturing concepts). Stalk and Hout's book on Time-Based competition makes some very strong claims about the profitability of such a strategy.

time-phased order point – An extension of the reorder point system that uses a demand forecast to plan when the inventory position will hit the safety stock level. An order is then planned to arrive at that time. The start date for the order is planned to be "L" time units earlier, where "L" is the planned leadtime.

time-series forecasting – A forecasting method that identifies patterns in historical data to make a forecast. Univariate time-series methods simply extrapolate a single time series into the future. Multi-variate times series consider historical data for several related variables to make the forecast. Examples include weighted averages, exponential smoothing, and Box-Jenkins methods. See exponential smoothing, Box-Jenkins.

time-varying demand lotsizing problem – This is the problem of finding the set of lotsizes that will "cover" the demand over the time horizon and will minimize the sum of the ordering and carrying costs. Common approaches for solving this problem include the Wagner-Whitin algorithm, the Period Order Quantity (POQ), the Least Total Cost method, the Least Unit Cost method, and the Economic Order Quantity. Only the Wagner-Whitin algorithm finds the optimal solution – all of the other methods are heuristics for this problem. Professor Hill has created an Excel workbook called "lotsize.xls" that implements a very efficient network algorithm for solving this problem. See Wagner-Whitin.

****Total Productive Maintenance (TPM)*** – TPM seeks to maximize the performance of an overall production system by providing a systematic way for managing equipment over its complete life cycle. TPM combines preventive maintenance concepts with the Kaizen philosophy of continuous improvement. Maintenance takes on its proper meaning to maintain – not just repair. TPM includes the concept of improvement of equipment, processes, and plants through the elimination of losses. A TPM system creates work orders for regular scheduled maintenance and maintains a repair history for each piece of equipment. See preventive maintenance, Overall Equipment Effectiveness (OEE), autonomous maintenance.

****Total Quality Management (TQM)*** – An approach for improving quality that involves all areas of an organization, sales, engineering, manufacturing, purchasing, etc. with a focus on employee participation and customer satisfaction. TQM can involve a wide variety of quality control and improvement tools. TQM pioneers such as Juran, Deming, and Crosby emphasized a combination of managerial principles and statistical tools. See SPC, Zero Defects, inspection.

T-Plant – One of the "VAT" classifications of manufacturing firms. The letter "T" describes the bill of material for a "T-plant." In a T-Plant, the product is assembled using standard parts up to a certain point (many parts are common to many end items). Beginning at the bottom of the "T," the basic parts and components that are common to all products are produced. When the basic parts and components reach the intersection of the crossbar, assembly takes place, combining these common parts into many different options to make the end product. Often the components for the lower part of the "T" are built to inventory and are "mixed and matched" in a wide variety of ways for a customer order. An example is appliances ("white goods") that have many standard inputs but can result in a large variety of end items. We master schedule this plant at the finished components level. (The term "T-plant" is probably not the best term. This is more of a description of the bill-of-material than it is of the plant itself.)

traceability – The identification of items and products that enables firms to track the batch number and the source of supply for every item. Lot traceability is required for nearly all medical products.

tracking signal – An exception report given when the forecast error has a consistent bias, e.g., consistently positive or negative. The exception report signals the manager or analyst to intervene to change the parameters in the forecasting model. The simplest form of a tracking signal is to accumulate the forecast error over time with the recursive equation $R_t = R_{t-1} + E_t$, where R_t is the running sum of the errors and E_t is the forecast error in period t. (Note that the running sum of the errors is a measure of the bias.) An exception report is generated when R_t gets "large." In order to evaluate if the forecast bias is large, we divide by the average absolute error, known as the *MAD* (mean absolute deviation). The *MAD* is defined as $MAD = \sum_{t=1}^{t=T} \left| E_t \right| / T$, assuming that we have T periods of history. A more computationally efficient approach to serve this purpose is to use the smoothed mean absolute error, which is defined as $SMAD_t = (1-\alpha)SMAD_t + \alpha|E_t|$. A similar approach is to use the smoothed error instead of the running sum of the error. The smoothed error is defined as $SE_t = (1-\alpha)SE_t + \alpha E_t$. In summary, the tracking signal is a measure of the forecast bias relative to the average absolute size of the forecast error and is defined by either $TS_1 = SE_t / SMAD_t$ or $TS_2 = R_t / SMAD_t$. Some authors replace the $SMAD_t$ with the square root of the smoothed mean squared error, where the smoothed mean squared error is defined as $SMSE_t = (1-\alpha)SMSE_t + \alpha E_t^2$. This gives us tracking signals $TS_1 = SE_t / \sqrt{SMSE_t}$ or $TS_2 = R_t / \sqrt{SMSE_t}$. It is not clear which method is best.

