The Encyclopedia of Operations Management Terms

by

Professor Arthur V. Hill

Curtis L. Carlson School of Management
321-19th Avenue South
University of Minnesota
Minneapolis, MN 55455-0413 USA

ahill@umn.edu

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P O M S
Production Operations Management Society

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The encyclopedia includes definitions 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.

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

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The Encyclopedia of Operations Management Terms
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The Encyclopedia of Operations Management Terms

5S concept – See the "Five S" concept.

ABC classification – A method for prioritizing items in an inventory system, where the "A" items are considered to be more important. This is an application of Pareto's Law. The ABC classification is usually implemented based on the annual dollar volume, which is the product of the annual unit sales and unit cost. In accounting, this is just the annual cost of goods sold for the item.

Higher dollar volume items should be ordered more often. (This can be proven using the economic model behind the economic order quantity – the EOQ.) This means that high dollar volume items will likely have a higher transaction volume, which means that they are more likely to have data integrity issues.

The high "annual dollar volume" items are classified as "A" items. 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.

In order to classify items, we create a ranked list of items by cost of goods sold (annual dollar volume). We then take the top 20% of these items and label them "A" items. The next 30% of the items in the list are labeled "B" items, and the remaining 50% are be labeled "C" items. Of course, these percentages can vary depending upon the needs of the firm.

Some firms use other methods for defining the ABC classification. For example, some firms use the stockout cost such as the medical criticality of the item to define the classification.

Note that the ABC inventory classification has nothing to do with Activity Based Costing.

Revised November 29, 2004. See Activity Based Costing, Economic Order Quantity, and Pareto's Law.

Acceptable Quality Level (AQL) – When deciding whether or not to accept a batch, a sample of *n* parts is taken from the batch and an decision is made to accept the batch if the percent of defects is less than the AQL. (Thanks to Professor Douglas N. Hales at Clemson University for helpful edits on this entry.) See acceptance sampling.

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 Costing (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 organize a large number of ideas, process variables, concepts, and opinions into naturally related groups to make sense of a complex problem. 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?"

Affinity diagrams or charts are a simple way for a group to cluster qualitative data and come up with a consensus view on a subject. It is often used with QFD to sort and organize the large amount of customer needs data. In this instance, statements of customer needs are written on cards or post-its. The group organizes the cards or post-its and then develops headings under which to cluster these needs. The cards or post-its are moved to the appropriate group headings. (Source: http://npd-solutions.com/glossary.html)

An affinity diagram is used for:

1. Adding structure to a large or complicated issue. For example, "What are the issues relative to implementing a thematic approach to teaching?" or "What are the central issues in the development of a particular new product?"
2. Breaking down a complicated issue into broad categories. For example, "Which departments are more likely to implement TQM in this school?" or "What are the major steps in the completion of a complex project?"
3. Gaining agreement on an issue or situation. For example, "Which direction should the school take to restructure its curriculum?" or "How should a new product be marketed?"

Steps in constructing an affinity diagram:

1. State the issue or problem to be explored. Start with a clear statement of the problem or goal and provide a time limit for the session-usually 45-60 minutes is sufficient.
2. Brainstorm ideas for the issue or problem. Each participant should think of ideas and write them individually on index cards, sticky notes, or have a recorder write them on a flip chart.
3. Collect the cards or sticky notes, mix them up, and spread them out (or stick them) on a flat surface (e.g. desk or wall). Index cards can easily be secured to a wall with a putty-type adhesive.
4. Arrange the cards or sticky notes into related groups. For approximately 15 minutes allow participants to pick out cards that list related ideas and set them aside until all cards are grouped.
5. Create a title or heading for each grouping that best describes the theme of each group of cards.

Source: Adapted from www.isixsigma.com, February 28, 2004.

See cause and effect diagrams, nominal group technique.

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. See carrying charge, carrying cost, MRP.

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. Sometime called a "life-time" buy.

all-time demand – The total future requirements (demand) 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 (demand).

Many empirical studies have found that end-of-life demand often follows a geometric decay pattern. The geometric series suggests that the demand in any period is a constant times the demand in the previous period $d_t = \beta d_{t-1}$. The demand *T* periods after period *t* is given by $d_{t+T} = \beta^T d_t$. The cumulative demand through *T* periods, therefore, is the sum of a finite geometric series and is given by: $D = \sum_{t=1}^{T} F_t = \sum_{t=1}^{T} \beta d_{t-1} = d_0 \beta(\beta^T - 1)/(\beta - 1)$. The cumulative demand for "all time" ($T = \infty$) is given by $D = d_0 \beta/(1-\beta)$. A technical note and a companion Excel workbook on forecasting lifetime demand are available from Professor Hill. Revised November 7, 2004. See all-time order.

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. Sometimes called committed inventory.

***Analytical Hierarch Process (AHP)* –** AHP is a methodology for (1) breaking down a complex, unstructured situation into its component parts and then arranging those into a hierarchy order, (2) assigning numerical values to subjective judgments on the relative importance of each component, and (3) synthesizing in pairwise the judgment to find out which component has the highest priority.

Without the AHP methodology, decision-makers easily fall into a trap. The most obvious case is about assigning direct numbers to represent a judgmental scale in order to pick up the best alternative. For example, there are 3 scales: 1, 3, 5 whereas 1=low, 3=medium, and 5=high. At the first glance, these scales should be correct because there is two units increase in each step. However, in a relative term, it is absolutely wrong and biased. In other words, moving from 1 to 3 is an increase of 200% [(3-1)/2] and from 3 to 5 yields only about a change of 67% [(5-3)/3]. This is a trap! Most people are fond of thinking in an absolute rather than relative terms. This problem can be seen in many places, particularly in the stock market where the level of competition is extremely high. Decision traps can be of many forms.

Decision makers can deal with decision traps in two ways. The first way is to ignore things coming from their memories to anchor their judgment. The second way is to make a comparison of all separated but interconnected components in a pairwise manner. Dr. Thomas L. Saaty had experienced this human decision problem and, thus creating the AHP methodology during 1970s to solve it. Until now, many academicians worldwide have used this methodology in supporting their decisions and researches extensively.

However, the AHP methodology alone is not capable of eliminating all decision traps. In reality, decision-makers must be aware of the traps and do not allow them to occur during the judgmental process by continuously strengthening their moral behavior, using innovative tools to increase feedback and sharing values with other people, and being agile to move forward for the better society, not being status quo or pessimistic.

See cause and effect diagram. (Adapted from meritdecision.com/ahp.htm, January 16, 2004)

andon – (pronounced Ann Don) A Japanese term that refers to a warning light on a machine or assembly line that calls attention to defects or equipment problems. The number of lights and their possible colors can vary, even by work center within a plant. Most implementations have three colors – green, yellow, and red. Like a stoplight, the green means normal, the yellow means trouble, and the red means stop. Another source (www.kbe.cov.ac.uk/EMDATA/5Bjapmfg.html, November 8, 2004) recommended the following colors:

- Red = Machine breakdown.
- Blue = Defective component.
- White = End of production batch.
- Yellow = Waiting for set-up.
- Green = Material shortage.
- No light = System operating normally

When a red light goes on, the assembly line is usually stopped until the problem is diagnosed and corrected. It is important to for management to define exactly who is responsible as the support person. Obviously, the big idea here is to have a very simple visual system that calls for the right kind of help from the right people when needed.

The Revised November 8, 2004. See error-proof device, Jidoka, lean manufacturing.

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).

appraisal cost – The expenses associated with measuring quality through inspection and testing. Many popular quality consultants argue that appraisal costs should be eliminated and that firms should not try to "inspect quality into the product," but should instead "design quality into the product and process." See cost of quality. Updated April 20, 2004.

****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 respond-to-order, make-to-stock.

attribute **–** A term used by quality professionals that deals with a binomial state of being, such as conforming to specification or not.

autonomation **–** Stopping a line automatically when a defective part is detected. See Jidoka, Toyota Production System.

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)

***avoidable costs* –**Avoidable costs include any expense that is not incurred if a new investment is made that would make the expense unnecessary. For example, if a conveyor belt is broken and must be fixed to operate the facility, there is a cost to fix the conveyor as well as the option to purchase a new on. If a new conveyor is purchased, there is no need for the repair expense and hence, it was avoided.

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 cost and number of inventory transactions by relieving (reducing) the inventory count for an item only when the order is complete (or shipped). For example, a computer keyboard manufacturer has two alternatives for keeping track of the number of letter "A"s that are stored in inventory. Alternative 1: The firm could count the number of keys that are issued to assembly. This can be quite costly. In fact, it is possible the cost of counting the inventory could even exceed the value of the inventory. Alternative 2 (Backflushing): The firm could reduce the letter "A" inventory count when an order is complete (or shipped). The bill of material for a keyboard calls for one letter "A" to be attached to each keyboard; if we ship 100 keyboards, we have probably also shipped 100 letter "A"s. Backflushing gives us an imprecise inventory count because of the delay, but it can reduce the shop-floor data transaction cost significantly.

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 tool 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)

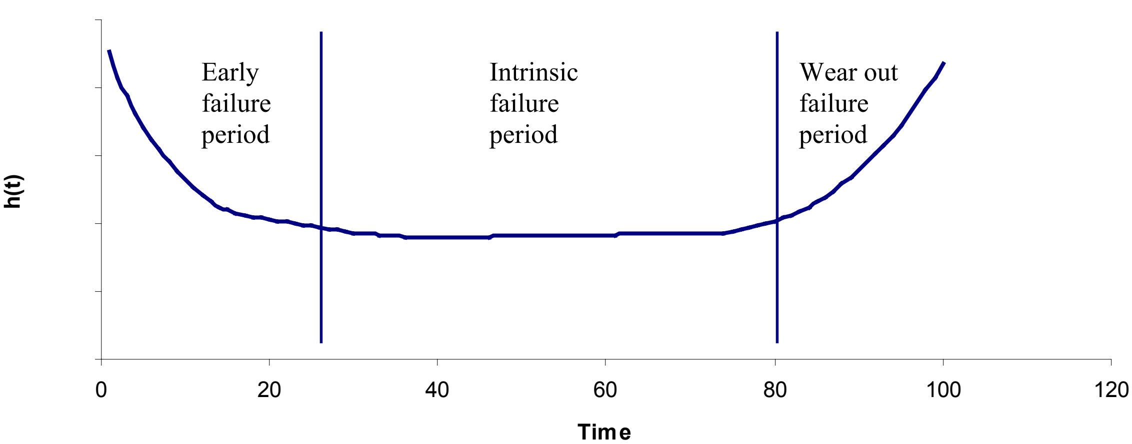
A balanced scorecard is a framework that translates a company's vision and strategy into a coherent set of performance measures. Developed by Robert Kaplan and David Norton (published in the ***Harvard Business Review*** in 1993), a balanced business scorecard helps businesses evaluate how well they 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 (such as customer satisfaction indices) and leading indicators (such as adoption rates for, or revenue from, new products).

(Source: www.adamssixsigma.com/Glossary_of_terms/six%20sigma%20glossary%20B.htm, 2003.)

Professor Hill has written a 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. The encoded information is a unique serialization that can be correlated with other information from a database. Bar codes are particularly well suited for tracking products through a process.

bathtub curve –Over many years and across a wide variety of mechanical and electronic components and systems, people have observed population failure rates as units age over time. These analyses have repeatedly obtained



a graph known as the "bathtub curve." The bathtub curve is a "U" shaped curve used in reliability theory that shows a typical hazard function with products more likely to fail either early or late in their useful life.

The initial region that begins at time zero when a customer first begins to use the product is characterized by a high but rapidly decreasing failure rate. This region is known as the **Early Failure Period** (also referred to as **Infant Mortality Period**, from the actuarial origins of the first bathtub curve plots). This decreasing failure rate typically lasts several hours to a few months. Next, the failure rate levels off and remains roughly constant for (hopefully) the majority of the useful life of the product. This long period with a level failure rate is known as the **Intrinsic Failure Period** (also called the **Stable Failure Period**) and the constant failure rate level is called the **Intrinsic Failure Rate**. Note that most systems spend most of their lifetime operating in this flat portion of the bathtub curve. Finally, if units from the population remain in use long enough, the failure rate begins to increase as materials wear out and degradation failures occur at an increasing rate. This is the **Wear Out Failure Period**. For example, when you buy a light bulb, it sometimes fails when you first install it (or very shortly thereafter). However, if it survives the first few hours, it is likely to last for many months until it fails. Another example is human life. (Please forgive the morbid example, but it makes the point very clear). The death rate of infants is high but the infant makes it though the first couple of weeks, the mortality rate does not increase until old age. Note that the bathtub curve also applies to repairable systems where the vertical axis is the Repair Rate or the Rate of Occurrence of Failures (ROCOF). Adapted from http://www.itl.nist.gov/div898/handbook/apr/section1/apr124.htm

***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** – The "best practices" for a process is the best known approach for designing and managing the process. The term is often 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 and nearly all of them 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 closed related to benchmarking. Revised November 7, 2004. See benchmarking.

Bill of Lading (BOL) – Bill of Lading. A document used to acknowledge the receipt of products. Shipper's form listing number of pieces shipped, weight and freight classification. Often used as a receiving document.

***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.

blackbelt – See Six Sigma.

***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. Another type of blanket P.O. does not specify the parts or the price. Purchasing issues a blanket P.O. for a "not to exceed value." Any company representative that knows the P.O. number can purchase items until the value of the P.O. is exceeded.

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 overproducing – producing before the output is needed. Blocking avoids "over-production" and keeps the total work-in-process inventory down to a reasonable level. Blocking for a bottleneck process is bad because it causes the system to lose valuable capacity. (Remember that an hour lost on the bottleneck is an hour lost for the entire system.) See JIT, kanban, CONWIP, theory of constraints.

bottleneck – A bottleneck is any constraint in the system the holds the organization back from greater achievement of its goals. In a system, a bottleneck is any resource that has capacity less than the demand placed on it. Goldratt expands this definition to include any philosophy, assumptions, mindsets, etc. that limit a system from performing better. Note that sometimes the market is the bottleneck. When this is true the system can often become more flexible to the market's needs so that the firm can better achieve its goal of making more money. See Herbie, Theory of Constraints.

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.

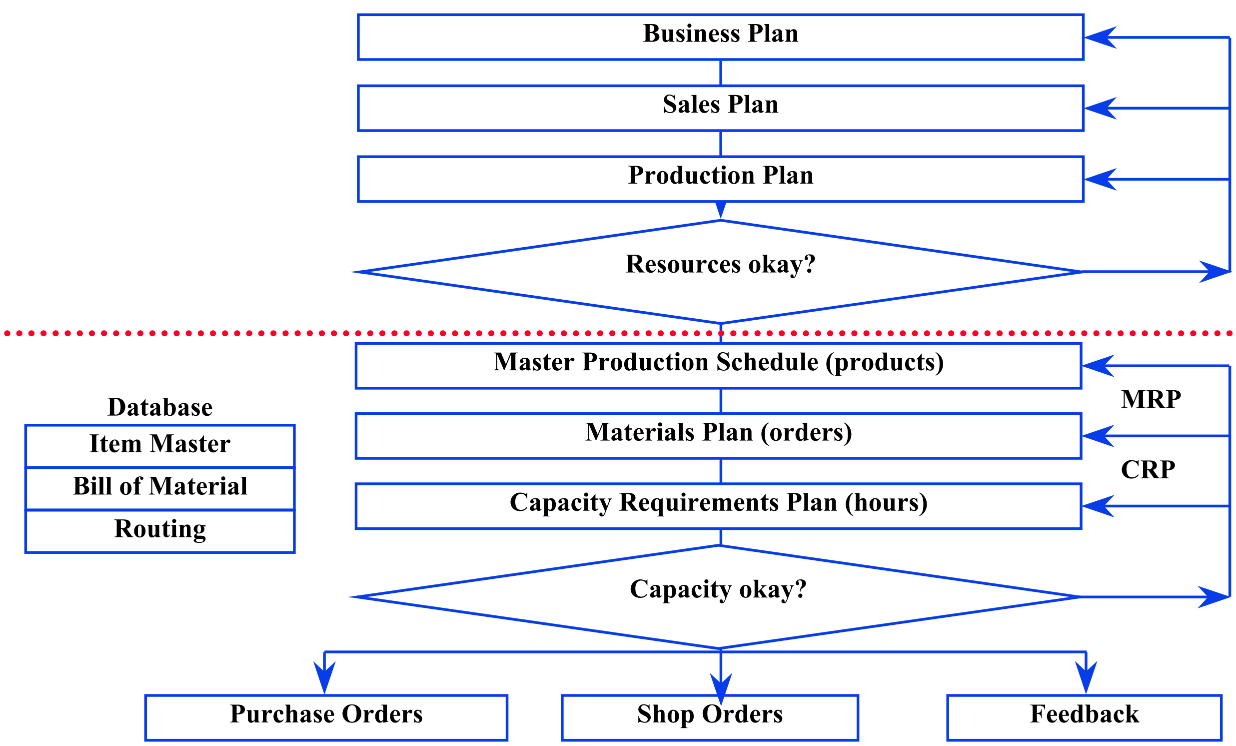
Price fluctuation. Frequent price changes--both up and down--lead buyers to purchase large quantities when prices are low, and avoid buying when prices are high. A common practice in the grocery industry, this forward buying creates havoc upstream in the supply chain. The answer here is for sellers to 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.

See leadtime syndrome, supply chain management.

***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). Professor Hill's "Process Improvement Checklist" includes a large number of ideas for how to improve a process. See error-proofing, job enlargement, job enrichment, work simplification, and work standardization.

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 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 few 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. The BRP model is below. See aggregate production planning, master scheduling. (Thanks to Professor Douglas N. Hales at Clemson University for helpful edits on this entry.)



c-charts – A quality control chart used to display and monitor the number of defects per sample in a production process. See control charts, SPC.

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.

Capability Maturity Model (CMM) – Many CMM models have been developed for software acquisition, people issues, project management, new product development, supply chain management, etc. This discussion focuses on the Capability Maturity Model for Software (SW-CMM). The CMM for Software is one of the best-known products of the Carnegie Mellon University Software Engineering Institute (SEI). CMM is based heavily on the work of Watts S. Humphries as described in his book ***Managing the Software Process***. The actual development of the CMM was done by the SEI at Carnegie Mellon University and the Mitre Corporation in response to a request to provide the federal government with a method for assessing the capability of its software contractors. In a nutshell, the SW-CMM is a model that documents and organizes software engineering practices that exist in organizations. It provides a framework for organizing evolutionary steps into five maturity levels that lay successive foundations for continuous process improvement. Each maturity level comprises a set of process goals that, when satisfied, stabilize an important component of the software process. The five levels are:

Initial – The software process is characterized as ad hoc, and occasionally even chaotic. Few processes are defined, and success depends on individual effort and heroics.

Repeatable – Basic project management processes are established to track cost, schedule, and functionality. The necessary process discipline is in place to repeat earlier successes on projects with similar applications.

Defined – The software process for both management and engineering activities is documented, standardized, and integrated into a standard software process for the organization. All projects use an approved, tailored version of the organization's standard software process for developing and maintaining software.

Managed – Detailed measures of the software process and products quality are collected. Both the software process and products are quantitatively understood and controlled.

Optimizing – Continuous process improvement is enabled by quantitative feedback from the process and from piloting innovative ideas and technologies.

(Contributed by Venk Reddy and Brian Dye, MOT 2004)

****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. Revised October 25, 2004.

See Little's Law, queuing theory, safety capacity.

***carrying charge** – A parameter used to estimate the cost of holding one dollar of inventory for one year. This parameter is used to help inventory managers make economic tradeoffs between inventory levels, order sizes, and other inventory control variables. The carrying charge is usually expressed as the cost of carrying one dollar of inventory for one year, and therefore, has a unit of measure of $/$/year. Reasonable values are in the range of 15-40%. The carrying charge is the sum of three factors: (1) the marginal cost of capital or the weighted average cost of capital (WACC), (2) a risk premium for obsolete inventory, and (3) a storage and administration cost. 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 (orders, receipts, etc). When deciding if a particular cost driver should be included in the carrying charge, ask the question, "how will this be effected if we double (or half) the inventory?" If the answer is "not at all," then that cost driver is probably not relevant. It is hard to make a precise estimate for the carrying charge. Many firms erroneously set this to the WACC, and therefore, dramatically underestimate the cost of carrying inventory. Professor Hill has written a technical note on this subject. Revised June 18, 2004. See carrying cost, setup cost.

***carrying cost** – The carrying cost is the average inventory investment times the carrying charge. For example, if the annual carrying charge is 25% and the average inventory is $100,000, the carrying cost is $25,000 per year. Many firms incorrectly use the end of year inventory in this calculation. This is fine if the end of year inventory is close to the average inventory over the year. However, it is quite common for firms to have a "hockey stick" sales and shipment pattern where the end of year inventory is significantly less than the average inventory during the year. Technically, this type of average is called a "time-integrated average" and can be estimated fairly accurately by averaging a number of points (say 12) during year. Revised June 19, 2004.
See carrying charge, hockey stick.

causal map – See cause and effect diagram, impact wheel.

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 and effect diagram (Ishikawa diagram, fishbone diagram, C&E diagram)** – A graphical tool often used as a brainstorming approach for identifying the root causes of a problem. The diagram illustrates the relationships among the wide variety of possible contributors to the effect. This tool is referred to by many different names including cause-and-effect diagram, C&E diagram, Ishikawa diagram, fishbone diagram, and Root Cause Analysis. The diagram shows the relationships between all major causes of the problem and helps management (1) identify a course of action for how to improve the situation and (2) identify where the system should be monitored and measured on a regular basis.

