MACMILLAN DICTIONARY OF PRODUCTION MANAGEMENT & TECHNOLOGY

John Bessant
Richard Lamming

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Preface

In writing a dictionary of Production Management and Technology, one is faced with the task of combining heady concepts such as electronic data interchange and manufacturing strategy with the basic techniques of milling and honing. On the one hand there is the concept of Shojinka, on the other the principles of investment casting. It has been our intention to concentrate on the management aspects of the subject but it has proven necessary to include many of the more basic concepts. Since the dictionary is intended to be of interest and practical use to industrial managers and students of engineering and business alike, we have tried to cover as broad a scope as possible. Nevertheless, we have dealt with the engineering principles of manufacturing to a lesser extent than many text books and the reader is referred to them for detailed investigation.

The field of Production Management and Technology has changed fundamentally in the last ten years, with many 'established' concepts turned upside down by new competitive threats. It is our hope that this book, without lapsing into 'fads', will help the reader to understand many of the new and strange concepts.

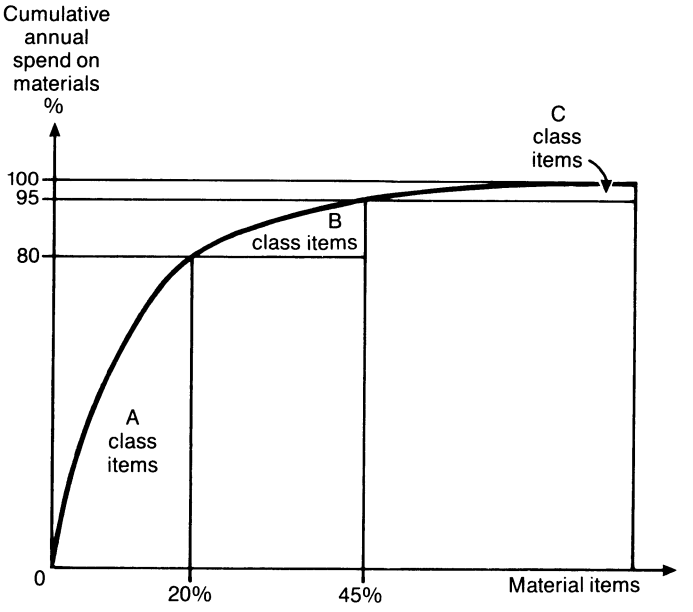
John Bessant
Richard Lamming

Brighton June 1990

A

ABC. ACTIVITY BASED COSTING.

ABC classification. In STOCK CONTROL, a process whereby components, sub-assemblies and other items are classified, usually by annual usage value. By multiplying the piece price and quantity used per year, the annual usage value of each item of stock held can be calculated. This is expressed as a percentage of the total annual materials spend. This information may be used in stock control policies: comparing the cost of stock control with the items being managed. Stock levels may be rationalized accordingly. Typically, such an analysis reveals that 20 percent of items account for 80 percent of total materials spend. These are then called 'A class items' and are usually controlled by the most sophisticated stock control systems, in order to eliminate



ABC analysis

excess inventory values, and STOCK-OUTS. A further 25 percent of items account for another 15 percent of annual material spend, and are called 'B class items', controlled by less expensive methods. The remainder are 'C class items' and may be controlled by the simplest methods, such as TWO-BIN METHOD. *See* PARETO ANALYSIS.

abrasives. Materials used in surface finishing, especially high quality finishes (e.g. grinding). The materials consist of grains of abrasive (e.g. crystalline aluminium oxide, silicon carbide, diamond, etc.) set into a bond material (e.g. rubber, vitreous material, metal, silicate, resin, etc.). The size and pattern of the grains or grit is designed to produce a desired finish – actually a series of fine scratches. *See* GRINDING, HONING, and LAPPING.

abrasive cutoff. Use of a thin grinding wheel as a precise circular saw, to give an accurate parting-off or incision in a workpiece (especially rotational). Many specialized variations exist, for example abrasive BANDSAWS.

abrasive flow machining. A technique for finishing internal surfaces (e.g. drilled holes) by flushing with abrasive liquids under pressure.

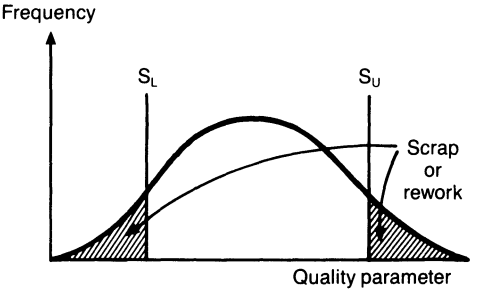
absolute. Reference to the origin in a measurement system. For example, absolute dimensions of a point are those referenced from the origin of the X and Y scales.

absolutes of quality. *See* CROSBY.

absolute physical parts control. A manufacturing management concept which creates a physical path for workpieces through the production are such that at all times it is impossible for them to be diverted. In this way, the levels of WORK IN PROGRESS can be very tightly controlled, and unplanned activities eliminated.

absorption costing. Principle whereby the costs of a product are calculated on the basis of all the different types of production cost – fixed, variable and semi-variable – being grouped together. Each activity in the business is categorised under a COST CENTRE and all the different costs associated with that activity are brought together (absorbed) into a single product cost.

acceptable quality level (AQL). A level of quality of manufactured components, generally expressed as defective items as a proportion of total output, which the company has



AQL

The proportion of good output (between lower and upper specification limits S_L and S_U) is considered an acceptable level.

deemed acceptable in the light of the production process involved. This concept is generally regarded as defunct, since competitive pressures in manufacturing industries now mean that the only 'acceptable' quality level is ZERO DEFECTS. Before these pressures, engineering manufacturers in the West might set an AQL of, say, 5 percent defective. Since the early 1980s, the same manufacturers have had to contend with actual defect rates of a few parts per million (e.g. Japanese engineering manufacturers; figures from electronics manufacturers are often even better). *See* TOTAL QUALITY CONTROL.

acceptance control chart. Chart used in STATISTICAL PROCESS CONTROL to record statistical data about the output from a specific stage in the process. The decision to accept the process output, based upon these data, signifies that the process is considered to be under control. Also used in ACCEPTANCE SAMPLING.

acceptance sampling. Decision-making technique in QUALITY CONTROL concerned with the acceptance or rejection of a batch of parts. The decision is based upon the results of tests made on a sample taken from the batch and subsequent statistical inference. The results are compared with predetermined standards, using ACCEPTANCE CONTROL CHARTS. The acceptance or rejection is thus made with an agreed degree of certainty – derived from the statistical inference.

access time. A measure of the speed of storage and retrieval of data, especially in a computerized system.

accuracy. The degree to which something conforms to a standard. The observer's ability to read an instrument, the instrument's condition, and the

Accuracy versus Precision

e.g. Measuring the length of a workpiece, taking a sample of 4 every hour.
Desired sample mean = 4.50 cm.
Sample Measurements

	1	2	3	4	mean
1	4.40	4.50	4.60	4.50	4.50
2	4.37	4.52	4.40	4.71	4.50
3	4.35	4.80	4.31	4.54	4.50
4	4.31	4.71	4.76	4.22	4.50
		etc			etc.

precision of machining is clearly deteriorating

but accuracy of sample mean is maintained

environment in which the reading is taken, all affect the accuracy of the reading. This is not the same as PRECISION.

A CLASS MRP II-user. A term invented by the American consultant, Oliver Wight, to encourage firms to implement MANUFACTURING RESOURCES PLANNING in a thorough manner, increasing the chances of successful adoption. To become an A Class user, a firm had to 'score' at least 23 points out of a possible 25 on Wight's questionnaire, regarding such items as DATA INTEGRITY, strategic approach to MRP II, use of specific parts of the program (CAPACITY RESOURCES PLANNING etc.). Whilst it was seen cynically by some as a sales gimmick for Wight's consultancy (a prime mover in the spread of MRP II), the prestige attached to being an A Class MRP II user was and is attractive to firms, and is sought after. Wight classified Classes A to D as:

Class D: – Not using Materials Requirement Planning (MRP)

Class C: – Only using MRP as an order-launching and expediting system

Class B: – Using MRP as a Production and Inventory Control System, but relying on other systems (such as SHORTAGE sheets, etc.) to effect control. (At least 20 out of 30 on the questionnaire.

Class A: – Using MRP II as a business planning strategic tool.

action line. *See* PROCESS CHARTS.

action plate method. The Nissan term for KANBAN. (The term 'kanban' was developed by Toyota – Nissan naturally chose its own name for the technique.)

activation. Chemical process used to prepare a metal surface for treatment (e.g. plating). The counter process is PASSIVATION.

activity based costing. (ABC). Approach to production cost accounting which differs from the traditionally used principles of ABSORPTION COSTING, in which overheads are recovered by spreading them over all production according to some predetermined formula. ABC, by contrast, aims to attribute costs more directly to each individual activity as they are incurred.

activity on arrow. A form of NETWORK plan in which the activities are represented as arrows.

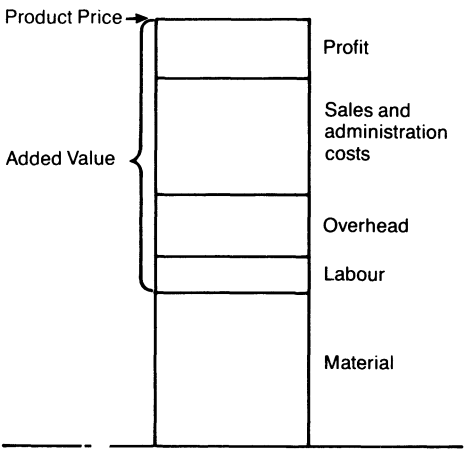
activity on node. A form of NETWORK plan in which the activities are represented as the modes between the arrows.

actuator. A device which transfers an electrical or physical signal into an impulse or physical force. Used within a control system to provide active output.

acoustic testing. A method of testing the strength or soundness of joints in structures by using acoustic vibrations as an input. The output (resonance, vibrations, cracking etc.) is measured and compared with standard data to

determine the acceptability of the structure. Usually non-destructive.

adaptive control. A system of automatic monitoring and adjustment which enables changes to be made in operating parameters in equipment, to reflect changes in operating conditions. The system decides which operating parameters (e.g. cutting tool position, coolant feed etc.) to *adapt* in order to allow for changes in conditions, such as tool wear, overheating etc. *See* IN-PROCESS GAUGING.



Added value

added value (value added). The increase in the value of a product as operations are carried out upon materials and the physical form is altered. Analysis of a production process, to provide an understanding of how much value is being added at each stage, is an important prerequisite to efficient design and management of that process. See JUST-IN-TIME, MUDA.

adhesives. Bonding substances. Adhesives are increasingly being considered as alternatives to other joining processes such as welding and fastening. This is encouraged by the use of ceramics and plastics to replace metals in many products (e.g. vehicles, consumer durables, etc.). The main classes are: *natural adhesives* (gums, starches, etc.), *chemical adhesives* formed from inorganic substances (sodium silicate), and *synthetic adhesives* made from organic chemicals (elastomers, resins, etc.).

Advanced Manufacturing Technology (AMT). Term used to indicate a comprehensive approach to a reassessment of manufacturing, employing all new hardware, software and human resource technologies.

AGV. AUTOMATIC GUIDED VEHICLE.

AIAG. Automotive Industry Action Group (USA).

ALGOL. High-level computer language, the name of which is derived from the term 'algorithmic language'. It was originally developed in the 1950s, with later versions being labelled by their year of introduction (e.g. Algol 58, Algol 60 etc.). It has now been largely superseded by more powerful languages, such as PASCAL.

algorithm. A set of rules for solving a problem. Algorithms are used extensively in SYSTEMS ANALYSIS and computer programming.

allowed time. A WORK STUDY term for the time allowed for performance of a standard task. *See* STANDARD TIME.

alloy. A mixture of metals, or metallic and non-metallic substances, to achieve desired physical properties (strength, MALLEABILITY, etc.). The term is also, less commonly, used to refer to a similar mixture of polymers, elastomers, etc.

alternative standard. A WORK STUDY term. If there are different ways of carrying out a task, then, when setting STANDARD TIMES, an alternative standard is also set for each different way.

aluminizing. Hot-dipping process to produce an anti-corrosion finish on a metal (usually steel) part. The dip is molten aluminium, or aluminium and silicon.

American Standard Code for Information Interchange (ASCII). A code used in the transference of data in computer and communications systems. There are 128 characters, each represented by a seven digit code identity.

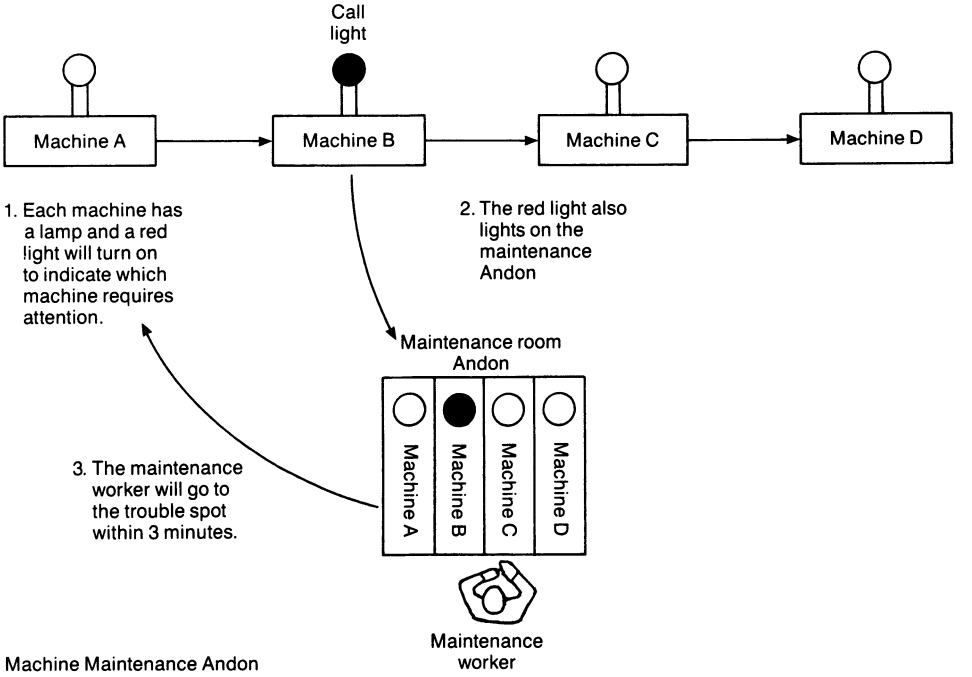
American Wire Gauge (AWG). The American (USA) system for sizing metallic rods and wires, in electrical installations. *See also* STANDARD WIRE GAUGE.

amortization. The recouping of fixed costs by spreading them across a number of products. *See* BATCH PRODUCTION.

AMT. ADVANCED MANUFACTURING TECHNOLOGY.

analogue. Continuously variable dimension or property of a measured feature. Used as a reference base for some control systems. *See* DIGITAL.

andon. ('Lantern' in Japanese.) A system of warning lights, and illuminated information boards, installed on or near work centres and controlled by the workers to indicate the condition of the equipment and process at that stage. Normal running condition (no problems) is indicated either by no light or a neutral colour (e.g. green, blue etc.). A minor problem (which, nevertheless, requires attention) is indicated by the next level light (e.g. yellow). The number of levels depends upon the actual application, but a red light usually represents a most serious problem, possibly requiring a LINE STOP. Production supervision, maintenance workers and neighbouring production workers will be aware of necessary procedure for each case. The use of andon lights accelerates the process of KAIZEN, or PERPETUAL IMPROVEMENT. Initial implementation (in the West) has always been difficult and usually phased-in gradually. As with most Japanese techniques, specific applications of the principle do not conform to any strict set of rules, but benefit instead from the development



Andon lights

Source: Y. Monden, *Toyota Production System*, Institute of Industrial Engineers GA. USA, 1983

of individual ideas from the personnel directly involved. Sophisticated systems involve not only lights but also sound signals, video cameras, automatic response timing devices, and so on. Andon illuminated information tables are used to indicate the synchronization of various parts of the process, so that all involved in production can see how it is progressing, and take any necessary action to ensure continuity. For a full explanation, see Y. Monden, *Toyota Production System*, Industrial Engineering and Management Press (Atlanta GA, 1983).

annealing. Heat treatment process in which a metal part is heated and then cooled slowly (usually in air). This reduces stresses in the piece, removing brittleness, reducing hardness and increasing MALLEABILITY. Many different types of annealing exist, for specific purposes. In most, the heating–cooling process time and environment are varied under close control, to achieve specific results.

ANSI. American National Standards Institute.

anthropometry. In WORK STUDY, the study of human body measurements and movements.

anticipation stocks. (1) Stocks of raw materials which are bought in anticipation of price rises. (2) Finished goods which are stockpiled ahead of favourable market movements.

AOQL. AVERAGE OUTGOING QUALITY LEVEL.

APICS. American Production and Inventory Control Society.

APL. High-level computing language. The name is derived from 'A Programming Language'.

APM. ACTION PLATE METHOD.

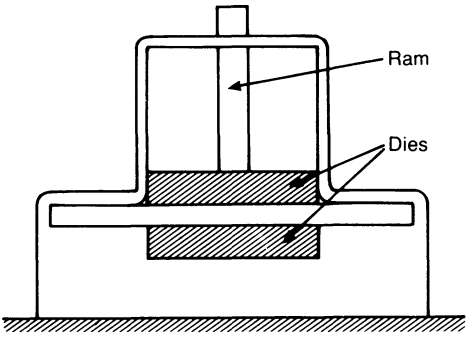
AQL. ACCEPTABLE QUALITY LEVEL.

arbor. The spindle of a grinding machine.

arbor press. A press tool used to insert (or remove) arbors or mandrels into tools.

arc welding. General name of welding processes which involve melting the surfaces to be joined by means of the heat generated by an electric arc. The metal parts form one electrode for the arc. The welding tool forms the other. For specific processes, *see* MIG, and TIG.

arc press. A small press whose upright frame members are curved (i.e. arc-shaped) to allow a wide bed.



Arc press

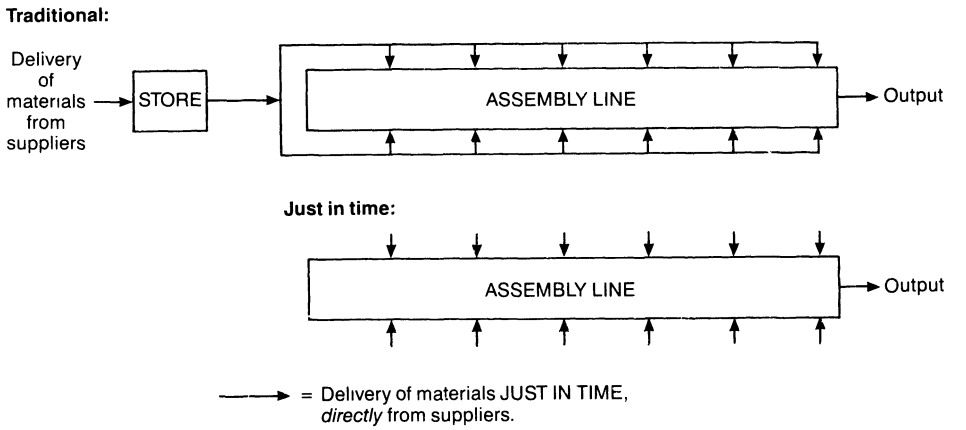
artificial intelligence (AI). The field of study in computing and information technology which attempts to model the information processing characteristics of the human brain. AI is particularly concerned with the development of expert systems in which the experience, accumulated knowledge and judgmental rules which human experts employ can be simulated by computer systems.

ASQC. American Society for Quality Control.

assembly. The process of fitting together component parts to make a complete product. The term implies no machining or other manufacturing processes are taking place.

assembly chart. *See* GOZINTO CHART.

assembly line. A production device on which the various stages of an assembly process are performed in a set sequence, at a set speed, in a set location. Developed from the SCIENTIFIC MANAGEMENT ideas,



Flow of materials in an assembly line

particularly by Henry FORD, for the assembly of vehicles in relatively high volumes. The assembly line technique became the predominant manufacturing PARADIGM of the Twentieth Century, in association with ECONOMIES OF SCALE. From Ford's time (early decades) until the spread of the Japanese techniques (JUST IN TIME *et al*) in the late 1970s and 1980s, the assembly line was generally accepted as the most efficient way of producing goods.

assignable causes of variation. In STATISTICAL PROCESS CONTROL, observed variations in output characteristics may be determined as *random* (inevitable, cause unknown, and 'acceptable') or *assignable* to a specific cause. Assignable variations may be removed from a process by attention to the identified cause. A process that is deemed to be running under control is said to exhibit only random variations.

asynchronous. Transmission of data employing character separation by extra bits attached to the beginning and end of characters. Characters may thus be transmitted without a regular time base ('asynchronously') and decoded accurately because of the separation.

ATE. AUTOMATIC TEST EQUIPMENT.

attribute sampling. QUALITY CONTROL technique in which a sample is tested on the basis of attributes (e.g. colour, texture, functional correctness, instead of MEASURED VARIABLES). Since the result of the test is either good or bad, CONTROL CHARTS used in attribute sampling are constructed on the basis of Binomial Distribution statistics, rather than an assumed Normal Distribution.

austenite. Steel made with GAMMA IRON and carbon.

autoclave. A pressure vessel in which temperature-dependent production processes are conducted under strictly controlled conditions (e.g. ENCAPSULATION).

autodeposition. Coating a metal by organic chemical processes not involving electrolysis ('ELECTROLESS PLATING').

autogenous welding. Welding process in which no filler material is used; that is, the join is made purely from the two melted metal surfaces.

automatic guided vehicle (AGV). A driverless or ROBOT cart which travels around a factory floor carrying components, materials, finished products, etc. It may be guided by a wire laid into the floor, or by true remote control. AGVs are usually a programmable part of a process, rather than 'general purpose' materials handlers.

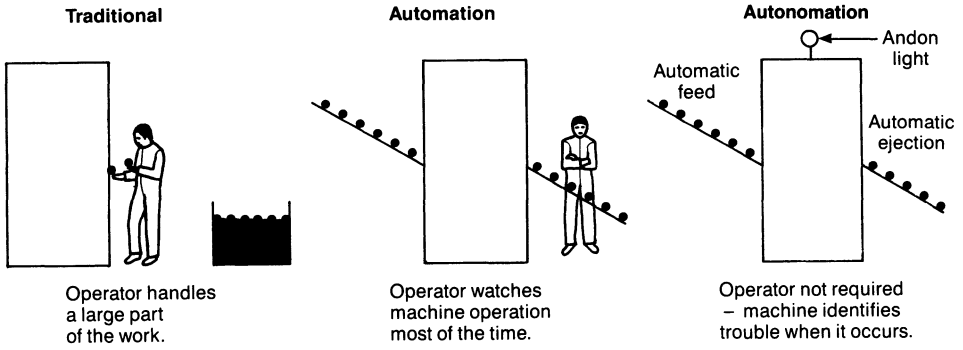
automatically programmable tooling. Computer-controlled tooling specification in which the system analyses the design of the product, determines the forming processes required (usually metal cutting) and identifies the tool selections needed to make the item.

automatic test equipment (ATE). Computerized equipment, custom-made (often from standard modules) to test a product in a predetermined manner. ATE can provide a system test (checking inter-relation of components), functional test (simulation of operation of the system or parts of it) and component, or logic testing. Based predominantly upon the Digital Equipment Corp's PDP11 series of mini-computers during the 1970s, ATE has developed recently towards simpler, PC-based systems which cost less and perform more varied and complex operations with greater reliability.

automation. Self-controlling operation (of production equipment) which does not require human intervention in normal practice. Automation developed from mechanization and differs from it fundamentally in its autonomous nature.

autonomation. (Autonomous control, or JIDOKA – Japanese/Toyota.) Literally translated as 'automation with a human mind' (Monden). An approach to detecting and correcting mistakes in either mechanical or manual processes. As with most Japanese techniques, autonomation concerns both the design of the process and its everyday operation. Thus during operation, ideas for building-in more detection devices will arise and be developed through experimentation. The other half of autonomation – correcting the defects, usually involves LINE STOP, and a team approach from the operatives, production engineers, and supervisors. Also in common with other Japanese ideas, autonomation is essentially linked to cost reduction, respect for human beings, and flexibility.

autonomous work groups. A pattern of work organization which gives a



Autonomation

Source: K. Sasaki, *The New Manufacturing Challenge*, Free Press, 1987

group of workers considerable scope and responsibility for planning and carrying out production. It is an important element in SOCIOTECHNICAL SYSTEMS. Research in the automotive industry in the late 1980s indicated differences between various approaches to autonomous work groups; for example, the Japanese approach tends to expose the factory to true reliance on the workforce performance, whereas some American approaches may be as simple as employee appeasement. For a discussion of this concept see J.P. MacDuffie, *Worldwide Trends in Production Systems Management: Work Systems, Factory Practice and Human Resources Management*, Proceedings of the International Motor Vehicle Program, Massachusetts Institute of Technology (1989).