transaction cost – The cost of processing one transaction. In a supply chain management context, this is the cost of processing one purchase order. See switching cost.

transfer batch – When a batch is produced on one machine, smaller batches can be moved (transferred) to the following machine. The smaller batch sizes are called transfer batches. This concept has been promoted in the "Theory of Constraints" literature.

traveling salesperson problem (TSP) – This is the problem of finding the minimum cost (distance or travel time) sequence for a single vehicle to visit a set of *N* cities (nodes, locations), visiting each city exactly once, and returning to the starting point. The computing time required to find the proven mathematically optimal solution for this problem increases dramatically as the *N* increases. (The problem is said to be "NP-hard.") The problem used to be called the "Traveling Salesman Problem." Extensions of the problem include the multiple vehicle problem (the m-TSP) and the Vehicle Scheduling Problem (VSP). The VSP can involve multiple vehicles, time window constraints on visiting each node, capacity constraints on each vehicles, total distance and time constraints for each vehicle, and demand requirements for each node. Both the TSP and VSP are important in logistics operations. The same problem occurs in other problem contexts. For example, the problem of finding the optimal sequence of jobs for a machine with sequence-dependent setups is a TSP. Some printed circuit board design problems can also be formulated as a TSP. (See sequence-dependent setup cost.)

triage **–** (1) A process for sorting injured people into groups based on their need for or likely benefit from immediate medical treatment. Triage is used on the battlefield, at disaster sites, and in hospital emergency rooms when limited medical resources must be allocated. (2) A system used to allocate a scarce commodity, such as food, only to those capable of deriving the greatest benefit from it. [French, from *trier*, to sort, from Old French.] (Source: American Heritage Dictionary, 1993).

In a battlefield context, triage means to sort (or prioritize) the wounded into groups, such as send them back into battle, put them to sleep and let them die, or send them to surgery right away. In a service quality context, it means to place a resource (a person, computer, or phone system) at the beginning of the process. This resource "triages" incoming customers and directs them to the right sub-process. The advantages of triage include (1) it protects valuable resources from being wasted on less important tasks, and (2) it helps gets customers to the right service. For example, a clinic should not have its best doctor seeing patients with minor problems. Therefore, the clinic should have a "triage nurse" directing patients to the right medical professional. Patients with minor problems should see a nurse or physician's assistant; patients with major non-urgent problems should be scheduled to see a doctor at a later date; patients with major urgent problems should see a doctor right away. With a good triage system, a patient will be quickly directed to the proper level for the proper medical help.

trend (for forecasting) – The average rate of increase for the demand. This will be the slope of a demand. One simple way to estimate this is with simple linear regression.

two-bin system – A two-bin inventory system is a very simple visual "reorder point" system with the main bin used for normal inventory. The reserve bin is only opened when the main bin is empty. When the reserve bin (the reorder point) is opened, an order is placed. It is a good idea to put a lock on the reserve bin in order to make sure that the ordering discipline is enforced.

unit of measure – The standard unit of an item used in the stock account and to construct order quantities.

utilization – The percent of the possible work time that a resource is busy. Utilization is often a bad goal. See capacity.

value chain **–** Michael Porter noted that firms create value for customers by designing, producing, marketing, delivering and supporting products. Porter labeled this series of activities the "value chain." The chain consists of primary activities that create value for customers plus related support activities, such as human resources development, accounting, and MIS. The concept was first communicated in Porter's text (Porter, Michael E., ***Competitive Advantage***, London, Free Press, 1985.) Many authors now use the terms "value chain" and "supply chain" almost interchangeably. However, most scholars make a distinction between the terms. The value chain takes a business strategy point of view, considers product design and after sales service, and emphasizes assignment of activities to firms based on core competencies. In contrast, supply chain management usually takes a materials flow point of view and emphasizes suppliers, inventories, information flow, and pricing. See supply chain management, bullwhip effect.

value engineering **–** The systematic application of recognized techniques by a multi-disciplined team to identify the function of a product or service, establish a worth for that function, generate alternatives through the use of creative thinking, and provide the needed functions to accomplish the original purpose of the project, reliably, and at the lowest life-cycle cost without sacrificing safety, necessary quality, and environmental attributes of the project.