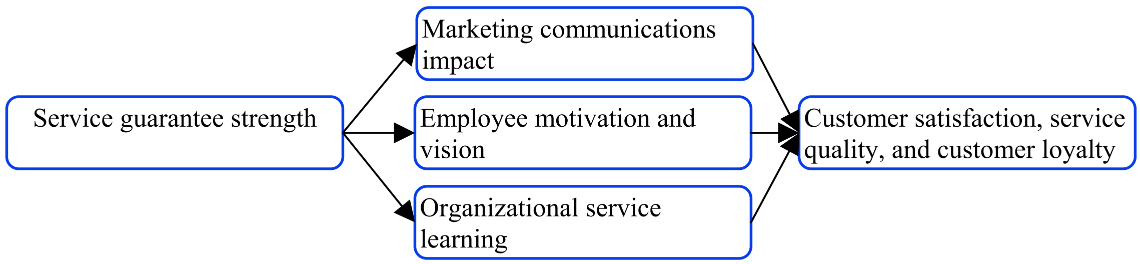
The fishbone diagram was developed Dr. Kaoru Ishikawa (1943-1969) who first used the technique in the 1960s. The basic concept in the fishbone diagram is that the name of a basic problem of interest is entered at the right of the diagram at the "head" of the main "bone." The main possible causes of the problem are drawn as bones off the main backbone. The categories often used as a starting point include materials, machines (equipment), manpower (people), methods, environment, and measurement. Other causes can be chosen as needed. 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.

Cause and effect diagrams are more general and generally do not have the fishbone structure. They can take any shape, and therefore are easier to construct. Academics generally put the result on the far right. Goldratt (Theory of Constraints) and Kaplan (Balanced Scorecard, strategy maps) put the result on the top.

With "issue tree" and FMEA analysis, the result is stated on the left and then broken into its root causes on the right. The example below is a causal map from research by Hays and Hill.

Brainstorming is usually used to create the diagram. The team brainstorms to identify the root causes of each node. The process continues until all causes (nodes) and relationships (arcs) have been identified. It is possible (and even likely) that some "loops" will occur in the diagram. A loop occurs when we have a vicious cycle (or in some cases a virtuous cycle). For example, a vicious cycle occurs when an alcoholic drinks and they are criticized by their family, which may, in turn, cause them to drink even more, be criticized further, etc. A virtuous cycle is similar except that the result is a positive instead of negative. See nominal group technique.

Software tools are available to help brainstorm and document the cause and effect diagrams (cf., www.skymark.com/pathmaker/tour/cause.asp and decision explorer).



See affinity diagram, FMEA, impact wheel, Pareto analysis, nominal group technique, and strategy maps.

cellular manufacturing – 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.

Rajan Suri states that the "ideal cell really should complete a sequence of operations that were traditionally completed in separate functional units. It is really important also that the people – the human recourses – in the cell have training on more than one of the operations in the cell. Ideally, of course, they would be able to do all of them, but that might be too much. They should at least have the ability to do two or three of the operations in the cell. Finally, it's really important that the team in the cell be a team-based organization and that it has ownership of everything that goes on in the cell. This includes deciding how to achieve performance goals." (Source: http://wiscinfo.doit.wisc.edu/erdman/pdf/News%20Summer2001.pdf, November 29, 2003).

In many factories, jobs go through many workcenters, where each workcenter has a single type of machine (e.g., drill presses). Then someone notices that many jobs (parts) require the same sequence of machines. From that they create a "cell" with these machines in the right sequence. At the same time, they create a "family" of parts that require this set of operations. The advantages of a cell include: reduced travel time, reduced setup time, reduced queue time, reduced work-in-process inventory, reduced materials handling cost, quicker detection of defects, simpler scheduling, better morale, easier training, etc. When many firms create a cell, they also implement self-managed work team and cross-training concepts to run the cell. While this is not necessary to have a cell, it is often a good approach. The main disadvantage of a cell is that if the machines dedicated to a cell may not have sufficient utilization to justify the capital expense. Cellular manufacturing is very difficult to implement if you have very expensive large machines. You just cannot go out and buy a bunch of "extra" $20 million machines so that each cell can have one.

This is good book on the subject written by some friends of mine:

Hyer, Nancy and Urban Wemmerlov, ***Reorganizing the Factory: Competing Through Cellular Manufacturing***, Productivity Press, 2002.

Professors Hyer and Wemmerlov have also written an article on the application of cellular thinking to administrative work: Hyer, Nancy Lea, and Urban Wemmerlov, "The Office that Lean Built," ***IIE Solutions***, October 2002, pp. 27-43.

center-of-gravity method for facility location **–** This is a method for locating facilities on an x-y coordinate system in order to attempt to minimize the weighted travel distances. This is called the "infinite set" facility location problem because the "depot" can be located at any point on the x-y coordinate axis. The model treats the *x* and

y dimensions independently and finds the first moment in each dimension. The location for the depot to serve the N markets with demand Q_i is $x_0=\Sigma Q_i x_i / \Sigma x_i$ and $y_0=\Sigma Q_i y_i / \Sigma y_i$. This model does not guarantee optimality and can only locate a single depot. The numeric-analytic model does guarantee optimality for a single depot location and can be extended (heuristically) to multiple depots. More information on this model can be found in a white paper and Excel workbook available from Professor Hill.

certification **–** See supplier qualification and 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." Channel partners for a manufacturing firm generally include distributors, sales representatives, logistics firms, transportation firms, and retailers.

****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 almost always the last digit in the number and is computed from the base number, the identifying number without the check digit. By comparing the check digit computed from the base number with the check digit, incorrect identifying 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" operation. See dot-com.

COD **–** Cash on delivery. Indicates payment must be made for goods and transportation charges at the time of delivery. See FOB, terms, waybill. Updated April 20, 2004.

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)

Collaborative Product Development **–** See Early Supplier Development.

****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.

In other words, commonality can lead to economies of scope. A technical note and a companion Excel workbook on this subject are available from Professor Hill. See economies of scope, mass customization.

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 Inspection (CAI) – A system for performing inspection through the use of computer hardware and software technologies. For example, some systems use infrared to detect defects. The most common methods of CAI are either contact methods or non-contact methods. Since contact methods involve touching the surface of a product these methods are undesirable where contamination is a concern. Contact methods are slower and cost less than non-contact methods. Non-contact methods are used for about 40% of CAI in 2003.

Contact methods

Coordinate Measuring Machines (CMMs) use a Computer Numerically Controlled (CNC) mechanical probe to inspect parts to an accuracy of as little as 0.0002 inches. However, the CMM probe may damage or deform a product surface. If you have many sample points or complex product contours, CMMs may be too slow to support the desired product inspection rate.

Non-contact methods

Vision systems: A camera is used to take a video image of a part. The image is processed by software and electronic hardware to compare it against a reference template. The vision system determines the placement, size, and shape of holes and the presence of part features. The snapshot of the image usually requires a strobe or high intensity light to produce an adequate part to background contrast.

Laser-scan micrometers: These systems use reflected laser light to measure part dimensions. These systems are used to inspect single dimensions on highly repetitive work, such as intervals, diameters, widths, heights, and linearity.

(Sources: MOT ‘04 student Mr. Brian Dye, http://www.qualitydigest.com/sept00/html/noncontact.html)

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

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

Computer Numerical Control (CNC) – Computer Numeric Controls is a type of controller that is typically found on machining centers and other machine tools. These controls process part programs in the form of M and G codes that describe tool paths required to machine production parts. Robots that are not machine tools are not considered CNC. Note that no all computer-controlled machines are CNC. Source: MOT ‘04 group Steven Gort, Keith McLaughlin, David Mitchell, Steven Siegel, Steven Smith, and Myra Urness.

concurrent engineering – Concurrent Engineering (CE) is a systematic approach to the integrated, simultaneous 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. Typically, concurrent engineering involves the formation of cross-functional teams. This allows engineers and managers of different disciplines to work together simultaneously in developing product and process designs. (Source: Institute for Defense Analyses, with edits by Professor Art Hill, updated December 18, 2002.) See also QFD, waterfall.

configuration management – Configuration management (CM) is the process of managing products, facilities and processes by managing their requirements, including changes, and assuring conformance in each case. The best CM process is one that can best (1) accommodate change, (2) accommodate the reuse of proven standards and best practices, (3) assure that all requirements remain clear, concise and valid, (4) communicate (1), (2) and (3) promptly and precisely and (5) assure that the results conform in each case. CM includes several elements: requirements management, change management, release management, data management, records management, document control, and library management. CM provides the infrastructure that enables an organization to “change faster and document better.” CM accommodates change and keep requirements clear, concise, valid, and synchronized. A strong CM process is the foundation of a sound business process infrastructure. Source: The Configuration Management Institute (http://www.icmhq.com/).

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. A website for this is: http://www.caenet.com/full_story.php?WID=963. See configure-to-order, mass customization, engineer-to-order.

configure-to-order (CTO) – In a configure-to-order system, a firm sells standard products that require that certain parameters, adjustments, or modules 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. Some people call this re-configure to order. See respond-to-order.

****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 inventory*** – Stock 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. Revised November 7, 2004. See vendor-managed inventory.

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.

consumer's risk – The risk of receiving a shipment of poor quality product and believing that it is good quality.

****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. See c-chart, p-chart, SPC, x-bar chart.

CONWIP **–** An approach for manufacturing planning and control that maintains a "constant WIP" (work in process inventory) in the system. The process is really quite simple. Every time the last step in the process completes one unit, the first step in the process is given permission to start one unit. Obviously, this approach maintains a constant WIP inventory. This is similar to the theory of constraints "drum buffer rope" (DBR) concept, except that CONWIP does not send a signal from the bottleneck, but rather sends the signal from the final step in the process. (See drum-buffer-rope.) This concept is similar to a JIT pull system, except that CONWIP does not need to have buffers (kanbans) between each pair of workcenters. Given that CONWIP does not require the firm to identify the bottleneck and does not need to implement any type of kanban system between workcenters, it is clearly easier to operate than many other systems. CONWIP and can be implemented with a simple visual control system that has the final operation signal the first operation every time a unit is completed. CONWIP can be applied at almost any level – at a machine, a workcenter, a plant, or even an entire supply chain. Some research suggests that CONWIP is superior to both DBR and JIT in terms of system performance (inventory, capacity, etc.). CONWIP was development by Professors Mark Spearman and Wally Hopp. Revised May 18, 2004. See Drum-Buffer-Rope, JIT, pull system, TOC, work-in-process.

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. Three requirements for a valid distinctive competence are:

1. It must be unique and present a barrier to entry for new competitors.
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 that it is possible to have two or more critical paths. Management should focus its attention only on critical path activities and not allow non-critical activities to become critical. The only way to speed up a project is to reduce the task time for activities along the critical path. This is sometimes called "crashing." Crashing non-critical activities will not improve the project completion date. A method for finding the critical path is presented in the discussion of CPM. Note that activities not on the critical path can become critical if they are delayed. This suggests that (1) project managers need to constantly monitor project schedules and (2) risk management (see FMEA) is important to prepare for contingencies. 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 early finish and 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)

From Karen Donohue's notes: Cross-docking refers to the process of using a warehouse facility as a transfer point where large shipments are broken down to the pallet level and consolidated into mixed assortments that are shipped out the same day, usually in full truck loads. Products that are good candidates for crossdocking have high demand, standardized packaging, and no special handling needs (e.g., security or refrigeration).

Customer Relationship Management (CRM) – CRM software manages a number of customer-facing activities including call centers, sales force automation, and direct selling. A good CRM system provide the following benefits:
(a) Collects timely complete information on customers through multiple customer interfaces, including call centers, e-mail, point-of-sale operations, and direct contact with the salesforce.
(b) Reduces the transaction cost for buying products and services.
(c) Provides immediate access to order status.
(d) Provides support that will reduce the costs of using products and services.
(e) Help management develop a deeper understanding of customer buying behavior, "sliced" in a number of ways – geography, demographics, channel, etc.

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. (This is now called takt time.) 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 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. Revised November 26, 2004. See balanced scorecard, inventory turnover, manufacturing leadtime, takt time.

delegation – Delegation is the practice of assigning tasks that you or your organization are now doing to others. Tasks should be assigned to the lowest cost resource, which may be outside of your organization. This is similar to but not identical to the division of labor principle. The division principle first splits a task into two and then delegates. The delegate concept does not require that we split a task. Note that international outsourcing also carries significant risks such as loss of intellectual property, longer cycle times, larger inventories, and others. Good questions to ask to help you decide if you should delegate or not: (a) Do you have time to complete the task? (b) Does this task require your personal supervision and attention? (c) Is your personal skill or expertise required for this task? (d) If you don't do the task yourself, will your reputation, or the reputation of your team, be hurt? (e) Is there anyone on your team with the skill or expertise to complete the task? (f) Is there someone on your team who would benefit from the experience of performing the task? Revised November 7, 2004. See outsourcing, vendor-managed inventories.

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 – The quantity that the market would buy of a product at a particular price. Most firms keep a sales history (which they sometimes called the demand history). This is a censured time series due to the fact that if sales were lost due to lack of inventory, the sales history is less than the demand history. Demand, therefore, is sales plus lost sales. Revised October 25, 2004. See forecasting.

***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 flow – Another word for JIT manufacturing. See JIT, lean manufacturing.

demand management – The practice of affecting demand to better meet the capacity. This can be done through pricing, advertising, promotions, replacing unscheduled arrivals with scheduled arrivals (e.g., appointments), and with customer communications. Many books and articles on demand management also include forecasting tools as a part of demand management. See forecasting.

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 Failure Mode and Effects Analysis (DFMEA) – Revised November 5, 2004. See failure mode and effects analysis (FMEA).

design for assembly (DFA) – Design for manufacturing concepts applied to assembly. See design for manufacturing.

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

This is one of dozens of DFx acronyms. Revised November 29, 2004. See Design for Assembly, design for disassembly, etc.

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

design for quality – See design for manufacturing.

Design for Six Sigma (DFSS) – An extension of the Six Sigma program that drives quality measurement into design. The rational is that it is much easier to design quality into the product than it is to try to fix problems after they occur. Instead of using the Six Sigma DMAIC framework, DFSS uses IDOV (Identify, Design, Optimize, and Validate) or DMADV (Define, Measure, Analyze, Design, and Verify). More detail on DMADV is below:

- Define - Define the project goals and customer (internal and external) deliverables
- Measure - Measure and determine customer needs and specifications
- Analyze - Analyze the process options to meet the customer needs
- Design - Design (detailed) the process to meet the customer needs
- Verify - Verify the design performance and ability to meet customer needs

DMAIC and DMADV have the following in common:

- Six Sigma methodologies used to drive defects to less than 3.4 per million opportunities.
- Data intensive solution approaches. Intuition has no place in Six Sigma -- only cold, hard facts.
- Implemented by Green Belts, Black Belts and Master Black Belts.
- Ways to help meet the business/financial bottom-line numbers.
- Implemented with the support of a champion and process owner.

The DMAIC methodology should be used instead of DMADV when a product or process is in existence but is not meeting customer specification or is not performing adequately. The DMADV methodology should be used instead of the DMAIC methodology when (a) a product or process is not in existence at your company and one needs to be developed, or (b) the existing product or process exists and has been optimized (using either DMAIC or not) and still doesn't meet the level of customer specification or six sigma level. Occasionally a project is scoped as a DMAIC for incremental process improvement when it really required a DMADV methodology improvement.

Revised November 8, 2004. See Six Sigma.

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.

DFSS – See Design for Six Sigma.

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. Revised May 18, 2004. See economies of scale.

***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.

***disruptive technology* –** The term disruptive technology was coined by Professor Clayton M. Christensen at Harvard Business School. He used the term to describe a new, lower performance, but less expensive product. The disruptive technology starts by gaining a foothold in the low-end (and less demanding part) of the market, successively moving up-market through performance improvements, and finally displacing the incumbent's product. By contrast, a sustaining technology provides improved performance and according to Christensen will almost always be incorporated into the incumbent's product. In certain markets, the rate at which products improve exceeds the rate at which customers can learn and adopt the new performance. Therefore, at some point the performance of the product overshoots the needs of certain customer segments. At this point, a disruptive technology may enter the market and provide a product, which has lower performance than the incumbent, but exceeds the requirements of certain segments thereby gaining a foothold in the market. Christensen distinguishes between low-end disruption, which targets customers that have been overshot and new-market disruption, which targets customers that could previously not be served profitably by the incumbent. The disruptive company will naturally aim to improve its margin (from low commodity level) and therefore innovate to capture the next level of customer requirements. The incumbent will not want to engage in a price war with a simpler product with lower production costs and will move up-market and focus on its more attractive customers. After a number of iterations, the incumbent has been squeezed into successively smaller markets and when finally the disruptive technology meets the demands of its last segment the incumbent technology disappears.

Examples of disruptive technologies

Disruptive Technology	**Displaced Technology**
Printing press	Manuscripts, Scriptoria
Railways	Canals
The automobile	Railways
Digital cameras	Photographic film
Mass-market cellular telephony	Fixed-line telephony
Voice over IP	Analog and fixed digital telephone systems
Hydraulic Excavators	Cable operated Excavators
ADSL	ISDN
Internet Protocol suite	Proprietary or fixed-configuration networks
EIDE/UDMA hard drives	SCSI hard drives
Mini steel mills	Vertically integrated steel mills
Minicomputers	Mainframe computers
Personal computers	Minicomputers
Personal video recorders	Video Home System
Desktop publishing	Phototypesetting and manual pasteup
Linux and BSD	Unix
Flash Drives	Floppy disk drives
Container Ships and Containerization	"Break cargo" ships and Stevedores

Not all technologies promoted as disruptive technologies have actually prospered as well as their proponents had hoped. However, some of these technologies have only been around for a few years, and their ultimate fate has not yet been determined. Unresolved examples of technologies promoted as "disruptive technologies" include:

- Music downloads and file sharing versus compact discs

- E-books versus paper books
- E-commerce versus physical shops
- Open-source software versus proprietary software (for example Linux versus Microsoft Windows, although Linux has already largely displaced proprietary Unix)
- Failed technologies originally promoted as "disruptive technologies" include:
- Betamax videotape
- Laserdiscs
- Cold fusion
- Japanese fifth generation computer systems project
- Virtual reality
- 3G
- WebTV
- 8-track_cartridge

Adapted from: http://en.wikipedia.org/wiki/Disruptive_technology, September 25, 2004.

An contrarian's view about disruptive technologies – excerpts from "The Myth of Disruptive Technology" by John C. Dvorak, ***PC Magazine***, August 17, 2004. In the Harvard Business School alumni bulletin highlighting this nonsense, there is a list of supposedly disruptive technologies. Not one is disruptive. At the top of the list are electric cars supplanting gasoline vehicles. On what planet? Internet sales supplanting bookstores. Hmm, Barnes & Noble is packed with people. Restaurants are being affected by the disruptive technology of grocers' takeout. Are you laughing yet? Motorcycles being affected by the disruptive technology of dirt bikes -- does anyone see a pattern here? Is this an April Fools' gag? The closest Christensen comes to a real disruptive technology is digital photography. But it was invented in 1972 and has never been "cheaper" than film. The atom bomb is surely disruptive, but neither cheaper nor inferior. The car replaced the horse, but it costs more, and it became a success because of the invention of pavement and the pneumatic tire; asphalt was never cheaper than or inferior to dirt. There is no such thing as a disruptive technology. There are inventions and new ideas, many of which fail while others succeed. That's it. This concept only services venture capitalists that need a new term for the PowerPoint show to sucker investors. One could almost make an argument for Linux as a disruptive technology. It's free, so that helps. But what is it disrupting? Microsoft? In 1992, when Linux was invented, Microsoft had about $2.2 billion in the bank. Now Microsoft has over $70 billion in the bank and continues to grow. Some disruption. One problem in our society is the increasing popularity of false-premise concepts that are blindly used for decision making. The amount of money squandered during the dot-com era because of "paradigm shifts" and "new economies" is staggering. People actually believed that all retailing would be online and that all groceries would be delivered to the home as they were in the 1920s, despite changes that make delivery impractical. Who cares about reality? We have a disruptive technology at work! The concept of disruptive technology is not the only daft idea floating around to be lapped up obediently by the business community. There are others. But the way these dingbat bromides go unchallenged makes you wonder whether anyone can think independently anymore.

Adapted slighted from: pcmag.com/article2/0,1759,1628049,00.asp, September 25, 2004.

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.

dock-to-stock – The practice of moving receipts from the receiving dock directly to inventory without performing any inspection. This reduces the cost of incoming inspection for the customer. Obviously, it requires that the supplier assure good quality products. Revised October 26, 2004. See supplier qualification and certification.

dot-com – Companies that sell products or services over the Intranet. Dot-com companies do not sell their products or services through brick and mortar channels. Products are typically ordered over the Intranet and shipped from warehouses directly to the customer; services are typically information services that provided through the Intranet. Amazon.com and ebay.com are probably the two most famous of these firms. Many companies have become hybrids of the "brick" and "dot-com" models and are referred to as "bricks and clicks." Many startup firms in the late 1990's selling had "two managers, two computers, and a dream that was too big." Many dot-coms have really struggled with operations – warehousing, forecasting, inventory control, shipping, etc.

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 leadtime, 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.)