AUTOSPOT. Automatic System for Positioning of Tools. Computer program used in preparation of NC instructions.

average outgoing quality level (AOQL). In QUALITY CONTROL, the average number of errors in output from a production process after ACCEPTANCE SAMPLING.

average outgoing quality limit. In traditional QUALITY CONTROL, the maximum number of errors acceptable in AVERAGE OUTGOING QUALITY LEVEL. Now largely discredited as a technique, along with other approaches based on anything less than perfect quality, or ZERO DEFECTS. *See* TOTAL QUALITY CONTROL.

axis. Mode of operation or possible plane of movement in a machine tool. For example, a three-axis machine could be orientated in vertical, horizontal and lateral planes or axes (CARTESIAN co-ordinates x, y and z). A six-axis machine would also be able to move in roll, pitch and yaw – rotational planes. Six axis is generally considered to be the maximum possible movement.

B

backflush. An INVENTORY CONTROL term, used in various systems including MRP. The procedure starts with finished goods which have left the plant and deducts the materials and components used in production of those goods from stock records, back through the inventory control system. The principle is that since the quantity of finished goods is known and the amount of materials required to produce them can be calculated from the BILL OF MATERIALS, the amount of inventory in the system can be determined accurately given the amount before the production and any inputs of new materials. This system relies upon high DATA INTEGRITY and can lead to the removal of PERPETUAL INVENTORY systems.

backlog. Accumulated overdue items. A backlog of work orders indicates a mismatch in capacity and load, either as a result of inefficiency or poor system design.

bag molding. A molding technique for reinforced plastic composite materials in which the mold is covered by a bag. The plastic being molded between the two, often in a vacuum chamber.

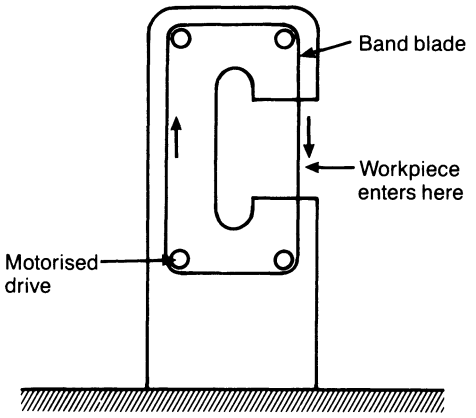
bakayoke. Same as POKAYOKE.

balanced line. An ASSEMBLY LINE in which the CYCLE TIME for each individual WORKSTATION is equal throughout the whole line (i.e. there is no wasted time). Balance is achieved by allocating the right amount of work and resources (operators and equipment) to each workstation. Since work activity is not infinitely divisible, it is usually the case that some imbalance exists in the line. This means that some workstations will be working at CAPACITY (i.e. fully loaded) whilst others have some time and capacity to spare. Fully loaded workstations are called BOTTLENECKS and their work rate determines the work rate, and thus output rate, of the line.

balance quantity. In INVENTORY CONTROL, the number of components or sub-assemblies which are needed by a specific stage in the process in order to guarantee the planned output of products.

ballscrew. High precision threaded shaft used for location control in machine tools. The drive is transmitted from the ballscrew to the movable part (e.g. tool holder) through a system of recirculating balls. This is more accurate than a rack and pinion system.

band saw. A sawing machine in which the blade is an endless loop driven (usually vertically) round two spindles. The cutting operation takes place on a horizontal table in the middle of the band. The same idea has been applied to other processes, for example band-filing, bandpolishing, bandmachining.



Bandsaw

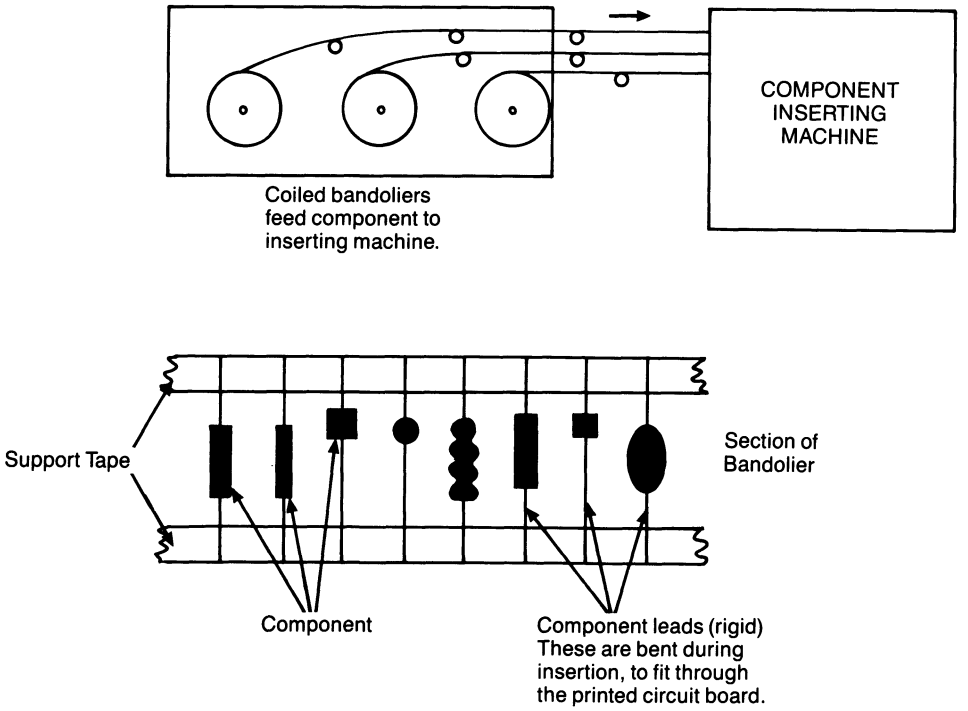
bandolier. A system for mounting electronic components in specified sequences for machine insertion into printed circuit boards. The components (resistors, capacitors etc.) are suspended by their connector wires between two long parallel strips of adhesive tape. The bandolier (the term comes from the old French name for a shoulder belt with bullet holders, as worn by soldiers) is coiled on drums, fitted to specialized feeder devices, which transmit the components to automatic insertion machines. See diagram on p. 14.

bar coding. An identifying label on an item which can be read by a scanning device – for example, a light pen connected to a computer. The thick and thin parallel black and white stripes represent binary numbers which form a code which may be used to store any necessary data about the product; for example, its part number, SHELF LIFE data, batch number, supplier name, and so on. Bar coding has become commonplace on retailed items, but is also of great value in stock control systems in production. The computerization of KANBAN systems in Japan, for example, has made extensive use of bar codes.

The method of developing a bar code is called symbology. There are two commonly used systems: the International Article Number – referred to by its old name, EAN (European Article Number); and the Unified Product Code (UPC) as used in North America. For information, contact: The Article Number Association, 6 Catherine Street, London WC2B 5JJ, or Bar Code Systems Ltd, 5 Observatory Road, London SW14 7QB.

barrel finishing. Surface finishing technology in which many parts are churned in a rotating barrel, in an abrasive slurry, or in contact with abrasive materials. The rotating barrel (which usually has a polygon section rather than circular form, to encourage tumbling) is sometimes replaced with an oscillating motion.

barrel plating. Surface finishing technology which utilizes the churning



Bandolier

motion of items within a rotating barrel to provide a good overall plating finish through plentiful contact between the workpiece and the plating solution. For electrolytic plating, the barrel must contain one electrode (the other being in the solution). Sequential treatment (e.g. cleaning, ACTIVATION, plating, cleaning, PASSIVATION, cleaning, drying) of small parts is usually carried out in a computer-controlled barrel plating line, in which temperatures, timing, sequencing and physical transfer of barrels between tanks is all carried out automatically.

BASIC. High-level, but simple, computer language. The name is derived from Beginner's All-purpose Symbolic Instruction Code.

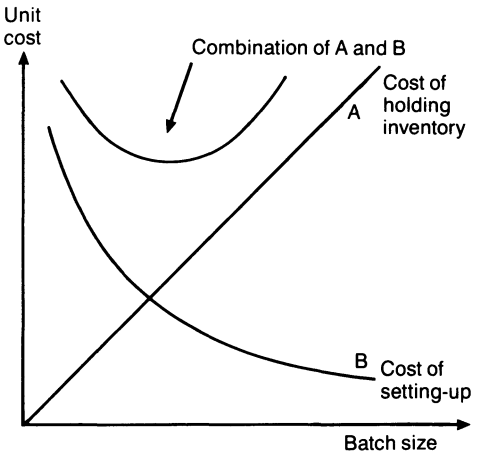
basic minutes. Measure of work: *see* BASIC TIME.

basic oxygen process. Steelmaking process which has largely superseded BESSEMER converters. Steel is produced through the injection of pure oxygen via a mobile lance into the molten iron.

basic time. In WORK STUDY, the measure of work content, calculated by combining the MEASURED TIME or OBSERVED TIME and the RATING. The sum of all the ELEMENTAL BASIC TIMES is the basic time for the job.

Basic Work Data (BWD). A proprietary system of WORK MEASUREMENT similar to PREDETERMINED MOTION-TIME SYSTEM.

batch production/manufacture. Production technology/strategy based upon the concept of ECONOMIES OF SCALE, developed during the early part of the Twentieth Century from ideas formulated much earlier (Adam Smith *et al*). Batch production became so popular that by the 1970s it was estimated that 80 percent of all manufactured products were made in this way. The basic idea is that making a large number of an item in a batch (in USA, 'lot') results in a lower unit cost since the fixed costs associated with setting up to make the product may be spread (AMORTIZED) over the large batch. The greater the number of items in the batch, the smaller the amount which much be recovered in the cost of each. As the batch size increases, however, so the amount of material to be held during production also becomes greater, with associated costs rising in proportion. Simple, traditional batch production theory suggests, therefore, that at some notional point an 'economic' batch quantity can be identified. At this point, the theory goes, the cost of holding stock is balanced with the cost of setting up (both expressed as variable indirect unit costs) and the 'total cost' (the sum of the two) is at a minimum. This is usually illustrated as shown in the following diagram.



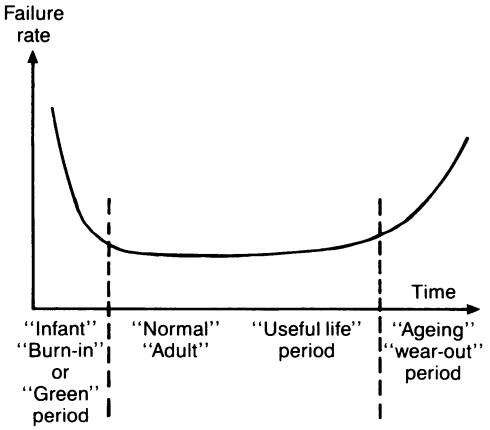
Batch manufacture

As batch size increases the AMORTISED cost of inventory increases proportionately and that of setting up decreases.

Since the advent of JUST-IN-TIME thinking (during the late 1970s in the West), batch manufacture has been attacked as wasteful, and ECONOMIC BATCH QUANTITY theory has been largely discredited. This change has come about as a result of the reductions in SETTING COSTS which have been made possible through improved technology in production equipment (e.g. ROLL-IN-ROLL-OUT-DIES), and better use of existing technology (*see* KAIZEN). It is now generally agreed that the setting cost per unit can be substantially reduced, whereas the costs of holding materials are even higher than first thought:

costs associated with demotivation of operators, scrap, and damage have been added to traditional considerations of capital tied up in INVENTORY and storage space/supervision costs.

bathtub curve. A chart used in the study of product failure over time, so called because the instance of failures is higher at the early and late stages of a product's life. The bathtub shape is a smoothed version of actual data, and can be used to predict failure rate: preventative action can be taken accordingly.



Bathtub curve

Baud rate. The speed of transmission of data in a computer system, in a SERIAL mode. One Baud is equivalent to one BIT of information per second. It is usually necessary to match the Baud rate of the transmitting and receiving devices to enable communication to take place. The lowest rate used is 300 Baud. High-speed systems can transmit data at several thousand Baud.

Bayes theorem. A statistical theorem which is used where several events might occur, and the probability of each has been estimated. Since only one event can occur, and it is certain that one will occur, the probabilities must add up to 1. Some outcome (usually financial in result) is estimated for each event, and the total outcome for the range of events may be calculated thus:

$$P_A(A) + P_B(B) + P(\ldots) = 1\,(E)$$

where P_A is the probability of event A
A is the outcome of event A
E is the expected outcome overall.

bed of nails. An ATE device, so called because it consists of a flat board, fitted with vertical contact 'nails' positioned precisely to touch specific components on a circuit (board). Appropriate signal currents are passed through the contact points to the components to test the function, logic, or integrity of the circuits.

benchmark job. In JOB EVALUATION, a job with which others are compared in the process of ranking. Used in a more general sense as an example with which competitors may

be compared, as shown in the table below.

Bessemer converter. Traditional high-temperature process which converts pig iron into steel, within an enclosed chamber, in the presence of various additives and process materials. Now largely superseded by the BASIC OXYGEN PROCESS.

best practice. Term used to denote the practices employed, in any area of operation, by the individuals or organizations seen to be achieving the greatest success.

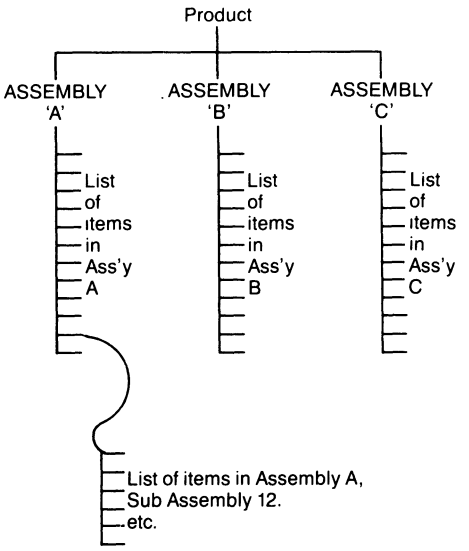
bilateral tolerance. Tolerance system which specifies maximum deviations (tolerances) to either side (i.e. above and below) of a nominal dimension; for example, 35.50 mm ± .05 mm ('plus or minus'). *See also* UNILATERAL TOLERANCE.

Bill of Materials (BOM). A computer file used in MATERIALS REQUIREMENTS PLANNING. The BOM file contains a structured, quantitative description of the materials necessary to produce a product. The design of the product is interpreted, for purposes of manufacture and assembly, as a series of sub-assemblies, building up from the basic materials and components. The simplest sub-assemblies fit together to make the next level, which are then combined into the next level (of complexity) and so on until the finished, or 'top level' product is assembled. The PRODUCT STRUCTURE thus formed reflects the way in which the product is designed, its relation to other products (use of common sub-assemblies, etc.) and the way in which it is assembled. The Bill of Materials reflects the product structure, listing all the items in terms of their position

Benchmark Job

	Step or Objective	Source or Method
1.	Identify superior performance in critical activities (in both competitors and non-competitors)	Trade journals, consultants, professional meetings, annual reports
2.	Expand information through direct contact	Visits to selected firms by small multi-functional operating teams
3.	Prepare reports and communicate findings	Summarise key findings; define benchmark levels of performance
4.	Develop and implement action plan	Turn benchmarks into targets; change practices and procedures to achieve targets

From: *Dynamic Manufacturing*, R. Hayes, S. Wheelwright and K. Clark, Free Press, New York, 1988



Bill of materials

in the sub-assemblies. In this way, commonality between products can be utilized by grouping together requirements for sub-assemblies and materials, across the entire production plan. The Bill of Materials is combined with the MASTER PRODUCTION SCHEDULE in Materials Requirements Planning, to determine what quantities of materials should be scheduled for production or purchase, at what times. *See* PRODUCT STRUCTURE DIAGRAM and PARTS EXPLOSION. There exists also the notion of single-level Bill of Materials. In this concept, all parts required to make a product are listed with equal status, and the system is designed so that any item can be produced immediately. This is part of JUST-IN-TIME operation, and part of the attempt to get away from the concept of BATCH MANUFACTURE (a basis of MRP).

bin card. In INVENTORY CONTROL, a record card kept at the place of storage, on which details of stock movements in and out of that stores location are recorded.

biotechnology. The technology of biologically-based processes (e.g fermentation, genetic engineering). In many cases, biotechnology offers low-energy alternatives to traditional techniques.

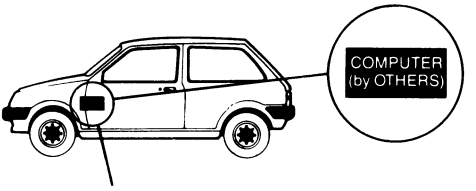
bird in a cage. An expression (derived from Japanese) used to describe operators who work in isolation from one another, separated by inventory, machinery, or distances. Production engineering may have been employed to optimize the operation of each individual but the overall system is essentially sub-optimal because of the break in communication between each 'bird' in its separate 'cage'. Similar in its implications to ISLANDS OF AUTOMATION.

bit. A binary digit (either 1 or 0) used in computerized communication. A group of bits (8, 16 or 32, depending upon the computer) is called a BYTE.

bit rate. Speed of transmission of data. *See* BAUD RATE.

black-hole engineering. Alternative, less common, name for BLACK-BOX ENGINEERING.

black-box engineering. Shared engineering of a product, in which one partner (usually a component supplier/subcontractor) takes responsibility for an entire part of the design (the 'black box'). The other partner



Component within vehicle e.g. computer for engine system control, is developed by supplier

Vehicle manufacturer does not know/ does not need to know "what goes on" inside it.

Item appears on manufacturer's drawings as a "black box".

Black-box engineering

does not need to know the functions within the 'black box', and uses only the boundary conditions (e.g. physical shape, size and weight, location, input/output signals, etc.). Black box engineering is a demonstration of trust between the two (or more) partner manufacturers, since one (the customer) will be selling a product which is reliant upon the design of the other (the supplier) for its performance. A modified form of this concept is called GREY-BOX ENGINEERING, in which some degree of discussion on the internal workings of the subcontractor's design takes place with the customer.

blanket order. A PURCHASING policy whereby a customer gives a vendor a long-term contract for supplies of a production item (component, material, etc.) which is covered by a set of general specifications and terms, including the price. As these details change over time, amendments are issued to the blanket order, but it remains in place as the principal contract between the two parties.

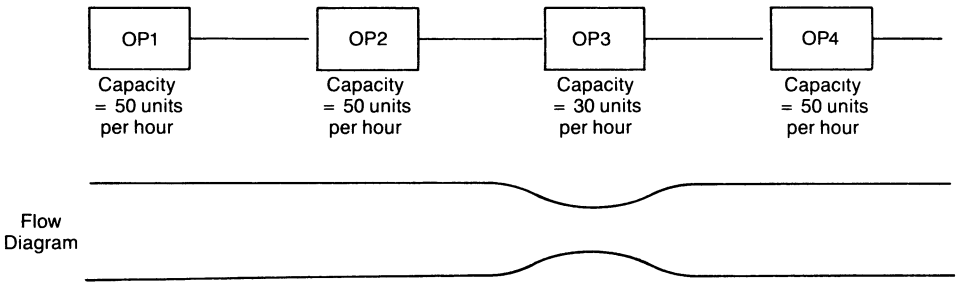
blanking. A pressing operation which removes the blanked piece from strip or sheet metal. Normally followed by other press operations; for example piercing, bending, and so on.

blast furnace. A furnace in which metal is obtained from its ore by smelting with a reducing agent. For example, iron ore is heated with coke to produce pure iron and carbon dioxide.

blind hole. A drilled hole which does not pass completely through the material: i.e. a 'dead end'.

block diagram. A SYSTEMS ANALYSIS tool in which the stages in a process are drawn as blocks, in the appropriate sequence. It is the order of the blocks and the relationships between them that are analysed in this way, rather than the activities within each stage in the process.

blow molding. A technique for extruding material (usually plastic) through a DIE under pressure. The resultant tube may be required in lengths (e.g. piping) or as sheared components (e.g. rings).



Bottlenecks

Operation 3 (Op. 3) is the bottleneck, or limiting factor in flow through the process. The line capacity is limited to 30 units per hour.

blue-sky research. Long-term, high-risk RESEARCH AND DEVELOPMENT which involves a high level of speculation (both financial and intellectual), but which might yield significant gains by providing the investor with an early position in new fields of opportunity.

BOM. BILL OF MATERIALS.

bond. (1) Adhesive joint. (2) The host material of an ABRASIVE wheel, into which the grains or grit are set. Bond materials vary according to the application. For example, rubber or resin is used for a softer abrasion, metal for a hard abrasion; vitreous material is used when it is intended that the bond material should be worn off in use, constantly exposing new abrasives grains.

bonus increment. In payment systems, an addition to STANDARD TIME, which is used as an incentive.

bonus schemes. Schemes which reward extra added value – expressed in terms such as improved output, quality, etc. – with extra payment. Various formulae exist for calculating bonus schemes, including many commercially available proprietary plans.

boring. Rotary machining process used to provide high-precision internal cylindrical surfaces ('bores'). A single point tool is used.

bottleneck. A stage in a process which is working at its maximum capacity, and thus becomes the limiting factor on the rate of operation for all related stages, before and after it. Identification of bottlenecks is a key step in improving CAPACITY, FLOW, and MACHINE UTILIZATION. *See* BALANCED LINE and OPTIMIZED PRODUCTION TECHNOLOGY.

bottom drive press. A PRESS in which the mechanisms for driving the ram are located beneath the bed.

brake press. A press tool used to bend sheet metal. Unlike a normal power press, in which the ram travels its full

distance, striking at the bottom of the revolution of the flywheel, the ram of a brake press is halted, mid-stroke, and lifted from the work piece without travelling the entire revolution of the flywheel.

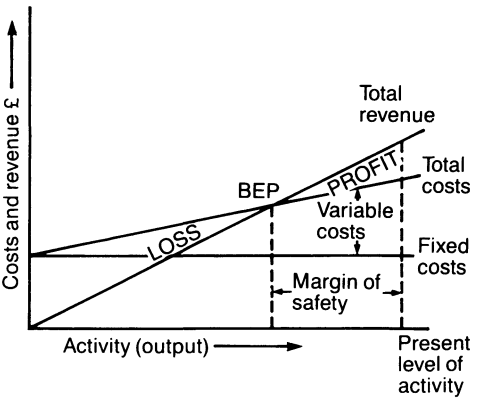
brazing. A metal joining process similar to soldering, in which the metal edges to be joined are not melted. A filler material is used, and a flux liquid. The filler is introduced to the joint by capillary action. Variations exist (e.g. BRIGHT BRAZING) employing controlled temperatures and environments, for example anaerobic. Brazing on small items is often carried out in conveyor furnaces.

breadboard. Experimental construction of an electronic circuit, or other device, in the design stage of a product. The construction bears little physical resemblance to the end product but simulates the function exactly.

break even. The point above which an operation begins to produce a profit; the volume of production at which revenue (assumed to be directly proportional to output/sales) equals the combination of fixed and variable costs.

bright brazing. Conveyorized tunnel BRAZING process in which oxidation of the brazed joint is prevented by excluding air from the environment (anaerobic) through use of an inert gas environment.

Brinell hardness number (Bhn). The hardness of a substance expressed as



Break-even analysis

determined by the Brinell hardness test. The test consists of measuring the impression made in the material by a steel or carbide ball which is pressed into it under controlled load.