Engineering with the purpose of simplifying products and processes by achieving equivalent or better performance at a lower cost. An approach of redesigning parts to try to get the same function at less cost.

value proposition – This how you have positioned your product in the market. For example, if you are offering a very low priced product that has few features, then your firm is trying to "proposition" your customers based on price and not on features.

****Vendor Managed Inventory (VMI) –*** In the VMI process, the vendor assumes responsibility for managing the replenishment of stock. Rather than a customer submitting orders, the vendor will replenish stock as needed. This is sometimes referred to as supplier-managed inventory (SMI) or co-managed inventory.
(Source: http://gartner4.gartnerweb.com/public/static/hotc/hc00088697.html, updated October 27, 2000)
Our suppliers not only supply us goods – but they also manage our inventory so that we can both benefit. VMI is not a new concept – 18-th century examples can be found from grocery stores and replenishing home heating oil and coal.

Advantages include:
- Retail sales up – reduces stockouts in stores.
- Supplier sales up – preferred trading relationship.
- Inventory carrying cost down – shorter cycle times less inventory.
- Transaction costs down – less ordering cost.
- Manufacturing costs down – more timely sales information, better priorities, less coordination cost.

Disadvantages include:
- Increases vendor's administrative costs.
- Hard to use with volume discounts & special pricing.
- Complicates system in the short run.
- Risk of loss of control and flexibility.
- The manufacturer takes a one-time volume reduction.

Professor Hill has a technical note on this subject. See JIT II.

****vertical integration*** – When a firm owns its sources of supply and/or its channel of distribution, it is said to be "vertically integrated."

virtual organization – When a firm is able to quickly put together business partners to satisfy a customer order, launch a new product, and/or supply product to a market without owning the key elements of the system, then this organization is said to be a virtual organization. Virtual organizations have significant flexibility benefits, but given the tenuous nature of the relationships they may not be sustainable.

V-plant – In this type of manufacturing process, we have very few inputs that are transformed into a variety of components, which in turn are transformed into a very large variety of end items. We master schedule this plant at the raw materials level. (The term "V-plant" is probably not the best term. This is more of a description of the bill-of-material than it is of the plant.)

voice of the customer (VOC) – Getting information from customers about their perspective on a product or process design issue.

Wagner-Whitin lotsizing algorithm – A dynamic programming algorithm for solving the time-varying demand lotsizing problem. See time-varying demand lotsizing problem. A good implementation of this algorithm (including the pseudocode) can be found in Evans, James R., "An Efficient Implementation of the Wagner-Whitin Algorithm for Dynamic Lot-Sizing," ***Journal of Operations Management***, Vol. 5, No. 2, pp. 229-235, 1985. An Excel workbook called lotsize.xls to implement this code is available from Professor Hill. See lotsizing methods, time-varying demand lotsizing problem.

Warehouse Management System (WMS) – A software application that manages the operations of a warehouse or distribution center. Application functionality includes receiving, putaway, inventory management, cycle counting, task interleaving, wave planning, order allocation, order picking, replenishment, packing, shipping, labor management and automated material-handling equipment interfaces. Some systems use bar codes and/or radio frequency technology to provide accurate information in real time.
(Source: http://gartner4.gartnerweb.com/public/static/hotc/hc00088697.html, updated October 27, 2000)

waterfall – This term is used in project management and new product development to suggest that a set of steps is not started until the previous set of steps is complete. The opposite of this is concurrent engineering. See project management, concurrent engineering.

work breakdown structure (WBS) – In project management, the work breakdown structure defines the hierarchy of project activities (tasks) needed to complete the project. The WBS is like a "bill of material" for the project and is often drawn like the roots of a tree. The WBS does not communicate the precedence relationships between tasks – it only defines the logical organization of the tasks. For example, the top level of the WBS for a wedding might include (a) wedding dress, (b) tuxes, (c) church, (d) reception, and (e) honeymoon. The WBS is a useful way for (a) identifying all of tasks needed for a project, (b) breaking down large tasks into more manageable ones, and (c) organizing and communicating the list of tasks required. This author heard a senior U.S. Air Force officer state that the policy of the USAF is to define its WBS so that all tasks require no more than one week of work. See project management, CPM, PERT, slack time.