The **drum** is the constraint. The un-constrained resources should be scheduled to serve the constrained resource. The **buffer** is a time buffer used to protect the drum from disruptions in the preceding production steps. Disruptions can be caused by breakdowns, longer-than-normal setup times, vendors who do not deliver raw materials on time, and so forth. The **rope** is a schedule that dictates the timing of the release of raw materials or jobs into the system. This schedule is designed to make all the workstations perform at the pace of the drum.

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 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 inventory. Operations managers use this analysis to show that return on investment is sensitive to changes in inventory investment. When inventory is reduced, the numerator (return) increases because when inventory investment goes down, inventory carrying cost also goes down and return (profit) goes up. When inventory is reduced, the numerator (investment) goes down because inventory investment goes down. If we increase the numerator and decrease the denominator of a ratio at the same time, the ratio gets much larger. This analysis usually assumes that revenue is not affected by inventory. This may not be true for a make-to-stock firm unless inventory reduction is managed very carefully. When interest rates (and carrying charges) are low, almost no one is interested in this analysis. 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. The new name for this is Collaborative Product Design. Your suppliers have core competence for their product – or they would not be your supplier. For example, one computer firm bought power supplies from Zytec, 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 report the following benefits: (a) reduced product development time, (b) improved quality and features, (c) reduced product or service costs, and (d) reduced design changes. Companies do best when they gave suppliers the leeway to come up with their own designs rather than simply manufacturing parts to the OEM's specifications. The supplier may have better information or greater expertise regarding these technologies than the buying company design personnel.

e-auction **–** An electronic auction is a web-based tool for making a market more efficient. The best example of an electronic auction is the popular eBay.com. A reverse auction is where the buyer calls for bids for something that it needs to buy. For example, General Electric will notify a group of qualified suppliers that they are invited to participate in an electronic auction. The date and product specifications are defined by the buyer. At the time of the auction, the participating bidders assemble at a common Internet site and bid for contract.

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 $EOQ = \sqrt{2DS/(ic)}$. The *EOQ* model is considered to be of limited practical value for three reasons. First, it is very difficult to estimate the parameters of the model. As a joke, the equation can be rewritten as $EOQ = \sqrt{2\,??/(??)}$. 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 high-volume expensive items should be ordered more often. 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 several 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. Revised October 26, 2004.

economy of scale – A concept from economics where a reduction in cost per unit results from increased production volume, realized through operational efficiencies. Economies of scale can be accomplished because as production increases, the cost of producing each additional unit falls. The increase in efficiency often comes by means of "shared resources" such as shared technologies. Revised May 18, 2004. See commonality, diseconomies of scale, and 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, and economies of scale.

efficiency – Ratio of the standard processing time to the average processing time. For example, if a process has a standard time of 100 minutes per unit and an operator can maintain an average of 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.

EDI can be used to electronically manage inter-company activity. EDI can be designed as an XML application. See XML.

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

employee turnover **–** The average percentage of employees who exit a firm per year. For example, the turnover for hotel staff is very high, often on the order of 100%. This means that the number of employees exiting a firm in a year (voluntarily or involuntarily) equals the number employed.

****Engineer-to-Order (ETO)*** – (Sometimes called "design-to-order.") 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 ECOs 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)

A good website for this is: http://www.caenet.com/full_story.php?WID=963

Note that an engineering process that produces *only* the design is not engineer-to-order, but rather make-to-order. See Respond-to-order, make-to-stock, commonality.

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 use 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. 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. The materials requirements planning (sometimes called the manufacturing resources planning) module in an ERP system supports 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 Business Requirements Planning (BRP), Materials Requirements Planning (MRP).

entitlement – A Six Sigma term used as a measurement of the best possible performance of a process without capital investment. Entitlement is one of the most important concepts in process improvement, and is particularly useful in project selection. It is defined as the best performance that you can reasonably expect to get from a process. As the term implies, leadership is essentially entitled to this level of performance based on the investments they have already made.

Knowing the process entitlement defines what's possible. If entitlement is 500 units per day and the baseline performance is 250 units/day, you can easily see that there is a lot of room for improving this process. On the other hand, if current baseline performance is 480 units/day there is little room for improvement. If higher production rates are needed, a search for a totally new process may be in order (i.e., reengineering or DFSS).

As an analogy, the concept of par for a golf hole is intended to represent the entitlement for a very good golfer. That is, for such a golfer par represents what score is possible and reasonable to expect. On one hole a golfer may score less than par, but it is unrealistic to expect such performance on every hole, or even on average. Of course, all golfers have their own unique capability, so the official par doesn't represent process entitlement for the average duffer. Proper analysis and/or calculations would reveal the appropriate individual entitlement, which for professionals would be better than par, and for most golfers much worse. Note that standard golfing handicaps are usually based on average performance, which is not the same concept as entitlement.

It is not uncommon to learn in situations where capital is being requested to increase capacity that baseline production is not near entitlement, once it is carefully calculated. Six Sigma projects are subsequently instituted to increase the capacity of the current process with solutions that don't require capital. Most companies deploying Six Sigma have been able to cancel existing capital expansion plans because of capacity that has been freed up through Six Sigma with no capital expenditures. For example, if a chemical plant with six production lines is running at a 25 percent waste level, reducing the waste levels to 10 percent (60 percent reduction) creates additional capacity of 6 x 15% = 90% of a production line, or essentially creates a new line with no capital expense.

Entitlement should be determined for all key process performance measures (yield, cost of poor quality, capacity, downtime, waste, etc.). It may be the performance predicted by engineering and scientific fundamentals, nameplate capacity provided by the equipment manufacturer, or simply the best, prolonged performance observed to date.

Entitlement can also be predicted from empirical relationships. In one instance it was observed that a process operating at a cost of $0.36/unit had at one time operated at $0.16/unit (correcting for inflation). This suggests that the process entitlement (as determined by best prolonged performance) should be $0.16/unit. On further investigation it was observed that there was a linear relationship between defects and cost/unit of the form: Cost = $0.12 + 3(defects)/1,000,000. Therefore if defects could be reduced to very low levels essentially zero) the true process entitlement may be as low as $0.12/unit.

Entitlement is used in project selection as follows:

- Look at the gap between baseline performance (current state) and entitlement (desired state).
- Identify a project scope that will close the gap and can be completed in less than 4-6 months.
- Assess the bottom line impact of the project and compare it to other potential projects. A Black Belt or a Green Belt is assigned as priority dictates.

The gap between baseline and entitlement is rarely closed in the course of a single project. It is not uncommon for several projects to be required. In each instance the business case for the project is determined, the project is prioritized relative to the other potential projects, and a Black Belt or Green Belt is assigned as business priorities dictate.

Entitlement defines the performance level it is possible for a process to attain. It provides a vision of possible process performance, thereby providing a performance level for which to aim. It tells you how close current performance (baseline) is to the best possible performance. It also provides a benchmark that you can use to compare your process to other processes in your company or to processes in other companies. It is prudent to compute process entitlement values before doing any benchmarking studies to provide a basis of comparison.

Keep in mind that process entitlement can, and often does, change as you learn more about it. In most cases, the process entitlement calculations are simply estimates of the true entitlement, and you can update and enhance them over time. After a few Six Sigma projects, it is not uncommon for a process to be performing beyond the entitlement level initially determined for the process. Changing the value of process entitlement, as you better understand the process is a natural result of Six Sigma projects, and the need to do so should not come as a surprise.

See benchmarking, Six Sigma.

***e-procurement* –** A web-based information system that improves corporate purchasing operations by handling the specification, authorization, competitive bidding, and acquisition of products and services through catalogs, auctions, request for proposals, and request for quotes.

***ergonomics** – Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance. (Source: This is the approved definition of the International Ergonomics Association, www.iea.cc/ergonomics, representing 19.000 ergonomists worldwide and was provided by Prof.dr.ir. Jan Dul, Professor of Ergonomics Management, Department of Management of Technology and Innovation, Rotterdam School of Management, Erasmus School of Business, Erasmus University Rotterdam.) Updated April 27, 2004.

***error-proofing –** The process of identifying and preventing the likely causes of failure for a process. This is also called mistake-proofing, fool-proofing, idiot-proofing, or fail-safing. The Japanese phrase "poke yoke" means a "foolproof device" or "avoid mistakes." Error-proofing principles can improve both product design and process design in all types of organizations -- manufacturing, distribution, service, etc.

For *product design*, error-proofing principles can help design products that can be assembled easier (in the factory or by the customer), learned quicker, and used more safely. For example, many cars will not allow you to put the car into drive unless your foot in on the brake.

For *process design*, error-proofing principles help us accomplish a task with more efficiency and more safety. A good example is the switch on a machine that is controlled by a rope attached to the worker's wrist. When the worker's hand is in the machine, the rope is stretched tight and the switch will not work. The switch will only work when the rope is loose and the worker's hand is out of the machine.

Error-proofing involves the following steps: (1) Identify what could go wrong (an error). (2) Determine ways that this type of error could be prevented or detected before or after it has occurred (the earlier the better). (3) Identify and select the type of action to be taken when an error is detected.

The basic types of error-proofing methods include (1) prevention and (2) detection/warning. *Prevention methods* can be further broken in to three types:

(a) *Control* -- An action that self-corrects the problem, like an automatic spell-checker.

(b) *Shutdown* – A device that shuts down the process when the error condition occurs. A home iron that shuts off after so ten minutes of non-use is a good example. The worker's safety rope example mentioned above is also a good example. The machine is shutdown when the worker's hand is in the machine.

(c) *Human factors* – Use colors, shapes, symbols, sizes, sounds, and checklists to simplify a process to make it less error-prone for human operators. An example here is a "shadow-box" for a tool. This is an outline of the tool painted on a pegboard to signal to the worker where the tool belongs.

Warning methods detect a problem and send a warning to the operator when an error is about to occur or has already occurred – but do not control or shutdown the system. A car's oil light is a good example. A detection device signals the user when a mistake has been made, so that the user can quickly correct the problem. Warnings are often ignored, so prevention methods are usually preferred methods.

We are surrounded every day by both detection and prevention poka-yoke devices, though we may not usually think of them as such. My microwave will not work if the door is open (a prevention device). My car beeps if I leave the key in the ignition (a detection device). A few years ago, some cars were designed not to start until the passengers had buckled their seat belts (a prevention device); but this prevention mechanism was too intrusive and was replaced by a detection device (the warning beep).

Good error-proofing process devices are usually: (1) Simple and cheap. (2) Part of the process, implementing what Shingo calls "100%" inspection. (3) Close to where mistakes occur so workers can quickly find and correct the errors.

Failure Modes and Effects Analysis (FMEA) is an approach for prioritizing error-proofing methods. See business process re-engineering, FMEA, work simplification.

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

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.

Fagan Defect-Free Process – A method of reviewing products that incorporates a formal process and encourages continuous improvement. Michael Fagan created the method when he was a product manager working for IBM. Products are reviewed by a team of four people who are assigned roles: Moderator, Reader, Author and Tester. At least three of the four team members must have sufficient knowledge of the product to allow them to decide whether the material violates a predefined set of rules. The team members individually review the product for two uninterrupted hours. After individually reviewing the product the team meets to inspect the material. The inspection consists of the reader introducing the material, in appropriately sized pieces, to the team (Documents would be introduced one paragraph at a time). The other team members ask questions about potential rule violations they think they have identified. The author answers questions raised by other team members. The moderator keeps the inspection moving and either records the problems found or delegates this to another team member. The tester can be a member of the quality team in the organization or someone who is involved in product testing. The objectives of the process are as follows:

1. The participants learn about mistakes that are being made when a product is produced. When the author learns about mistakes they have made they have an opportunity for continuous improvement. Team members are not restricted to workers that produce the product. In fact, management personnel are encouraged to be team members. However, all team members must play an active role. The process expressly prohibits observers.
2. The process provides a way to identify systemic problems with work products. These lessons learned can then be applied to other, similar products that have not been subjected to the inspection process.
3. The process allows early detection of problems before the product is used as an input for other activities. This process is applied to software products such as source code but it can be applied to other work products such as documents, drawings, or other processes.

Companies that have implemented the Fagan Defect-Free Process have reported the following benefits:

- 50% reduction in cycle time (much of this is due to reducing test time and effort).
- 10 to 20x reduction in customer reported defects.
- 50% increase in meeting schedules and maintaining budget.
- 2x increase in productivity.
- 40 - 60% improvement in customer satisfaction.

The Fagan Defect-Free Process is explained in greater detail in the Michael Fagan Associates website www.mfagan.com. (Source: Brian Dye MOT '04, www.mfagan.com)

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 (FMEA) 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)

Failure Modes and Effects Analysis (FMEA) is a systematic way of looking at process or product failure modes, and their effects. Numerical values of Severity, Occurrence, and Detection are multiplied to produce a Risk Priority Number.

Severity – Impact of the failure. What is the impact in terms of cost, time, and quality of a failure?

Occurrence – Frequency of occurrence. What is the probability that this failure will occur?

Detection – Ability to detect the problem, chance of detection. How good are we at detecting the failure so that if it does occur, it does not impact the customer?

RPN = Severity x Occurrence x Detection

Factors with high RPN indices are candidates for improvement actions. (Adapted from www.uniworldconsulting.com/glossary1.htm#Entitlement, October 31, 2003).

The following steps are from a healthcare website (http://www.qimacros.com/200212Six.htm, October 31, 2003):

1. Identify each part or process step (e.g., preparation for an MRI-magnetic resonance imaging-in a hospital)
2. Identify potential failure modes -- All of the manners in which the part or process could fail: cracked, loosened, deformed, leaking, oxidized, overlooked, etc. (e.g., MRIs produce intense magnetic fields. One patient was killed by a flying fire extinguisher pulled off the wall by the MRI.)
3. Identify any Potential Effect(s) of Failure -- Consequences on other systems, parts, or people: noise, unstable, inoperative, impaired, injury, death, etc.
4. Rank Severity of the Effect (1-10) -- from none to "hazardous without warning" (e.g., tire blow out or fire extinguisher to the skull).
5. Evaluate Potential Cause(s)/Mechanism(s) of Failure -- List every potential cause and/or failure mechanism: incorrect material, improper maintenance, fatigue, wear, etc.
6. Rank the Possibility of Occurrence (1-10) -- Remote (6-sigma) to high (3-sigma).
7. List Your Current Design Controls -- List prevention and detection activities to assure design adequacy and prevent or reduce occurrence.
8. Rank Your Ability to Detect a Failure Using these Controls (1-10) from almost certain to absolute uncertainty.
9. Calculate the risk-priority number for each part or step: RPN = (severity) x (occurrence) x (detection)
10. Design Recommended Improvement Action(s) -- Design additional actions to reduce severity, occurrence, and detection ratings. Severity of 9 or 10 requires special attention.
11. Assign Responsibility and Target Completion Date for implementing designed improvements.
12. Monitor Actions Taken and effects on RPN.

It is not true that DFMEA (Design Failure Mode and Effects Analysis) is just another term for FMEA. Though analogous, product and process FMEA are different in method and create different results. A process FMEA assumes that there is a process in place that one is trying to assess root causes on (extruders, laminators, customer complaint processing). The DFMEA, on the other hand, looks at the actual design of the product or process. The biggest difference to deal with in facilitating the DFMEA tool is in regard to the root cause column of the tool. In this column on a process FMEA, you are looking for causes that create problems within a given process; in a DFMEA one opens the entire range of design options as failure causes. This is particularly significant when one gets to grade the detection, which is always challenging. Where a process FMEA grades "detection" on whether it can be prevented on detected within the existing process, a DFMEA looks at both the prevention of the cause and now level of understanding or amount of experimentation completed becomes part of the detection grade. It is extremely difficult to find a consistent detection grading criteria that covers both process and DFMEA, so it is necessary to use different types of FMEAs.

For example, if we are dealing with an extruder, a process FMEA might have a row like this:

Cause: Thermocouple broken
Mode: Extruder runs too cold and there is poor flow polymer
Effect: Uneven web caliper
Detection score: 2 (occasional preventive maintenance plus machine readouts give high likelihood that you will detect the cause before it is an issue)

This FMEA run on the design of the extruder might look at the extruder design from this angle:

Cause: "hanger" design of die incorrect
Mode: Extruder flows unevenly for good polymer flow
Effect: Uneven web caliper
Detection score: 8 (unless modeling was done on polymer flow through the die, it is unlikely that the design would catch this before building)

The source for this comparison of DFMEA and FMEA is adapted from an email from Rodney Hehenberger, Technical Supervisor -- Elastic Laboratory, 3M Personal Care and Related Products, November 10, 2004.

Revised November 10, 2004.

See cause and effect diagram, error-proofing, Pareto analysis, risk management, and Six Sigma.

***fault tree analysis* –** An analytical tool that graphically renders the combination of faults that lead to the failure of a system.

***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 fill rate, line fill rate, order fill rate)*** – 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 that filled immediately from stock. (Note that each 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, reorder point, safety stock, 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.

****finished goods inventory* –** This is inventory in its "finished" (completed state) ready for sale to a customer. Other types of inventory include raw materials, work in process (WIP), MRO (maintenance, repair, and operations), and pipeline (in-transit) inventory.

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.

***fishbone diagram* –** See cause and effect diagram.

****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.

****five S (the 5S's)* –** 5S is a simple but effective methodology for workplace organization – for simplifying, cleaning, developing, and sustaining a productive work environment. The methodology originated in Japan and is based on the simple idea that the foundation of a good production system is a clean and safe work environment. Translated from Japanese words that begin with an "S," the closest English equivalents are:

Sort – Housekeeping – Get rid of clutter.

Set in order – Workplace organization – Organize the work area (one author called this "storage").

Shine – Cleanup – Clean the work area.

Standardize – Cleanliness – Use standard methods to keep Sort, Set In Order, and Shine at a high level.

Sustain – Discipline – Maintain through empowerment, commitment, and discipline.

If we combine the above list with a list from Tom Meline (Phillips Temro) we have the following 5S's:

Sort, separate, and scrap – Get rid of clutter.

Set in order, straighten, and store – Organize the work area (red/yellow campaign, shadow boards).

Shine and scrub – Clean the work area. Sweeping, washing, and cleaning everything around working area. Note: Andersen Windows calls this "Sweep" instead on "Shine."

Standardize and sustain – Use standard methods to maintain the above at a high level. Keep everything clean for a constant state of readiness.

Systematize and sustain – Spread through the entire organization through empowerment, commitment, and discipline. Everyone understands, obeys, and practices the rules when in the plant.

Here is a more detailed explanation of each concept.

Sort (Seiri) focuses on eliminating unnecessary items from the workplace. An effective visual method to identify these unneeded items is called red tagging. A red tag is placed on all items not required to complete your job. These items are then moved to a central holding area. This process is for evaluation of the red tag items. Occasionally used items are moved to a more organized storage location outside of the work area while unneeded items are discarded. Sorting is an excellent way to free up valuable floor space and eliminate such things as broken tools, obsolete jigs and fixtures, scrap and excess raw material. The Sort process also helps prevent the JIC job mentality (Just In Case.)

Set In Order (Seiton) focuses on efficient and effective storage methods. You must ask yourself these questions: What do I need to do my job? Where should I locate this item? How many of this item do I really need? Strategies for effective Set In Order are: painting floors, outlining work areas and locations, shadow boards, and modular shelving and cabinets for needed items such as trash cans, brooms, mop and buckets. Imagine how much time is wasted every day looking for a broom? The broom should have a specific location where all employees can find it. "A place for everything and everything in its place."

Shine (Seiso) focuses on cleaning the work area. Once you have eliminated the clutter and junk that has been clogging your work areas and identified and located the necessary items, the next step is to thoroughly clean the work area. Daily follow-up cleaning is necessary in order to sustain this improvement. Workers take pride in a clean, clutter-free work area, and the Shine step will help create ownership in the equipment and facility. Workers will also begin to notice changes in equipment and facility location such as air, oil and coolant leaks, repeat contamination and vibration, broken, fatigue, breakage, and misalignment. These changes, if left unattended, could lead to equipment failure and loss of production. Both add up to impact your company's bottom line.

Standardize (Seiketsu) concentrates on standardizing best practice in your work area. Allow your employees to participate in the development of such standards. They are a valuable but often overlooked source of information regarding their work. Think of what McDonalds, Pizza Hut, UPS, Blockbuster, and the United States Military would be without effective work standards.

Sustain (Shitsuke) is by far the most difficult "S" to implement and achieve. Human nature is to resist change and to let entropy (the second law of thermodynamics) take control. More than a few organizations have found themselves with a dirty cluttered shop a few months following their attempt to implement 5S. The tendency is to return to the status quo and the comfort zone of the "old way" of doing things. Sustain focuses on defining a new status quo and new standard for work place organization.

Sources for the above: tpmonline.com/papakaizen/articls_on_lean_manufacturing_strategies/5s.htm, mfgeng.com/5S.htm, and a talk on Lean Manufacturing given to CEMBA '04 by Tom Meline, Plant Manager of Phillips & Temro.

The benefits of an 5S program include: improved safety, reduced waste, improved morale, ownership of workspace, improved productivity, improved quality, improved maintenance, and a better impression on customers. Not only will employees feel better about where they work, the effect on continuous improvement can lead to less waste, better quality and shorter lead times. Any of which will make your organization more profitable and competitive in the market place.

Indications that a firm needs a 5S program: (1) space crowded with parts and tools, (2) unneeded items are stacked between workers, (3) excess inventory, (4) excess items and machines make it difficult to improve process flow, (5) equipment is dirty and a collection point for miscellaneous materials, and (6) needed equipment such as tools are difficult to find.