Brisch classification. A coding system for the engineering industry which aims to assign particular codes to all items of resources – materials, labour, equipment, etc.

British Standards (BS). A certification given to indicate compliance with established standards of procedure or performance, set by the BRITISH STANDARDS INSTITUTE.

British Standards Institute (BSI). The independent British organization, established by Royal Charter, responsible for setting and monitoring standards in products and practice in British firms. The BSI was the first national standards organization to be established. It is now linked with the

European standards organizations, CEN/CENELEC, and is a member of the International Standards Organisation. The BSI catalogue has over 10,000 BRITISH STANDARDS, with 700 new or revised standards each year. Two offices are of key interest to manufacturing industry. One is the BSI Quality Assurance office – responsible for all BSI's certification, assessment and inspection activities. It is based in Milton Keynes and controls such areas as Kitemark and Safety Mark accreditation. It also acts as an agent for British and overseas purchasers and certificating organizations. The other is the BSI Testing centre in Hemel Hempstead, which provides confidential testing services to a wide range of industries, on a commercial basis. It is one of the largest and most respected facilities of its kind in the world.

British Standard Rating. *See* BS 3138.

British Technology Group. An organization set up in 1981 as a result of the merger of the National Research and Development Council (NRDC) and the National Enterprise Board to provide support to innovative activities in the UK. The BTG is part of the Department of Trade and Industry (DTI) and funds research and development in new products and processes, either as a loan or as an equity partner. It currently holds over 2000 patents and 600 licences.

broaching. A metal-cutting process similar in principle to MILLING, except that the cutting teeth are arranged in increasing size along the spine of a straight rod. The broach is passed through a hole or slot in a workpiece, in a single pass, forming the shape of the largest and last tooth. *See* TURNBROACHING.

broadcast system. A production control system, developed in Japan, which uses electronic communication to deliver a production schedule to several points in a factory at once. For example, in vehicle assembly, the sequence of different models is broadcast to the assembly line itself, and to the sub-assembly areas which supply it in SYNCHRONOUS mode (seating, engines, axles, etc.). In this way, all the related departments know the plan and work to the same sequence of variants. The system is applied to option mixes which are too complex for KANBAN. See also GOLF BALL SYSTEMS and NAGARE systems.

broad band. A communications channel (e.g. a cable) which can carry a wide variety of signal frequencies simultaneously.

brownfield site. A term used to describe the redevelopment of existing industrial premises, involving substantial investment, possibly total renewal. It is the use of an existing site (and, by implication, workforce) with all its infrastructural dimensions (road/rail links, social geography, national identity, etc.), which differentiates the brownfield site from the GREENFIELD SITE.

BS. BRITISH STANDARD.

BS 3138. Defines British Standard Ratings for use in WORK STUDY for rating achievement in measured work. Standard performance (for the 'motivated worker') is fixed at 100 (equivalent to walking at four miles per hour).

BS 5750. The BS setting out the requirements for certification for QUALITY ASSURANCE and QUALITY CONTROL within a firm. Introduced in 1979, this UK standard for the design of systems to monitor and control QUALITY has gained widespread respect and status within manufacturing industry, especially since the Government's National Quality Campaign, in 1983. By 1988 more than 9000 UK firms had been registered for BS5750. The standard does not prescribe how to achieve fitness for purpose: it identifies the disciplines and specifies the procedures and criteria needed to ensure a product or service meets customer require ments. BS5750 complies with the international standard ISO 9000 which was issued in 1987 and is derived largely from the British standard. In the same year, BS5750 was itself reissued. The EEC standard, EN27000 is also based upon BS5750.

BS5750 Part 1 covers design, PROCUREMENT, Marketing and customer service; Part 2 covers manufacturing and inventory control; Part 3 covers warehousing and materials management.

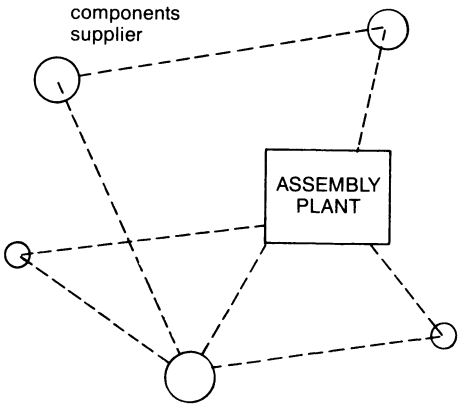
BS 9000. BSI scheme for electronics manufacture, quality and specifications.

bucket/time bucket. A time period, in a planning process, especially MRP. In a time bucket, a specified number of products will be produced.

buffers/buffer stocks. INVENTORY which is held to guard against the danger of STOCKOUTS. Once considered a normal feature of INVENTORY CONTROL SYSTEMS, buffer stocks are now seen as unnecessary waste (see MUDA). Efforts to reduce costs and improve QUALITY through JUST-IN- TIME operation often focus upon removal of buffer stocks. This action tends to expose problems previously hidden by the buffers, which must be solved in order to reduce costs, etc. The term BUFFERS is used in a wider sense to denote any feature of the production system which protects the people within it from feeling the effects of the problems which they are not solving. The principle of KAIZEN and PERPETUAL IMPROVEMENT is to remove buffers, identify the problems, and then search for solutions. *See* R.J. Schonberger, *Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity*, Free Press (New York, 1983).

bumble bee program. A concept devised by Mazda, in Japan, in which the automobile company's links with its component suppliers were improved through frequent visits made by 250 of its engineers. The name came from the nature of the activity – engineers making frequent brief visits to suppliers, like bees collecting pollen from flowers and forming part of the creative process as a result. On a

more general level, the bumble bee concept is part of the JUST- IN-TIME philosophy of constant attention to detail and PERPETUAL IMPROVEMENT.



Bumble Bee programme

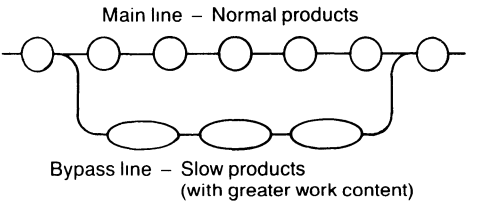
Engineers from suppliers and the assembly plant (customer) pick up ideas from plants which they visit and pass them on to other plants.

burden. INDIRECT COSTS or OVERHEAD (American).

burning-in. Running a product or new equipment non-stop for a prescribed period to detect any components likely to fail under normal operation.

burnishing. Surface finishing process in which a highly polished effect is achieved using rollers or balls rather than abrasives. The surface is not scratched (as with abrasion) but slightly deformed.

bypass line. A line balancing technique which is used to allow for long-cycle time operations. The bypass line contains a BUFFER STOCK of work which enables the main line to work at a higher output rate than the long cycle time operation (BOTTLENECK). The latter works for longer, in order to produce the necessary output.



Bypass line

byte. A sequence of binary digits, or BITs, used for data transmission. A byte may consist of 8, 16 or 32 bits, depending upon the system.

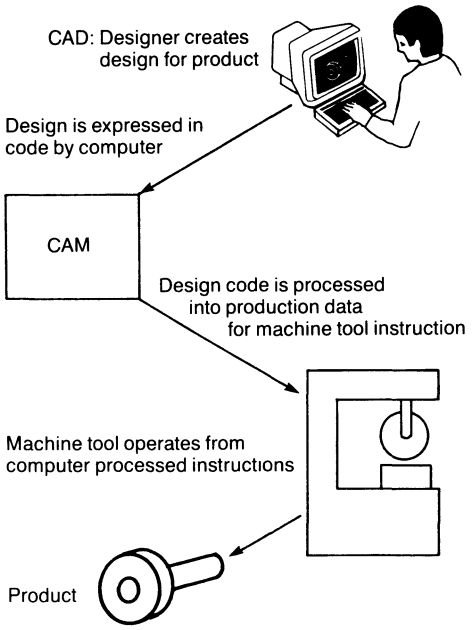
C

CAD. COMPUTER-AIDED DESIGN.

CAD/CAM. COMPUTER-AIDED DESIGN/COMPUTER-AIDED MANUFACTURE. The two technologies of CAD and CAM were, from the outset, linked in the minds of manufacturers. It was some time before practical linking was possible (by which time minds had turned to COMPUTER-INTEGRATED MANUFACTURE). The principle of CAD/CAM is that the computerized product design data generated by a CAD system should be fed into a CAM system, to control the manufacture of the product. For example, if the same encoding/decoding PROTOCOL is being used in both systems, it is logical to assume that design details of a machined radius on a metal part could be translated into machine instructions, to control a CNC milling machine to produce the radius. CAD/CAM is now used in press tool manufacture, and is becoming an achievable target for more complicated processes.

CAE. COMPUTER-AIDED ENGINEERING.

CAI. COMPUTER-AIDED INSPECTION.



The CAD/CAM link

calibration. Adjustment of a measuring instrument in order to obtain output readings within specified degrees of ACCURACY.

calling sequence. In COMPUTER NUMERICAL CONTROL, a set of machine instructions connected to a subroutine, used to move to and from the subroutine, within a larger program.

canned cycle. (American) A subroutine in a NUMERICAL CONTROL program.

capacity. A measure of the ability of resources to produce goods. Capacity has two dimensions: quantity (i.e. how *many* items per time period can the equipment produce) and scope (i.e. how many different types of item, different sizes, different materials, etc.). With the move towards FLEXIBILITY, away from DEDICATED EQUIPMENT, the scope dimension of capacity has increased in its importance. Flexible (broad scope) capacity may enable a firm to respond to the VARIETY demanded by the market, by producing many different items on the same equipment. So, for example, a modern automobile manufacturer might be able to produce several fundamentally different models (large and small 'platforms' or floor pans) on the same ASSEMBLY LINE, whereas the previous BEST PRACTICE would have suggested high volume of one type (VANILLA PRODUCTS).

capacity planning. Technique for determining how to manufacture the goods required by the PRODUCTION SCHEDULE (and, thus, the sales plan). There are two main approaches: FINITE and INFINITE CAPACITY PLANNING. If finite planning is used, the load implied by the production schedule is allocated to known resources and the timing (e.g. completions dates) is calculated accordingly. If infinite planning is used, the desired timing is fed into the calculations along with the implied load from the schedule, and the plan indicates what resources are required to comply (e.g. how much OVERTIME, SUBCONTRACTING, extra equipment, etc.). Capacity planning is almost always computerized, since there are many simple packages (PC-based) and the process involves a great deal of 'number crunching'.

capacity requirements planning (CRP). Part of MANUFACTURING RESOURCES PLANNING. CRP is carried out after the MRP program is run, to ensure that the manufacturing plan which has been generated is practicable. It is the task of CRP, therefore, to translate production requirements into practical implications for manufacturing resources (people and equipment) and to compare these implications with the capacity available over the period in question. *See also* ROUGH-CUT CAPACITY REQUIREMENTS PLANNING.

capital equipment/plant. Substantial production equipment for which expenditure must be cleared by senior management, either because of the large investment required, or for some strategic reason (e.g. choice of process).

capital intensive. A process which is largely dependent upon machinery (CAPITAL EQUIPMENT) rather than labour. AUTOMATION and ROBOTS are examples of ways in which a process can be made more capital intensive. Management of a capital intensive process is concerned with

the technical and financial details (e.g. rates of return on investment, PREVENTIVE MAINTENANCE SCHEDULES, etc.), rather than HUMAN RESOURCE MANAGEMENT. *See* LABOUR INTENSIVE.

CAPM. COMPUTER-AIDED PRODUCTION MANAGEMENT.

capstan. A type of lathe on which tools are mounted at the tail stock end in a rotating hexagonal (or octagonal) fixture (resembling a capstan on an old sailing ship). Capstan lathes are a traditional design still found in TOOL ROOMs but largely superseded in manufacturing areas by more advanced technology.

carbon arc welding. An early form of ARC WELDING, no longer used. The arc was formed between the workpiece and a simple carbon rod, without filler or controlled environment.

carbon nitriding. Heat treatment processes in which both carbon and nitrogen are absorbed into the metal, case harden ıg it. *See also* NITRIDING.

carbon teel. Steel which contains only iroı and carbon, i.e. no significant amo nts of further additives such as vanaa ım or chromium. Also called SIM. LE STEEL.

carburizing HEAT TREATMENT process in whicn ferrous metal is heated in the presence of carbon (solid or fluid). When QUENCHED, the metal has a hard surface. The depth to which the hardness penetrates can be precisely controlled.

cascading. A control systems technique. One system is responsible for controlling the operations of another, lower level, system. This second system may, in turn, be responsible for controlling the operations of another, and so on. The term is applied both to technical (e.g. computer) systems, and to management/organizational systems.

CASE. COMPUTER AIDED SOFTWARE ENGINEERING

case hardening. (American = surface hardening.) Heat treatment and other processes which provide a greater hardness on the surface of a metal object, whilst leaving the centre unchanged; for example, CARBURIZING.

cast iron. Iron, obtained from iron ore through a smelting process, containing not more than 2 percent carbon and small amounts of silicon and sulphur. Cast iron is strong but brittle and vulnerable to corrosion. When further carbon and other additives are introduced, steel is formed.

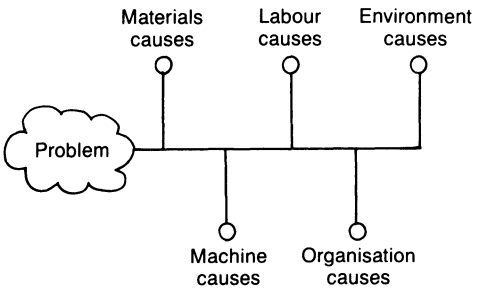
casting. One of the oldest manufacturing processes, casting consists of pouring molten metal (or other material) into a mold and letting it cool and solidify. Automated casting processes now enable the production of castings which do not need machining before assembly into products. Problems with POROSITY in Aluminium and INCLUSIONS in steel casting can be controlled through mold design, pressure control, etc. *See* DIE

CASTING, PRESSURE DIE CASTING, GRAVITY DIE CASTING, SAND CASTING, INVESTMENT CASTING, LOST WAX.

CAT. COMPUTER-AIDED TESTING.

catalyst. A substance which is introduced into a chemical reaction to change the rate of activity (accelerating and retarding), or other parameter. The catalyst is not altered by its involvement in the activity and may be reused many times.

cause and effect diagram. Problem-solving technique in which possible causes for some observed factor are analysed by tracing backwards from their effects. The problem to be solved is described in terms of 'effects' which are part of it. For each effect, all possible causes are then identified (within the abilities of the problem-solving team. Solutions are then discussed in the light of this analysis, and effort may be concentrated on the causes identified.



Cause and effect diagrams

CE. CAPITAL EXPENDITURE.

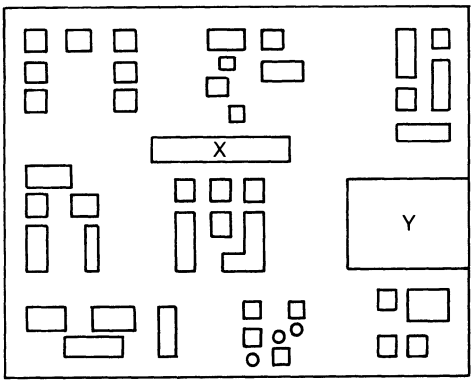
cell. Closely defined area of production activity. *See* CELLULAR MANUFACTURING, GROUP TECHNOLOGY and U-LINES.

cellular manufacturing. Concept developed from GROUP TECHNOLOGY, in which manufacturing facilities (machines, people, support or transfer equipment, etc.) are arranged within the factory into cells, rather than production lines. A cell is designed to carry out all the necessary operations to produce specific products, and is often autonomous in its scheduling activities. In this way, a series of small factories is set up, each responsible for its own output. Cellular manufacturing places responsibility on the operators who become involved with PRODUCTIVITY and QUALITY, rather than basic machine operation or assembly. Experience has shown that motivation is improved and other benefits accrue. *See also* U-LINES, and GROUP TECHNOLOGY.

cementite. Iron carbide (Fe_3C) in which the carbon exists in small particles, evenly spread throughout the iron.

Central Processing Unit (CPU). The main information processing unit, or 'brain' of a computer control system.

centre lathe. A LATHE which is designed to hold long workpieces between the CHUCK at one end (the headstock) and a non rotating point at



Cellular manufacturing

The factory is arranged into cells – each operating like a small factory itself. Box X represents some piece of equipment which is shared by several cells. Box Y represents some central facility (stores, tool stores, supervision etc.). There is theoretically no reason why both X and Y should not be removed eventually, with all functions carried out at the cell level.

the other (the tailstock). The diameter of the workpiece is then worked upon.

centreless grinding. Grinding process in which the item being ground is not supported between fixed points, but instead 'sits' on the grinding wheels. It is free to move as it is ground, thus producing a specific desired ground finish.

centres. Workpiece support points in a machine tool which make contact only with the centre of a rotating surface at each end of the item.

centrifugal casting. Casting in which the mold is rotated during the solidification process, in order to achieve a desired structure within the cast product (e.g. with some additive material positioned predominantly towards the outer edges of the product).

centronics interface. A standard PARALLEL INTERFACE extensively used in connecting peripherals to computers.

ceramic-mold casting. Casting in which the mold is ceramic, rather than steel or sand. The ceramic molds are cured after forming, which hardens them, ready for casting. The fact that the pre-cured molds are easily removable from the patterns means that ceramic-mold casting enables the casting of fine-detail products without the need for dies.

CFG. Compact flake graphite iron.

CFM. CONTINUOUS FLOW MANUFACTURE.

changeover time reduction. *See* SINGLE MINUTE EXCHANGE OF DIES and SETTING-UP TIME REDUCTION.

chargehand. Senior production operator given responsibility for some supervisory tasks, particularly to do with organizing other operators.

chemical plating. *See* ELECTROLESS PLATING.

chemical milling. A metal removal process which employs strong etchants to reach difficult parts of a workpiece. Other surfaces of the workpiece are protected from the 'milling' process by masking.

cherry picking. Selecting the easiest tasks from a list of activities to be

carried out, leaving the more difficult ones until last. This common practice may be seen as a failing of human nature but it is very damaging in a production environment since it destroys control of the process by upsetting the order of operations. The term is also used in the more general sense of picking the most desirable parts of something; for example, successful firms may be said to cherry pick a market for the most profitable products.

chip formation. The size, shape and other properties of the chips of metal made during a metal cutting process are of great importance in modifying that process to achieve desired results. A great deal of study has been made into tool design and machining dynamics, to provide better control and efficiency in the cutting process.

chuck. Rotating vice used to hold workpieces in a lathe or other rotating cutting machine.

CIM. COMPUTER INTEGRATED MANUFACTURING.

CKD. COMPLETELY KNOCKED DOWN.

clean room. Controlled environment specifically designed for a manufacture or assembly process which requires dust-free air. Regulations exist to guide design and construction of clean rooms, and classification of a room will depend upon which operations are to be carried out in it. Special clothing is worn in clean rooms, with entry gained through air showers, etc. Many of the techniques involved were transferred from hospital operating theatres. Used for microelectronics, foods, drugs, etc. *See* LAMINAR FLOW.

clearance fit. A fit between two parts which is designed with TOLERANCES such that, even if the male part is at top tolerance (as large as possible within tolerance) and the female as small as allowed by tolerance, there will still be a clearance between the two parts when fitted together.

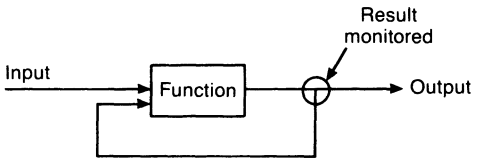
clock gauge. Measuring device which has a 'clock' type dial indicator, operated by a plunger which is in contact with the surface to be measured.

clock-in. Method of recording time spent working by employees, in which a clock-card is inserted into a specialized recording device, which punches holes through the card, or prints onto it. Hours thus recorded are called clock hours and may be used in calculating EFFECTIVENESS.

clock rate. The rate at which a computerized controller transfers data (instructions) to operating equipment.

closed die forging. *See* IMPRESSION DIE FORGING.

closed loop. A control systems term, now widely used to refer to any system in which a feedback signal is taken from the output to modify the input.



Closed loop system

Features of the output are fed into the input side of the function. *See also* FEEDBACK and ERROR SIGNAL.

close-to-finish design. Product design aimed at reducing machining (to a forging or casting) in order to remove unnecessary work and cost. *See* COSWORTH PROCESS.

clustered – flow line. Manufacturing facilities layout in which machines are grouped in 'clusters' by function (e.g. all milling machines together, etc.) but arranged so that the work flows from one cluster to another. This flow is naturally dependent upon the product type.

clustered – jumbled. Clustered layout in which no clear flow is possible: the machines are grouped in clusters without any logical inter-relation between them. *See* STRING DIAGRAM.

CMOS. Complementary Metal Oxide Semiconductors. Low energy, integrated circuitry components.

CNC. COMPUTER NUMERICAL CONTROL.

CNMA. COMMUNICATIONS NETWORK FOR MANUFACTURING APPLICATIONS.

COBOL. Common Business-Oriented Language. A high-level computer language developed for business applications.

co-extrusion. Extrusion of two materials together, often pressed into one part. Heat can be applied to weld the two materials together for a firm bond.

coining. A closed-die press operation. Since the die is closed, all surfaces of the workpiece are constrained and may be worked on.

cold forging. FORGING in which the metal workpiece is not heated. This is usually an automated operation, processing metal in thick wire form, producing items such as bolts, screw blanks etc.

cold heading. Manufacture of bolts in a cold forging process; the head of the bolt is shaped in a forging die, from a round blank.

collective bargaining. A process in industrial relations whereby agreement is reached on factors like wages, working conditions etc. by negotiations between employers and trade unions acting collectively on behalf of their members, leading to some form of collective agreement. Such bargaining takes place at a number of levels, from individual plant through regional and up to national level.

comaker. A concept of CUSTOMER-VENDOR RELATIONSHIPS developed by several management consultancies

during the 1980s, now used as general term to refer to a partnership between an industrial manufacturer and a components supplier, in which each considers the mutual benefit resulting from close co-operation in supply/quality matters etc.

common kanban. A WITHDRAWAL or CONVEYANCE KANBAN which may also be used as a PRODUCTION KANBAN for the supplier WORKSTATION, if the distance between supplier and customer is small. *See* KANBAN.

Communications Network for Manufacturing Applications. European Commission-funded research project, under the ESPRIT programme, started in 1986, directed towards determining a standard protocol for computerised communications on the shopfloor (i.e. between machines and other equipment). The project is managed by British Aerospace in Preston. *See also* MANUFACTURING APPLICATIONS PROTOCOL.

company-wide quality control (CWQC). The concept of building quality awareness into the working attitude of every member of the company and into all systems. CWQC begins by refuting traditional ideas that the quality control inspectors alone are responsible for quality. Other schemes, such as TOTAL QUALITY CONTROL, and CROSBY plans are practical applications of CWQC which remains, nevertheless, a vitally important policy issue. *See* QUALITY CIRCLES.