****work in process inventory (WIP)*** – Inventory that is currently being worked on in the factory. This includes orders in queue, orders waiting for a setup, and orders currently being run.

workforce agility -- The main motives for pursuing workforce agility can be classified as follows:

(1) *Improved efficiency:* Deadlines may be met with greater accuracy, cycle times are reduced, and a desired throughput is achieved with less WIP because idle time in the production line is decreased.
(2) *Enhanced flexibility:* Overtime costs and productivity losses due to absenteeism and turnover may be significantly reduced because cross-trained workers can absorb some or all of the work of absent workers. Furthermore, shifts in the production environment over time can be adapted to more quickly.
(3) *Increased quality:* Workers' overall knowledge of the system increases, which enables them to spot and fix quality problems and to pursue both incremental and innovative improvement.
(4) *Improved culture:* The working environment may be improved due to increased job satisfaction, worker motivation, and reduced ergonomic stress.
Source: Hopp, W.J. and M.P. Van Oyen, 2001. "Agile workforce evaluation: A framework for cross-training and coordination." ***Proceedings 2001 NSF Design and Manufacturing Grantees Conference.*** Tampa Florida.

x-bar chart – A quality control chart that monitors the mean of the process. A sample of *n* parts is collected from the process every so many parts or time periods. The mean of the sample is plotted on the control chart and a determination is made if the process is "under control" or not.

XML (eXtensible Markup Language) **–** A robust and flexible next generation alternative to EDI.

****yield*** – The percent of product produced that is not defective. This can be used as a performance measure or for a planning factor used to inflate the required production start quantity.

****yield management*** – For many capital-intensive businesses such as airlines, theaters, stadiums, and utilities, the goal is to maximize revenue because nearly all costs are fixed. Yield management is an approach to maximizing revenue given that the capacity-related costs are relatively fixed. Yield management systems change prices and capacity allocations over time as the date of the event approaches. For example, it is said that airlines change their prices 60,000 per day. Note that the goal is not to maximize utilization (although that is usually the result); the goal is to maximize revenue per unit of resource ($/room night, $/seat mile, etc.). This is sometimes also called "revenue management" or "perishable asset resource management."

Zero Defects (ZD) **–** A concept introduced by Japanese manufacturers that stresses elimination of all defects. This contrasts to the traditional American approach promoted by American military standards such as Mil Standard 105D that allowed for a certain percentage of defects, known as an "Acceptable Quality Level" or AQL.

Zero Inventory – This is a name used by some (such as Bob Hall) to describe a JIT inventory system. See JIT.

Links and references:

- On line encyclopedia of technical terms: http://whatis.techtarget.com/
- On line glossary of manufacturing terms: http://www.successfulleanmanufacturing.com/Glossary.htm
- On line Japanese KAIZEN/CI Terminology: http://www.fredharriman.com/services/glossary/vocab01e.html
- The ***APICS Dictionary*** defines many manufacturing terms. APICS members receive one copy of the dictionary as a member benefit. 102 pp./1998 APICS Stock #01102, $15.00 nonmember -- $10.00 APICS member. See www.apics.org.
- ***Industrial Engineering Terminology*** (2000), an official standard of the American National Standards Institute, defines and indexes technical terminology in 17 subject areas related to Industrial Engineering. The 12,000+ definitions can be found in the comprehensive index of each term including cross-references to related terminology or within each of the following sections: Analytical Techniques & Operations Research; Anthropometry & Biomechanics; Computer & Information Systems; Cost Engineering & Project Management; Distribution & Marketing; Employee & Industrial Relations; Engineering Economy; Facility Planning & Design; Human Factors (Ergonomics) Engineering; Management; Manufacturing Systems; Materials Processing; Occupational Health & Safety; Organization Planning and Theory; Quality Assurance and Reliability; Work Design and Measurement. Prices: IIE Member $110.00, Non-Member $135.00, 662 Pages; Hardcover; 2001, ISBN: 0-89806-205-5. See http://www.acob.com/t_bookstore.mv?IIE.

This document is a group effort intended to benefit the entire POMS community. Please send corrections and additions to Professor Art Hill at ahill@umn.edu. The author thanks Mr. Ron Pergande (CEMBA 2001), Mr. Eishi Kimijima (Carlson MBA 2002), Mr. Rick Christensen (MOT 2002), many other University of Minnesota students and IMD-International MBA students for their contributions to this document.