Guidelines for 5S (source: http://net1.ist.psu.edu/chu/wcm/5s/guide.htm):

- A place for everything and everything in its place.
- Place tools and instructional manual close to the point of use.
- Design the storage areas such that the entrance is wider and the depth is shallower.
- Layout the storage area along the wall to save space.
- Place items such that they are facing toward passage for easily access.
- Store similar items together. Different items in separate rows.
- Do not stack items together. Use rack or shelf if possible.
- Use small bins to organize small items.
- Use color for quickly identifying items.
- Clearly label each item and its storage areas (lead to visibility).
- Use see-through cover or door for visibility.
- Use special designed cart to organize tools, jigs, measuring devices, etc., that are needed for each particular machine.

The source for the five S's in Japanese is http://net1.ist.psu.edu/chu/wcm/5s/5s.htm, November 7, 2004.

整理・整頓・清掃・清潔・躾

Revised November 7, 2004. See lean manufacturing.

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.

floater **–** A direct labor employee used to fill in on a production line when the regular worker is absent.

flowshop **–** A academic research term used to describe a process that involves a sequence of machines where jobs move directly from one machine to the next. Dudek *et al.* recognized that "there is no precise definition of a flowshop," but point out that "the following general assumptions are common in the literature. Jobs (work orders) are to be processed in *m* stages sequentially. There is one machine at each stage. Machines are available continuously. A job is processed on one machine at a time without preemption and a machine processes no more than one job at a time." Source: Dudek, R.A., S. S. Panwalkar, and M. L. Smith, "The lessons of flowshop scheduling research," *Oper. Res.*, vol. 40, no. 1, pp. 7–13, 1992. New York: Macmillan, 1979. Also see http://hifive1.isye.gatech.edu/hifive-references/s01/95-00/1_97_001.pdf. See jobshop.

FOB **–** This is a common freight/shipping acronym used to mean "Free on board." When a buyer purchases something and pays for it with terms "FOB origin," it means that the responsibility of the seller stops when the goods are delivered to the transporting company in suitable shipping condition. It is the buyer's responsibility to pay for transportation. Also, if something gets lost or is damaged during transport, it is between the buyer and the transportation company to settle it. See terms. Updated April 20, 2004.

***focused factory** – A focused factory is a process that is "aligned with its market" and therefore requires a limited range of operations objectives. For example, an operationally excellent focused factory making high volumes of standard products at low cost will likely have relatively low paid workers, fairly automated processes, and a focus on lean manufacturing (pull systems, 5S, JIT delivery of supplies). Conversely, an engineer to order focused factory, will focus on the new product development process and will have highly paid workers, a project management orientation, job order costing, and be concerned about customer service. A focused factory reduces the "variability" of the requirements in the process and therefore can help the process achieve its stated operations objectives. Focused factories align their processes to their market, which has implications for many issues such as workforce (skill levels, salaried versus direct, customer-facing skills, etc.), recognition and reward systems, customer interface, planning and control system, accounting system, layout, supplier relationships, etc. "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 several "focused factories" in any one factory building. Wickham Skinner's seminal article "The Focused Factory" was published in The Harvard Business Review in 1974 and is still available from Amazon.com.

The following concepts are adapted from www.strategosinc.com/key_manufacturing_task.htm (March 6, 2004): A Focused Factory strives for a narrow range of products, customers, and processes. The result is a factory that is smaller, simpler, and totally focused on one or two Key Manufacturing Tasks. The Focused Factory rests on the following concepts: (1) Strategic business units can compete on many dimensions, not just cost. (2) A factory cannot perform well on every measure, (3) Simplicity and repetition bring competence. The main benefits of focus are that your focused factory will be able to deliver superior customer satisfaction in your vertical market and be able to dominate that market segment. Skinner's research suggests that a particular factory can excel with no more than one or two overall objectives. These might be quality, delivery reliability, response time, low cost, customization, short life cycle products, or other competitive dimension that are important in that particular market. Some factories are unfocused originally because designers fail to recognize the limits and constraints of technologies and systems. Other factories are highly focused at first but lose it over time. Several forces and factors diffuse the original focus. Among these are product and market proliferation. In a sense, losing focus is "scope creep" for a factory. "The focused factory will out-produce, undersell, and quickly gain competitive edge over the complex factory." (Skinner, Wickham, The Focused Factory, Harvard Business Review, May-June, 1974.)

See cellular manufacturing.

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. Another approach for handling forecast bias is to use a recursive equation for the cumulative bias over time, $R_t = R_{t-1} + E_t$. Note that with this approach, even a small bias can add to a large number over many periods. A better approach is to use an exponentially smoothed average of the form $SE_t = SE_{t-1} + \alpha E_t$, where SE_t is the smoothed average error at the end of period t and α is the smoothing constant ($0 < \alpha < 1$). The ideal forecast has a zero forecast bias. An exception report called a tracking signal can be used to signal that the forecast bias is large and requires intervention. See demand filter, forecast error, and tracking signal.

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 demand filter, forecast bias, and tracking signal.

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. See all-time demand, Box-Jenkins, exponential smoothing, Delphi forecasting, CPFR, demand, demand filter, linear regression, tracking signal, 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.

freight bill **–** Invoice for the transportation charges of goods shipped or received. Updated April 20, 2004.

fuzzy front end **–** The fuzzy front end is the process for determining customer needs or market opportunities, generating ideas for new products, conducting necessary research on the needs, developing product concepts, and evaluating product concepts up to the point that a decision is made to proceed with development. This process is described as the fuzzy front end because it is the least defined and most unstructured part of product development. (Source: http://npd-solutions.com/glossary.html.)

The messy “getting started” period of product development, when the product concept is still very fuzzy. Preceding the more formal product development process, it generally consists of three tasks: strategic planning, concept generation, and, especially, pre-technical evaluation. These activities are often chaotic, unpredictable, and unstructured. In comparison, the subsequent new product development process is typically structured, predictable, and formal, with prescribed sets of activities, questions to be answered, and decisions to be made. (Source: http://www.pdma.org/library/glossary.html).

See new product development.

gate **–** See stage-gate process.

****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 – See “all-time” demand.

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 belt **–** See Six Sigma.

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*≈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. See learning curve, Moore’s Law.

Hawthorne Effect – The Hawthorne Studies (or experiments) were conducted from 1927 to 1932 at the Western Electric Hawthorne Works in Chicago, where Harvard Business School professor Elton Mayo examined productivity and work conditions. The studies grew out of preliminary experiments at the plant from 1924 to 1927 on the effect of light on productivity. Those experiments showed no clear connection between productivity and the amount of illumination but researchers began to wonder what kind of changes would influence output. The basic concept is that ***the mere act of showing people that you're concerned about them often spurs them to better job performance.*** (Note: You will find many different interpretations of the Hawthorne Effect and tremendous variation in the historical notes.)

For example, if you give a management trainee specialized training in management skills that she does not now possess. Without saving a word, you've given the trainee the feeling that she is so valuable to the organization that you'll spend time and money to develop her skills. She feels she's on a track to the top, and that motivates her to work harder and better. The motivation is independent of any particular skills or knowledge she may have gained from the training session. That's the Hawthorne Effect at work.

The Hawthorne Effect has also been called the "Somebody Upstairs Cares' syndrome." When people spend a large portion of their time at work, they must have a sense of belonging, of being part of a team. When they do, they produce better. That's the Hawthorne Effect.

Historical notes: Professor Elton Mayo wanted to find out what effect fatigue and monotony had on job productivity and how to control them through such variables as rest breaks, work hours, temperature and humidity. In the process, he stumbled upon a principle of human motivation that would help to revolutionize the theory and practice of management. Mayo took six women from the assembly line, segregated them from the rest of the factory, and put them under the eye of a supervisor who was more a friendly observer than disciplinarian. Mayo made frequent changes in their working conditions, always discussing, and explaining the changes in advance. He changed the hours in the working week, the hours in the workday the number of rest breaks, and the time of the lunch hour. Occasionally, he would return the women to their original, harder working conditions. The investigators selected two girls for their second series of experiments and asked them to choose another four girls, thus making a small group of six. The group was employed in assembling telephone relays - a relay being a small but intricate mechanism composed of about forty separate parts which had to be assembled by the girls seated at a lone bench and dropped into a chute when completed. The relays were mechanically counted as they slipped down the chute. It was intended that the basic rate of production should be noted at the start, and that subsequently changes would be introduced, the effectiveness of which would be measured by increased or decreased production of the relays. Through out the series of experiments, an observer sat with the girls in the workshop noting all that went on, keeping the girls informed about the experiment, asking for advice or information, and listening to their complaints. The experiment began by introducing various changes, each of which was continued for a test period of four to twelve weeks. The results of these changes are as follows:

- Under normal conditions with a forty-eight hour week, including Saturdays, and no rest pauses, the girls produced 2,400 relays a week each.
- They were then put on piece-work for eight weeks and output went up
- Two five-minute rest pauses, morning and afternoon, were introduced for a period of five weeks, and output went up once more
- The rest pauses were lengthened to ten minutes each, and output went up sharply.
- Six five-minute pauses were introduced, and the girls complained that their work rhythm was broken by the frequent pauses, and output fell slightly
- Return to the two rest pauses, the first with a hot meal supplied by the Company free of charge, and output went up.
- The girls were dismissed at 4.30 p.m. instead of 5.00 pm, and output went up.
- They were dismissed at 4.00 p.m., and output remained the same.
- Finally, all the improvements were taken away, and the girls went back to the physical conditions of the beginning of the experiment: work on Saturday, 48 hour week, no rest pauses, no piece work and no free meal. This state of affairs lasted for a period of 12 weeks. Output was the highest ever recorded averaging 3000 relays a week.

What happened was that six individuals became a team and the team gave itself wholeheartedly and spontaneously to co-operation in the experiment. The consequence was that they felt themselves to be participating freely and without afterthought and were happy in the knowledge that they were working without coercion from above or limitation from below. They were themselves satisfied at the consequence for they felt that they were working under less pressure than ever before. In fact regular medical checks showed no signs of cumulative fatigue and absence from work declined by 80 per cent. It was noted too, that each girl had her own technique of putting the component parts of the relay together - sometimes she varied this technique in order to avoid monotony and it was found that the more intelligent the girl, the greater was the number of variations (similar to McClelland's research findings into achievement motivated people.) The experimental group had considerable freedom of movement. They were not pushed around or bossed by anyone. Under these conditions they developed an increased sense of responsibility and instead of discipline from higher authority being imposed, it came from within the group itself. (Adapted from accel-team.com /human_relations August 23, 2004.)

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)

Heavyweight new product development team **–** An empowered project team with adequate resourcing to complete the project. Personnel report to the team leader and are co-located as practical. In contrast, a "Lightweight Team" has resources that are not dedicated and the team depends on the technical functions for resources necessary to get the work accomplished. (Adapted from www.pdma.org/library/glossary.html, October 25, 2003.)

A good reference on this subject is Clark, K., and S. Wheelwright, "Organizing and leading heavyweight development teams," ***California Management Review***, 34(3), 1992, 9-28.

New product development team structure

	Functional	**Lightweight**	**Heavyweight**	**Autonomous**
Description	• Members are grouped by discipline. • Entire project is decomposed into independent function responsibilities	• Members still reside in their functional areas • Liaison person (middle or junior level Manager) to coordinate their project committee.	• Dedicated team leader with big responsibility. • Core Group is co-located with their heavy weight project leader, but still have a reporting relationship with functional bosses. • Core team "contract."	• Similar to heavyweight team. • No functional reporting relationships.
Advantages	• Good means of evaluating functional performance. • Functional managers bring experience and knowledge.	• Greater coordination and better scheduling.	• Focused task objectives. • Handle cross-functional integration very well. • Rapid and efficient development of new products and processes.	• Few conflicts with functional management.
Disadvantages	• Project tends to move sequentially through functional areas • No one directly involved in the	• Speed and coordination advantages are seldom realized.	• May raise conflicts with the functional management. • Teams want control over	• Teams want control over secondary activities as well. • May inhibit development of

	project is responsible for results.		secondary activities as well. • May inhibit development of deep functional excellence. • Possibly requires more testing and quality assurance.	deep functional excellence. • Possibly requires more testing and quality assurance.
Best when	• Need deep expertise.	• Derivative product	• System solution required.	• Radical new concept.

Herbie – The bottleneck in a process. The question, "Where's your Herbie?" is asking, "where is your bottleneck." This is based on the popular Goldratt Institute film and book entitled ***The Goal***. See bottleneck, Theory of Constraints.

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. One creative potential solution (which I have never seen implemented) is to have different sales regions with offset quarters – so the eastern region has a quarter ending in January, the mid-west ending in February, and the west in March. See carrying cost. Another creative solution (again never implemented to my knowledge) is to shorten the reporting reward period from quarters to months or even weeks. This gives the organization less time to change between the extreme priorities, and therefore motivation to avoid the hockey stick. See carrying cost.

holding cost – See carrying charge, carrying cost.

Hoshin Kanri (Hoshin) **–** A policy deployment approach to strategic planning originated by Japanese firms. The image most often depicted in U.S. literature on Hoshin Kanri is that of a ship's compass distributed to many ships, properly calibrated such that all ships through independent action arrive at the same destination, individually or as a group, as the requirements of the "voyage" may require. The purpose of Hoshin Kanri (or Policy Deployment) is to make it possible to get away from the status quo and make a major performance improvement by analyzing current problems and deploying strategies that respond to environmental conditions. Policy Deployment cascades, or deploys, top management policies and targets down the management hierarchy. At each level, the policy is translated into policies, targets, and actions for the next level down. Policy Deployment ensures that everyone in the company is made aware of the overall vision and targets, and the way that these are translated into specific requirements for their own behavior and activities. (Adapted from http://www.mcts.com/Hoshin-Kanri.htm.)

Hoshin is a one-year plan for achieving objectives developed in conjunction with management's choice of specific targets and means in quality, cost, delivery, and morale. Hoshin can be described as: Hoshin = Targets + Means. A target statement can be established by combining at least one direction word, performance measure, target value for the performance measure, and time period. The following is a simple example:

Direction word: Decrease
Performance measure: New product development cycle time
Target value: From 8 to 4 months
Time period: By December 2005
Means: (1) Establish an effective development process, (2) Develop documentation for the product development, (3) Implement QFD within the quality assurance system

The hierarchical management levels, such as top management and middle management, need to determine the Hoshin according to the above rules.

Much of the above was adapted from http://www.iqd.com/hoshin.htm (August 14, 2003).

House of Quality – See Quality Function Deployment.

impact wheel – In today's complex world of interdependent economic, social, and technologic systems, each change has many diverse impacts, which in turn can have additional impacts of their own. While most of managers understand this concept, they often fail to clearly identify and communicate all of the potential impacts. Some research indicates that many business failures can be traced to a limited understanding of the consequences of a change. The Impact Wheel is a simple structured brainstorming approach designed to help managers fully explore the potential consequences of specific events and to identify implications that they might otherwise fail to anticipate. One benefit of the Impact Wheel is that it can help managers uncover and manage both unexpected and unintended consequences of a decision. In spite of this simplicity, the Wheel is used by many firms and government organizations and has been found to be a useful method for exploring the future.

The Impact Wheel process is quite simple. The facilitator writes the name for the change in the center of a large piece of paper and then engages the participants in a discussion of (1) the "impacts" extending out from the change (drawn like the spokes of a wheel), (2) the likelihood (probability) for each impact, and (3) implications of each impact (costs, benefits). The group then focuses on each impact and repeats the process. This approach can be supported by environmental scanning (to consider external issues), scenario development (to consider best-case, worst-case, status-quo, and wild-card scenarios), and expert interviews (to gain insights from subject matter experts).

See cause and effect diagram.

Adapted from davidpearcesnyder.com/the_impact_wheel.htm and jws-edcv.wiley.com/college/bcs/redesign/student/weblinks/1,12288,_0471435708_BKS_1055__224_76_1256_,00.html, February 4, 2004.

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.

Web based technology that is typically used within an organization's internal network to centralize applications or data. An Intranet is usually segmented into data or applications that all employees have access to and data or applications that are restricted to only authorized users. The term Intranet refers to a private network as opposed to Internet that is the public network. 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 – The number of times that the inventory investment is replaced during a period (usually a year). The standard accounting measure for inventory turnover is the cost of goods sold divided by the average inventory investment. For example, if a firm has annual cost of goods sold of $10 million and an average inventory investment of $5 million, the firm has 2 turns per year.

Many firms compute inventory turnover with the end of year inventory investment rather than the average inventory investment. In many firms, the year-end inventory is much lower than the average because of seasonal demand and/or reward systems that drive sales people to sell more at the end of the year. As a result, these firms overstate their true inventory turnover ratio.

Many people use the "quick and dirty" measure of sales divided by the average inventory investment. In the accounting literature, this is called "coverage." The two measures are the same if the organization values it's inventory at the sales price.

Inventory turnover should not be confused with other "turnover" measures. Employee turnover is the number of times that employees are replaced during a period (usually a year). Outside of the United States (particularly in Europe), the word "turnover" means sales or revenue.

The inverse of the inventory turnover ratio is an estimate of the period's supply or cycle time. For example, two turns translates into six months supply or cycle time of six months. Note that this is a dollar-weighted estimate because the more costly items are given more weight.

It can be proven mathematically that inventory turnover should increase as the demand increases. If sales double, the turnover ratio should increase by a factor of roughly $\sqrt{2} \approx 1.414$, an increase of about 41%. Therefore, caution should be used in benchmarking inventory turnover ratios between firms (or divisions) that have differing demand rates and within a firm if the demand rate is changing over time.

Thanks for Professor Jack Wacker (formerly Iowa State University now at ASU), for his insights into conceptual definitions. Revised November 26, 2004. See balanced scorecard, carrying cost, cycle time, employee turnover.

Ishikawa diagram **–** See cause and effect diagram.

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." Some criticize ISO 9000 as a non-value added activity that focuses on documentation rather than on process improvement. Others argue that Europeans created ISO as a barrier to entry and that its primary value for North American firms is to help them sell their products in Europe. (Adapted from Chase, Aquilano, and Jacobs's text, 2002, updated May 18, 2004.)

ISO9000 provides general requirements for various aspects of a firm's operations including Purchasing, Design Controls, Contracts, Inspection, Calibration, etc. For example, ISO9001 requires that statistical process controls (SPC) be applied to a firm's operations. This is more than simply documenting activities. The most recent standard is ISO9001:2000 which is a bit different than the older ISO9001:1994 standard in its emphasis on SPC and process flow diagrams. (Source: David Learner, MOT 2004)

ISO14001 – Certification Standards created by the International Organization for Standardizations related to environmental impact. The standard specifies requirements for an environmental management system to enable an organization to formulate a policy and objectives taking into account legislative requirements and information about significant environmental impacts. It applies to those environmental aspects that the organization can control and over which it can be expected to have an influence.

ISO 16949 quality standard – See TS 16949.

item number **–** See stock keeping unit, check digit.

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. The Japanese characters are from fredharriman.com. Revised November 7, 2004. See autonomation, andon.

自働化
JI DOU KA
JIDOKA
Autonomation

JIT – See Just in Time manufacturing.

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. In addition, job enlargement develops a worker's skill set and gives them a broader base of experience that can be leveraged to help the firm "learn" faster. Workers with a broader skills set are more flexible and can be moved to where the work is, thus reducing cycle time. See job enrichment. (Revised August 31, 2004.)

****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. My standard joke here is that with job enlargement, you get to clean both the urinals and the toilets. With job enrichment, you get to decide which to clean first. Note that the management literature does not have consistent definitions of the terms "job enlargement and job enrichment." See job enlargement. (Revised August 31, 2004.)

job rotation – The movement of workers between different jobs in an organization. This policy can be an effective method of crosstraining -- and can improve communication, increase process understanding, and reduce stress and boredom. Job rotation can also prevents muscle fatigue and reduces work place injuries.

****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. Typical performance metrics include the mean flow time, mean lateness, and mean tardiness. See job shop, dispatching.

****Just-in-Time manufacturing (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).

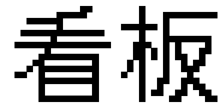
An integrated set of activities designed to achieve high volume production using minimal inventories of raw materials, work-in-process, and finished goods. Parts arrive at the next workstation "just-in-time" and move through the operation quickly. JIT is a management philosophy that strives to eliminate 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, one-part flow, lean manufacturing.

****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)

For many years, the Association for Manufacturing Excellence has sponsored "Kaizen Events," which are typically short term (3-5 work days) activities with a number of people working as a team to make order of magnitude process improvements. It is a little ironic that Kaizen now has two opposite means – the Japanese meaning of an orderly continuous improvement and an American meaning of a focused short-term, quick-hit improvement event. Some firms call this a "rapid process improvement" event. The Japanese characters are from www.fredharriman.com. Revised November 7, 2004.

kanban system – A simple device that sends a pull signal. "Kanban" is the Japanese word for sign, signboard, card, instruction card, visible record, doorplate, or poster. In the US, a kanban might be a card, container, or 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. 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 leadtime, 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. Revised November 10, 2004. See faxban, just-in-time, lean manufacturing.