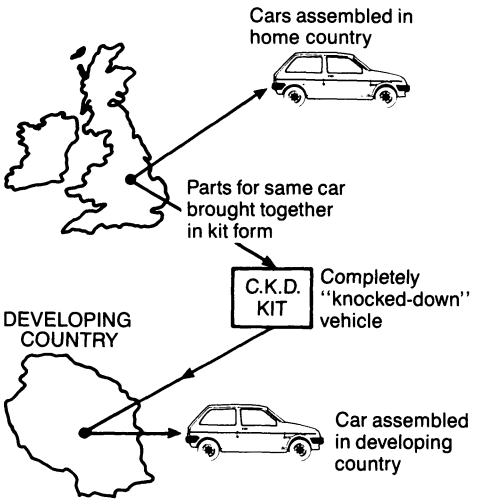
compiler. A program which converts high-level computer language programs into machine code for speedy operation by manufacturing hardware.

completely knocked down. Technique employed in international operations where products (especially large ones, e.g. automobiles) are shipped from the manufacturing plant in a KIT form, for simple ASSEMBLY in a less industrially-developed country. The implications of this practice make it unpopular with all but the most underdeveloped countries, where employment of any type is still welcome. Usually, the kit assembly country is keen to develop full manufacture (i.e. from basic materials) and thus build skills in its workforce, and so on. *See* SCREWDRIVER PLANTS.

component. A part intended for assembly into a product or one of its sub-assemblies.

composite. Material consisting of a combination of other materials: a binder; for example resin, and reinforcement (e.g. fibre or fabrics). In some products, composites are now being considered as alternatives to traditional materials (e.g. steel), to achieve cost and weight savings, manufacturing simplicity and desired behaviour characteristics.

compression molding. Plastic molding technology (thermosets) in which



Completely Knocked Down (CKD) operations, e.g. automobile

heated plastic material is put into the mold and formed into a component by closing the mold and heating to cure the material.

computer-aided design (CAD). A design system which involves drawing using a visual display unit screen linked to a computer rather than a paper and pencil. Images can be stored and manipulated electronically and can also be converted into electronic information via some form of DIGITIZING device. CAD systems offer considerable advantages over conventional design systems in terms of speed, flexibility and the ability to make minor changes quickly. A 2-D or TWO DIMENSIONAL system works in the same way as a drawing – by expressing solid objects in one plane – as plan and elevation representation. A 3-D system can hold and manipulate enough information about the solid object to display it as a solid, and carry out operations on it (e.g. simulating stresses, etc.). There is also 21/2-D CAD, which is between the two: handling three-dimensional objects, but not as solids. In some cases a wire frame (the shape of the object) is used in the display. *See* CAD/CAM, and SOLID MODELLING.

computer-aided engineering (CAE). A computer-aided process of moving from design (via COMPUTER-AIDED DESIGN) through to COMPUTER-AIDED MANUFACTURE. This is similar to CAD/CAM, but has its focus on the engineering implications of the conversion process.

computer-aided inspection (CAI). The use of computerized inspection equipment ranges from automatic calculation of sample data, through to vision systems designed to detect defects in products. As in any computerized system, the design of the applications (specific tasks) determines how successful the equipment will be. The support system (for registration, calculations, etc.) is usually a simpler matter. There have been cases in which companies have sought to buy a 'TECHNOLOGICAL FIX'; for example, a vehicle manufacturer installed a gas-sensing robot to test the cars for leaks, instead of the traditional water spray test. The result was that every car failed the inspection: they were rain proof, but not gas tight. *See also* IN-PROCESS GAUGING.

computer-aided production management (CAPM). The use of computers in all functions normally associated with production management: STOCK CONTROL, CAPACITY PLANNING, PRODUCTION SCHEDULING, tooling management, WORKS ORDER RAISING and TRACKING, BATCH MONITORING, etc. The prime example of CAPM is MANUFACTURING RESOURCES PLANNING (MRP II) – being the integration of all the minor functions into a strategic approach to production management.

A study for the UK Department of Trade and Industry in 1987, by the ACME Directorate (Applications of Computers in Manufacturing Engineering) identified four levels of use in CAPM.

computer-aided software engineering (CASE). The use of mathematical and engineering techniques to produce economic and reliable software applications to meet stipulated objectives. Amongst widely-used CASE tools are FOURTH GENERATION LANGUAGES.

computer-aided testing (CAT). The development of AUTOMATIC TEST EQUIPMENT (ATE) towards an integrated approach to testing throughout a process, co-ordinated by computer. (ATE is generally designed for specific, individual stages of the process.)

computer-integrated manufacturing (CIM). The combination of CAD, CAM and CAPM, in an integrated system. All functions of manufacturing: design input, machine control, production management, are incorporated and coordinated by one computer system and linked to the company's commercial system. A particular feature of CIM systems is that there is some form of shared use of information – either via network or a DISTRIBUTED PROCESSING SYSTEM. The diagram shows how, over time, there has been integration of activities, first within the main areas of manufacture and, more recently, with the aid of computers between these areas. Full CIM is still some way off but integration between areas such as computer-aided design and manufacture or FLEXIBLE MANUFACTURING SYSTEMS, linking production with coordination is now well established. A good review of CIM is given by J. Jarvis, *Computer-integrated Manufacturing and Status*, London Institution of Electrical Engineers (London, 1986).

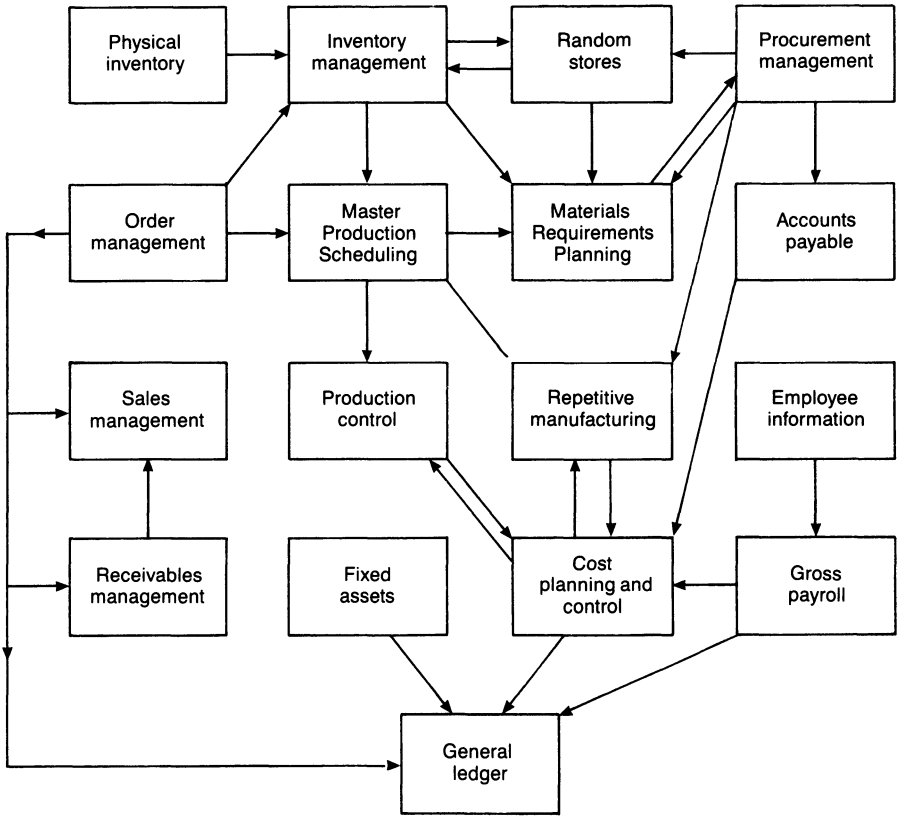
computer numerical control (CNC). Applications of computers to NUMERICAL CONTROL systems, enabling such developments as interpolating (automatically planning the route a machining head should take to get from point A to point B), continuous path machining, and CAM. CNC is usually applied to one machine. A linked system (one controller to several machines) is called DISTRIBUTED or DIRECT NUMERICAL CONTROL.

contingency allowance. In WORK STUDY, an allowance for other occasional tasks, not studied when

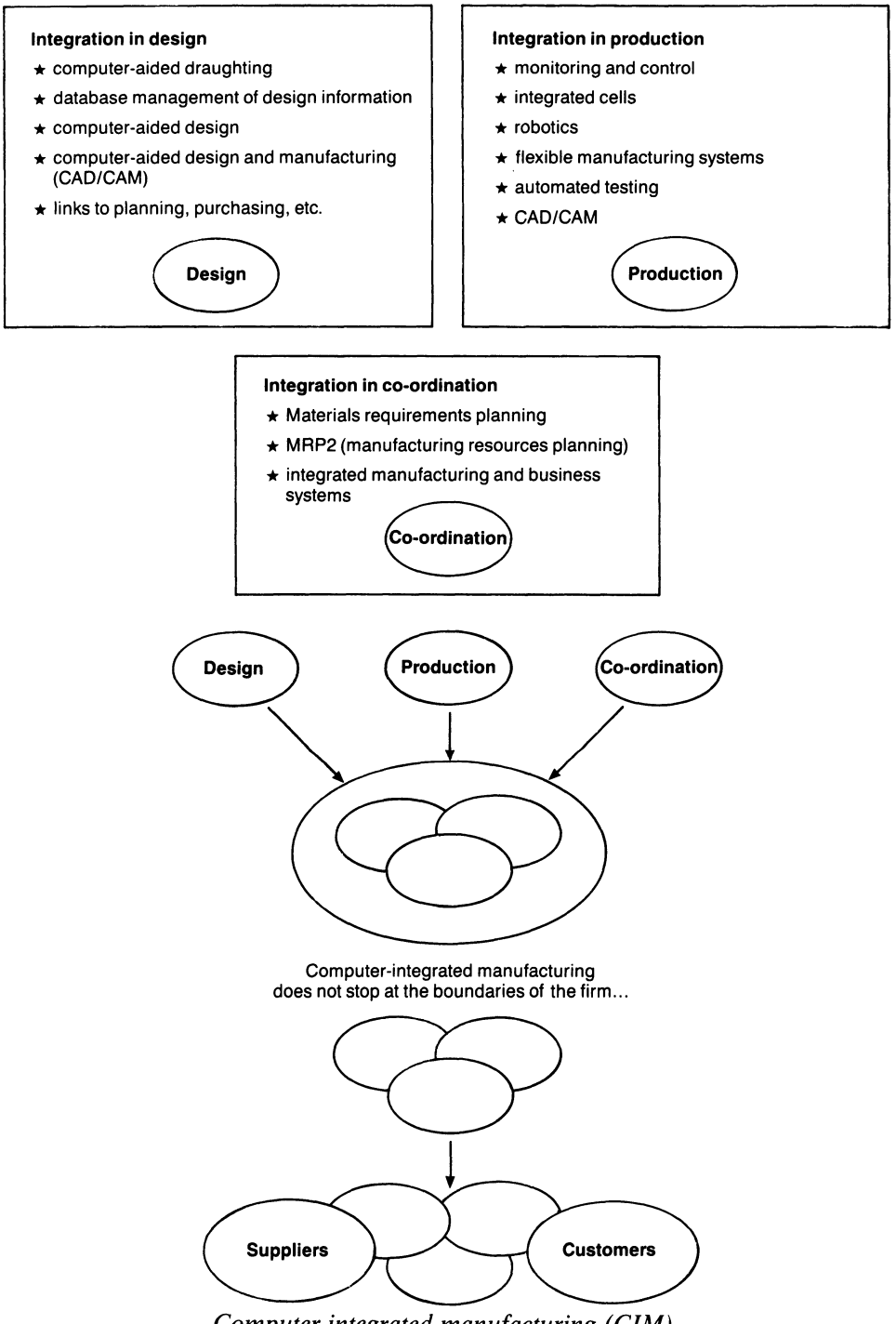
Levels of integration in CAPM systems

Level	Integration status	Definition
0	No CAPM	No CAPM or only beginning installation
1	No integration	Several functions computerised but without regard to integration
2	Partial integration	Several functions linked via common files and co-ordinated controls
3	Full integration	All CAPM functions linked using common databases
4	Integration of manufacturing systems	CAPM systems designed in conjunction with systems for material conversion, handling and quality and against manufacturing strategy objectives

A typical CAPM system



Computer-aided production management (CAPM)



Computer integrated manufacturing (CIM)

establishing a STANDARD TIME for a job.

continuous casting. A casting process in which a continuous metal bar is drawn from a molten source, through a die, to form an unbroken casting, as it cools and solidifies.

continuous flow manufacturing. Synonym for JUST-IN-TIME manufacturing, originally used by IBM. Never adopted generally as a replacement for OHNO's term (just-in-time), CFM nevertheless expressed the philosophy well – an unbroken stream of production, without costly stopping and starting.

continuous improvement. *See* PERPETUAL IMPROVEMENT, and KAIZEN.

continuous improvement groups. *See* QUALITY CIRCLES.

continuous movements. In MOTION STUDY those movements which require no sudden changes of direction.

continuous path. In COMPUTER-NUMERICAL CONTROL, a technology which enables the computer to move the machining head along a predetermined path, controlling position, direction of travel, and speed, continuously.

continuous production. *See* FLOW PRODUCTION.

continuous welding. An unbroken weld which runs the complete length of the joint.

control charts. Charts used in STATISTICAL QUALITY CONTROL to check the results of ACCEPTANCE SAMPLING, or sampling in PROCESS CONTROL against standard data. The decision to accept or reject the batch in question is made with a known degree of confidence on the basis of comparison of results with the control charts.

Control of Substances Hazardous to Health (COSHH). Regulations introduced into the UK in October 1989, intended to improve safety at work. There are nineteen regulations covering such subjects as Monitoring Exposure (to substances) at the Workplace, Maintenance Examination and Test of Control Measures, and Training, Instruction and Information, relating to dangerous substances. In addition there are four Accepted Codes of Practice. The regulations require such things as personal monitoring equipment for anyone working with dusty machines, etc. Details and advice are available from specialist consultancies, or from the Health and Safety Executive.

controlled work. Work which has been organized and measured by agreed WORK STUDY.

conversational mode. Term used to describe the operation of a computer which can receive questions (via a keyboard or other input device) from a human operator, and provide answers. The operator and computer are said to have a 'conversation'.

conveyance kanban. Kanban which is used to authorize and request transfer of materials or parts from a supplier WORKSTATION to a customer workstation. *See* KANBAN.

conveyor. Mechanical material transfer system, usually motorized. Once the sign of a 'modern' factory, conveyors are now regarded as problem avoidance, rather than problem solving. For example, if two consecutive operations are some distance apart, it is better to move them close together than to 'conveyorize' the parts between them. *See* MUDA.

coolant. Liquid sprayed or poured onto a machining process to keep the workpiece and the cutting tool below dangerous temperatures at which damage might occur. Also known as 'suds' since the liquid is sometimes a soapy solution. Water-based and oil-based coolants are in common use.

copy lathe. A LATHE in which the point of the cutting tool can be moved along a path which exactly copies the profile of a sample part. This type of traditional mechanical system has largely been superseded by NUMERICAL CONTROL systems, where the profile to be machined is expressed in data which are used to control the cutting profile accordingly.

core. (1) Disposable part of a casting mold, made of glued sand or other materials. Cores are inserted in molds in order to form internal cavities in the casting. Once the casting has solidified, the core may be removed by burning or washing out. (2) In computing, the physical memory of the CPU.

corner engineering. The concept of redesigning products as an assembly of modules. Developed during the 1980s in the automobile industry, this technology is closely linked with shared engineering (*see* BLACK-BOX ENGINEERING): a components supplier may take responsibility for a whole area of a vehicle (not necessarily literally a corner) – e.g. the entire cooling system – rather than simply supply a part, for example the radiator. In this way, the final assembly of the vehicle is simplified, and the supplier becomes a more significant part of the VALUE- ADDING process.

COSHH. CONTROL OF SUBSTANCES HAZARDOUS TO HEALTH.

cost centre. Form of financial control based upon identifying defined areas of operations to which costs can be attributed.

cost plus contract. An outmoded principle of subcontracting in which the costs of developing a product and a fixed profit margin would be agreed between supplier and customer. If, over the life of the contract, the costs increased, the supplier would still be entitled to the agreed profit, the customer agreeing to pay the increase in costs on the understanding that they were not the fault, nor under the control, of the supplier. This practice, which was widely used in defence industries (i.e. where the customer

was a government) until the late 1970s, has now been largely superseded by competitive tendering for such contracts, in a more usual commercial manner.

Cosworth process. Technique for casting aluminium without pressure dies, but with extremely high quality in terms of porosity and little need for machine finishing of fitting surfaces (e.g. gasket-facing surfaces of cylinder heads for internal combustion engines). Developed by the UK engineering firm, Cosworth, during the early 1980s.

C_p, C_{pk}. Capability index used in STATISTICAL PROCESS CONTROL. Basically, the index relates the achieved performance, in terms of the distribution of measurements, to the required performance, in terms of the specified tolerance. For a full explanation see the article: *Process Capability Indices*, by V.E. Kane, in the Journal of Quality Technology (USA) 1986, No. 18(1), pp 41–52. *See* PROCESS CAPABILITY.

CPA. CRITICAL PATH ANALYSIS.

creep feed. Very slow rate of feed in a machine tool.

crimp. Squeeze operation to deform a (metal) part and thereby fix it to another.

Critical Path Analysis. Project management technique in which activities are represented on a diagram in their necessary interdependent sequences, with time and resource implications visible. Since some activities can be carried out simultaneously with others, and some must follow other specific stages, CPA is used to determine the one (or more) sequence which has no spare, or slack, time within it, and which is therefore 'critical' in finishing the project on time.

Crosby, Philip. One of the most influential leaders in the move towards TOTAL QUALITY CONTROL (TQC). Basing his early work on experiences as a senior director in ITT, in the USA, Crosby developed several 'packaged' approaches to implementing total quality, admirably summed up in his book, *Quality is Free!* McGraw-Hill (New York, 1979). His principal developments were: the 'Fourteen Steps to Quality' plan for achieving ZERO DEFECTS; his management grid, for analysing a company's approach to TQC; and his four 'ABSOLUTES OF QUALITY'.

Crosby's Absolutes of Quality: (1) The Definition of Quality is Conformance to Requirements; (2) The System of Quality is Prevention; (3) The Performance Standard is Zero Defects; (4) The Measurement of Quality is the Price of Non-Conformance. These absolutes are explained in Crosby's second book: *Quality Without Tears*, McGraw-Hill (New York, 1984). *See also* ZERO DEFECTS DAY.

cryogenics. Technology which deals with materials at very low temperatures. Liquid oxygen and liquid nitrogen are often used in cryogenics, to

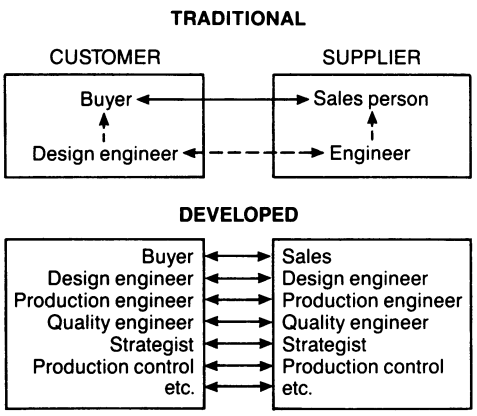
cool materials to levels where their physical properties change, and they may be used or worked on in unusual ways.

cumulative timing (continuous timing). A WORK STUDY technique for job timing in WORK MEASUREMENT which uses continuous monitoring of a job over time, as opposed to a FLYBACK TIMING approach.

cure. To set or dry by heating a workpiece, possibly in a controlled environment. Curing sometimes requires an agent, or CATALYST.

customer's risk. *See* PRODUCER'S RISK.

customer-vendor relationships. During the 1980s the nature of the relationship between a manufacturer and its suppliers (component vendors) altered significantly. It was realized that suppliers were being used in a similar way to workers under a TAYLORISM system. Relationships developed in which the supplier played a more substantial role in factors such as product development, quality achievements, etc. In many cases this process was hampered by old arguments which had permanently soured relationships. The Japanese subcontracting methods were studied extensively in the West and attempts made to transfer them. The same development took place between vendors of CAPITAL EQUIPMENT and their customers. For example, machine tool manufacturers began to specify manufacturing systems for their customers, etc.



Customer-vendor relationships in manufacturing subcontracting

cyanide hardening (cyaniding). CASE HARDENING heat treatment process in which ferrous metal is heated in the presence of molten cyanide salts. Nitrogen and carbon are absorbed. The part is QUENCHED to provide the hardened surface.

cybernetics. Technology concerned with simulating human activities in those of machines and computers. Named after the Greek word for steersman.

cycle compression. *See* SIMULTANEOUS ENGINEERING.

cycle table. A production plan device, used with KANBAN systems. The quantities of each type of product required and the overall CAPACITY are used to work out a sequence of production: so many of product A, then so many of product B, then so many of product C, etc. This simple

device enables the operators to see the way in which production is being sequenced, and thus work accordingly. *See also* BROADCAST SYSTEMS

cycle time. The time taken by a WORKSTATION in a process to carry out all the tasks required of it. The entire line (a sequence of workstations) also has a cycle time – the inverse of the rate of production (i.e. if the line is producing 20 products per hour, then the cycle time is three minutes). Attempts are made to BALANCE the line, so that the individual cycle times of all the station are as close as possible to that of the overall line.

cylindrical grinding. Grinding the outside diameter of a rotating part.

D

data capture. The process of collecting data on a process in order to effect control. This may be a special project, capturing data for the first time, for a specific reason, or it may be part of the continuous process of feeding data into a system in order for it to work. *See* SHOP-FLOOR DATA COLLECTION.

data integrity. The degree to which data can be trusted, or assumed correct. For example, for MRP II to work, it is generally agreed that data integrity in the INVENTORY records must be at least 95 percent. This means that 95 percent of the inventory records (i.e. quantity of the part held in STOCK) must be within TOLERANCE. It is possible to check this factor during a STOCKTAKE; for example the actual quantity of each part (in stores, on the shopfloor, etc.) is physically counted and compared to the amount which the stock record suggests should be there. If the difference between the actual and the record is within tolerance (e.g. ± 5 percent) in 95 percent of the cases, then data integrity for that factor (i.e. inventory records) is 95 percent. The principle must be extended to all factors in a system. For example, in the same MRP II system, the BILL OF MATERIALS FILE data integrity must be at least 98 percent if the company wishes to be an A CLASS MRP II-USER.

data logger. A device (usually electronic) for logging (recording) data about the performance of a production process. Such devices are usually designed to be compatible with micro computer PROTOCOLS, so that the data logged may be directly transferred into the computerized process control system.

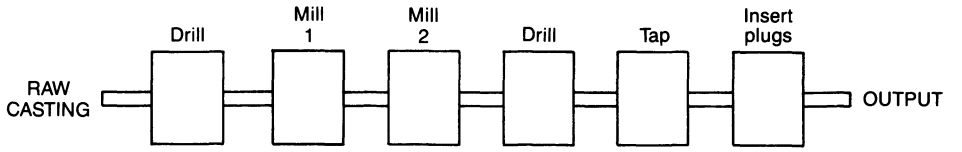
datamation. American term: literally an abbreviation of data and automation. Refers to automatic data processing.

dawn shift. The early morning shift in a three-shift system.

day shift. The morning, or middle shift in a three-shift system.

daywork. A payment scheme based on a rate per hour and the amount of time worked in a day, to which other payments – such as bonus – may be added.

dB(A). Decibel (adjusted). A measure to approximate the effects of noise upon the human ear. Under an EEC code of practice, 90 dB(A) is the



Transfer line – dedicated plant

Transfer line for a machined casting. All operations including transfer between stages are controlled automatically. The line is designed to produce high volume, low variety products. This is DEDICATED automation. Modern transfer lines are designed for FLEXIBILITY. *See* FLEXIBLE MANUFACTURING SYSTEM.

maximum permissible continuous level in a working environment (although there is provision for higher levels for brief periods, at specified intervals). There is also a 'first action level' at 85 dB(A), at which the employer must assess the implications of the noise levels being experienced. New Noise at Work Regulations were issued by the UK Health and Safety Commission on 1 January 1990.

deadtime. In PAYMENT BY RESULTS payment systems, the time spent by operators waiting for work for which there may be an agreed rate of pay. Causes of deadtime must be carefully analysed and recorded as a matter of course, so that faults in the process may be understood, and corrective action taken on a continual basis.

deburring. Removal of burrs and other excess material from machined metal components.

decoders. In control systems, devices which receive coded signals and convert them into desired forms of output; for example, remote control transmissions carried as electrical signals may be converted into control voltages, which will in turn activate the equipment.

dedicated plant/dedicated automation. Plant/automated plant which is designed to carry out one (or a small number) of production activities, in an optimized manner. Early TRANSFER LINES were usually dedicated, with the result that the investment made in them had to be recouped on the product for which the line was designed. If that product changed, or was replaced, the dedicated equipment would not be able to make the new product, and would thus require further investment in order to modify it. This proved inefficient investment. The solution is FLEXIBILITY in plant/automation. It is generally agreed that totally dedicated plant is almost never justifiable, since no product can be assumed to be permanent.

degrees of freedom. In machine tool technology, the number of ways in which a workpiece can move. These are planar and rotational. For example, a machine may be so designed that the workpiece may be moved in the vertical and horizontal

planes only (two degrees of freedom), or it may be possible to rotate the workpiece around its longitudinal AXIS – another degree of freedom. Degrees of freedom must be specified in the design of processes, in order to retain control. They correspond to axes (e.g. a 'six-axis' robot) in machine tool design.

demand pull innovation. *See* NEED PULL.

Deming. Dr. William Edwards Deming was one of the most influential people in the achievement of QUALITY in manufactured products in the second half of the Twentieth Century. Originally influenced by the seminal 1930s work on STATISTICAL QUALITY CONTROL, by SHEWART at Bell Laboratories in the USA, Deming was part of the Stamford University 'Think Tank', during World War II. He developed ideas in TOTAL QUALITY CONTROL which did not find favour in wartime USA, and was subsequently sent as a statistician by the US government to Japan in 1946 and again in 1948. In the rebuilding of the Japanese manufacturing industry under the control of the American occupation, Deming (and fellow Americans, JOSEPH JURAN and ARMAND FEIGENBAUM) played a key role in generating enthusiasm for quality. The Deming Prize, inaugurated in 1951 and awarded annually to the Japanese company which showed the greatest achievements in TOTAL QUALITY CONTROL, was funded partly by royalties from the sale of his books in Japan, and became the most coveted honour in Japanese industry. In later life, honoured by 'guru' status in Japan, Deming returned to his native USA where Western manufacturing was beginning to recognize the value of total quality control. He remained a consultant to industry, and an authority on all matters concerning QUALITY CONTROL.

dependent demand. In INVENTORY CONTROL, a component for which demand is calculated on the basis of the sub-assemblies in which it is used, rather than on estimates of its individual usage, is said to be a dependent demand.

design for manufacture. The concept of taking into account, during the design of a product, the opportunities and limitations represented by the manufacturing processes which will be employed in converting the idea into reality. Initially, this is a process of limitation: restricting the design to processes which may be used without excessive cost or practical problem. However, once the communication (between design and production engineer/operator) is established, design for manufacture becomes an enabling technique which can provide competitive advantage. For example, the standardization of subassemblies and components can enable a company to make more cost effective products, without loss of PRODUCT DIFFERENTIATION in the marketplace. Designing a more 'manufacturable' product can also enable a company to change from that product to its replacement

more easily and quickly, possibly giving the company a lead over competitors, and so on. The use of MRP systems, in particular the BILL OF MATERIALS, encourages design for manufacture, as the production and engineering design processes become linked. Experience in the West has shown that the technical problems in design for manufacture are generally less than the communication problems involved in bridging the traditional 'gap' between designers and manufacturers. In Japan, the technique is a well established part of the manufacturing organization: the factory is sometimes referred to as 'the laboratory', meaning that a product may be seen as the prototype for its successor. *See* GROUP TECHNOLOGY, SIMULTANEOUS ENGINEERING, QUALITY CIRCLES, FMEA and QUALITY FUNCTION DEPLOYMENT.

design management. (1) The use of design, and the stimulation of innovation creativity, and commercially sound product design, to provide a company with sustainable competitive advantage. (2) The management of the design process and department, including policies such as level of representation. An influential UK report by Kenneth Corfield in 1981 was the first time that many British companies had considered appointing a board member responsible for design. The classic problem of recognizing excellence in design, and bringing it to commercial advantage, remains one of the fundamental challenges of manufacturing industry.

design quality. The degree to which the specification or design of a product complies with the requirements of the customer, so that if excellence in MANUFACTURED QUALITY is achieved, the QUALITY of the product will be exactly as intended.

deskilling. The reduction in the level or range of skills required for a specific job. The term is often related to the replacement of LABOUR INTENSIVE work by CAPITAL INTENSIVE operations.

diagnostics. Systems built into equipment (e.g. automated plant) which enable it to find the sources of faults and other functional irregularities.

die casting. Casting process using a permanent metal formed die (as opposed to a disposable sand impression) in order to produce high-volume production (i.e. quantity), identical parts. Die casting, in which molten metal is fed or injected into a die, either under gravity feed or pressure, is used for high precision, small to medium parts, often made in multiple impression dies. Advanced processes (*see* COSWORTH PROCESS) can result in castings (especially aluminium) with surfaces which do not need machining (e.g. milling – usually necessary to provide sufficient flatness etc. for a joint face).

die sinking. The process of making an impression in a blank die – the 'female' of the part to be die cast. This is a difficult process which employs techniques such as ELECTRICAL

DISCHARGE MACHINING to produce desired shapes in parts of the die to which access is restricted.

Diesematic. Automated die casting equipment developed by the German manufacturer of that name, which has allowed mass production techniques to modernize the traditional process.

digital readout (DRO). Data display which provides digital (e.g. decimal numbers in a LED format) rather than analogue form (e.g. a clock dial).

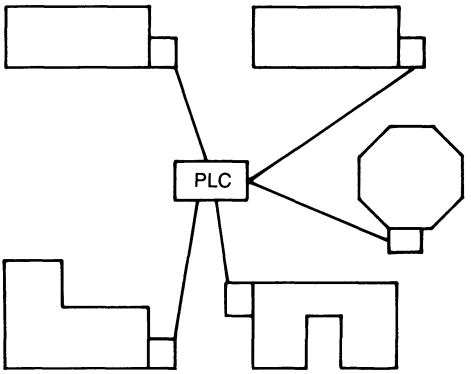
digitizing. Making a numerical control 'map' of a surface to be machined, recording the precise coordinates (e.g. in Cartesian form) of a series of points on that surface. This may be done by placing a probe on each of the points and then interpreting (by computer) the information fed back by the probe. These data can then be fed directly into CAD equipment, for design development, or CNC machines which are to be used in the manufacture of the item which has been digitized.

dimensional product. A product which is described and measured in terms of one or more of its dimensions (in the scientific sense, e.g. length, weight, volume, area, etc.). Thus, oil is a dimensional product – it is usual to express output in terms of the number of barrels produced. Likewise, textiles are measured in metres (or thousands of metres, etc.). *See* DISCRETE PRODUCTS.

direct costing. The concept of transferring traditionally INDIRECT or OVERHEAD activities to DIRECT EMPLOYEES, and subsequently treating the costs as direct. For example, many QUALITY CONTROL functions, traditionally done by INSPECTORS may be done by operators. Similarly, machine maintenance may be done by operators (who are less involved in the operation itself, since it is now more AUTOMATED.) Before this change, both quality control and maintenance costs would have been classed as indirect, or overhead (American = BURDEN). When they are done by the direct employee, they are more visible, controllable costs. This is part of JUST- IN-TIME philosophy, and the so-called WORLD-CLASS MANUFACTURING principle.

direct labour. Those members of the workforce directly involved in producing goods (or services) as opposed to carrying out support or supervisory functions, such as maintenance or management activities. Definitions vary from company to company, with some roles constantly in question (e.g. product test as part of the production process). With the adoption of increased CAPITAL INTENSITY in manufacturing, direct labour, as a concept, loses much of its significance – operators become responsible for the work which is done by the equipment they control/monitor. Direct labour – basically an accounting device used in the calculation of overhead recovery – may well become a thing of the past. *See* INDIRECT LABOUR.

direct numerical control (DNC). Also referred to as distributed numerical control. COMPUTERIZED NUMERICAL CONTROL in which a central, or host computer (a PROGRAMMABLE LOGIC CONTROLLER) is used to coordinate several manufacturing functions at once, dealing with specific NUMERICAL CONTROL (NC) needs of the various machines (PART PROGRAMMING), and also the scheduling activities required to make the entire system operate efficiently.



Direct numerical control

Programmable Logic Controller acts as supervisory computer. NUMERICAL CONTROL programs are passed to individual machines in the correct order. Each machine has a POST PROCESSOR in order to customise/translate the codes being received.

discrete product. A product for which output is expressed in units; for example, 200,000 cars per year, or 300 chickens per day, etc. The alternative is DIMENSIONAL PRODUCT.

diseconomies of scale. Factors which reduce the economic or commercial viability of a process as the scale of the process increases. For example, as the size of a manufacturing facility increases it may be seen that communication between management and shopfloor deteriorates, and thus control breaks down. The resulting output will suffer accordingly, becoming less economic or commercially sound.

distributed numerical control. *See* DIRECT NUMERICAL CONTROL.

distribution resource planning (DRP). Computerized control system for finished product distribution, similar to MRP in its design, and often linked to it. DRP was pioneered by Oliver Wight, who also developed MRP II.

DNC. DIRECT NUMERICAL CONTROL.

do-and-check cycle. Part of the philosophy of STATISTICAL PROCESS CONTROL, in which the operator (not an inspector) is encouraged to check the work being done on a continuous basis (do it, check it, do it, check it, etc.). In this way, departures from desired performance can be detected immediately and corrective action taken without loss of production.

dock-to-stock deliveries. The system in which deliveries of components and materials from suppliers are transferred directly to the production area in the customer's factory, without passing through any goods inward inspection process. Since the supplier is

well developed and certified, there is no need to check quantity and quality of the delivery. This way, a classic form of MUDA – GOODS INWARD INSPECTION – is removed.

download. To transfer programs from one computer to another, usually from a large system (in which the programs are generated or stored) to a smaller machine (on which they will be used).

downstream/downstream process. Something which occurs, or a process which is carried out, later in a production process. The notion is one of a river, flowing from source (raw materials) to its destination (the eventual market). Thus, product assembly is a downstream process when viewed by the component manufacturer or raw materials processor, but is an UPSTREAM process when considered by the customer. *See* VERTICAL INTEGRATION.

downtime. The time for which a machine is not available owing to breakdown or maintenance work.

DRAM. Dynamic Random Access Memory. A memory chip in a computer.

DRP. DISTRIBUTION RESOURCE PLANNING.

drop forging. Metal forming process in which the blank is heated in a furnace and then formed into the desired shape by being hit, within an open die, by the other half of the die; the latter driven by a heavy vertical force (from a 'drop hammer' – actually a driven, vertical ram). The part is then QUENCHED to harden it. Drop forging produces metal parts which have controllable internal stresses, and thus toughness. This is required for products which will be subjected to repeated and continual shocks (e.g. drive shafts for a vehicle). Machining processes are usually required to render the forged part usable, but developments such as SQUEEZE FORGING are reducing this requirement. Research has been conducted for years to remove the need for forging (by producing better castings – a more controllable and economic process) but it is still a vital part of manufacturing.

Dutch auction. Practice employed in subcontracting in which a customer convinces one subcontractor or supplier to reduce the price, under threat of losing the business to a competitor. Having achieved this reduction, the customer then does the same with the other subcontractor/supplier, and so on. Generally seen as a part of traditional, short-term, purchasing activity, the Dutch auction is now recognized as a wasteful and dangerous folly which leads to long-term uncompetitive positions.

DX. Data transfer (in a computer) between the processor and storage devices. DX lines are interface connections for data transfer, generally grouped into four types: MOVE, MATRIX, EXTENDED ARITHMETIC, and PRINT.

E

EBQ. ECONOMIC BATCH QUANTITY.

ECM. ELECTRO CHEMICAL MACHINING.

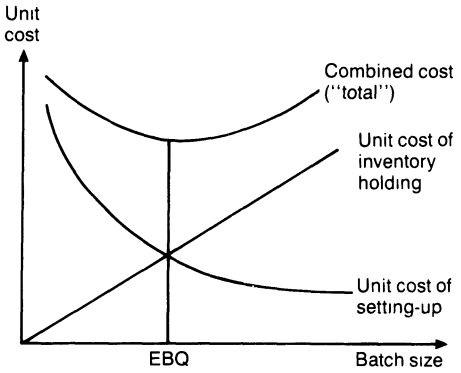
ECO. ENGINEERING CHANGE ORDER.

economic batch quantity (EBQ). (Also called economic lot quantity.) The batch size for manufacture calculated to provide a trade-off between ancillary UNIT COSTS which increase with batch size and those which decrease, thereby determining the minimum (most economic) cost for the item. In PURCHASING it is known as the ECONOMIC ORDER QUANTITY (EQQ). There are many mathematical methods of determining this size, the best known being:

$$EBQ = \sqrt{\frac{2SD}{IC}}$$

where: S = setting-up or purchasing cost per batch; D = annual usage of the part; I = annual holding cost as a fraction of the value; C = cost/price of the item.

The problem with economic batch quantity theory is that many assumptions are made in its use, for example: the item is never out of stock; LEAD TIME is constant; the UNIT COST or purchase price is constant; the usage rate is constant; orders are filled in one delivery; the cost of SETTING-UP/PURCHASING is fixed; other costs, not taken into account, do not invalidate the calculation.



Economic batch quantity

In practice, almost all these conditions are not met. Lead times are notoriously unreliable, and constant usage of a part implies perfectly balanced production, which is seldom the case. Prices vary for most parts. It is the last two conditions, however, which have led to the general discredit of EBQ theory in recent years. One of the principles of JUST-IN-TIME is that no undesirable factor should be taken as inevitable, or fixed. SETTING-UP TIME has continually been reduced as a matter of course in operations run under the new PARADIGM, with

similar reductions possible in purchasing costs. There are also many other costs associated with BATCH MANUFACTURE and purchasing which EBQ theory does not address (e.g. PRODUCTION ENGINEERING, MAINTENANCE for manufacture, SUPPLIER DEVELOPMENT, in PURCHASING.

As a result of these problems, it is now generally agreed that EBQ theory is inappropriate for use in many situations. It has been overtaken by the more thorough approaches included in JUST-IN-TIME operation.

economic lot quantity. *See* ECONOMIC BATCH QUANTITY.

economic order quantity. *See* ECONOMIC BATCH QUANTITY.

economies of scale. The concept of combining operations into large units in order to spread ancillary costs (such as administration and supervision) over large volumes of production, and thus keep UNIT COSTS low. At the micro level, the principle is contained in ECONOMIC BATCH QUANTITY theory. At the macro level, it is at the heart of investment decisions such as whether to build one large factory to supply a whole region, or two smaller factories, each to supply to half of the region. Whereas the principle of non-duplication of ancillary costs is attractive, there are also DISECONOMIES OF SCALE which combine to produce a limit to the extent to which economies of scale may be beneficial.

economies of scope. The benefits which are said to accrue from grouping manufacturing facilities together in such a way that each factory can produce a broad range of products, rather than high quantities of one or two. This requires FLEXIBILITY, rather than DEDICATED equipment. It also challenges the principle of ECONOMIES OF SCALE, since it may result in many small plants, each capable of producing a wide range of items, rather than one large plant, in which the items are made in high volumes. Benefits of economies of scope include improved customer service (by arranging production to fit customer requirements, rather than internal economies of production) and the more subtle advantages of flexibility (ability to adapt, etc.).

EDI. ELECTRONIC DATA INTERCHANGE.

EDICT. Electronic Data Interchange network, developed by the UK consultancy, ISTEL.

EDM. ELECTRICAL DISCHARGE MACHINING.

effective capacity. That CAPACITY which a production process is actually employing at a given time. This is the capacity figure which is used in CAPACITY PLANNING calculations. *See also* IMMEDIATE CAPACITY and POTENTIAL CAPACITY.

effectiveness and efficiency. In INDUSTRIAL ENGINEERING, measures of the actual work produced (by

an operator or group of operators) compared with the expected work in the time taken. After the processes of WORK STUDY and WORK MEASUREMENT have been employed to estimate the amount of work expected in a period (typically one week), the amount of work actually completed is measured and the time taken for this work. The effectiveness is the amount of work obtained divided by the time allowed (both expressed in STANDARD HOURS). The efficiency is the amount of work obtained divided by the amount expected.

electric arc furnace. Steel-making process in which the heat is generated by a large electrical arc created within the furnace.

electrical discharge machining (EDM). (Also called SPARK EROSION.) A method of removing metal from a workpiece by subjecting it to rapidly repeated electrical discharges. The workpiece itself is one electrode, the tool is the other. The metal is removed in very small particles, thus enabling minute details to be machined in this way.

electrochemical machining (ECM). Process similar to ELECTRICAL DISCHARGE MACHINING in which the action of chemicals is employed in addition to that of the electrical discharge.

electroless plating. Metal or plastic finishing process in which the coating (usually metal, e.g. gold) is deposited onto the surface without the use of electrolysis. Sometimes called CHEMICAL PLATING.

electronic data interchange (EDI). The transfer of data between two points (within one company, or between two firms) by an electronic medium and an agreed PROTOCOL. Technically, any exchange of data in this way is EDI (e.g. Fax transmissions), but the term is usually reserved for more advanced, computerized applications. These include transmission of CAD data, enabling one company to work with another on engineering development work (particularly significant in CUSTOMER-VENDOR RELATIONSHIPS) and linking MACHINE TOOLS via the MANUFACTURING APPLICATIONS PROTOCOL, MAP.

electronic time study systems. WORK STUDY tools enabling data collection and record storage and analysis by computer. Such systems are replacing the traditional stopwatch and enable observers to concentrate their attentions more fully on analysis rather that measurement.

ELQ. Economic Lot Quantity. *See* ECONOMIC BATCH QUANTITY.

emergency kanban. A KANBAN which is issued temporarily to produce inventory which is required to make up for some interruption in production (e.g. machine breakdown). It may be a PRODUCTION or CONVEYANCE KANBAN, and must be withdrawn immediately after it has been satisfied. *See* KANBAN.

employee involvement (EI). The concept of regenerating the craft ethic in manufacturing, in which the operator is involved in the development of the process rather than simply carrying out the tasks demanded. As such, true employee involvement goes against the principles of TAYLORISM and PIECEWORK. Radical concepts such as JUST-IN-TIME and TOTAL QUALITY CONTROL rely on a basis of employee involvement. *See* R.J. Schonberger, *World Class Manufacturing: the Lessons of Simplicity Applied*, Free Press (New York, 1987).

encapsulating. (Also called POTTING). A process in which electronic parts are given a strong protective coating by being dipped in plastic material which is then baked to dry and harden.

encoders. Control systems devices which convert an input signal (analogue or digital) into a code which the transfer mechanism or medium is able to use.

encryption. The encoding or 'scrambling' of electronic data which is to be transmitted via some medium in which it could be intercepted by a third party. Encryption is thus a security measure.

end mill. MILLING cutter on which the cutting edges are arranged radially on one end. Used to mill holes or slots in flat surfaces.

engineering change. The need to alter the design of a product, after its release to production, results in engineering changes which have implications for INVENTORY CONTROL, PURCHASING, and manufacturing itself. The procedures for dealing with engineering changes are often complicated, and traditionally wasteful. The number of times the design of a component in an engineering product is changed may run to a hundred in complex products (e.g. aero engines). Design engineers see such changes as an inevitable part of manufacture. PRODUCTION ENGINEERS see them as symptoms of incomplete original design. Through better DESIGN FOR MANUFACTURE and general communication between the two areas, engineering changes can be reduced in their number and cost to the firm.

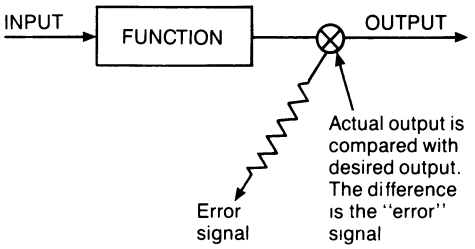
engineering change order (ECO). *See* ENGINEERING CHANGE.

EOQ. Economic Order Quantity. *See* ECONOMIC BATCH QUANTITY.

EPROM. Erasable Programmable Random Access Memory. An electronic 'chip' found in computer memories, used to store software within the machine.

ergonomics. The study of work, or humans in working environments. Ergonomics is a recognized field of study in its own right and draws upon others (biology, dynamics, anthropometry, etc.) in order to analyse working situations, and to provide the basis for developments and improvements.

error signal. A feature of control systems: an electric current (or other transmitting signal) which is generated by the difference between an expected reading and an actual reading. The error so formed can be corrected by the error signal being fed into a feedback subsystem, activating an appropriate physical response.



Error signal

etching. Removal of material from a workpiece by exposure to a chemical which causes that material to decompose. Etching is usually done with the help of a masking material coated onto the work, in which the shape to be etched appears as a shaped aperture. An example of this is the production of printed wiring, for printed circuit boards. The process starts with a LAMINATE (plastic or paper) board, coated in copper. The 'negative' of the circuit is printed (photolithographically or by screen printing) onto the copper surface in some resist chemical (e.g. thick ink) which is resistant to the etching chemical (e.g. ammonium hydroxide). The masked board is then passed through a conveyorized etching machine in which it is subjected to alternate sprays of etchant, cleaner fluid, warm air, etc. When the ink is removed from the etched board, the copper which was beneath it remains – as the printed wiring circuit. The copper which was not masked (the 'negative') has been removed, leaving the laminate board beneath exposed.

Ethernet. Widely-used proprietary type of LOCAL AREA NETWORK, which is finding increasing application in integrated factory automation.

expediting. Production control or purchasing procedure in which pressure is applied to people, departments, or suppliers to deliver parts or materials on time. Otherwise known as PROGRESS CHASING, expediting is now generally recognized as a wasteful process, only in existence because of inefficiencies. As such, it is an example of a problem which has been built in to a system – MUDA – and should not exist in the modern manufacturing environment. *See* JUST-IN-TIME.

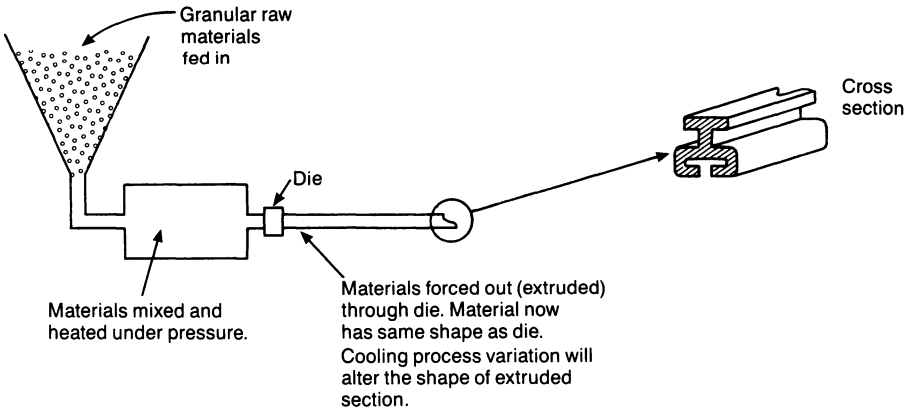
express kanban. A kanban used when there is a shortage on a part. In TWO-CARD KANBAN systems, the normal combination of CONVEYANCE and PRODUCTION KANBANS is used, and withdrawn from the system immediately after use. *See* KANBAN.

external set-up. SETTING-UP work which can be done while the machine is in operation, for example the preparation of the next set of dies to be used in a press tool. By identifying

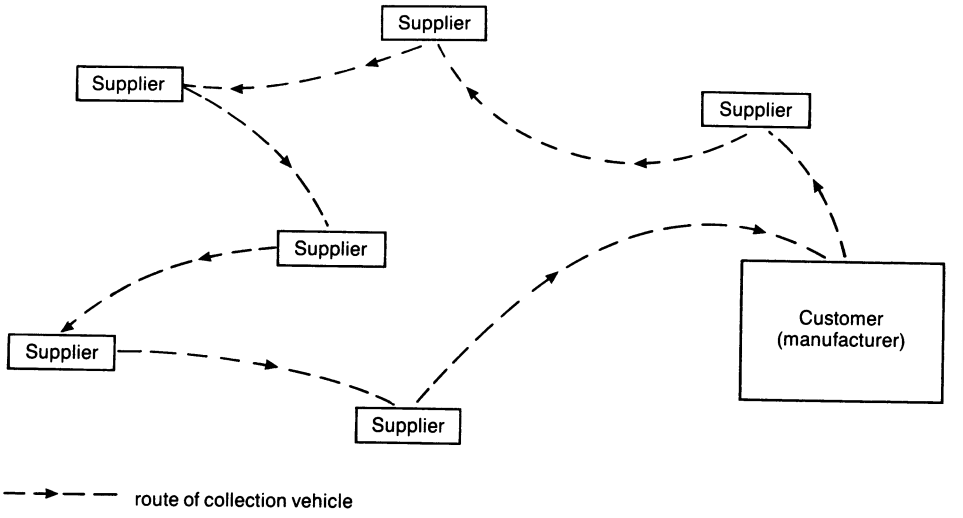
external set-up work within the total setting-up activity it is possible to reduce the time for which a machine is stopped for set up. *See also* INTERNAL SET UP and SINGLE MINUTE EXCHANGE OF DIES.

extrusion. Metal or plastic forming process in which the molten material is forced through a die, under pressure, and hardens immediately with a cross section in the same shape as the internal orifice of the die. Extrusion has been transferred from its traditional roots in the metal and plastics industries to other applications; for example, food – flat crackers – may be produced in this way.

ex-works. Goods supplied directly from the factory to the customer, rather than via a retailer. The buyer is responsible for cost of delivery. This traditional concept has found a new application in the field of JUST-IN-TIME supply of components and materials to industrial customers. An alternative to many suppliers delivering parts to the customer is provided by a system in which the customer collects the items, in specific quantities, at specific times, and in a specific order. This allows the customer to control incoming materials more effectively.