Keiretsu – A Keiretsu is a Japanese term for a set of companies with interlocking business relationships and shareholdings. The "Big Six" keiretsu are Mitsui, Mitsubishi, Sumitomo, Fuyo (formed pricipally from the old Yasuda zaibatsu), Sanwa, and Dai–Ichi Kangyo. The keiretsu were established after World War II, following the dissolution of the family-owned conglomerates known as Zaibatsu by the American Occupation authorities. It was the belief of the Americans that they could hasten the spread of democracy in Japan by reducing the concentration of wealth and hence economic power. Shares of companies owned by the Zaibatsu were distributed to employees and local residents, with the result that in 1949 when the stock market reopened, 70% of all listed shares were held by individuals.

The zaibatsu dissolution was done in a haphazard manner, however. Often a single factory that merely assembled products for its group found itself an independent company, lacking a finance department, marketing department or even procurement department. To deal with this precarious situation, companies within the former Zaibatsu banded together through a system of cross-shareholding, whereby each company owned shares in all other group members. Within this structure, the major shareholders tended to a bank, a general trading company, and a life insurance company. The "Big Six" keiretsu are all led by their respective banks, which are the largest in Japan.

Because listed companies bought and held onto shares in other listed companies, the ratio of shares owned by individuals in Japan has steadily declined to around 20% by 2003. There has also never been a hostile takeover of a listed Japanese company simply because its shareholders refuse to sell at any price. This has made management rather complacent, and greatly reduced shareholder rights. Annual shareholders meetings in Japan tend to be held on the exact same day, and usually end quickly without any questions.

In the 1990s, when the Japanese stock market showed a relentless decline, stable shareholding began to decline. Banks needed to sell their shareholdings in order to realize gains to cover their credit costs. Life insurers had to sell to realize higher returns to pay their policyholders. Even corporations are selling shares because the original rationale for holding them has disappeared.

The term is rarely used by Western companies; one notable exception is the venture capital firm of Kleiner, Perkins, Caufield & Byers, which encourages transactions among companies in which it holds a stake. Source for the above: http://www.free-definition.com/Keiretsu.html, November 11, 2004.

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 for the above: 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.

Revised November 11, 2004. See Just-in-time.

key performance indicator (KPI) – A metric of strategic importance.

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. Many manufacturing consultants argue that kitting is a bad idea because it tends to increase inventory. They advocate that firms have "logical" kitting where they use their computer system to make sure that all of the parts are available before being released for assembly. Revised September 27, 2004.

knock-down kit – A kit or box of parts that can be used to assemble a product. When I visited northern Hungary many years ago, I toured a GM plant that received knock-down kits of cars from Germany and then assembled them into cars using Hungarian workers. Revised November 10, 2004.

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 actual time (a random variable) required to produce the order. Note that this is a random variable, which has a mean, standard deviation, etc. The ***promised customer leadtime*** is the promised customer wait time for an order. The ***actual customer leadtime*** is the actual wait time (a random variable) experienced by the customer. The planned leadtime, actual leadtime, promised customer leadtime, and actual customer leadtime might all be different. 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, two-week average leadtime, two-week minimum leadtime, two-week modal leadtime, two-week promised customer leadtime, etc. See cycle time, purchasing leadtime, and takt time.

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 design **–** Lean design is a set of tools for reducing the new product development cost and time with a focus on reducing variation, addressing bottlenecks, eliminating rework, and managing capacity. See lean manufacturing, new product development.

lean manufacturing – Lean Manufacturing is an approach to organizing manufacturing activities that seeks to eliminate waste of all types. 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.) Revised November 2, 2004. See andon light, jidoka, JIT II, lean sigma, manufacturing cycle effectiveness, one-piece flow.

lean sigma **–** A combination of lean manufacturing and Six Sigma programs. The best way to do this is to use the Six Sigma program framework to provide an organizational structure for process improvement projects. This structure helps the firm to make sure that the projects are in alignment with the organization's goals, staffed appropriately, and have proper accountability. Some of the Six Sigma projects may well be using lean manufacturing principles and tools (cycle time reduction, lotsize reduction, etc.). The DMAIC approach can be used for all projects. At Medtronic the program is called "Lean Sigma Solutions" – evidently someone has trademarked the term "lean sigma." According to Scot Webster, VP of Quality Shared Services at Medtronic, "Six Sigma makes a science of process capability and lean makes a science of process flow process flow – and both are implemented with the DMAIC approach." Mr. Webster maps Womack's five steps of lean thinking into the DMAIC steps:

Lean thinking steps	**DMAIC steps**	
Specify value	D	Define process in terms of customer value
Map the value stream	M	Measure the value stream
Make the value flow	A	Analyze for waste elimination
Pull	I	Improve flow via customer pull
Seek perfection	C	Control to continuously improve

Mr. Webster argues that the standard Six Sigma equation $Y = f(x_1, x_2, \ldots, x_N)$ works for both Six Sigma and for Lean. The only difference is that for Six Sigma the challenge is to find the vital few x_i variables among a large number of possible variables; for lean, the challenge is to find the vital few from only 18 potential variables. He lists eleven of the eighteen in his publicly available talk. These include: transfer lot size, process lot size, options, rework, downtime, external set up, internal set up, attended machine, unattended machine, move, and labor. He summarized his talk on lean sigma by arguing that both Six Sigma and Lean were all about leadership development. He asserted that lean sigma at Medtronic was 70% leadership development and 30% process improvement.

Revised November 2, 2004. See lean manufacturing, Six Sigma.

****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 $y_n=y_1n^b$, 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(0.8)/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. See half-life, Moore's Law.

***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. Learning organizations have the ability to transform experience into improved work processes and knowledge that is accessible to the whole organization and relevant to its core purpose.

Specifically, organizations need 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 new product and process technologies being 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.

Cycle-counting – to find the source of data integrity problems.

***life-time demand* –** See all-time demand.

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. A linear regression model is of the form $y_i = \beta_0 + \beta_1 x_{1i} + ... + \beta_N x_{Ni} + \varepsilon_i$, where ε_i is the error term for the i-th case and the β_j parameters are estimated from a least squares fit with historical data. See time-series forecasting.

line extension – A form of derivative product that adds or modifies features without significantly changing the product functionality. (Source: www.pdma.org/library/glossary.html, October 25, 2003.)

***line of visibility* –** The line that separates a service operation into the back office operations that take place without the customer and front office operations in direct contact with the customer. See service blueprinting.

***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 $L_s = \lambda W_s$. In other words, the average number of customers (units, calls, etc.) is equal to the average arrival rate times the average time in system. For example, if average arrival rate is $\lambda = 6$ customer/hour and the average time in system is $W_s = 1$ hour, the average number in system is $L_s = 6$ customers. Similarly, the relationship between the average time in queue, average arrival rate, and average number in queue is given by $L_q = \lambda W_q$, which means that the number of customers waiting in queue is the average arrival rate times the average time in queue. 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. Note that the average time in system is just the average time in queue plus the average 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.

Revised November 16, 2004. See capacity, queuing theory, and waiting time.

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.

***logistics* –** Logistics is the organizational function that is responsible for managing the flow of materials between facilities (suppliers, warehouses, plants, distributors, and customers) and the associated flows of information and cash. For any one facility, logistics involves the planning and control of the inbound and outbound materials flow plus the inventory at the facility. In the military, logistics also involves the movement of personnel. See inventory management, materials management, supply chain management.

***lot tolerance percent defective (LTPD)* –** The maximum level of percent defective acceptable in production lots.

****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 – These are techniques for determine the quantity to be ordered for a production and/or inventory control system. An Excel workbook is available from Professor Hill that illustrates all of these (and other) lotsizing methods for production planning with time-varying demand. Revised October 26, 2004. See EOQ, Period Order Quantity, Wagner-Whitin, time-varying demand lotsizing.

***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.

***maintenance* –** The work of keeping something in proper condition, upkeep, or repair. Revised November 8, 2004. See bathtub curve, mean time between failures, mean time to repair, predictive maintenance, and preventive maintenance.

****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. See Respond-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). See service level.

****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 may go in the direction of outsourcing and can lead the firm into the "death spiral." In the death spiral, your firm outsources and finds itself with the same overhead but fewer units, which means that the overhead per unit goes up, which leads you to more outsourcing. A company should never outsource a core competence. Revised October 26, 2004. See outsourcing, supply chain management.

****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 – See cellular manufacturing.

Manufacturing Cycle Effectiveness (MCE) – The ratio of the "touch time" (direct value added processing time) over the total cycle time (total throughput time). Throughput time is the sum of the queue time (wait time), touch time, inspection time, and move time. MCE, therefore, is the percentage of the total cycle time that is value-added time. This measure can be applied to services as well as manufacturing. In a service context, this is the percent of the time that the customer is receiving actual value-added service divided by the time that the customer is in the system. When MCE is close to zero, the process is considered to be an inefficient process; when MCE approaches one, it is considered an efficient process. Many processes in practice have an MCE less than 20%. Revised November 2, 2004. See lean manufacturing, queue time.

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 Entreprise Resources Planning (ERP).

****mass customization*** – A business model that uses a routine approach to efficiently create high variety in products and/or services in response to customer-defined requirements. The word routine means "a prescribed, detailed course of action to be followed regularly; a standard procedure." (Thanks to Kevin Thayer (CEMBA '06) for his help in writing this definition.)

Many people (especially students) mistakenly assume that mass customization is all about increasing variety. However, some of the best applications of mass customization maintain the same variety and focus on the "mass" part of the concept. One Minneapolis firm named AbleNet was able to create a modular design that provided the customer with the same variety, while at the same time reducing the number of products that it produced and stored.

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 -- ideally increasing margin. One of the primary approaches for mass-customization is postponement, where customization is delayed until after the customer order is received. For example, IBM in Rochester, Minnesota, builds the AS400 using "vanilla boxes," which are not differentiated until after the customer order has been received. IBM customizes the vanilla boxes by inserting hard-drives, modems, etc. into slots on the front of the box. A nice website for configurators can be found at: http://www.caenet.com/full_story.php?WID=963.

Professor Hill's lecture on mass customization includes eight strategies. These include:

1. Design products for MC.
2. Use robust components.
3. Develop workers for MC.
4. Apply lean/quality concepts.
5. Reduce setup times.
6. Use appropriate automation.
7. Breakdown functional silos.
8. Manage the value chain for MC.

Revised November 2, 2004. See assemble-to-order, commonality, configurator, economies of scope, engineer-to-order, flexibility, make-to-order, pack-to-order, postponement, print-to-order, respond-to-order.

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.

materials management – Materials management is the organizational unit that coordinates the flow of materials across a system. The system could be defined at almost any level – a department, a plant, a firm, or even a supply chain. In some ways, materials management is the old term for supply chain management. Materials management must balance the conflicting objectives of marketing and sales (have lots of inventory, never lose a sale, high service level) and finance (keep inventories low, minimize working capital). Materials management generally includes manufacturing planning and control, distribution management, transportation, and inventory management. See inventory management, supply chain management, logistics.

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 for 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 often 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 that 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.

See Enterprise Requirements Planning (ERP).

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

***maximum inventory* –** See periodic review system.

****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; the average of the absolute percent forecast errors. $MAPD = 100\sum_{t=1}^{T} |E_t / D_t| / T$, where E_t is the forecast error in period t, D_t is the actual demand (or sales) in period t, and we have T observed values. Revised November 8, 2004. See exponential smoothing, forecasting, forecast error, and mean absolute deviation (MAD).

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. Revised November 8, 2004. See bathtub curve, maintenance, mean time to repair.

***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 using one assembly process. 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 (modularity)*** – 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)

Modularity is a general systems concept: it is a continuum describing the degree to which a system's components can be separated and recombined, and it refers both to the tightness of coupling between components and the degree to which the "rules" of the system architecture enable (or prohibit) the mixing and matching of components. Since all systems are characterized by some degree of coupling (whether loose or tight) between components, and very few systems have components that are completely inseparable and cannot be recombined, almost all systems are, to some degree, modular. Source: Schilling, Melissa A., "Toward a general modular systems theory and its application to interfirm product modularity," Academy of Management Review, April 2000, Vol. 25, p. 312 .

****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 employees to show the customers that they really care about them – and to ask customers for feedback on about how products and services might be improved. 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.

***Monte Carlo simulation* –** See simulation.

Moore's Law – A law that states that the number of transistors on a circuit doubles every 18 months. This exponential growth model can be generalized and applied to many fast-growth contexts, such as millions of instructions per second (MIPS) for the fastest computer, the number of Internet users, the growth of the mosquito population in Minnesota, etc. This concept is not a new one. Benjamin Franklin noted in his 1751 essay "Observations concerning the Increase of Mankind, peopling of Countries, etc.," that the population doubled in the English colonies in America about every 25 years. Franklin observed that "This million doubling, suppose but once in 25 Years, will, in another Century, be more than the people of England, and the greatest number of Englishmen will be on this side the water." The mathematical model for Moore's Law is the identical as the half-life "time-based learning" model ($y(t)=a\bullet\exp(bt)$), except with Moore's Law the performance variable increases (exponential growth) instead of decreases (exponential decay) over time. Whereas the performance variable for Moore's Law doubles every h time periods, the performance variable for the half-life curve "halves" every h time periods. The constants for Moore's Law are $a=y(0)$, $b=\ln(2)/h$, and $h=\ln(2)/b$. (Note that the signs for b and h here are opposite those of the half-life model.) See half-life, learning curve.

****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 can be proven to be mathematically equivalent to simple exponential smoothed average with smoothing constant $\alpha = 2/(N+1)$. See exponential smoothing.

MRO (Maintenance, Repair, Operations) – Purchased "non-production" items – items not used directly in the product. Examples may include office supplies, cutting oil for machines, 3M sandpaper, etc. MRO categories include (a) Electrical and mechanical, (b) Electronic, (c) Lab equipment and supplies, and (d) Industrial supplies. These items are generally not handled by the firm's ERP system, but are often a significant expense for many firms. Note that "MRO" has various (but very similar) meanings, including "Maintenance, Repair, and Operating supplies," "Maintenance, Repair, and Operations," and "Maintenance, Repair, and Overhaul."

Deloitte Consulting uses the term "operating resource management" (ORM) for "the strategic purchase of non-production goods through the effective use of aggregate buying, volume discount, lowered transaction costs, and decision support techniques to identify vendor discount operations." General and Administrative expenses generally include: Computer related Capital equipment, Travel & Entertainment, MRO (maintenance, repair and operations). MRO is usually the most significant and most mission-critical of these.

****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. Adapted from fredharriman.com. Revised November 7, 2004. See lean manufacturing.

****Murphy's Law*** **–** If it can go wrong, it will. Some people argue that Murphy's Law is really just a result of the Second Law of Thermodynamics, which suggests that all systems move to the highest state of disorder (the lowest possible state of energy) and tend to stay there unless energy is supplied or order is restore them. This is sometimes called the law of entropy. Revised October 23, 2004. See Parkinson's Laws.

****new product development (NPD)*** **–** A defined set of tasks outlining the necessary steps taken to develop and bring a new product to market. The innovation process is often divided into three fundamental steps:

The fuzzy front-end – The front-end activities that proceed the new product development in order to generate, evaluate, and select concepts to be started into the new product development process. Clearly, organizations want to only start ideas into new product development that have high probability of market and financial success.

New product development – The process of translating product specifications into specific designs that can be manufactured and brought to market.

Commercialization – The process of managing a new product through pilot production, production ramp-up, and product launch into the channels of distribution.

Revised November 5, 2004. See line extension, fuzzy front-end, heavyweight teams, simultaneous engineering, concurrent engineering, project management, stage-gate process, QFD, and waterfall.

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.

no fault receiving **–** A way of inventory accounting used in retailing. Employees are only required to "count boxes" and put the items away. They are not required to account for the item count in each box. This form on inventory accounting is usually used in conjunction with an annual, formal inventory count.

normal time – An industrial engineering term for the time observed from a time study, adjusted for performance ratings. The steps in estimating the normal time are as follows:

1. The average time from a time study (t_i) is collected for N operators. We also collect a subjectively determined performance rating (r_i) for each operator. This is scaled so that r=100 for a person working at a normal rate and r=110 for someone working 10% faster than normal.
2. Each operator's average time is adjusted by the performance rating. The average of these times is called the normal time for the operation, $NT = \sum_{i=1}^{N} r_i t_i / N$.
3. The normal time is adjusted for percent allowances (A) to compute the standard time, $ST = NT(1 + A)$. The percent allowances (A) is for bathroom breaks, rest time, etc. and is usually on the order of 15%. The standard labor cost is the standard time (ST) times the standard cost per hour.

Revised October 9, 2004

See standard time.

nominal group technique (NGT) **–** Originally developed as an organizational planning technique by Delbecq, Van de Ven, and Gustafson in 1971, the nominal group technique is a consensus planning tool that helps prioritize issues. The nominal group technique can be used as an alternative to both the focus group and the Delphi techniques. It presents more structure than the focus group, but still takes advantage of the synergy created by group participants. One nice outcome of the NGT is that it helps to build consensus (agreement) on the issues.

I have facilitated NGT brainstorming sessions with a many different groups over the years. (Thank you Andy Van de Ven for showing me how to do this early in my career.) The approach that I like to use:

1. **Prepare** – Find a highly skilled facilitator, carefully select a group of experts, and instruct them how to be prepared for the meeting.
2. **Kickoff –** The group experts meets with the facilitator in a room with a whiteboard and a large quantity of Post-it Notes. (Full disclosure: This author regularly works as a consultant for 3M.) Spend a few minutes to motivate the problem and scope and then clearly define the question to be explored (e.g., How can we reduce our waiting lines?). Overview the process and then see if the participants have any questions about the scope or process before you begin.
3. **Generate –** Spend about 15 minutes to have the participants silently write down their answers to the question on Post-it Notes. Each participant should be instructed to write ***one*** idea on each note with only one or two words in very large letters on the top half of their note, followed by a longer description on the bottom half of the note. See the example to the right. You will have to work very hard to get your participants to follow these simple instructions. Many

MONDAY CAPACITY

We don't have enough workers for the Monday morning rush.

people want to write in small print that no one can see from two meters away. It's a good idea to have your participants consider the issue before the meeting. However, I have not had success in having participants bring their notes to meeting. Too often some people bring notes and others do not. Those who bring notes feel that their time is wasted while others create their notes.

4. **Share –** Go around the room and have each person share their highest priority note one at a time and add their note to the wall in sequential order. Discussion is not allowed during this time, except to ask short clarification questions. Ask people to not repeat an idea that is already on the board. If a new note very similar to one already on the whiteboard, then put them together. Give people freedom to pass. Continue to go around the room until everyone has had a chance to share all their notes.
5. **Vote –** Each participant is now allowed to "vote" on up to five notes that they believe are the most important. Tabulate the votes for a summary report to the group. Our purpose here is to separate the "vital few" from the trivial many.
6. **Group –** Have the group arrange the notes into related groups. Give each group a short name and write the name on the whiteboard with a circle around the notes. Go back and make sure that all of the notes are in the correct group.
7. **Delegate –** If you are in a problem solving exercise, you might end the meeting by asking people to take ownership of a particular issue.

As the name suggests, the nominal group technique is only "nominally" a group, since the rankings are provided on an individual basis.

Research on the Nominal Group Technique is extensive and shows that in numerous circumstances the process produces better results than unstructured group interactions (Campbell, 1966; Dunnett, Campbell, and Jaastad, 1963; Vroom, Grant, and Cotton, 1969; Gustafson, Shukla, Delbecq, and Walster, 1973; Van de Ven, 1974; Stumpf, 1978). Data suggests the following three principles for why Nominal group process is successful: (a) Ideas should not be evaluated one at a time. Rather the facilitator should collect many ideas before any one of them are evaluated. Postponing evaluation increases creative solutions. (b) In estimating numbers, thinking again improves the accuracy of the numbers. A sort of bootstrapping occurs, where the group members best themselves by listening to other group members and revising their own opinions. (c) Individual generation of ideas leads to more ideas and more creative ones than generating ideas while listening to other group members. (Source: gunston.doit.gmu.edu/healthscience/708/frteam.asp, February 21, 2004.)

While the Nominal Group Technique is widely used, it is not intended for all situations. It is especially not intended for tasks that require ordering or judging the worth of several alternatives. In these circumstances, this technique may produce judgments inferior to the judgment of the most knowledgeable group member (Holloman and Hendrick, 1972; Nemiroff, Pasmore, and Ford, 1976). But by far, the most serious problem with the process is that participants feel awkward about restrictions in their interactions. After the group meeting they may feel that the process and not they led them to the conclusions they arrived at. Therefore, they may not be committed to the group's consensus. Data show that Nominal group process is the wrong process when acceptance of the group's conclusions rather than originality is important. Acceptance is crucial as to whether the model is put to use. In these situations, less structured processes produce more widely accepted group decisions than Nominal Group Technique (Stumpf, 1978, Maier and Hoffman, 1964, Miner, 1976). (Source: gunston.doit.gmu.edu/healthscience/708/frteam.asp, February 21, 2004.)

The following website gunston.doit.gmu.edu/healthscience/708/best.asp provides an excellent overview of alternative brainstorming/group decision making ideas. Revised October 18, 2004.

See affinity diagram, cause and effect diagram, and impact wheel.

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.

***one-piece flow* –** A policy of making only one part at a time (a batch size of one) before moving the part to the next step in the process. See JIT, lean manufacturing, setup reduction.

***offshoring* –** Developing a source of supply in another country (typically in Asia or Europe) using either your own source of supply or another party. In contrast, by definition, outsourcing requires the use of another party. The primary issues that managers should consider when they relocating services offshore are (1) expertise in managing remote locations, (2) quality of the workforce, (3) the cost of labor, (4) language skills, (5) telecom bandwidth, (6) cost and reliability, (7) infrastructure, (8) political stability, (9) enforceability of intellectual property rights and business contracts, and (10) and general maturity of the business environment. See ebstrategy.com/Outsourcing/default.htm for more information. See outsourcing.