Extrusion process



Ex-works delivery system

F

fabrication. Assembly process in which pressed or stamped parts are joined together with other items, such as fasteners, hinges, springs, etc.

Factories Act 1961. Legislation now largely superseded by the HEALTH AND SAFETY AT WORK ACT 1974 which sets out various requirements on health, safety and so on for factories in the UK.

factoring. (1) Form of trade in which an agent sells a stock of goods on behalf of someone else – a principal. The agent receives a commission on the goods sold but the principal bears the risk of a lack of sales.

(2) Pseudo-manufacturing in which little or no value is added to the product. A manufacturer buys a complete product from another company and sells it as part of a range of products, possibly modifying the external appearance so that the product blends into an established style. Often used when a manufacturer wishes to provide a broad range of products but knows that it cannot compete in certain areas with established competitors. Factoring may become part of an international deal, leading to more substantial relationships. Differs from SUBCONTRACTING since the design and development of the product are the concern of the supplier, not the customer.

factory-within-a-factory concept. An approach to improvements in productivity, quality, cost reduction and worker motivation, based upon the belief that smaller working units are more manageable and potentially efficient. Similar to GROUP TECHNOLOGY or U-LINES/FLOW LINES, in that equipment is arranged in cells, each with its own range of products to manufacture. The factory-within-a-factory concept goes beyond the other concepts, however, in that the cells are treated as separate entities – PROFIT CENTRES – with cell leaders acting as directors of small, semi-autonomous companies. DIRECT COSTING is used, with direct labour operatives carrying our the tasks traditionally associated with staff functions (accounting, MATERIALS CONTROL and PURCHASING, QUALITY CONTROL, etc.)

fail-safe. A device which automatically adopts a safe position when power fails. For example, a machine might stop with the power failure and require activation to start again once the power returns – rather than simply starting up, possibly causing an accident.

failure mode effects analysis (FMEA). Technique used in quality control in which the design of a product is reviewed during the development stage to consider what effects it would cause if it failed in operation, and how it might do so. This is done in a strictly controlled manner both by the design engineer and the manufacturer of the product, to ensure that the benefits of all views are gained. If the item is to be subcontracted, the supplier is involved in the FMEA, and the technique has been a major part of some SUPPLIER QUALITY ASSURANCE schemes employed in, for example, the automobile industry.

family of parts. Concept used in FLEXIBLE MANUFACTURING, GROUP TECHNOLOGY, FACTORY-WITHIN-A-FACTORY, and MRP. Products or parts are grouped together on the basis of similarities in their features and/or production processes. A group or 'family' of products is then assigned to a CELL in the factory for production. When a similar part is required for a new project/product, the design engineer is required to use an existing part from the family if at all possible. Failing that, a new part should be designed so that it fits into an existing family. *See also* DESIGN FOR MANUFACTURE.

FAS. FLEXIBLE ASSEMBLY SYSTEM.

fastener. A part which is designed to join other parts together. Basic fasteners (nuts and bolts, screws, etc.) are being replaced in many cases by simpler devices (e.g. press-fit fasteners, requiring no tools to fit and remove) or more complex items (e.g. special design, multi-function fasteners, one of which might replace several basic items at once).

fat work. Work in which it is relatively easy to earn bonuses.

FEA. FINITE ELEMENT ANALYSIS.

feed forward. In control systems, a signal which is sent from one part of the system to provide a control input to a later stage.

feedback. In control systems, a signal which is sent back from one part of the system to provide a control input to an earlier stage. This is usually an ERROR SIGNAL, intended to modify the input to the system on the basis of a difference between the desired and actual outputs.

feeder line. A production line or CELL which feeds components to a final production line. Synchronized scheduling of the two (or more) lines is essential to ensure that the feeder line provides the right parts at the right time to the final line. The application of U-LINE technology has been used to improve the linking of feeder lines to final production lines, to good effect. *See* SYNCHRONIZED MANUFACTURING and NAGARE.

feeds and speeds. The range of control inputs traditionally associated with machine tool setting. The rate at which a tool traverses a workpiece

and the speed with which that workpiece is turning are related to the finish or thread required on the work. Standard tables on feeds and speeds are an essential parts of a machine setter's toolkit.

Feigenbaum, Armand. An American writer who coined the phrase 'TOTAL QUALITY CONTROL' in an article in *Industrial Quality Control* magazine (May 1957), and latterly in his book *Total Quality Control*, McGraw-Hill (New York, 1961); pointing out that the traditional approach to quality in the West had been the 'death certificate' method – throwing out bad parts. The correct approach, said Feigenbaum, was to design systems to build in quality and make everyone quality-conscious. He considered, however, that the central role in QUALITY must always lie with the specialist. His ideas were very influential in Japan, and later elsewhere. *See* COMPANY-WIDE QUALITY CONTROL.

FIFO. FIRST IN – FIRST OUT.

fine blank. A precision presswork process in which the press tools are designed to produce a very accurate size and finished edge.

finished goods. General reference to INVENTORY consisting of manufactured items which have been produced but not shipped.

finite capacity. *See* CAPACITY PLANNING.

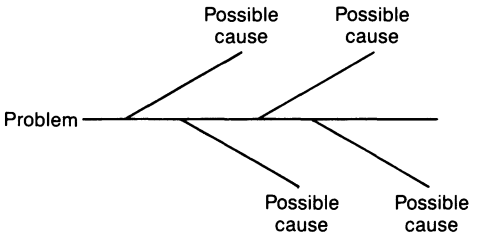
finite element analysis (FEA). CAD technique whereby the designer is able to consider a product as a system of parts – finite elements – and analyse the behaviour of each one under simulated conditions. For example, a simulation might show the product undergoing a temperature rise as a result of loading. The effects upon each finite element could then be analysed and the design altered to amend any unwanted features.

firefighting. Slang term for problem-solving activity which takes place on a continually late basis. A symptom of bad control and management, too often taken as a necessary part of manufacturing. Replacement of firefighting by firm control is an objective of JUST-IN-TIME philosophy.

first in – first out (FIFO). STOCK CONTROL principle in which the items received first should be used first, to avoid some items spending too long in stores. Particularly important with PERISHABLE items with short SHELF LIFE.

first off. The first item in a batch – usually taken for close inspection to ensure compliance with specification, before the remainder of the batch is produced.

fish-bone charts. Problem-solving technique using a diagram to work backwards from the identified effect to trace potential causes. Used in QUALITY CIRCLES, etc. *See* ISHIKAWA.



Fishbone diagram

fixed cost. Costs associated with factors not directly related to the volume of manufacture. Thus if the manufactured quantity of a product increases, but no extra space or supervision is required, the unit cost (i.e. per product) of these two factors is smaller than before the increase in volume. The reverse is also true – as scale of production decreases so fixed costs play an increasing part in the cost of the product. Fixed costs are therefore a focus for attack under JUST-IN-TIME and traditional approaches alike.

fixed interval system/fixed quantity system. *See* STOCK POINT GENERATION.

flat-pack. Provision of products in kit form, for assembly by the customer.

flexibility. The ability of a person or piece of equipment to change quickly from one task to another and to adapt, or 'flex' to accommodate changes in requirements. For operators this is a matter of attitude and physical ability. This almost always requires extensive training or retraining and good industrial relations practice. For example, operators who are accustomed to working in LARGE BATCHES, on the same product for long periods, with INSPECTORS to check QUALITY, may not find it easy or palatable to become flexible enough to work on many different products, changing from one to another frequently, in small quantities, and taking responsibility for their own quality. Nevertheless, this sort of flexibility, and more, is what is required by new manufacturing techniques.

Making manufacturing equipment flexible is a matter of systems design and physical layout. Flexibility is the opposite of DEDICATION. Flexible plant is designed to operate on many different products (usually grouped into FAMILIES) and to be reset in negligible time to cope with any of the designs. (*See* FLEXIBLE MANUFACTURING SYSTEMS).

Flexibility is required in both operators and equipment, to deal with the rapidly increasing VARIETY and PRODUCT DIFFERENTIATION demanded by modern product markets.

Flexible Manufacturing Cell (FMC). A self-contained FLEXIBLE MANUFACTURING SYSTEM built around a central MACHINING CENTRE, and sold as a customized package, often specified by the manufacturer in response to the application described by the customer.

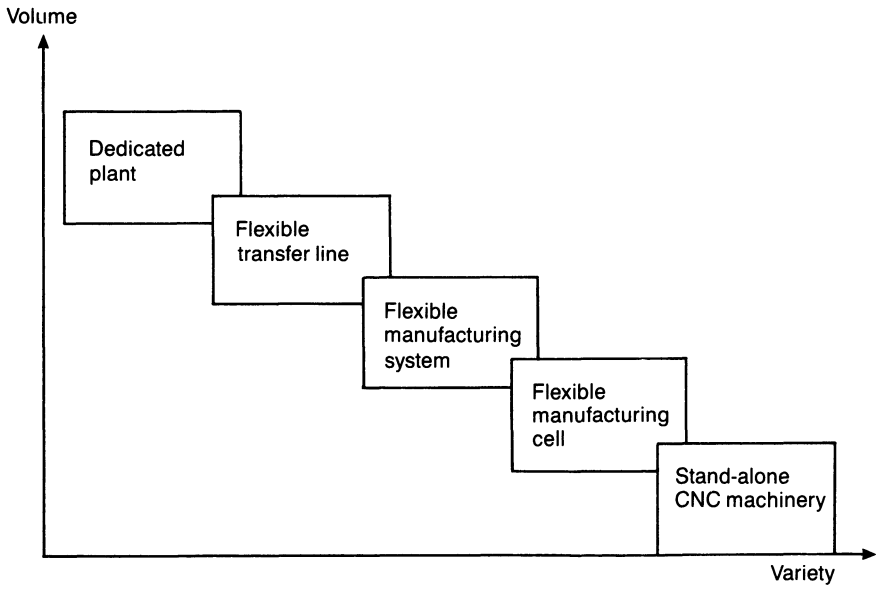
Flexible Manufacturing System (FMS). An arrangement of computer-

controlled machine tools and transport and handling systems which operates as an integrated system under the supervisory control of a larger computer. Such systems began to emerge in the 1980s and offer considerable improvements in the speed with which products can be made, employing FLEXIBILITY and FAMILIES OF PRODUCTS. FMS can enable smaller manufacturers to compete with larger firms, by providing ECONOMIES OF SCOPE.

Experience with FMS has shown, however, that they cannot be treated as traditional capital investments in manufacturing: investment payback periods are much longer for FMS than for other types of equipment, and defy the rigours of traditional accounting techniques. Such period are often quoted as seven years for full payback – a factor which would never be accepted by conventional payback calculations.

As with many types of ADVANCED MANUFACTURING TECHNOLOGY, FMS also requires fundamental changes in working practices, and substantial investment in training.

flexible pcb. A printed circuit board which is made of flexible material, so that it can be bent or otherwise shaped to fit into a restricted space within a product. For example, the wiring of automobile instrument panels has to fit in a small space within the dashboard. To do this, it is necessary to fit the wiring to the curved back of the panel casing: a flexible pcb is used.



Flexible manufacturing systems: characteristics

flexible specialization. Term coined by Michael Piore and Charles Sabel in *The Second Industrial Divide*, Basic Books (New York, 1984). The basic idea is that small manufacturing companies would emerge offering very flexible services, within fairly narrow specializations. The crucial factor in such a manufacturing economy would be the co-ordination of all the specializations to ensure that all needs were covered.

flow lines/flow production. Production in which products are said to flow through the process without stopping. Originally associated with CONTINUOUS or MASS PRODUCTION on PRODUCTION LINES, flow production is now more broadly linked with attempts to remove BATCH PRODUCTION (e.g. U-LINES, GROUP TECHNOLOGY etc.). The principle of flow production is that there should only be the minimum, necessary inventory within the process to ensure continued activity. In this way, problems are highlighted (sometimes by stoppages – interrupting the flow and indicating a fault) and corrective action can be taken.

flyback timing. A technique used in WORK STUDY where a stopwatch is used to time each element of a job and then zeroed.

flypress. Small press in which the downwards force is provided by a rotary lever, operating via a thread. When the lever 'flies' round (above the operator's head) the press tool is forced downwards. Used for light operations only.

FMC. FLEXIBLE MANUFACTURING CELL.

FMEA. FAILURE MODE AND EFFECTS ANALYSIS.

FMS. FLEXIBLE MANUFACTURING SYSTEM.

focused factory (focused manufacturing). A manufacturing facility specially designed for a particular product or groups of products. This does not entail DEDICATED plant, however, rather the application of GROUP TECHNOLOGY, U-LINES, FLEXIBILITY etc.

Similar to the FACTORY-WITHIN-A-FACTORY concept but literally a separate factory.

Ford, Henry. Originator of the Ford Motor Company, which was at one time the world leader in automobile production, before being overtaken in volume terms by General Motors (*see* SLOAN). Ford is particularly noted for his development of the MASS-PRODUCTION methods. He was the first to use a moving production line in which the product (the vehicle) moved and the operators stayed in their stations, carrying out the same operation (e.g. fitting the seats) to each product in turn. The method became the predominant manufacturing PARADIGM for producing consumer durable goods during the Twentieth Century, until challenged by JUST-IN-TIME and LEAN MANUFACTURING. Despite its drawbacks

Characteristics of the Ford/Taylor system for manufacturing, circa 1920

- standardisation of products and components, of manufacturing process equipment, of tasks in the manufacturing process, and of control over the process.
- time and work study, to identify the optimum conditions for carrying out a particular operation and job analysis, to break up the task into small, highly controllable and reproducible steps.
- specialisation of functions and tasks within all areas of operation. Once job analysis and work study information was available, it became possible to decide which activities were central to a particular task and train an operator to perform those smoothly and efficiently. Those activities which detracted from this smooth performance were separated out and became, in turn, the task of another worker. So, for example, in a machine shop the activities of obtaining materials and tools, or maintenance of machines, or of progressing the part to the next stage in manufacture, or quality control and inspection were all outside the core task of actually operating the machine to cut metal. Thus there was considerable narrowing and routinisation of individual tasks and an extension of the division of labour. One other consequence was that training for such narrow tasks became simple and reproducible and thus new workers could quickly be brought on stream and slotted into new areas as and when needed.
- uniform output rates and systemisation of the entire manufacturing process. The best example of this is probably the assembly line for motor cars, where the speed of the line determined all activity.
- payment and incentive schemes based on results – on output, on productivity, etc.
- elimination of worker discretion and passing of control to specialists.
- concentration of control of work into the hands of management within a bureaucratic hierarchy with extensive reliance on rules and procedures – doing things by the book.

Fordism

(excessive INVENTORY, worker demotivation, division between quality and productivity, etc.: *see* MASS PRODUCTION) the method remained the basis for later techniques, especially in the automobile industry, where it was born. It was latterly referred to as 'Fordism' (giving rise to the inevitable 'POST-FORDISM'). Henry Ford saw his company rise to success and his descendants play a major role in its management. For a full story on Henry Ford, see H. Halberstam, *The Reckoning* (New York, 1988). *See* MASS PRODUCTION.

Fordism. *See* POST-FORDISM.

foreigner. Slang term for work done in company time, with company resources, for private purposes.

foreman. Shopfloor supervisor in a manufacturing area, with responsibilities for planning and control or resources and operatives. No standard definition of this role exists, each company deciding individually on the best use of such an individual.

forging. Metal-forming process in which the raw material is formed into a semi-finished part (i.e. it will need subsequent machining processes to provide mating surfaces, bearing surfaces, etc.) in a mold, under repeated beating. Just as traditional forging (e.g. horseshoes) requires the red-hot metal to be beaten with a hammer by a blacksmith, and then QUENCHED in liquid (oil or water), so mechanized forging employs a furnace, a hammer, and a quenching vat. The main difference from the traditional process lies in the hammer: in manufacturing, this is a heavy press machine in which one half of the mold is fixed in the base, the other being fixed to the surface of the ram. The ram is moved quickly, repeatedly and with great force (i.e. like a hammer) against the hot metal, in the fixed half of the mold. The workpiece is sometimes turned to ensure correct relief of stresses in the metal (which result in ruggedness in the finished item – the chief benefit of forging over CASTING). Forging is a noisy, potentially dangerous, hostile-environment process, despite the application of modern manufacturing technologies (e.g. automation) but provides product characteristics (strength, ductility, etc.) not achieved by other processes.

fork lift truck. Specialized industrial vehicle designed for lifting heavy loads.

form tool. In metal cutting, a tool which is so shaped that it produces a desired form on the rotating workpiece, without the need to move the tool in complicated paths.

foundry. Factory in which CASTING is carried out.

four-wall inventory system. Technique for high accuracy control of materials in a system in which lead times (for delivery and processing) have been reduced to hours or days.

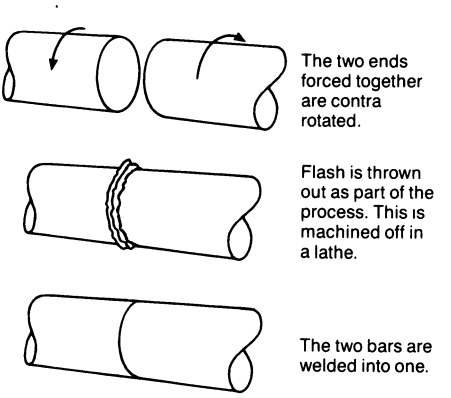
The idea is that inventory is added to the system when it enters the 'four walls' of the factory (typically in a FACTORY-WITHIN-A-FACTORY or GROUP) and deducted from it when it leaves. This assumes that there is no scrap and that only planned amounts actually arrive and leave. In practice, sub-systems are required, at least at first, to accommodate departures from the perfect performance which is sought. The system is only possible when other factors (LEAD TIME, DATA INTEGRITY, etc.) have been optimized.

fourth generation language. (4GL). Class of high-level computer languages which utilise good software engineering practice such as modular structures and user friendliness. The name is derived from the view that there have been three previous generations of software – early machine language programming, assembly languages, high level programming languages (such as BASIC and FORTRAN) – from which various design lessons have been learned. 4GLs are particularly

useful in the development of user-specific applications for particular tasks, since their modular construction allows a building-block approach to be adopted, combining the required functional segments of program and applying them to a particular DATABASE of user information.

fragile. Term developed by John Krafcik, John Paul MacDuffie, and Haruo Shimada (MIT) to describe a production system or factory which is designed to rely on perfect working conditions, and to work without any sort of BUFFER. It may therefore be said to be 'fragile' – vulnerable to stoppage. Operating such a system requires the most careful and expert management, which brings rewards in terms of quality and throughput. *See* LEAN MANUFACTURING.

frazing. DEBURRING.



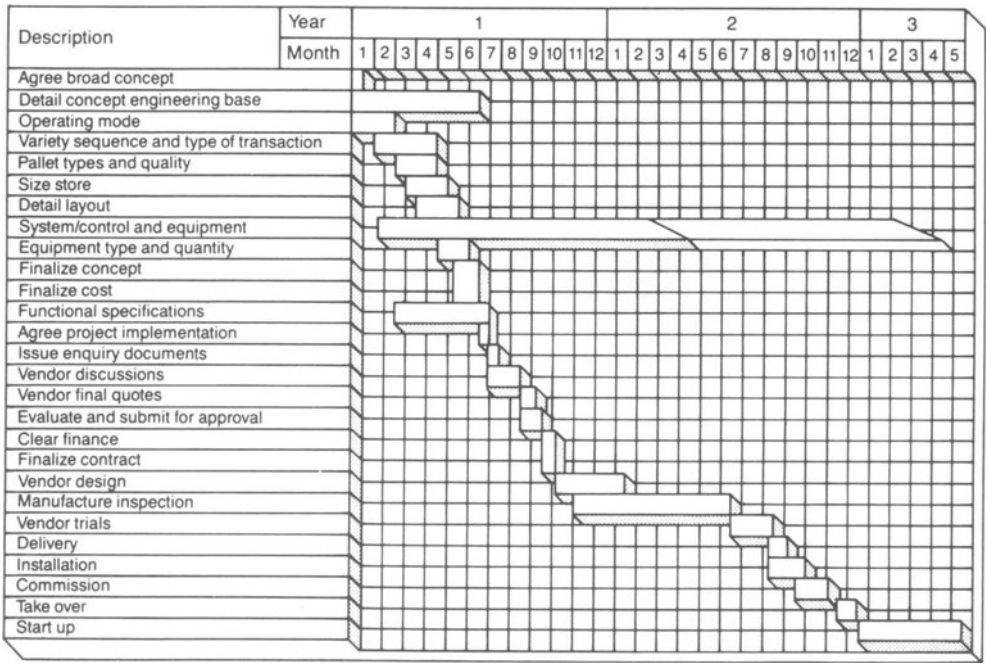
Friction welding

friction welding. Metal-joining technique in which two parts are counter-rotated together under pressure, the friction thus caused literally welding them into one, without the need for flux or other material. Typically used for joining the end of one bar to another, to lengthen it. A 'flash' is produced by the process, in the form of a ring round the circular join.

G

Gage's 12 steps to Value Analysis. An approach to VALUE ANALYSIS developed by the industrial engineer, Gage. The technique is based upon asking explicit questions about the item to be analysed: (1) What is it? (2) What does it cost? (3) How many parts? (4) What does it do? (5) How many required? (6) Which is the primary function? (7) What else would do? (8) What would *that* cost? (9) Which three of the alternative ways of doing the job shows the difference between 'cost' and 'value'? (10) Which ideas are to be developed? (11) What other functions and specification features must be incorporated? (12) What is needed to sell the idea and to forestall 'road blocks'?

Gantt chart. A diagrammatic representation of activities in a project,



GANTT chart

set against a timescale. The system, invented by US engineer Henry Gantt, develops the simpler bar chart (so called because the activities appear as horizontal bars, the lengths of which represent the length of time required for the activities). The activities may be grouped according to resource requirements or other key factors.

Garvin, David A. Influential US writer on quality management, whose detailed studies of the relative quality levels in the US and Japanese air conditioner markets brought home to US managers the serious challenge on quality which manufacturing was experiencing in the 1980s. In an influential article in *Sloan Management Review* (Autumn, 1984), Garvin identified eight dimensions to QUALITY:

Dimension	*Example*
1. performance	acceleration of a car
2. features	electric windows
3. reliability	no breakdowns
4. conformance	lack of defects
5. durability	long lasting tyres
6. serviceability	ease of maintenance
7. aesthetics	'looks'
8. perceived quality	prestige

gatekeeper. A term used in analysing technical change in organizations. An individual in the organization who acts as an unofficial communication focus, collecting information from a variety of sources external to the company and passing it on to individuals within the company to whom it might be relevant. *See* T.J. Allen, *Managing the Flow of Technology* (MIT Press, 1977).

geometrical tolerance. Method of setting a TOLERANCE using a feature of the part (e.g. roundness, flatness, etc.) rather than a single dimension (e.g. length or diameter). The system is more complicated than simple tolerancing, but provides more comprehensive scope for control of physical shape.