***on-time-delivery* –** see service level.

open-book management – Sharing key financial information openly with employees and other stakeholders. Some firms go so far as to share their financial information with their customers and/or suppliers. Revised October 26, 2004.

operating characteristic (OC) curve **–** An assessment of the probability of accepting a shipment, given the existing level of quality of the shipment. See acceptance sampling.

****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*** – 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. Revised October 24, 2004.

****order winner*** – See order qualifier.

order-up-to system **–** See periodic review system.

****outsourcing*** – Buying products and services from an outside supplier. 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. Historically, many firms have outsourcing the manufacturing of components. More recently, we have seen firms outsourcing final assembly, new product development, and services.

A good example of traditional outsourcing is Guidant's clean room gowns. Guidant's core competence is designing, manufacturing, marketing, and selling implantable medical devices – not managing gowns. However, their gown 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.

An example of outsourcing services is Best Buy, which recently announced that it was outsourcing nearly all of its Information Technology organization.

It is widely said that "firms should never outsource their core competence." However, it is often unclear which processes are in fact core to the firm's business model.

Updated May 18, 2004.

See activity based costing, core competence, make versus buy, offshoring.

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%. World Class OEE is better than 85%. (Source: www.mfgeng.com/TPM.htm, April 14, 2004.)

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.

However, managers should be careful to never use OEE to build inventory long before it is needed.
(Adapted from: www.oeetoolkit.nl/OEEAlgemeen/what_is_oee.htm, November 9, 2001.)
See TPM, utilization, yield.

p-chart – A quality control chart used to monitor the percent defective for the process. A sample of *n* parts is collected from the process every so many lots, 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. See control chart, SPC.

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 respond-to-order, make to order.

paradigm **–** A way of thinking or thought frame that can inhibit us from thinking creatively about a new problem.

****Pareto Chart/Pareto analysis*** – A histogram (bar chart) that helps identify and prioritize the most common sources of error or defects. The chart shows the problem frequencies and is usually sorted from highest to lowest. See Pareto's Law.

****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 (Milano), he found that 20% of the people earned 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. and that the two numbers do not have to add to 100. 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 phrase "The trivial many and the important few." The implication of Pareto's Law is that manager need to find and focus on the important few -- and not spend too much time on the "trivial many" that do not matter very much. My roommate at West Point used to say, "Don't sweat the small stuff" and my Tactical Officer at West Point used to say, "Major on the majors." Both of these statements are variants of Pareto's Law. See ABC classification, error-proofing, FMEA, Pareto Chart, and Theory of Constraints -- all of these are applications of Pareto's Law.

****Parkinson's Laws*** – Professor C. Northcote Parkinson wrote a book entitled Parkinson's Laws. His most famous law is "Work expands to fill the time allotted to it." (Parkinson's actual wording was "Work expands so as to fill the time available for its completion.") Here are a few other examples of Parkinson's main laws:

- Expenditure rises to meet income.
- Expansion means complexity, and complexity decay.
- Policies designed to increase production increase employment; policies designed to increase employment do everything but.
- Democracy equals inflation. (By this Professor Parkinson meant that where the working population, through control of the electoral process, ultimately determines its conditions of employment, there will be more demand for higher pay than for increased production.)

- When something goes wrong, do not “try, try again.” Instead, pull back, pause, and carefully work out what organizational shortcomings produced the failure. Then, correct those deficiencies. Only after that return to the assault.
- Delay is the deadliest form of denial.
- The matters most debated in a deliberative body tend to be the minor ones where everybody understands the issues.
- Deliberative bodies become decreasingly effective after they pass five to eight members.

Professor (Source: http://www.globalideasbank.org/socinv/SIC-117.HTML, October 18, 2003.)

The British 20th century author and Professor of History Cyril Northcote Parkinson (1909-1993) wrote some sixty books. These included historical fiction, often based on the Napoleonic period, and sea stories. He is even more famous for his satire of bureaucratic institutions, notably his “Parkinson’s law and other studies.” This is a collection of short studies explaining the inevitability of bureaucratic expansion, why driving on the left side of the road (see road transport) is natural. As early as the 1930s Parkinson had successfully predicted that the British Navy would eventually have more admirals than ships. (Source: http://en2.wikipedia.org/wiki/C._Northcote_Parkinson, October 18, 2003.)

Professor Hill has written a few operations management corollaries of Parkinson’s Laws. These include:

- Warehouse inventory expands to fill the space allotted to it.
- Factory equipment and inventory expand to fill the space allotted to it.
- The best way to improve on time delivery is to reduce cycle time – so that you have the product on the customer’s doorstep before they have time to change their mind.
- Lying begets lying. If you lie to your customers about the expected delivery dates, they will in turn lie to you about their actual need date.
- The later a project becomes, the more unlikely it is that the project manager will inform the customer of the project lateness.

Revised June 18, 2004.

See Murphy’s Law.

part number – See stock keeping unit (SKU), check digit.

***PDCA* –** The Plan-Do-Check-Act cycle. This is very similar to the DMAIC approach used in Six Sigma.

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.

***phantom bill of material* –** A bill of material coding and structuring technique used primarily for transient (non-stocked) sub-assemblies. A phantom bill of material represents an item that is physically built but rarely stocked before being used in the next level in the bill of material.

***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.

***platform strategy* –** a new product development strategy that plans new products around a small number of basic product designs (platforms) that allow for a many different final products with differing features, functions, and prices. This strategy is well known in the automotive industry where a platform is often a chassis/drive-train combination upon which many different models are built (e.g., Chevrolet, Oldsmobile, Buick, Cadillac, etc.).

***point-of-use* –** Storing parts, tools, and/or supplies very close to where they are used instead of storing them in a separate storage area. This eliminates non-value added time for moving these and also increases the visibility of the process. Revised October 26, 2004.

***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 $(b\quad a)^2/36$. 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, project management.

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. This is 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 is 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 an order. The system requires a larger average safety stock inventory than the order point system because it must also protect against stockouts during the review period. The periodic review system makes good economic sense when the firm has economy of scale in transportation cost. In other words, we use the periodic review system when we can save money by having our supplier ship many items at the same time. For example, many retailers replenish their stores from their distribution center once per week. Each store has a target inventory level for each SKU (stock keeping unit) and every week the stores order enough to bring their inventory position up to the target inventory level.

The optimal review period is $P = EOQ / \overline{d}$. However, in most situations, the review period is determined by other factors such as the transportation schedule.

The periodic review system is often implemented in conjunction with an order-up-to lotsizing rule. This rule orders a quantity that brings the inventory position up to a "target" inventory at the end of each review period. The target inventory is $T = \overline{d}(L + P) + SS$, were $\overline{d}$ is the average demand per period, L is the replenishment lead time, and P is the review period. The safety stock inventory is $SS = k\sigma_1\sqrt{L + P}$, where σ_1 is the standard deviation of demand per period and k is the safety factor. The average lotsize is $\overline{Q} = \overline{d}P$ and the average inventory is $\overline{Q}/2 + SS$. See continuous review system safety stock.

****perpetual inventory system*** **–** An inventory control system where a "real-time" record is kept of the amount of inventory for each item. These systems often provide real-time visibility of inventory position (inventory on-hand and inventory on-order). If an inventory system is not a perpetual system, the organization either updates inventory records periodically or has no inventory records at all.

phase review **–** A step in the new product development process where approval is required in order to proceed to the next step. See new product development, stage-gate process.

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 – See error-proofing.

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. Predictive maintenance should be targeted at equipment with high costs of failure and only makes sense when the precision of the predictive tools is high. For additional details: see McKone, K. and E. Weiss (2002), Guidelines for Implementing Predictive Maintenance, ***Production Operations Management***, 11:2, pg. 109-124. Revised November 1, 2004. 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 Respond-to-order.

process capability and process performance measures **–** In the Six Sigma quality methodology, process performance is reported to the organization as a sigma level. The higher the sigma level, the better the process is performing. Another way to report process capability and process performance is through the statistical measurements of C_p, C_{pk}, P_p, and P_{pk}.

C_p = Process Capability. A simple and straightforward indicator of process capability.
C_{pk} = Process Capability Index. Adjustment of C_p for the effect of non-centered distribution.
P_p = Process Performance. A simple and straightforward indicator of process performance.
P_{pk} = Process Performance Index. Adjustment of P_p for the effect of non-centered distribution.

The **process capability index**, C_{pk}, measures how close a process is running to its specification limits, relative to the natural variability of the process. The larger the index, the less likely it is that any item will be outside of the limits. In target shooting, if your shots are falling in the same spot forming a good group this is a high C_p and when the sighting is adjusted so this tight group of shots is landing on the bull's-eye, you have a high C_{pk}. C_{pk} measures how close you are to your target and how consistent you are to around your average performance. A person may be performing with minimum variation, but he can be away from his target towards one of the specification limit, which indicates lower C_{pk}, whereas C_p will be high. On the other hand, a person may be on average exactly at the target, but the variation in performance is high (but still lower than the tolerance band (i.e. specification interval). In such case also C_{pk} will be lower, but C_p will be high. C_{pk} will be higher only when you are meeting the target consistently with minimum variation. The general rule of thumb is that if a C_{pk} value is less than 1.33, the process is incapable of producing a repeatable part.

The **Process Performance Index** tries to verify if the sample that you have generated from the process is capable to meet Critical to Quality customer requirements. It differs from Process Capability in that Process Performance only applies to a specific batch of material. Samples from the batch may need to be quite large to be representative of the variation in the batch. Process Performance is only used when process control cannot be evaluated. An example of this is for a short pre-production run. Process Performance generally uses sample sigma in its calculation; Process capability uses the process sigma value determined from either the Moving Range, Range, or Sigma control charts. In summary, C_{pk} is for short term, whereas, P_{pk} is for long term.

Equations:
UTL = Upper Tolerance Limit
LTL = the Lower Tolerance Limit.
$C_p = (UTL - LTL)/(6\sigma)$
$C_{pu} = (UTL - \mu)/(3\sigma)$
$C_{pl} = (\mu - LTL)/(3\sigma)$
$C_{pk} = \min(C_{pl}, C_{pu})$

This entry still needs more work.

Revised October 26, 2004. See Six Sigma.

***process control* –** See Statistical Process Control (SPC).

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.

process map (process flow chart) – 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). A good way to show the handoffs is to use "swim-lanes" – horizontal or vertical dotted lines that show where the paperwork, parts, or people in the process are "handed off" (move) from one process (organization) to another. Many industrial engineering books have a long list of special symbols that can be used to indicate inventories, decisions, actions, delays, etc. Most people find that all you really need are rectangles to show an action and diamonds to show a decision point. Revised October 12, 2004. See value stream map.

***product data management (PDM)* –** Software for product development. The best PDM systems are web-based collaborate applications for product development that allow enterprises to integrate business processes and product data with dispersed divisions, partners, and customers. The Challenge is to maximize the time-to-market benefits of concurrent engineering while maintaining control of your data and distributing it automatically to the people who need it - when they need it. The way PDM systems cope with this challenge is that master data is held only once in a secure "vault" where its integrity can be assured and all changes to it monitored, controlled and recorded. Duplicate reference copies of the master data, on the other hand, can be distributed freely, to users in various departments for design, analysis, and approval. The new data is then released back into the vault. When a "change" is made to data, what actually happens is that a modified copy of the data, signed and dated, is stored in the vault alongside the old data, which remains in its original form as permanent record. This is the simple principle behind more advanced PDM systems. (Source: www.windchill.com, http://www.pdmic.com, http://www.pdmic.com/undrstnd.html#brief)

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.

Total factor productivity = output/input (goods and services produced/resources used)

Partial factor productivity: output/labor, output/capital, output/materials, output/energy, etc.

Multi-factory productivity: output/(labor + capital + energy), output/(labor + materials), etc.
Example: Your firm consumed 2400 hours of labor to process 560 insurance forms. What is your labor productivity? Answer: 560/2400 = 0.23 hours/form.
Revised October 24, 2004. See efficiency, OEE, utilization.

***project management** – The planning, organizing, scheduling, directing, and controlling of a one-time activity to meet or exceed stakeholder-defined constraints on scope, schedule, and cost. According to the Project Management Institute's Project Management Book of Knowledge (PMBOK), "A project is a temporary endeavor undertaken to create a unique product or service."

The following is a list of project management "Laws" that Professor Hill has collected and written (with some humor). Many of these have been adapted from long lost sources. Well-managed organizations will resist the downward pull of these laws!

1. **Murphy's Law:** If it can go wrong, it will.
2. **Second Law of Thermodynamics (Law of Entropy):** All systems tend towards their highest state of disorder. (Murphy's Law is really just an application of this law.)
3. **Parkinson's Law:** Work expands to fill the time allotted to it. (Parkinson's exact wording was "Work expands so as to fill the time available for its completion.") This is only one of many laws found in his book.
4. **The Pi Rule:** All projects take π times longer than originally predicted – unless managed very carefully. (We think the completion path is a straight line -- when it's really a circle. Note $\pi \approx 3.1416$.)
5. **The optimistic time estimate law:** Projects rarely do what was promised, and are rarely completed on time, within budget, and with the same staff that started them. **Corollary a:** It is highly unlikely that your project will be the first. **Corollary b:** A carelessly planned project will take $\pi \approx 3.1416$ times longer to complete than expected – a carefully planned project will take only $e \approx 2.7183$ times as long. **Corollary c:** When the project is going well, something will go wrong. **Corollary d:** When things cannot get any worse, they will. **Corollary e:** When things appear to be going better, you have overlooked something.
6. **The last 10 percent law:** Projects progress rapidly until they are 90 percent complete. The last 10 percent then takes 50 percent of the time.
7. **Brooke's Law:** Adding people to a late project generally makes it later.
8. **The project employment law:** Projects requiring more than 18 months tend to lose their identity as a "project" and become a permanent part of the organization. **Corollary:** If the project objectives are allowed to change freely, the team might unintentionally turn the project into guaranteed long-term employment.
9. **The project charter law:** A project without a clearly written charter will be subject to scope creep -- and will help you discover many of your organization's worst political problems.
10. **The project correction law:** The effort required to correct a project that is off course increases every day it is allowed to continue off course.
11. **The matrix organization law:** Matrix organizations tend to be dysfunctional. All employees really have only one boss -- the person making their next salary decision. However, matrix organizations are essential in the modern firm.
12. **The project leader law:** A great way to sabotage an important project is to assign whoever is currently completely idle as the project leader.
13. **The technical leadership law:** The greater the project's scope and organizational complexity, the less a technician is needed to manage it. **Corollary:** Get the best project manager you can. A good project manager will find the right technical people for the project.
14. **The belief in the system law:** If the user does not believe in the system, a parallel informal system will be developed -- and neither system will work very well. **The post mortem project law:** Organizations that do not do a post-project review very well are doomed to repeat their mistakes over and over and over and over again.

Well-managed organizations will resist the downward pull of these laws! Revised October 24, 2004.

Project Management Institute's Project Management Book of Knowledge (PMBOK), is dry reading but it is the accepted standard for project management practices. The condensed version of the book can be found at the following website pmi.org/prod/groups/public/documents/info/pp_pmbokguide2000excerpts.pdf. Another source of project management knowledge is the Automotive Project Management Guide published by AIAG (Automotive Industry Action Group, website: www.aiag.org). AIAG publishes a set of books used by Ford, GM, and Daimler Chrysler for managing automotive projects and suppliers.

See CPM, critical path, critical chain, gate, load leveling, Murphy's Law, new product development, PERT, Parkinson's Laws, slack time, scope creep, and work breakdown structure.

***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.) Revised October 7, 2004. 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

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 system **–** See pull systems.

QS 9000 **–** A supplier development program developed by a Chrysler/Ford/General Motors supplier requirement task force. The purpose of QS 9000 is to provide a common standard and a set of procedures for the suppliers of the three companies.

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 circles **–** Brainstorming sessions involving employees of a firm whose goal is improving processes and process capability. These were very popular in the 1980's and early 1990's, but have since fallen out of favor and have essentially been replaced by a better understanding of how to use teams to accomplish objectives.

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.

quick response manufacturing (QRM) **–** An approach for reducing leadtimes developed by Professor Rajan Suri, Director of the Center of Quick Response Manufacturing, University of Wisconsin – Madison. See lean manufacturing, time-based competition.

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. Note that the word "queuing" can also be spelled "queueing."

The basic queuing theory equations for the single-server model with the standard assumptions about the arrival and service processes (known as the M/M/1 queue) are as follows:

- Define: μ = average processing rate (customers/period) = 1/(average service time).
  λ = mean arrival rate (customers/period) = 1/(average time between arrivals).
- Average time in system: $W_s=1/(\mu - \lambda)$
- Average time in queue: $W_q=\lambda/[\mu(\mu - \lambda)]$
- Average number in system: $L_s=\lambda/(\mu - \lambda)$
- Average number in queue: $L_q=\lambda^2/[\mu(\mu - \lambda)]$
- Utilization: $\rho=(\lambda/\mu) P(0)=1-\rho$
- Probability of n customers in system: $P(n)=(1-\rho)\rho^n$
- Probability of the time in system greater than t time periods: $P(TIS>t)=\exp(-\mu(1-\rho)t)$
- Probability of the time in queue greater than t time periods: $P(TIQ>t)=\rho\exp(-\mu(1-\rho)t)$
- Little's Law: $L_s= \lambda W_s$ (i.e., Inventory = demand rate times cycle time).

Revised October 24, 2004. See capacity, Little's law, utilization, wait time.

queue time **–** See wait time.

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. See control charts, SPC.

Radio Frequency Identification (RFID) **–** 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. The acronym sometimes used here is RFITD – Radio Frequency Identification and Tracking Devices. Although these technologies are generally used inside a plant, some interesting new options are now available to use the Internet and even satellite technologies to help with this.

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 items decrease, and (4) the demand for other products increase. All four of these issues create problems because the firm needs to reallocate space to the "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; however, random storage systems require much more information to keep track of where items are stored. With random storage, it is almost impossible for people to remember where an item is stored. Most firms use a combination of fixed and random storage systems. See fixed storage location system.

red tag **–** This is a procedure used to label parts, tools, furniture, etc. that is no longer needed. This is a natural result of a good application of the "sort" process in 5S. Note that "red tag" can be either a noun or a verb. Revised October 26, 2004. See Five S.

refurbished (refurb) **–** In a retail channel, these are products that have been returned by the customer. They are repaired if possible, tested, and repackaged for sale. They are sometimes stamped "refurb" and sold at a discount with a shorter warranty.

****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 $R = \overline{d}L + SS$, where $\overline{d}$ 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.

In order to find the safety factor (k) needed to achieve a desired (target) unit fill rate service level (SL), for a given order quantity (Q) and a given standard deviation of the demand during leadtime (σ_L), use the following series of equations: $G = (1 - SL)Q / \sigma_L$, $z = \sqrt{\ln(25/G^2)}$, $k_t = a_0 + a_1 z + a_2 z^2 + a_3 z^3$, $k_b = b_0 + b_1 z + b_2 z^2 + b_3 z^3 + b_4 z^4$, $k = k_t / k_b$, with parameters (a_0, a_1, a_2, a_3) = (−5.3925569, 5.6211054, −3.8836830, 1.0897299) and (b_0, b_1, b_2, b_3, b_4) = (1.0, −0.72496485, 0.507326622, 0.0669136868, −0.00329129114). Source: Silver, Pyke, and Peterson (1998), page 735-736. Professor Hill has tested this approximation for $0<k<5$ and found that the maximum absolute percent error is less than 1.89%.

See fill rate, periodic review system, safety stock, and service level.

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.

****respond-to-order (RTO)*** – This is term was invented by Professor Art Hill to include Assemble-to-order, Make-to-order, Engineer-to-order and many other customer-interface systems that support customization.

System	Concept	Inventory	Customer lead time	Examples
Make-to-stock (MTS)	Standard finished products are stored in inventory waiting for customer demand.	Large finished goods inventory. Usually also has WIP and raw materials.	Only the delivery time from the finished goods to the customer.	Medical devices, many consumer products, retailers.
Assemble-to-order (ATO)	Standard modules and assembled in response to a customer order.	Inventory of modules. Usually also WIP and raw materials.	Only the assembly and delivery time.	Dell computer, picking an order from a distribution center. Pack-to-order is a special case.
Make-to-order (MTO)	Standard raw materials are transformed into a final product.	Usually inventories of raw materials. It is possible to implement with no inventory.	Fabrication, assembly, and delivery time. This could also include time to purchase raw materials.	Customized clothing, injection-molded parts. Print-to-order is a special case.

Engineer-to-order (ETO)	A design is developed and produced for a particular customer need.	Potentially no inventory. Could inventory standard modules and raw materials.	Design, fabrication, assembly, and delivery time.	Custom home construction.

See Assemble-to-Order, Engineer-to-Order, Make-to-order, Print-to-order, Pack-to-order, Configure-to-order, Make-to-Stock, service level.

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 engineering **–** The process of dismantling a competitor's products to understand the strengths and weaknesses of the designs.

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.

Reverse logistics involves managing movement of goods, and related information, from the points of consumption towards upstream facilities in a manufacturing or service system. These reverse flows are common in a variety of industries, such as consumer goods, reusable components, and packaging material. Returned items can be directly reused, repaired, recycled, re-manufactured or disposed. Recently, integration of the forward and reverse logistics activities attracted considerable attention, resulting in a growing body of literature on closed-loop supply chains.