GIGO. Garbage in – garbage out. Slang term used to refer to the fact that a system which is fed with poor quality data will produce poor quality output, regardless of how well the system works or is designed. *See* DATA INTEGRITY.

GMP. GOOD MANUFACTURING PRACTICE

Goal, The. *See* OPTIMIZED PRODUCTION TECHNOLOGY.

go-no-go. A gauge which has two measuring devices – one that should 'go' (i.e. fit, when compared to the workpiece), and one that should not. Such gauges are often used to check diameters (internal or external). For an internal diameter, for example, one end of the gauge would have an outside diameter at the lower tolerance whilst the other would be just larger than the higher tolerance. Thus one end of the gauge should always 'go' and the other should 'not go'. The go-not-go gauge is an old idea but it

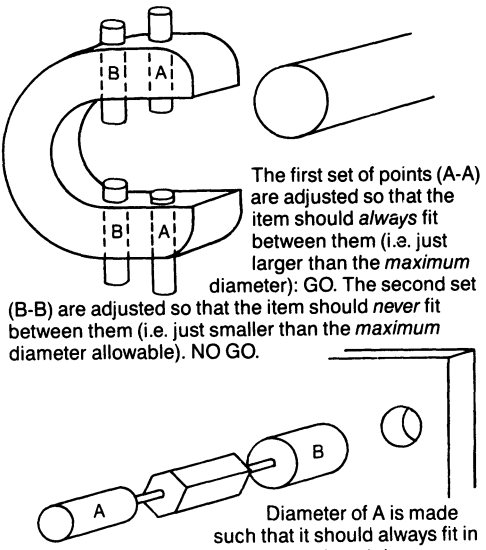
shows some of the modern thinking of simplicity. *See* POKA-YOKE.

golf ball system. KANBAN system ('single card') in which coloured golf balls are used as signals for delivery of goods. The system was developed in Japan, within factories, to link WORKSTATIONS. When a delivery of parts is required, the 'customer' workstation sends a golf ball down a tube which leads to the 'supplier' workstation (simply by gravity). The colour of the ball indicates the part required (in the standard quantity, always used for that item).

Good Manufacturing Practice. An American QUALITY ASSURANCE standard, similar to BS5750 and ISO 9000, based upon building-in quality by monitoring the entire manufacturing process.

goods inward. The receiving area of a factory where materials and components are delivered by suppliers.

goods inward inspection. Traditional technique, now largely discredited, of inspecting goods received from suppliers. This custom was based upon the assumption that some of the items delivered would be faulty. It is now seen as an example of waste, or MUDA. The expectation is now that the supplier should provide only perfect quality, and that there is therefore no requirement for goods inward inspection. If faults do appear in delivered items (e.g. when they are used in the subsequent process) the response should be to remove the cause of the fault (i.e. in the supplier) rather than revert to inspection. (*See* SUPPLIER DEVELOPMENT.) The removal of goods inward inspection is seen as a prerequisite for JUST-IN-TIME operation.



The first set of points (A-A) are adjusted so that the item should *always* fit between them (i.e. just larger than the *maximum* diameter): GO. The second set (B-B) are adjusted so that the item should *never* fit between them (i.e. just smaller than the *maximum* diameter allowable). NO GO.

Diameter of A is made such that it should always fit in the hole (GO), i.e. just smaller than the minimum diameter allowable. Diameter of B is made so that it should never fit in the hole (NO GO), i.e. just larger than the maximum diameter allowable.

Go–no go gauges

goods received note. Documentation raised by goods inward department to certify receipt of goods. True JUST-IN-TIME systems have done away with much of this documentation (since it complicates the system), relying instead upon output of the finished products as a measure of components delivered. Thus, if the customer produces 100 finished products, and there are four of a certain component in each product, the supplier is credited with having supplied four hundred

components. Naturally, such a system requires trust between the two parties, and perfect QUALITY.

go-slow. Restrictive working practice in which labour operates at a reduced rate in order to inconvenience a company, bringing pressure to bear in a dispute.

Gozinto chart (assembly chart). A chart which indicates the way in which complete assemblies are built up. It details the sequence in which components go into subassemblies and how these in turn are made into complete assemblies.

gravity die casting. DIE CASTING in which the metal enters the mold under gravity alone, no pressure being applied. Traditionally this has resulted in a lower quality casting but new techniques, such as the COSWORTH PROCESS have enabled gravity casting to develop.

greenfield site. Factory that is built in an area not previously used for that purpose – literally a green field. The significance of such a project may be great: new jobs, but for a 'green' workforce; that is, one which has no history of skills or organized labour in that area and will therefore require training, but will offer little resistance to management ideas. A greenfield site factory is likely to be more efficient than an older plant, since it will be built with the most advanced ideas incorporated. This means that companies often need to re-establish manufacturing facilities simply to remain competitive. When a new factory is built on an old site (which has, perhaps, been razed for the purpose) it is called a BROWNFIELD SITE.

greensand. Sand which is used for casting. The sand is mixed with water and chemical binding agents and used, while still wet, to form the mold or cores.

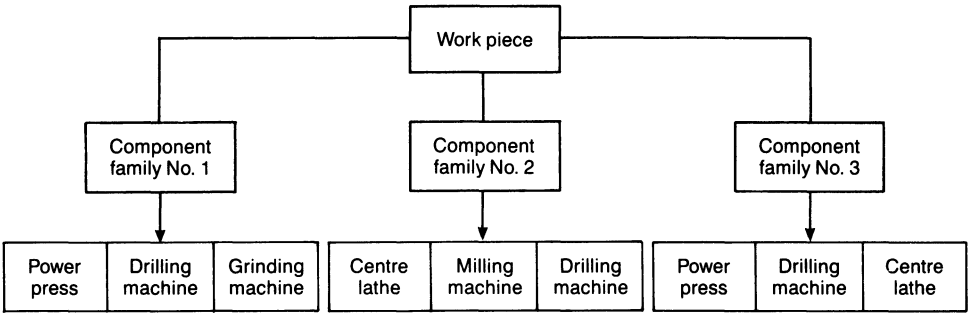
grey-box engineering. Similar to BLACKBOX ENGINEERING. In grey-box engineering, however, the customer is involved to an extent in the internal workings and design of the component system in question. More common than black-box engineering, in most industries.

grinding. Metal-finishing process in which small amounts of the metal are removed by bringing it into contact with an abrasive wheel, turning at very high speed. The surface finish thus generated is to a very high specification.

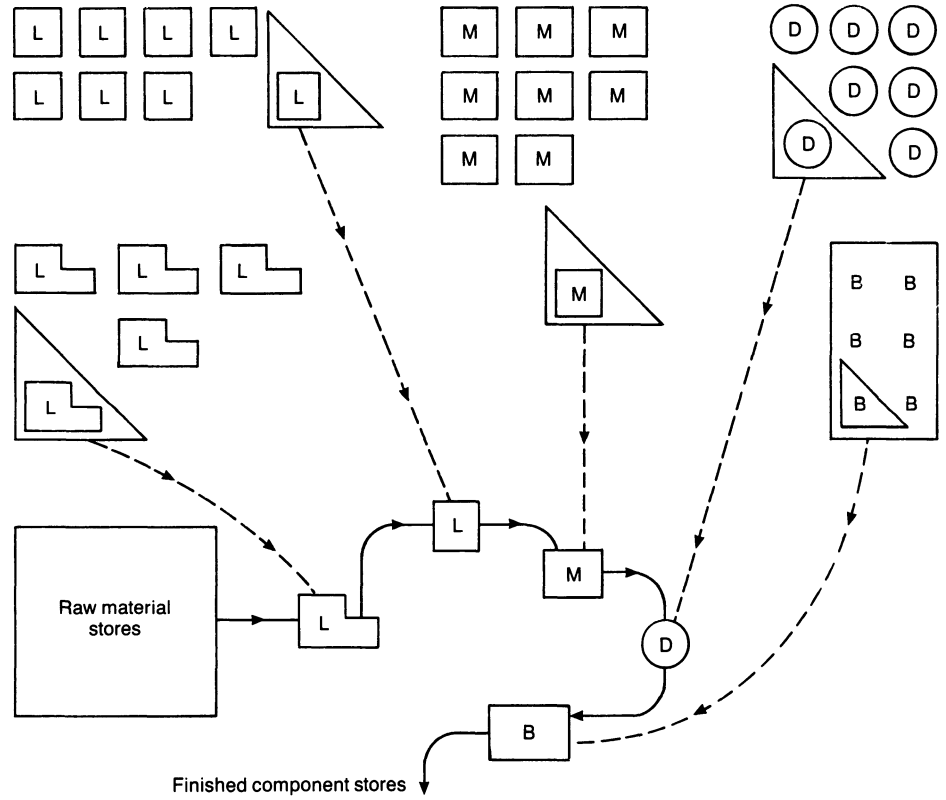
gross requirements. In materials requirements planning, term used to denote the materials required for planned production, not taking into account existing stocks. *See* MATERIALS REQUIREMENTS PLANNING and NET REQUIREMENTS.

group technology (GT). The principle of manufacturing based upon grouping machines together into cells, with regard to the products which will be made in the factory, and the ways in which they too may be grouped

1. Development



2. Shopfloor Arrangement



L: Lathe B: Boring machine
D: Drill M: Milling machine

Group technology

together (on the basis of physical form, production requirements, etc.). Group technology may employ a flow-line, in which machines are placed on either side of a central transport system (a conveyor); or a cellular system, in which a horseshoe arrangement is generally used. In either format, the principle is that materials move only the minimum distance in the process of production and that WORK IN PROGRESS is kept to a minimum. GT can be extended to encompass design policies, requiring design engineers to incorporate the potential and constraints of the production facilities within new designs (i.e. fit new parts into existing families or groups). Group technology is similar in its concept to U-LINES, and JUST-IN-TIME in general, since the physical relocation of machines also provides improvements in operator motivation and product quality.

grupu. The large industrial groups of Japan, often called the Zaibatsu, or KEIRETSU.

GT. GROUP TECHNOLOGY.

H

Halsey scheme. A bonus scheme in PAYMENT BY RESULTS. A bonus is awarded for on-target performance. However, the bonus payable is not related to the degree to which standard performance is exceeded, as with a conventional incentive scheme.

HaSaWa. *See* HEALTH AND SAFETY AT WORK ACT.

Hawthorne effect. The improvement in motivation felt by those involved in some special project which attracts a lot of attention. The term comes from the Hawthorne Studies, or Experiments, which were carried out under the leadership of Elton Mayo between 1927 and 1932 in the USA (the Hawthorne plant of Western Electric Co.). These experiments led to the creation of the Human Relations School of Management Thinking. The experiments attempted to examine the influence of physical factors in the environment – such as heating and lighting – on output and productivity. Results showed that these factors had little effect but that interpersonal relationships between the workers – and indeed, the very fact of management being seen to take an interest in them – were very influential. The results are widely published and a good summary is to be found in F. Roethlisberger and W. Dickson, *Management and the Worker*, Harvard University Press (Cambridge Mass., 1939).

heat treatment. Any process in which materials (usually metals) have their physical properties (hardness, malleability, etc.) altered by exposure to heat, often in the presence of some other material. For example, steel may be heated in the presence of coal to increase the amount of carbon, and thus the hardness of its surface. *See* CARBURIZING, CYANIDE, NITRIDING.

Health and Safety at Work Act 1974 (HaSaWa). A UK law passed in 1974 to update and rationalize earlier legislation (such as the Factories Act 1961) covering working conditions, safety procedures, and employee welfare in factories in the UK. It was essentially a piece of enabling legislation and in many areas gave general aims rather than setting specific standards; some of these have subsequently been developed into codes of practice. *See* CONTROL OF SUBSTANCES HAZARDOUS TO HEALTH.

heijunka. Toyota method of smoothing production – an essential prerequisite for successful KANBAN

and JUST IN TIME operation. See Y. Monden, *Toyota Production System*, USA Institute of Industrial Engineers (1983).

high-bay warehousing. The technology employed in warehousing (ROBOT vehicles to store and retrieve goods, PALLETIZING, etc.) coupled with the rising costs of land, and therefore warehouse floorspace, has meant that the ability to stack goods higher and closer together provides a lower cost, and possibly greater control for warehousing. Aisles between racks are narrower, with rails for the automatic handling devices in use, etc. The bays in which goods are stored are thus higher.

high-level language. A computer language which allows the user to program instructions for the computer in a series of logical statements which approximate to human language and which make it easy to work with the computer. It differs from low-level language or machine code, in which the actual instructions which control the computer must be represented and which is based upon binary numbers. High-level languages exist for many general and specific applications and examples include FORTRAN, PASCAL, ALGOL, COBOL, BASIC, LOGO, C. In each case, the languages are translated within the computer into machine language by an interpreter or compiler. *See* FOURTH GENERATION LANGUAGE.

hobbing. Process for making gears or splined shafts. The teeth on the gear are formed (from a ring or flange on the central body of the gear) by repeated vertical shaving. The gear blank and the hobbing tool are rotated through a set angle after each shave.

Hocus. A simulation language used for planning production layouts, workflow, etc.

honing. Machining process designed to produce a very fine finish on circular metal parts.

host computer. In distributed computer systems (e.g. DNC), the central computer to which all other processors are linked. The host computer carries out management tasks, allocating and scheduling work via the various machines.

house of quality. Concept of creating a communication system within a company in order to improve product quality by bringing together the various parties involved. Used extensively by such successful companies as Toyota, ITT, Hewlett Packard, Ford and AT&T. For a good explanation see *The House of Quality* John R. Hauser and Don Clausing, Harvard Business Review, May–June 1988.

HRM. HUMAN RESOURCE MANAGEMENT.

human engineering. *See* ERGONOMICS.

human resource management (HRM). The management discipline

concerned with the control and maintenance of the people involved in an organization. The title for this discipline, in an industrial context, appears to cause endless difficulty, changing regularly; for example, personnel, human resource management, employee relations, resource management, etc.

hybrid technology. Machine or process design in which more than one basic technology is applied, for example electronics and fluidics.

hydraulic press. Press tool in which the force is applied by means of an hydraulic system, not simply mechanical.

hydrodynamic machining (HDM). High-pressure, high-volume, water-jet cutting of metal. Water pressure of up to 60,000 psi are used. Numerical control systems and other automation features are applied.

I

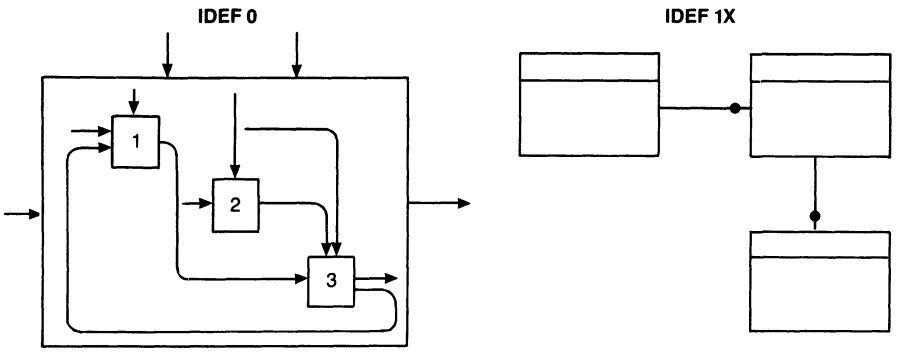
I Mech E. (UK) The Institution of Mechanical Engineers.

I Prod E. (UK) The Institution of Production Engineers. Due to change its name to the Institution of Manufacturing Engineers in 1990.

IDEF. Integrated definition modelling methodologies are standards used for modelling functionality (IDEF 0) and information structure (IDEF 1X) during systems analysis. They were developed and defined by the US Air Force Program for Computer-Aided Manufacturing. IDEF 0 is used to analyse human or automated systems, producing a hierarchical, 'top-down' structured diagram, showing the functions within the system and the data or information flows between them. IDEF 1X produces a logical model of the system, showing how it functions.

ident. Abbreviation for identification. Refers to any mark or sign placed on material or a component in order to show its identification and other relevant information about it.

idle time. Time for which a machine is not being used. It is important to realize that this is not the only time for which a machine is not being profitably used. For example, the machine may be used for a high proportion of the time, but not necessarily on work which is actually required. *See* UTILIZATION.



IDEF methodologies

IGES. INITIAL GRAPHICS EXCHANGE SPECIFICATION.

IIE. *See* INSTITUTE OF INDUSTRIAL ENGINEERS.

immediate capacity. The CAPACITY which is available within existing budgets; i.e. no application for CAPITAL EXPENDITURE or extra SUBCONTRACTING or overtime need be made. *See also* EFFECTIVE CAPACITY, and POTENTIAL CAPACITY.

incentive schemes. *See* PAYMENT-BY-RESULTS.

independent demand. In STOCK CONTROL, demand for an item which is not deemed to be primarily dependent upon demand for another, more major, item. An independent item must thus be managed separately, rather than as a function of another.

indirect labour. Support and supervisory functions within the manufacturing process which do not add value in themselves but provide the means for DIRECT LABOUR to do so. Indirect labour is an OVERHEAD cost.

indirect material. Materials which are not eventually part of the product but are consumed in its manufacture.

industrial action. The various kinds of response made by employees, usually organized by their TRADE UNION, to action by employers. Industrial action can take the form of a complete stoppage of production (a STRIKE) a slowing down (GO-SLOW or WORK TO RULE) a restriction on OVERTIME (OVERTIME BAN) or restriction on operator FLEXIBILITY.

industrial diseases. A range of diseases and illnesses which are caused by some aspect of work or its environment – for example, asbestosis (lung damage from asbestos dust), silicosis (similar to coal dust), dermatitis (skin irritation from contact with oils etc.).

industrial engineering (IE). Engineering discipline which incorporates PRODUCTION ENGINEERING (the study of equipment in use with a view to obtaining the best results from the most economic use of resources) and WORK STUDY, or ERGONOMICS (the same, but for human resources).

Industrial Health and Safety Centre. A UK agency set up by the Department of Employment, providing guidance on health and safety-related questions.

Industrial Injuries Advisory Committee. A UK committee serving the Department of Health and Social Security, which advises on payment of benefits due as a result of industrial injuries, accidents and diseases.

Industrial Injuries Fund. A UK fund, administered by the Department of Health and Social Security, which provides the resources for payments to the victims of industrial injuries. Its work is guided by the INDUSTRIAL INJURIES ADVISORY COMMITTEE and its resources are drawn both from taxes and from employer/employee

contributions. Its disbursement is covered by various pieces of legislation in the National Insurance Acts.

industrial relations (labour relations). Issues raised by the relationship between employers and employees, usually via the latters' representation by a TRADE UNION.

Industrial Relations Act 1971. Legislation introduced in the UK in an attempt to rationalize and strengthen much fragmentary earlier legislation on INDUSTRIAL RELATIONS. The Act was repealed by the Labour government in 1974 and replaced by the TRADE UNION AND LABOUR RELATIONS ACT which was itself repealed by the next Conservative government, which reintroduced many of the features of the Industrial Relations Act again in the Employment Acts of 1980 and 1982.

Industrial Safety Advisory Council. A UK Committee reporting to the Department of Employment on matters pertaining to industrial safety.

industrial trade union (industry union). A TRADE UNION which is empowered to represent all workers in an industry. It is common in countries like West Germany where, for example, all workers in a steel works are represented by IG Metall, the metalworkers' union, even though there may be electricians, plumbers or supervisors, etc. in the workforce. In the UK, the more common pattern is one of multi-unionism, in which representation is by skill or craft grouping, so that one site may have several unions involved.

Industrial Training Act 1974. Legislation which covers the area of manpower planning and training in the UK and which resulted in the setting up of a number of statutory INDUSTRIAL TRAINING BOARDS for particular sectors of industry.

industrial training boards (ITBs). A number of statutory bodies set up in the UK under the INDUSTRIAL TRAINING ACT 1974, responsible for education and training provisions within various industrial sectors. Each board is made up of employers' and employees' representatives, plus specialist government assessors. Most ITBs were disbanded by the new Conservative government in 1979, leaving only six. There are some other, private venture, training boards.

industrial tribunals. UK organizations set up under the INDUSTRIAL TRAINING ACT 1974 to hear appeals pertaining to levies imposed upon employers. They were subsequently expanded to cover a variety of employment-related cases, such as those concerning equal opportunities or dismissal. There are currently 27 of these in England and Wales. They are usually chaired by a solicitor or barrister and have two lay members: one nominated by the Confederation of British Industry, and the other by the Trades Union Congress. One feature

of industrial tribunals is that they do not have the same strict laws of evidence as other courts, so employees may plead their own case rather than requiring a solicitor to plead on their behalf. Around 80 percent of the cases heard are concerned with some form of unfair dismissal.

Industry Act 1972. A major piece of industrial policy legislation in the UK. It covers several issues, including the provision of investment in new plant and equipment and the setting up of regional development support for special areas.

infinite capacity. *See* CAPACITY PLANNING.

ingot. Bar of metal, freshly cast, ready for use in a CASTING or FORGING process.

in-house. Term used to describe something which happens in the company, especially the factory. For example, inhouse goods are made in the factory (as opposed to being BOUGHT-OUT).

Initial Graphics Exchange Specification (IGES). A computer PROTOCOL, developed in the early 1980s, which may be used to enable one CAD system to send or receive design data to or from another. CAD equipment of different makes, using different computer languages may communicate in this manner.

injection molding. Plastic molding process in which molten plastic is injected under pressure into the mold, forming a solid product. This is often a high-speed process, with multi-impression molds enabling high volumes of production at low cost.

innovation. To make something new. Usually taken to mean technological innovation, which is defined as the technical, organizational and commercial steps involved in the introduction of new manufactured products to the marketplace and of new manufacturing processes to the factory, or of new working technologies into the production and delivery of services.

in-process gauging. Technique for measuring the workpiece during the machining process. The gauge is built into the machine tool and either monitors the required dimension continuously, or at intervals. In some cases there is physical contact between the gauge and the workpiece (similar to measuring with a MICROMETER); in others, techniques such as lasers are used.

inspection. The traditional approach to ensuring quality in a product was to inspect a sample of the parts after production of each BATCH. Using the STATISTICAL QUALITY CONTROL techniques (first postulated by Walter SHEWART in the 1920s), inspection was used to determine which parts conformed to specification and which did not. The rejects would then be reworked, or even scrapped. This wasteful process has now been generally replaced by the use of STATISTICAL PROCESS CONTROL,

which enables the operator, rather than the inspector, to tell when the process is likely to go out of control (in terms of product dimensions etc.) and to take preventative action. The role of the inspector has thus changed from 'policeman' to 'policy maker' as quality control has become a more integrated part of the production process and less of a retrospective matter of sorting and apportioning blame.

Institute of Industrial Engineers (IIE). (USA) Professional organization of INDUSTRIAL ENGINEERING.

integrated definition modelling. *See* IDEF.

integration. The development of a manufacturing system in which several individual machines operate and communicate together. In an automated integrated system, instructions and control data which were traditionally the domain of human operators and supervisors are handled by the machines themselves, and their related computers. There is, however, evidence to show that there is a key role for operators (i.e. human) within an integrated system, and that the flexibility thus injected can improve the operation of the system greatly.

intellectual property rights. The legal and moral right to benefit from an original idea, or application of an idea (e.g. copyright, patents, etc.). As manufacturers and their component suppliers work closely together on development of new products, it is often difficult to determine where the credit for invention should lie. This is particularly so where CAD is being used, with data being constantly transferred and shared. In many technologies, patenting is still an important record of competitive position, and intellectual property rights remain the subject of lengthy legal battles.

interactive video. Computerized video technique in which information is stored on a video disk and may be displayed (as a video film) on a normal television. The user responds to questions put by the video (e.g. choosing from a menu of items). The choice which is made determines which part of the video will be shown next. The technique has been widely used in industrial training; for example, an operator may be introduced to a new machine by seeing it work on video and having questions answered by the system, rather than by reading a manual.

interactive. A system which responds to interrogation. Such a control system on a machine tool (i.e. where the operator can ask the system questions and receive answers), is sometimes said to be working in CONVERSATION MODE.

interface. The point at which two parts of a system meet and communicate. In both human and automated systems, it is often at the interface that difficulties in communication arise. For example, different technologies may be employed in the two systems – for example, different designs of plug

and socket. Where computers and humans are involved, there may be two or more different languages in use, requiring efficient translation.

interfacing. The technique of providing efficient INTERFACES.

interference fit. The specification for two parts which are intended to fit tightly together. For example, a round bar which is to be machined to fit into a circular hole would have an outside diameter dimension larger than the internal diameter dimension of the hole. In this way, when the two are fitted together, the material of the bar would 'interfere' with that of the part in which the hole has been made. Force would be needed to fit the two together, leaving them firmly joined. *See also* CLEARANCE FIT.

internal grinding. GRINDING process in which the metal cutting takes place on the inside diameter of a hole. This process is used to produce high specification finishes and accuracies in holes (either inside hollow cylinders, in which case the workpiece is rotated, or in holes BORED in larger, non-cylindrical parts, in which case the tool itself may rotate.)

internal set-up. SETTING-UP activities which must be undertaken whilst the machine is stopped. *See also* EXTERNAL SET-UP and SINGLE MINUTE EXCHANGE OF DIES.