See remanufacturing. Similar terms include "return logistics."

RFID **–** See Radio Frequency Identification.

risk assessment **–** The identification and evaluation of nearly all possible causes (modes) of failure. For each mode the evaluation considers (1) what can go wrong, (2) how likely it is to occur, and (3) what are the consequences of the failure. See FMEA, risk mitigation.

risk mitigation **–** Actions taken to (a) prevent a potential failure and (b) lower the impact of a potential failure. Part (b) includes planning the means by which recovery should be implemented. Created May 18, 2004. See FMEA, risk assessment.

****robust*** – The dictionary definition for "robust" is "full of health and strength, vigorous, sturdy." In an operations or engineering context, robust 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." A process is said to be "robust" if it is hard to break. If a part is very sturdy and almost never breaks, it too is said to be robust. Robust design is "designing such that an increase in variability will not result in defective products." Revised May 18, 2004. See commonality, FMEA.

runtime **–** The time required to produce a single part or product. The total runtime for an order is the batch size times the runtime. Revised May 18, 2004. See setup time.

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.

Sales and operations planning is the set of vital communications and decision-making processes for developing a company game plan that balances market demand with resource capability. A working Sales and Operations Planning process provides a way to draw out functionally conflicting objectives and resolve them so as to develop a true manufacturing/marketing contract, integrate all functions of the business by developing a "single set of numbers" from which all other plans and schedules can be developed, and provide a forum for evaluating company performance. (Source: http://www.grayresearch.com/sopworks.htm, January 1, 2003.)

The main reference on this subject is Ling, Richard C., and Walter E. Goddard, ***Orchestrating Success: Improve Control of the Business with Sales & Operations Planning***, John Wiley & Sons, 1995.

The first paragraph on Page 5 of ***Orchestrating Success*** follows (with apologies for the sexist language): Any good general manager can harmonize his company through a process called "Sales and Operations Planning," in which he meets with his top managers on a regular and frequent basis to update plans for all departments. The plans take into account projections made by the sales and marketing departments, the resources available from manufacturing, engineering, purchasing, and finance, and are directed toward hitting the company's objectives. Sales & Operations Planning is done on an "aggregate" or "family" level, and covers a sufficient span of time to make sure that the necessary resources are available. The approved aggregate plans drive the individual departmental plans. Each month – or more frequently if the market conditions are volatile – the representatives meet again to determine whether the overall company plan is on course, and to adjust for changes in the marketplace and changes or problems within the company.

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. Safety capacity is not just having too much capacity; it is capacity that is not actually working, but can be called to work in case of emergency. Note that safety capacity is very different from safety stock. Revised October 25, 2004. See capacity, 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.

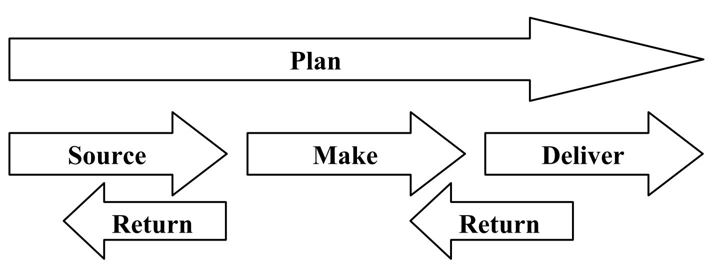
****safety stock (buffer stock)*** – The average inventory on hand when an order is received. Most textbooks and most firms define safety stock in terms of the standard deviation of demand during the replenishment leadtime. However if the firm has forecasting system with the variance of the forecast error during the leadtime less than the variance of the demand during the leadtime, the safety stock should be a function of the standard deviation of the forecast error during the leadtime. However, many firms either do not understand this concept, or have bad forecasting systems, or both. Revised October 25, 2004. 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. Scope creep is reflected in requirements changes that enter into a project after baselining without the baseline being changed to reflect the change in requirements. Revised October 25, 2004. See project management.

SCOR model – The Supply-Chain Operations Reference-model (SCOR) is a process reference model that has been developed and endorsed by the Supply-Chain Council as the cross-industry standard diagnostic tool for supply-chain management. SCOR enables users to address, improve, and communicate supply-chain management practices within and between all interested parties. The SCOR framework attempts to combine elements of business process design, best practices, and benchmarking. The basic model can be found below. An overview can be found at http://www.supply-chain.org/slides/SCOR5.0OverviewBooklet.pdf. The main website for the Supply Chain Council is http://www.supply-chain.org/public/scor.asp. Revised October 25, 2004. See Supply Chain Council, value chain, bullwhip effect, supply chain management.

The SCOR model



scrap – The number units of products or raw material that are defective and cannot be sold or reworked to produce saleable product. Material outside of specifications and possessing characteristics that make rework impractical.

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 blueprinting – A service blueprint describes a service in enough detail to implement and maintain it. During the process design stage, business process managers, architects, interior designers, marketing managers, operations managers, and IT professionals use the blueprint to guide the design process. After the design is complete and implemented, the blueprint defines the required features and quality of the service for the service managers. Some recommended steps for service blueprinting include:

1. Clearly identify the targeted customer segment.
2. Develop a process map from the customer's point of view. This should include the choices the customer needs to make when they buy, use, and assess the service. It should also include all activities, flows, materials, information, failure points, and customer waiting points (queues).
3. Map employee actions, both onstage and backstage -- This involves drawing the lines of interaction and visibility then identifying the interactions between the customer and employee and all the visible and invisible employee actions.
4. Link customer and contact person activities to needed support functions -- This involves drawing the line of internal interaction and linking the employee actions to the support processes.
5. Add evidence of service at each customer action step -- This involves showing evidence of the service that the customer sees and receives at each point of the service experience.

The service blueprint should show all points of interaction between the customer and service providers (known as "moments of truth"), identify "fail points" and the "line of visibility," and should include fairly precise estimates of the times required for each step, including the queue times. The line of visibility separates a service operation into back office operations that take place without the customer's presence and front office operations in direct contact with the customer. Some people argue that the only real difference between a normal process map and a service blueprint is the identification of the fail points and the demarcation of the line of visibility.

The advantages of a service blueprint over a verbal description is fairly obvious – the service blueprint is more formal, structured, detailed, and shows the interactions between processes. The blueprint provides a conceptual model that facilitates studying the service experience prior to implementing it – and makes the implementation much easier.

See experience engineering, moments of truth, service failure, and service guarantee. Updated October 4, 2004.

****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. A carefully defined service guarantee can have the following benefits:

1. Defines the value proposition for both customers and employees.
2. Supports marketing communications (e.g., advertising) in attracting new customers, particularly those who are risk-adverse.
3. Helps the service firm retain "at risk" customers.
4. Lowers the probability that dissatisfied customers will share negative "word of mouth" reports with others.
5. Motivates customers to provide useful process improvement ideas.
6. Motivates service firm employees to learn from mistakes and to improve service process over time.
7. Clearly predefines the service recovery process for both the customer and the employee.
8. Ensures that the service recovery process does not surprise the customer.

Professor Hill's research has found that a service guarantee often has more value for operations improvement than it does for advertising.

A service guarantee is generally applied to customers serving external customers, but it can also be applied to internal customers as well. However, service guarantees are not without risk. Offering a service guarantee long before you are ready can lead to serious problems. Announcing the withdrawal of a service guarantee is tantamount to announcing that you are no longer committed to quality. 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 a promise relating to the physical attributes of the product (durability, physical performance, etc.). Product warranties are very similar to service guarantees from a legal perspective and have many of the same benefits and risks. See Professor Hill's service guarantee research website for further articles and the SG.xls Excel workbook for an analysis tool.

Revised May 14, 2004. See service quality, service recovery, and warranty.

service level – For a **make to stock** (MTS) product, the service level is the percent of the units (or lines or orders) that are immediately available from stock. The order fill rate is sometimes called the percentage of orders shipped complete. Some 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 has little relevance to practical inventory management. Some retail firms use a measure of the time that the inventory is stock (or out of stock). See fill rate and perfect order.

A **respond-to-order** (RTO) product is assembled, built, fabricated, cut, mixed, configured, packaged, picked, customized, printed, or engineered in response to a customer's request (order). The **customer leadtime** for a respond-to-order product is the actual time between the order receipt and the delivery to the customer. Customer leadtime, therefore, is a random variable that has a mean, mode, standard deviation, etc. The **planned leadtime** (or planned customer leadtime) is usually a fixed quantity, which may be conditioned on some attribute of the order (quantity, complexity, routing, materials, size, etc.). For example, a firm might offer a two-week leadtime for standard products, and a three-week leadtime for non-standard products. The **service level** for respond-to-order systems is measured in terms of on-time delivery (OTD). OTD is the percent of orders received (or shipped) within the promise date (or request date). Ideally, a firm should compute OTD based on the customer request date. The promise date may or may not satisfy the customer's requirements. Most firms find this difficult to implement and therefore use only the promise date. This is complicated by the fact that the promise date can be "updated" as the situation changes. In other words, it is possible that the promise date is updated (e.g., revised, manipulated) so that orders are rarely late. Ideally, a firm should compute OTD from the customer's perspective. Therefore, firms should measure OTD based on the customer receipt date rather than the ship date. However, most firms do not have access to the customer receipt date information, and therefore measure OTD against their shipping dates -- and then hold their distribution/transportation partners responsible for their portion of the customer lead time. OTD can be improved by either (1) setting a very long planned customer to make safer promises (e.g., promise 20 weeks instead of two weeks), or (2) reducing the mean and/or variance of the manufacturing leadtime. The first alternative can have a negative impact on the demand. The second alternative requires Six Sigma thinking to reduce the mean and variability of the customer leadtime. Professor Hill has written research articles and white papers on related topics such as the leadtime elasticity of demand and finding the "optimal" customer leadtime to offer to the market.

Some academics define additional measures for respond-to-order products such as the mean and standard deviation of lateness, earliness, and tardiness. Defining A as the actual delivery date (or time) and D as the due date (or time) for a particular order, lateness is defined as $D-A$, earliness is defined as $\max(D-A, 0)$, and tardiness is defined as $\max(A-D, 0)$. Using more sophisticated mathematical notation, earliness=$(D-A)^+$ and tardiness=$(A-D)^+$, where $(x)^+=\max(x, 0)$. Note that lateness can be either positive or negative. Negative lateness means that the delivery is early.

See fill rate, make-to-stock, respond-to-order.

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 reasons, 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. Revised May 18, 2004. See runtime, 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 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, which means that the computer processes one "event" at a time, schedules the next event, and then goes to the next event in time order. In contracts, continuous simulation models are used to represent the movement of continuous variables changes continuously over time (e.g., the course of a rocket in flight). Simulation models can be categorized into deterministic and stochastic. Deterministic simulations always produce exactly the same results, and therefore, only need to be "run" once. On the other hand, stochastic simulations generate random variables and allow the user to explore the variability of the system. For example, a financial planning model might specify the mean and standard deviation of the demand and the mean and standard deviation of the unit cost. The simulation model might be run for many, many replications in order to compute the net present value of a number of different strategies. Stochastic simulations are also known as Monte Carlo simulations. Note that Monte Carlo simulations do not require a time dimension. For example, we could have a Monte Carlo simulation of the results of rolling two die several million times.

****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, and (5) the company benefits from a reduced cost of service delivery in a "once and done" environment.

****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.

SIPOC Diagram – A SIPOC diagram is a tool used by a team to identify all relevant elements of a process improvement project before work begins. It helps define a complex project that may not be well scoped, and is typically employed at the Measure phase of the Six Sigma DMAIC methodology. It is similar and related to Process Mapping. The name prompts the team to consider the Suppliers (the "S" in SIPOC) of your process, the Inputs (the "I") to the process, the Process (the "P") your team is improving, the Outputs (the "O") of the process, and the Customers (the "C") that receive the process outputs. See process map, supply chain management.

(Source: isixsigma.com/library/content/c010429a.asp.)

****Six Sigma*** – Six sigma has both a tactical and a strategic definition. At a strategic level, Six Sigma involves a firm assigning its best people to address the firm's most important strategic problems. At a tactical level, Six Sigma involves projects that follow a disciplined process to address problems. Most successful Six Sigma applications involve both the strategic and the tactical viewpoints.

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.

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, usually called DMAIC -- Define, Measure, Analyze, Improve, and Control.

D	Define	Requirements, Goals, Problems, Scope
M	Measure	Validate problem, inputs, key steps, efficiency data
A	Analyze	Develop/validate hypothesis, identify root causes, assess process design
I	Improve	Remove root causes, standardize solutions, implement new process
C	Control	Establish standard measures and reviews to maintain performance

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 are normally assigned to manage Six Sigma projects full-time for a limited period (normally two years); and (c) ***greenbelts*** who are team members with between two and four weeks of training. Certification programs for these roles are now available.

Four-sigma represents an average performance level across many industry sectors. This translates into some rather alarming performance standards:

- 20,000 lost articles of mail per hour
- Unsafe drinking water almost 15 minutes per day
- 5,000 incorrect surgical operations per week
- 2 short or long landings at most major airports each day
- 200,000 wrong prescriptions each year
- No electricity for almost 7 hours each month

See Design for Six Sigma, entitlement, lean manufacturing, TQM.

****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.

SOP – Standard operating procedures. Work standards. Revised October 26, 2004.

SPC – See statistical process control.

spaghetti chart – A chart that shows the travel paths for one more products (or people) that travel through a facility. The numerous colored lines make it look a little bit like a bowl of spaghetti. This tool helps identify opportunities for reducing travel time in the process. Revised October 26, 2004.

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.

stage-gate process – In project management and in new product development, a stage-gate (phrase review or simply a "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.

A process typically used in projects where significant investment is being made, such as capital improvements or new product development programs. Stage-gate processes are especially useful when the level of investment increases with subsequent decision points. The process is composed of stages and gates, hence the name. A stage is the time between gates, typically with activities and deliverables. A gate is a decision point where the merits and progress of the project are evaluated before further progress is allowed. Examples of stages from the Advanced Product Quality Planning (APQP) process of the Automotive Industry Action Group (AIAG) are: Concept Approval, Program Approval, Prototype, Pilot, and Launch. Typical decisions at gates include: go forward, redirect, hold, or kill the project.

A typical stage-gate process is as follows:

- Stage 1: Business Analysis -- A product concept that addresses a market need is identified.
- Stage 2: Commitment -- The technical feasibility of the product concept is determined and design requirements are defined.

- Stage 3: Development-- Includes all the activities necessary to design, document, build, and qualify the product and its associated manufacturing processes.
- Stage 4: Evaluation -- Final design validation of the product is conducted per evaluation plans during this Phase. Clinical and/or field studies are conducted and regulatory approval to market and distribute the product is also obtained.
- Stage 5: Release -- The product is commercially distributed in markets where regulatory approval has been obtained.

***statistical process control (SPC) –** A tool used to monitor the performance of an operation to determine if it is in "control" or not. The tool usually is implemented using graphical methods to check if the process performance is within the upper and lower control limits. Ideally, the control charts will detect all special (unusual) causes of variation and ignore normal variation. See acceptance sampling, c-chart, control charts, p-chart, r-chart, x-bar chart.

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 sample 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 $n-1$ in the denominator.

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.

standardization – Ensuring the workers perform tasks consistently in the same manner, usually to ensure safety, productivity, and quality.

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 system. Starving a non-bottleneck process generally has few consequences for the overall output of the system. Starving at a non-bottleneck process signals that we should use that worker somewhere else in the process. Starving at a bottleneck resource occurs because of a disruption at an upstream process – or simply because of poor planning and improper priorities.

strategy map – A strategy map is a cause and effect diagram that shows the relationships between the critical elements of the organization's business system. Kaplan and Norton proposed strategy maps as a tool for communicating the critical relationships and metrics needed to understand and implement the organization's strategy. Relationships in a strategy map often include:

- 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 an example. See cause and effect diagram.

stickiness – The ability of a website to hold the attention of the visitor. This is generally accomplished through intriguing, useful, and/entertaining content.

****stock keeping unit (SKU)*** – Sometimes called a part number or an item number, an SKU is a unique identification number (or alphanumeric string) that defines an item for inventory management 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 a part number is used to identify the "generic" item, but the SKU is used for recording the inventory count for that part number 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. In addition, 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.

story board – Large, visual communications of important information and key points. Consultants often talk about their "story board" for a PowerPoint presentation. This is just a high level overview of the main points that they want to make in their presentation.

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. See dock-to-stock.

supplier managed inventory – See vendor managed inventory. Revised November 7, 2004.

Supply Chain Council – A non-profit organization formed in 1996 to develop and standardize supply chain concepts. www.supplychain.org. PRTM (a consulting organization) was heavily involved with this along with a number of firms. The Supply Chain Council is famous for its "SCOR" model. See SCOR.

****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 SCOR model, value chain, bullwhip effect.

supply chain view – The view that competition is not firm against firm, but supply chain against supply chain.

****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 USA. (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 – "Takt" is the German word for a baton that an orchestra conductor uses to regulate the beat for the orchestra. Similarly, takt time is the "beat time" or "heart beat" of a factory. Lean production uses takt time to set the production rate for a product. For example, if a factory has a takt time of two minutes, it should complete one unit every two minutes (on average). Takt time should be set by the customer demand rate, and should be adjusted when the market demand rate changes. If the Takt time and the customer demand rate do not match, the firm (and the supply chain) will have either too much inventory or poor service. (Source: A few of these ideas were taken from isixsigma.com/dictionary/Takt_Time-455.htm, March 9, 2004.)

In summary, takt time is simply the inverse of the target production rate. If you are selling 100 units per day, then your target production rate should be 100 units per day. If you are working an 10 hour operation, then your production rate should be 100 units/10 hours = 10 units/hour. Taking the inverse of this gives you a takt time of 0.1 hours/unit.

Do not confuse takt with cycle time or throughput time. It is possible to have a very long cycle time (say 6 weeks), but still have a takt time of 5 seconds. Takt time is the time between completions – the time between units "falling off of the end of the line." Cycle time is generally defined as the total throughput time.

Revised September 13, 2004. See cycle time, lead time.

****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?

***target inventory* –** See periodic review system.

***terms* –** A statement of a seller's payment requirements. Included would be discounts for prompt payment, if any, and the maximum time allowed for payment. See FOB. Updated April 20, 2004.

****time in system* –** See queuing theory, waiting time.

***total cost of ownership* –** The total cost of ownership includes all of the costs that a customer incurs from before the purchase until the final and complete disposal of the product. These costs include the acquisition, purchasing administration, shipping, expediting, inspection, rework, scrap, maintenance and repair, service, downtime, and disposal.

***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.

The three primary TOC metrics are (1) throughput (T), (2) inventory (I), and (3) operating expenses (OE). Throughput is defined as sales revenue less direct materials per time period. Inventory is defined as direct materials at materials cost. Operating expenses include both labor and overhead. Better bottleneck management will generally result in increased throughput, reduced inventory, and the same or better operating expense.

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:

- 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)

Revised October 24, 2004. See Professor Hill's whitepaper on Theory of Constraints. See blocking, critical chain, drum-buffer-rope, lean manufacturing, setup cost, setup cost reduction methods, starving.

throughput accounting – Accounting principles based on the 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 contribute to this goal by managing three variables:

- Throughput (T) = Revenue less materials cost less out of pocket selling costs. Note that this is a rate and is not the same as the throughput time.
- Inventory (I) = Direct materials cost and other truly variable costs with no overhead.
- Operating expenses (OE) = Overhead and labor cost (the things that turn "I" into "T")

Throughput accounting is a form of contribution accounting, where all labor and overhead costs are ignored. The only cost that is considered is the direct labor 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.

Revised October 11, 2004. See theory of constraints. See Professor Hill's whitepaper on throughput accounting.

***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 Box-Jenkins, exponential smoothing, linear regression.

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. Revised October 26, 2004. See lotsizing techniques, 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. Many of the best firms use TPM to increase operator and team member involvement in the inspecting and cleaning of productive equipment. TPM will improve Overall Equipment Effectiveness.

Some indications that a TPM program might be needed include:

- Emergency maintenance – Frequent emergency maintenance.
- Breakdowns – Long interruptions.
- Repair cost – Expensive repairs.
- Setup and changeover – Taking much longer than needed.
- Idling and minor stoppages – Hard to quantify, add up to big losses.
- Reduced speed – Equipment cycle times have gradually deteriorated.
- Defects and rework – Quality losses and unhappy customers.
- Startup losses – Too long to get to steady state after a change.

(This list was adapted from www.mfgeng.com/TPM.htm, April 14, 2004.)

See autonomous maintenance, Overall Equipment Effectiveness (OEE), preventive 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 inspection, Six Sigma, SPC, Zero Defects.

Toyota Production System (also called the Toyota Manufacturing System) – A relative new approach to manufacturing developed by Eiji Toyoda and Taiichi Ohno at Toyota Motor Company in Japan. The system includes a Kanban system for Just-in-time production, set-up time reduction for flexibility, system flexibility through machine layout and worker training, continuous improvement using quality circles and SPC, lean manufacturing through the reduction of muda, and a visual control system to achieve the autonomation. See autonomation, lean manufacturing, and muda, just-in-time.

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 $MAD = \sum_{t=1}^{t=T} |E_t| / T$, 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 following machines. The smaller batch sizes are called "transfer batches" whereas the larger batch produced on the first machine is called a "production batch." 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 problem used to be called the "Traveling Salesman Problem." This is one of the most studied problems in all of operations research and many methods are available for solving the problem. The methods can be divided in to optimal ("exact") methods and heuristics. While optimal methods are guaranteed to find the best (lowest cost or lowest travel time) solution, the computing time can be extremely long. On the other hand, heuristic methods are generally very fast computationally, but may solutions that are far from optimal. 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.")

Extensions of the problem include the multiple-vehicle 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.)

The mathematical programming formulation of the problem is:

$$\text{Minimize} \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}x_{ij}$$

$$\sum_{i=1}^{n} x_{ij} = 1 \quad \text{for } \forall_j , \qquad \sum_{j=1}^{n} x_{ij} = 1 \quad \text{for } \forall_i$$

$$y_i - y_j + (n-1)x_{ij} \le n-2 \qquad \forall_{(i,j), j \neq \text{depot}}$$

$$x_{ij} \in \{0,1\} \quad \text{for } \forall_{i,j}$$

where, c_{ij} is the cost (time or distance) to travel from city i to city j and x_{ij}=1 if node i immediately follows node j in the tour and x_{ij}=0 otherwise.

***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 for the demand. One simple way to estimate this is with simple linear regression using time as the "*x*" variable. Revised November 11, 2004. See exponential smoothing, forecasting.

TS 16949 quality standard – Beginning in 1994 with the successful launch of QS 9000 by DaimlerChrysler, Ford and GM, the Automotive OEMs recognized the increased value that could be derived from an independent quality system registration scheme and the efficiencies that could be realized in the supply chain by "communizing" system requirements. In 1996, the success of these efforts led to a move towards the development of a globally accepted and harmonized quality management system requirements document. From this, the International Automotive Task Force (IATF) was formed to lead the development effort. The result of the IATF's effort is the ISO/TS 16949 specification. ISO/TS 16949 forms the requirements or the application of ISO 9001 for automotive production and relevant service part organizations. ISO/TS 16949 used the ISO 9001 Standard as the basis for their development and included the requirements from these Standards with specific "adders" for the automotive supply chain. The 2002 revision of TS builds off the ISO9001:2000 document. Source for the above is: http://www.ul.com/services/ts16949.html. Revised November 11, 2004. See ISO 9000.

two-bin system – A two-bin inventory system is a very simple visual min-max 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, the min) is opened, an order is placed to fill up both bins. It is a good idea to put a lock on the reserve bin in order to make sure that the ordering discipline is enforced. Revised November 11, 2004. See reorder point system.

unit of measure – The standard method for counting an item used for inventory records and order quantities. This can be very tricky when a "package" is inside a package, which is inside a package. Revised November 11, 2004. See inventory management.

****utilization*** – The percent of the available work time that a resource is busy. High utilization is often a bad goal. This is because utilization and service (customer wait time or inventory) often require tradeoffs. For example, the ideal utilization for an emergency vehicle such as a fire engine is close to zero. Revised November 11, 2004. See capacity.

value chain –** Michael Porter's Value Chain Analysis describes the activities that take place in a business and relates them to an analysis of the competitive strength of the business. Porter suggested that the activities of a business could be grouped under two headings: (1) **Primary Activities** - those that are directly concerned with creating and delivering a product (e.g. component assembly); and (2) **Support Activities**, which whilst they are not directly involved in production, may increase effectiveness or efficiency (e.g. human resource management). It is rare for a business to undertake all primary and support activities. The concept was first communicated in Porter's text (Porter, Michael E., ***Competitive Advantage, London, Free Press, 1985.) According to Porter, the primary value chain activities are:

1. **Inbound Logistics** – All relationships with suppliers and include all the activities required to receive, store, and disseminate inputs.
2. **Operations** - All activities required to transform inputs into outputs (products and services).
3. **Outbound Logistics** - All activities required to collect, store, and distribute the output.
4. **Marketing and Sales** – All activities to inform buyers about products and services, induce buyers to purchase them, and facilitate their purchase.
5. **Service** - All activities required to keep the product or service working effectively for the buyer after it is sold and delivered.

Secondary activities are:

1. **Procurement** - Acquisition of inputs, or resources, for the firm.
2. **Human Resource management** - All activities involved in recruiting, hiring, training, developing, compensating and (if necessary) dismissing or laying off personnel.
3. **Technological Development** - Equipment, hardware, software, procedures, and technical knowledge brought to bear in the firm's transformation of inputs into outputs.
4. **Infrastructure** - Serves the company's needs and ties its various parts together, it consists of functions or departments such as accounting, legal, finance, planning, public affairs, government relations, quality assurance and general management.

Porter suggests that firms can gain competitive advantage through either cost leadership or differentiation. In a **cost leadership** strategy, a firm sets out to become the low cost producer in its industry. The sources of cost advantage are varied and depend on the structure of the industry. They may include the pursuit of economies of scale, proprietary technology, preferential access to raw materials, and other factors. In a **differentiation** strategy, a firm seeks to be unique in its industry along some dimensions that are widely valued by buyers. It selects one or more attributes that many buyers in an industry perceive as important, and uniquely positions itself to meet those needs. It is rewarded for its uniqueness with a premium price.

Value chain analysis can be broken down into a three sequential steps:
(1) Break down a market/organization into its key activities under each of the major headings in the model.
(2) Assess the potential for adding value via cost advantage or differentiation, or identify current activities where a business appears to be at a competitive disadvantage.
(3) Determine strategies built around focusing on activities where competitive advantage can be sustained.
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, SCOR model.

***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.

A statement of differentiated and timely value of a product or service, which meets a need or solves a problem for an individual customer or group of customers. It consists of a package of benefits from which a customer is persuaded that he/she derives greater value than from a competitor's offering. In an economic sense, the value proposition is the sum of features divided by the life-cycle cost. Simply stated it is what you offer to your markets and customers.

****Value stream analysis/value stream mapping*** – Value Steam Analysis is based on the Material and Information Flow maps developed at Toyota and later adapted as Value Stream Mapping by James Womack's Lean Enterprise Institute in the ***book Learning to See***. Value Stream Mapping is a visual tool that graphically identifies every process in a product's flow from "door-to-door," giving visibility to both the value-adding steps as well as the non-value-adding steps. The processes that create value are thoroughly detailed for complete process flow of a particular product or product family. The current state is drawn from observation and data gathering of the actual processes. This exercise makes the waste and redundancy very clear. Based on lean principles and World Class benchmarks we define the Future State Map and ultimately a road map for a Lean Enterprise. Value stream analysis activities include:

1. Review demand profile (Pareto Chart, histogram)
2. Conduct flow analysis (Parts process matrix, Spaghetti diagram)
3. Calculate takt time (peak demand, average demand)
4. Value Stream Mapping (Material & Information Flow diagram using Learning to See format, Current State and Future State Gap Analysis)
5. Deliverables (Current State Map, Future State Map, Change loops and kaizen breakthroughs, Vision for the Lean Transformation, Implementation plan)

Benefits claimed for Value Stream Mapping include:

- Helps break down communication barriers.
- Provides the basis for an implementation road map.
- Identify waste so it can be eliminated thereby improving customer satisfaction.
- Creates a vision of the future by uncovering wastes and opportunities to create flow and making them visible to all.
- Enables broad participation in shaping the future.
- A greater understanding of product cost.
- A clear picture of manufacturing processes.
- A reduction in work in progress (WIP).
- A reduction in production lead-time.
- Faster response to demand charges.
- Faster response to quality concerns.
- An emphasis on pull from the customer.
- An increase in value added contribution.
- Standardization of the production process.

Adapted from bec.msoe.edu/course_offerings/ValueStreamMapping.shtml (June 4, 2003), industryforum.co.uk/products/value.shtml (January 21, 2004), kaizen-consulting.com/aim_vsm.htm (January 21, 2004), and from other sources. Updated June 2, 2004. See process map.

****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. Our suppliers not only supply us goods – but they also manage our inventory so that we can both benefit.

Vendor Managed Inventory (VMI) is a supplier/customer agreement in which the supplier is responsible for maintaining the customer's inventory levels. The supplier has access to the customer's inventory data and is responsible for generating purchase orders. In a typical supplier/customer relationship, the customer evaluates its own inventory position and places an order when it believes it is time. With VMI, the supplier generates the order not the customer. VMI is sometimes called "Supplier Managed Inventory" (SMI). To some, the word "vendor" connotes a distant, non-partner, almost adversarial relationship, whereas the word "supplier" connotes a closer relationship. VMI does not change the ownership of inventory. With consignment inventory, the supplier retains ownership of the inventory and payment is not made until the item is sold.

In VMI, the normal trading relationship is reversed. Instead of the customer managing its own stock and deciding when and how much more to buy, the supplier does it. For many of the companies that have tried it, VMI has produced remarkable results: sales, service and profitability are better by turning the tables on which trading partner does the supply planning.

With VMI the supplier provides not only items but also provides inventory management services for the customer. These services might include deciding when and how much to replenish in order to satisfy mutually agreeable service levels (fill rates). This practice is sometimes called continuous replenishment or Quick Response. However, some would argue that continuous replenishment is broader because it focuses on the use of point of sale customer data to trigger warehouse shipping, whereas VMI focuses on the manufacturer or distributor taking responsibility for the inventory in a customer's facility.

Today there is a sharp spike of interest in VMI. KPMG surveyed a cross section of large Canadian companies at all stages of their supply chain and found that more than 75% are keenly interested in VMI. They are either doing it already, about to start, or looking at it closely. In fact, the interest in VMI is worldwide. KPMG offices are reporting strong interest in Europe, the U.S., and the Asia Pacific region.

VMI is not new: What we are calling VMI today has been going on for quite a long time. Several examples include:

1. Supermarkets and vending machines have used this concept for decades.
2. Military has used it for maintenance of Air Force base flight line maintenance.
3. Frito Lay's drivers/salespersons stock the shelves for their small retail customers to keep the shelves full, the product fresh, and the paperwork simple. Much fresh product moves into convenience shops in the same way.
4. Hopson Oil, a home heating oil jobber, automatically schedules deliveries for fuel oil based on consumption forecasts for each customer, and has for more than 20 years. In this way, they keep their order-taking costs down and keep it simple for their customers, who need not order competing fuels.

As the examples show, many suppliers have looked after tracking inventory and ordering for customers who are too small to have inventory systems of their own, or have done it as a value added service for larger customers. The same motivations are at work today.

VMI Implementation: VMI is relatively easy to implement. The ready availability of EDI, bar-coding, cheap computing power and good software from companies such as Manugistics, Demand Solutions and E3 means that the technical aspects can be pretty well routine. There are two recurring obstacles to a successful VMI program, one is strategic, and the other is operational. At the strategic level, a high level decision must be made about how the company wants to position itself. Are there benefits to stronger supply chain co-operation? If so, has a high level decision been made to share the necessary information? Operationally job functions, processes, and performance measurements will all need to change in order to get the most benefit. Resistance will be felt from employees who fear change.

Pros for VMI:

- Fosters co-operation in the supply chain - forms partnerships and cross-functional lines of communication that can help to improve the pipeline process and relationships. A true partnership is formed between the supplier and the customer. They work closer together and strengthen their ties.
- Fast way to improve results - can be implemented in a short amount of time and provide considerable benefits over existing performance.
- Maximizes in stock position - can increase customer service levels and reduce stock-outs through better understanding of demand and more sophisticated inventory policies.
- Reduces overall supply chain costs - a fresh look at supply chain processes will identify shortcomings and better information helps to smooth demand and reduce inventory.
- Sales are higher for vendor and customer - increased service levels will maximize in stock positions and notch up sales levels.
- Both parties are interested in giving better service to the end customer. Having the correct item in stock when the end customer needs it, benefits all parties involved.
- Data entry errors are reduced due to computer-to-computer communications. Speed of the processing is also improved.
- A reduction in customer ordering errors (which in the past would probably lead to a return)
- The goal is to have an improvement in fill rates from the supplier and to the end customer. In addition, a decrease in stockouts and a decrease in inventory levels.
- Planning and ordering cost will decrease due to the responsibility being shifted to the supplier.
- The overall service level is improved by having the right product at the right time.

- The supplier is more focused than ever in providing great service.
- Visibility to the customer's Point of Sale data makes forecasting easier.
- Promotions can be more easily incorporated into the inventory plan.
- Visibility to stock levels helps to identify priorities (replenishing for stock or a stockout?). Before VMI, a supplier has no visibility to the quantity and the products that are ordered. With VMI, the supplier can see the potential need for an item before the item is ordered.

Cons of VMI:

- Vendor's administrative costs increase -- vendor's responsibilities increase and more work needs to be done.
- Hard to use with volume discounts and special pricing -- alternate pricing strategies will have to be worked out to the agreement of both parties.
- Complicates the system in the short run -- new systems can start immediately but roles of employee, vendor, and customer may be unclear at first.
- Retailer risks loss of control/flexibility -- especially when procedures are new, understanding and ability to control procedures is low.
- Manufacturer takes one-time volume reduction -- inventory is withdrawn from the supply chain, which reduces production requirements.
- Minimal benefits for manufacturer until critical mass -- manufacturers do not integrate DRP into MPS or MRP until 50% of overall sales volume is through VMI.
- EDI problems: Extensive EDI testing should be done to validate the data being sent. Is the distributor sending all the data that should be sent? Is each field populated with the correct data?
- All employees involved in the process may not fully understand and accept this new way of doing business. It is not enough to just sell the concept to senior management; all employees who are involved must be willing participants.
- Promotions and special events can cause major problems. Anything that adds or takes away from the normal ordering pattern must be properly communicated.
- Any large customers, either gained or lost, must be communicated to the supplier. The customer must guide the manufacturer on how this will affect sales.
- An agreement must exist between the supplier and the customer on what to do if an overstock does occur (or in the case of an ordering error). In addition, both parties must agree on how to handle obsolete stock.
- Both parties involved must understand that this is a learning process. Errors will occur. Firms will not have a perfect process in place on day one.

Conclusions: Although VMI is not a new concept; it has grown dramatically in the last few years. Firms, researchers, and consultants are still trying to figure out when and where it is most applicable. However, it is clear that many firms have been able to gain significant benefits when VMI concepts are applied carefully.

References: Johnson, George, "Vendor-Managed Inventory," ***APICS Performance Advantage***, June 1998, pp. 30-32. This article provides an extensive bibliography.

See Professor Hill's whitepaper on vendor managed inventories.

Revised November 7, 2004. See delegation, JIT II, outsourcing, supply chain management.

***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.

***visual control* –** One of the main points of lean manufacturing is that we need to have very simple visual systems. Visual controls are simple easy-to-see clues that give managers and workers information about the status of a system. For example, a shadow board shows that all of the tools are present. In contrast, a computer control system often requires that we have to find and read the right screens. See lean manufacturing.

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. Revised October 26, 2004.

voice of the customer (VOC) – Getting information from customers about their perspective on a product or process design issue. Revised October 26, 2004. See quality function deployment.

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.

****wait time (waiting time, queue time)* –** A random variable that is the time that a customer (or an order) is delayed before starting in service. The average wait time (queue time) is an important system performance measure. A similar measure is the time in system. The time is system is just the wait time (queue time) plus the time in service. The average time in system is just the average queue time plus the average service time. These concepts are all taught in the discipline of queuing theory. In the lean manufacturing literature, all wait time is considered to be wasteful. See Little's Law, queuing theory, utilization.

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)

***warranty* –** A guarantee given from the seller to the purchaser that a product is reliable and free from known defects and that the seller will, without charge, repair or replace defective parts within a given time limit and under certain conditions. From Old North French, from feminine past participle of warantir, to guarantee. (Source: Adapted from dictionary.com, May 14, 2004.) Here are two good research articles on the subject:

Blischke, W.R., and D.N.P. Murty, 1992. Product warranty management – I: A taxonomy of warranty policies, ***European Journal of Operational Research*** 62 (2), 127-148.

Murty, D.N.P., and W.R. Blischke, 1992. Product warranty management – II: An integrated framework for study, ***European Journal of Operational Research*** 62, 261-281.

Definition added May 14, 2004. See product design, service guarantees.

waterfall – This term is used in project management and new product development to suggest that a steps is not started until the previous set of steps is complete. In other words, the steps do not overlap and are non-iterative. The term is often in the software development process. The waterfall process only works well when with a full specification, well-structured and well-understood domains. The opposite of this is concurrent engineering. See project management, concurrent engineering, and new product development. Updated April 20, 2004.

***way bill* –** A shipping document identifying shipper, date of shipment, carrier, number of parcels, weight, receiver and date received. See FOB, terms. Updated April 20, 2004.

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 has been started but is not yet complete in the factory. This includes orders in queue waiting to be started, orders being setup, orders currently being run, and orders waiting to be moved to the next operation. WIP inventory is usually valued as the sum of the direct labor, materials, and overhead for all operations that have been completed. Some factories assign manufacturing overhead to a product when it is started; others assign manufacturing overhead when it is completed. Goldratt recommends not assigning overhead at all. Revised October 26, 2004. See CONWIP, finished goods inventory, Little's Law, throughput accounting.

***work simplification* –** The process of reducing the complexity in a process. This typically involves designing the job to have fewer stages, steps, moves, and interdependences thus making the job easier to learn, to do, and understand. This is sometimes called work standardization. While normally applied only to repetitive factory and service workers, it can also be applied to less repetitive knowledge work done by professionals and salaried workers. Dan Madison from Value Creation Partners challenges his course participants with these questions: (1) Are the instructions immediately available, easy to understand and self-explanatory? (2) Do people make errors filing out the forms? (3) Could a template be used to simplify performing the activity? (4) Is the process effectively systematized or performed haphazardly? (5) Would a different layout make work smoother and easier with less handling and wasted motion? (6) Can this activity or stage be combined with another? See business process re-engineering, error-proofing, FMEA, job enlargement, work standardization.

***work standardization* –** This is the process of writing a single procedure for a job that might be performed by many people in many different locations. While normally applied only to repetitive factory and service workers, it can also be applied to less repetitive knowledge work done by professionals and salaried workers. The standard procedures should (1) be realistic and based on careful analysis, (2) be clearly written (not be open to interpretation, easy to understand), (3) define limits of authority, (4) cover emergency situations and define where the worker should go for help, (5) define training requirements, (6) define minimum performance standards. See business process re-engineering, job enlargement, work simplification. Adapted from material by Dan Madison, Value Creation Partners.

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. The name of this chart is often given the mathematical notation $\overline{x}$, which means the mean of the random variable x and is read "x-bar." See control charts, SPC.

***XML (eXtensible Markup Language)* –** A language used for creating web pages. It is an extensible version of HTML (Hypertext Markup Language). Another popular way to create web pages is ASP (Active Server Pages). XML is also 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."

The following are yield management terms from the airline industry:

ASMs -- Available Seat Miles. This refers to how many seat miles were actually AVAILABLE for purchase on an airline. This is a measure of capacity. This tells us just how much space was available for purchase by a passenger.

RPMs -- Revenue Passenger Miles. This refers to how many of those seats were actually sold. This is a measure of an airline's traffic.

Load Factor -- If you take RPM and divide by ASM to get the load factor. Or, you get the percentage of seats that were sold, versus the number of seats that could have been sold.

Yield -- Yield is the term we use to tell us just how much an airline makes per revenue passenger mile (RPM). In other words, how much did the airline make on each seat it sold?

RASM -- The related term to this one is RASM (Revenue Per Available Seat Mile), or "unit revenue" as many airlines call it. This figure represents how much a carrier made spread across ALL the available seats that were available (ASM). This number is now more or less the industry standard that is tracked religiously each month by airline revenue management folks--as it gives us a better overall picture of how an airline is performing than the yield figure alone.

CASM -- This is the cost per ASM figure. This is the generally accepted figure by which costs are calculated in the industry. This is the figure you hear bantered about when an airline is said to have " 7.5 cents per mile costs." It is the cost incurred by an airline, spread against the available miles that could have been flown (not the miles actually flown) whether those seats were sat in or not.

Stage Length -- Stage length refers to the length of the average flight of a particular airline. As stage length increases, costs tend to go down--so consequently, increases in the stage length of an airline will tend to bode well for the cost side---all other things being equal. This is a big advantage of the long-haul transcontinental airlines. Longer flights--fewer take offs and landings--equals lower costs.

Adapted from "Airlines Speak a Language All Their Own," planebusiness.com/perspectives/planebasics.html.

***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.

zone picking – A warehouse order picking method where the warehouse is divided into several pick zones. Order pickers are assigned to a specific zone and only pick items in that zone. Orders are moved from one zone to the next (usually on conveyor systems) as they are picked.

Links and references:

- Online dictionary of Six Sigma terms: http://www.isixsigma.com/dictionary
- Online encyclopedia of technical terms: http://whatis.techtarget.com/
- Online glossary of manufacturing terms: http://www.successfulleanmanufacturing.com/Glossary.htm
- Online glossary of manufacturing terms: http://www.glossaryofmanufacturing.com
- Online glossary of the Council of Logistics Management: http://clm1.org/Website/Resources/Terms.asp
- Online Dictionary of International Trade: http://www.itds.treas.gov/glossaryfrm.html.
- Online Japanese KAIZEN/CI Terminology: http://www.fredharriman.com/services/glossary/vocab01e.html
- Online glossary of new product development terms: http://npd-solutions.com/glossary.html
- Online glossary of new product development terms: http://www.pdma.org/library/glossary.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. The searchable database can be found at www.iienet.org/terminology, but unfortunately, it is only available to members.

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