International Standard Industry Classification (ISIC). United Nations organization: the International Standard Industry Classification of all Economic Activities was issued in 1948 and has been revised every ten years since. The classifications are based upon economic records kept by the various member nations, and thus limited in their flexibility in use to predetermined factors. In the UK the ISIC codes are administered by the Central Statistics Office.

International Standards Organisation (ISO). A specialized international agency of the United Nations, based in Geneva, comprising the national standards organizations of over 90 countries. The object of the ISO is to promote the development of standardization and related activities in the world with a view to facilitating international exchange of goods and services and to developing co-operation in the spheres of intellectual, scientific, technological and economic activity.

inventory control. Collection of techniques employed in maintaining the right quantities of INVENTORY (especially RAW MATERIALS), also known as STOCK CONTROL. A traditional problem in Western manufacturing has been concern over running-out of materials (and thus stopping production) and this has resulted in inventory control being designed to hold 'plenty' of materials. It was realized in Japan in the 1950s, and in the West in the 1980s, that such concern actually led to far too much inventory being held in many manufacturing operations and that it was counter-productive, resulting in a lack of concern for scrap, poor quality, poor

operator motivation etc. *See* JUST-IN-TIME.

inventory. Stock: RAW MATERIALS, WORK IN PROGRESS, and FINISHED GOODS. *Note:* In the USA, the term STOCK is not used as a synonym for inventory, but only in its financial sense (i.e. stocks and shares).

investment casting. CASTING process used to make small, intricate parts. The model is made of wax or similar material. This is coated in ceramic material which becomes the mold when the model is burned out. The ceramic material is then filled with the molten metal, and is itself destroyed in order to obtain the finished casting.

invisible conveyor. The idea of perceiving the production process as one long conveyor (even though the separate operations may not be physically connected). This concept encourages the creation of a 'flow' process, minimizing inventory, etc.

invisible inventory. Term used to describe the paperwork and other system features in manufacturing and its related activities (e.g. ordering materials, etc.) which add to the cost of the operation (and thus to the product) without actually adding value. Referring to this as 'inventory' focuses attention upon it, and upon its reduction.

Ishikawa, Kaoru. One of the most influential thinkers and writers on QUALITY, especially QUALITY CIRCLES. Ishikawa is generally credited with the development of such techniques as FISH-BONE CHARTS, and is sometimes called 'the Father of the Quality Control Circles'. He is also credited with the axiom, 'the customer is the next process'.

ISIC. INTERNATIONAL STANDARD INDUSTRIAL CLASSIFICATION.

islands of automation. The incomplete implementation of an automation technology in manufacturing which leaves some parts of the process unchanged, whilst others have been significantly updated. The 'islands' which have been developed may achieve excellent results but the process itself may be let down by the non-automated parts. The term is not meant to imply that everything should always be automated, rather it is a criticism of incomplete or 'piecemeal' approaches to introducing technology without true integration.

ISO. INTERNATIONAL STANDARDS ORGANISATION.

isolated island. Similar to the concept of ISLANDS OF AUTOMATION but more generally applied: people working within the same production process, but unable to communicate directly because they are separated by distance, work-in-progress or poor

communication devices, are seen as islands in a 'sea' of wasteful practices.

issue number. Reference number attached to a specification or drawing of a part to indicate the stage in its design. Thus, 'Issue B' is replaced by 'Issue C' when a design or ENGINEERING CHANGE has been made, etc.

J

Jacquard. Revolutionary type of weaving loom control mechanism invented in 1805 by the Frenchman, Joseph Marie Jacquard (1752–1834). The method of lifting specific threads in specific order enabled the user of a Jacquard loom to produce repeatable patterns in the woven material. This is now regarded as the first application of numerical control, since the order of lifting threads was controlled by punched cards which were fed in succession through a 'reading' mechanism. The holes in the cards corresponded to specific threads in the pattern. Jacquard technology is still in use although CNC technology has replaced it in many cases.

Japanese techniques. The range of novel approaches to manufacturing which arose in Japan after World War II has been recognized as a radical PARADIGM – questioning and in some cases refuting many of the established concepts. For example, the principle of KAIZEN, or PERPETUAL IMPROVEMENT, may be applied to reducing the time and cost of resetting or adjusting production equipment between BATCHES. In this way, the theory of ECONOMIC BATCH QUANTITY is refuted since it is based largely on fixed setting costs. The principle of JUST-IN- TIME is the central theme of Japanese techniques, allied to the concept of TOTAL QUALITY CONTROL. The latter technique, whilst it was developed in Japan, owes much of its origin to the American influencers, DEMING, JURAN and FEIGENBAUM. For a clear and interesting explanation, *see* Richard J. Schonberger, *Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity*, Free Press (New York, 1983).

jidoka. The original Japanese word for AUTONOMATION.

JIT. JUST-IN-TIME.

job enlargement. A technique to motivate employees in which additional tasks are assigned to an operator in an attempt to make the overall job more interesting and varied. Such a process may involve training and adjustments in pay. It is also important to consider the danger of overload.

job evaluation. A technique used for describing and measuring specific jobs, usually with a view to constructing a payments scheme which compares jobs of different types. Job evaluation is concerned with the job itself rather than the person doing it.

The latter factor may be taken into account by adding a MERIT RATING scheme, in which individuals are rewarded separately for their own ability and experience in doing the job.

job order kanban. Kanban which is used to control individual JOBBING orders rather than repetitive production (as most kanbans are designed to cover). *See* KANBAN.

job rotation. A technique designed to improve the quality of working life and thus provide benefits to individuals and companies, through requiring employees to move from one job to another periodically. In this way it is intended to remove the boredom of doing one job all the time. The technique may put extra stress on the employee, however, since it is necessary to readjust constantly to the new job (even though it may be familiar). Job rotation has been successful but must be approached with full consultation between management and workforce in order to avoid distress and subsequent losses.

job shop. Manufacturing factory which is designed to produce very small quantities of each item – often one at a time – instead of batches. Requirements for special items, where only one or a small quantity are required, demand FLEXIBILITY of a manufacturer (the ability to turn constantly to something new) and this traditionally results in high costs for such items. The principles of the job shop (flexible, skilled workforce, flexible layout of equipment) have been studied by batch manufacturers and have much in common with the principles of FLEXIBLE MANUFACTURING SYSTEMS.

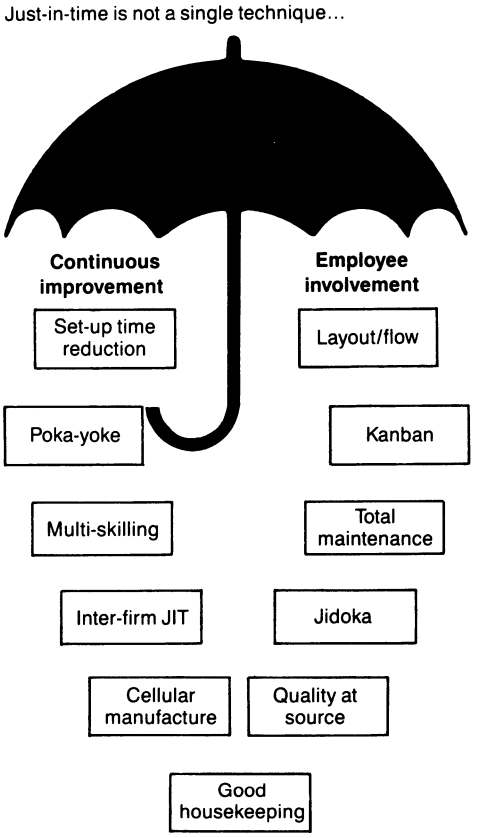
jobbing. Very small batch, or one-at-a- time manufacture.

Juran, Joseph. One of the most influential writers on QUALITY following World War II. Juran went to Japan as part of the American presence there after the war and was instrumental in developing the techniques of TOTAL QUALITY CONTROL, etc. In later years he returned to the USA, founding the Juran Institute and publishing an authoritative handbook and training videos on quality.

JUSE. Japanese Union of Scientists and Engineers.

just-in-case. With the rise in awareness of JUST-IN-TIME in the West came the need to characterize traditional Western manufacturing. This term was originally used in a lighthearted way by commentators but became more seriously used, especially in text books. It refers to the preoccupation of manufacturers with INVENTORY: literally, the term suggests a system in which products are made 'just in case' they are needed. Whilst it is an overstatement, it serves a useful purpose in highlighting the anomalies of traditional methods.

just-in-time (JIT). A radical philosophy, developed in Japan following



Just-in-time systems

World War II, which has become popular as an approach to manufacturing, as well as other parts of business. The basic idea of JIT is to acquire materials and components just in time to assemble them into products, and to assemble the products just in time to sell them. The effects of this are a reduction in INVENTORY, through not holding stock (materials are used as soon as they arrive, and leave – as products – as soon as they have been worked upon), and improvements in QUALITY and operator motivation and performance (as the need to perform well is encouraged by the lack of 'safety' buffers – WIP, etc.). LEAD TIMES can also be improved (reduced) as waiting time is removed from the production process. The goal of reducing batches to very small quantities, or even unit levels (one-offs), is considered to be distant – just-in-time becomes the search for that goal – a process of PERPETUAL IMPROVEMENT, or KAIZEN. Throughout, there is a principle of removing waste, or MUDA, and thus improving performance. Experience in the West has shown that JIT can be employed anywhere in the world, but that its implementation is an immensely complicated matter despite the very simple idea which lies at its heart. In particular, since it challenges and refutes many established concepts, a personal threat is sometimes perceived by managers and operators and careful explanation and negotiation are necessary at every stage of introduction. The term 'just-in-time' was invented – in the English language – in Japan, by the Japanese. There is some debate about its precise origin: it is said to have evolved in the shipbuilding industry where modular construction techniques were developed in order to improve lead times and reduce waste (possibly influenced by the American concept of building modular 'liberty ships' during the war) and also in the Toyota Company, by Taichi Ohno. The Toyota production system is explained in an excellent book of that name by Yasuhiro Monden (USA Institute of Industrial Engineers, 1983).

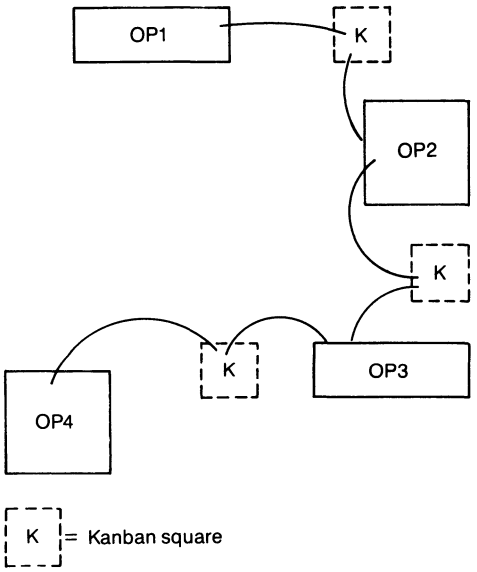
K

kaizen. ('Ky-zen.') The principle of PERPETUAL IMPROVEMENT, embodied in the Japanese technique of JUST-IN-TIME. The philosophy behind kaizen is that nothing is ever optimized: some improvement, however small, must be possible, and must be found, as a part of normal operating duties. This very gradual but constant series of small improvements to a process or product results in a steady increase in performance, and thus competitive position. Some of the benefits resulting from kaizen are tiny in themselves – for example, 0.4 seconds removed from a cycle time – but constitute a profound dedication to improvement which is at the heart of JUST-IN-TIME manufacturing. For a discussion of the concept, see M. Imai, *Kaizen – the key to Japan's competitive success*, Random House (New York, 1986).

kanban. Part of JUST-IN-TIME manufacturing, kanban is a system of controlling production, and the materials required within it, by 'pulling' requirements into place rather than forecasting well in advance. The Japanese word literally means 'visible plate' or 'visible record', terms which reflect the importance given to openness in the system, with all those involved knowing, via a simple visual mechanism, what is going on. (Compare this with the 'closed' nature of a computerized system, in which only those able to work the computer are able to tell what is happening.) Two distinct systems may be identified: one in which two separate types of kanban are used ('two-card kanban') and another in which there is only one type ('single-card kanban'). Within this context, however, there are many different applications, varying from plant to plant within companies. An excellent explanation is given in an appendix to Richard J. Schonberger, *Japanese Manufacturing Techniques: Nine Hidden Lesson in Simplicity*, Free Press (New York, 1983), and in Yasuhiro Monden, *Toyota Production System*, USA Institute of Industrial Engineers (1983). Further reading might include Kiyoshi Susaki, *The New Manufacturing Challenge*, Free Press (New York, 1987). *See also* EXPRESS KANBAN, JOB-ORDER KANBAN, THROUGH KANBAN, TUNNEL KANBAN, EMERGENCY KAN BAN, COMMON KANBAN, CONVEYANCE KANBAN, and PRODUCTION KANBAN.

kanban square. An area designated between two parts of a process which acts as the KANBAN or indicator of requirements. The idea is simple:

when the square has the standard quantity of parts in it, no delivery is needed. When the square is empty, a delivery is required. This simple control enables all involved to see what is going on. It is also unambiguous – the square is either full or empty. Despite its simplicity, however, it requires strict discipline to operate in this fashion and a true dedication to JUST-IN-TIME.



Kanban squares

KD. KNOCKED DOWN. *See* COMPLETELY KNOCKED DOWN.

keiretsu. The correct name for the large Japanese commercial/industrial groups which are credited with much of the success of that country in economic terms. Strictly speaking, the old ZAIBATSU groups were disbanded in Japan by the American administration there following World War II. The KEIRETSU groups which have reformed since then, however, resemble their forbears in many ways.

key operation. In WORK STUDY, the longest operation in a series of tasks, which must be completed before work can move on to the next stage.

kinaesthetics. The study of human movement, used in WORK STUDY and MOTION STUDY.

kit/kitting. The practice of collecting all components and materials necessary for the assembly of a product, or a batch of products, prior to assembly. The principle is logical – to ensure that everything that is required is put together beforehand. In practice, however, there have been two common problems with kitting. First, it has become a source of extra INVENTORY – holding perhaps a week's worth of stock ready for future production. This is an example of MUDA and has become a frequent target for KAIZEN and JUST-IN-TIME improvement projects. Second, a kit is usually assumed to be complete and is useless unless it is so. In practice, problems with getting supplies often mean that kits are issued to shop-floor areas with some items missing. This leads to disruption in assembly, and even to cannibalizing of other kits to make up for the omissions. Once a kitting operation reaches this stage, it

is no longer viable and must be totally rectified.

knife-and-fork. Informal reference to completing a manufacturing task in an unconventional manner – usually to overcome a problem which has prevented the normal process from being followed. This type of working indicates a serious lack of control, and is almost always extremely expensive.

knocked-down (KD). Assembly of parts which have been pre-manufactured into a kit (literally a 'knocked-down' product). *See* COMPLETELY KNOCKED DOWN.

knurl. Cross-machined finish applied to a solid object, usually to improve the grip which may be obtained on it in subsequent use. For example, a metal control knob may be knurled to remove the chance of an operator's hand slipping when turning it.

Kondratiev long wave. A form of cyclic activity in economics noted by the Russian economist, Nikolai Kondratiev. He found that there were 'long waves' in the economic development of boom and recession, running roughly every 45–50 years. The boom side corresponded to major technological innovations – such as the invention of steam power, the spread of railways, the spread of electrical power, the automobile – and the recession side with the widespread use of these innovations to reduce costs. A good description of long waves appears in Christopher Freeman, *Unemployment and Technical Innovation: a Study of Long Waves and Economic Development*, Pinter (London, 1982).

L

labour intensive. Term used to describe a manufacturing process which incorporates a great deal of human (labour) involvement. It may be that the process is intrinsically labour intensive (i.e. under current calculations/technologies it is necessary to involve a great deal of labour) or that the company concerned has chosen not to automate the process. Replacing labour with CAPITAL EQUIPMENT would make the process more CAPITAL INTENSIVE.

labour-only subcontracting. Subcontracting based upon hiring labour from someone else, rather than goods or services.

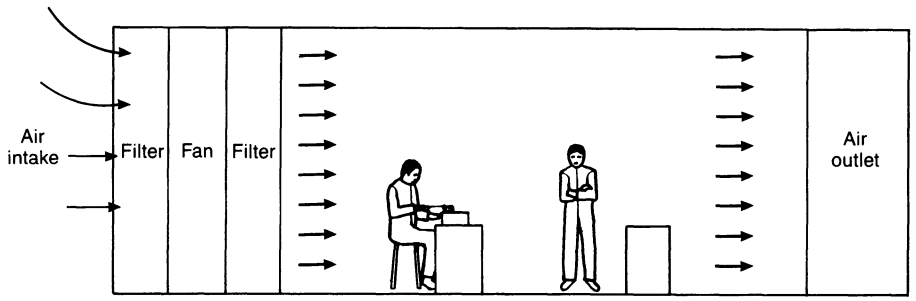
ladder logic (ladder programming). A simplified form of computer programming using a small vocabulary of logical symbols. It is used for relatively small programs on devices such as machine controllers (e.g. some CNC machine tools) where the range of information processing is small.

laminar flow. In CLEAN ROOMS some products must be manufactured in perfectly dust-free conditions (e.g. microelectronics, drugs, etc.) which requires a laminar flow (straight-line flow) of air across the work area. This may be done by installing laminar flow cabinets within the clean room – usually arranging for a downdraft of laminar flow filtered air. In extreme conditions it may be necessary to provide the entire clean room with laminar flow air supply – either vertically (ceiling to floor) or horizontally (from one end of the room to the other). This is a very expensive undertaking, however, and it is more common to find laminar flow cabinets (designed as stand-alone pieces of equipment) fitted into a less sophisticated clean room.

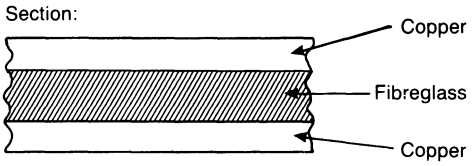
laminate. Process of bonding together two or more sheets of material, usually as a 'sandwich' of different types. For example, the base material for a printed circuit board consists of a laminated sandwich of copper/fibreglass/copper (paper-based material may be used rather than the fibreglass). Laminated materials may be designed for specific purposes – such as the example given above – or for strength, in which case they are referred to as COMPOSITE MATERIALS.

LAN. LOCAL AREA NETWORK.

lap. A visible fault in the surface of a material (especially metal sheets)



Laminar flow



Copper laminate material for printed circuit manufacture

which was caused by a fold in the material prior to a rolling process.

lapping. A finishing process for metal parts in which they are ground between two flat, contrarotating discs. A grinding paste is used. Both sides of the flat parts are lapped at the same time. Lapping produces a very accurate surface finish, removing faults and correcting dimensional imperfections from previous operations.

large batch. Production of parts in large batches has been traditionally considered good economic sense, since the costs of setting up for the batch (machine adjustment, tools replacement etc.) may be AMORTIZED over a large quantity of the product, thus reducing the unit cost of setting-up. This has now been questioned as a principle and in many cases refuted. (*See* ECONOMIC BATCH QUANTITY.)

The traditional preoccupation with the economic 'sense' of large batch has been so strong that the great majority of manufactured products are still made in this way.

laser cutting and welding. High-powered lasers are used to amplify radiation in a particular waveband and emit a coherent near-parallel beam which can be focused to produce an energy density capable of melting or vapourizing the material in the workpiece. This can be used to cut or weld the material. Both types of industrial laser – solid state and gas – are used.

lathe. Machine tool used for shaping ROTATIONAL PARTS which are held in the jaws of a rotating chuck. A CENTRE LATHE has a further support for the workpiece at the opposite end of the bed of the lathe. In this way, long rotational products may be shaped (by cutting tools introduced perpendicularly to the axis of the workpiece). A CAPSTAN LATHE has tools mounted on a hexagonal stand opposite the chuck. Each tool can be fed into the end of the workpiece, creating such effects as internal drilling (into the end of a solid bar), external thread cutting etc. Multi-spindle lathes were developed during the 1950s to be used in high-volume production of rotational parts. In such a machine there are often six spindles working at once. This means that six different operations may be carried out simultaneously on six pieces. The parts are held in chucks, often fed from behind by bar feeders which rotate after each operation, bringing the workpiece into contact with the next set of cutting tools. In many modern factories lathes have been replaced by MACHINING CENTRES. Multispindle lathes were developed before NC technology had risen to its zenith and employed systems of CAM control. The inherent limitations of such systems meant that NC and CNC technology quickly replaced them.

layout by function. The traditional concept of locating pieces of production equipment on the basis of common function. Thus all lathes would be grouped together, all milling machines, all presses, etc. This traditional thinking has been largely replaced by the ideas of GROUP TECHNOLOGY and U-LINES, since it led to batches of WORK IN PROGRESS and excessive distances around the factory. *See* STRING DIAGRAMS.

LCD. Liquid crystal display.

leadscrew. A controlling mechanism within a machine tool, consisting of a long threaded bar, made with extreme precision, and a travelling device which moves along it. Combined with a system of sensors and electronic controls, this enables the machine tool to convert signals into physical positions. *See also* BALLSCREW.

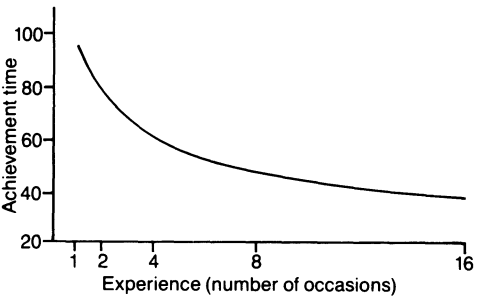
lead time. The time it takes for a requirement to be satisfied. The most common example is the delivery time on ordered items (the time between date or hour of order and date or

hour of delivery). Modern manufacturing techniques and technologies require shorter and more accurate lead times. (*See* JUST-IN-TIME.) Traditionally there has been a problem of reliability in lead time estimates, with suppliers of materials working to a self-determined tolerance of several days or even weeks (e.g. 'delivery four to six weeks'). Such inefficiency is not acceptable in modern manufacturing.

lean manufacturing. Term developed by the International Motor Vehicle Program of the Massachusetts Institute of Technology (1986–90) to describe BEST PRACTICE manufacturing in the automobile industry. The best ideas from Japanese automobile manufacturers in developing FRAGILE systems – factories dependent upon employee contribution and true JUST-IN-TIME operation – were extended to incorporate the entire manufacturing process, including components supply and finished product distribution. For a full explanation, *see* J.P. Womack, D.T. Jones and D. Roos, *The Machine that Changed the World*, Macmillan (New York, 1990).

lean work. In PAYMENT BY RESULTS systems, work at which bonus levels are low. By contrast, FAT WORK is work where it is easy to earn high bonuses.

learning curve (improvement curve). The rate of progress made by an individual or organization in acquiring new skills, absorbing new technological capability etc. In general, the more experience in doing something which an individual or organization has, the faster or better she/it is able to perform; for example, the ability to produce a better or more consistent quality, or to make improvements (i.e. not simply to reduce the time required to carry out an operation). In the case of operator performance, this learning effect is often expressed as a logarithmic relationship. One implication of this is that after a certain point – the learning 'plateau' – it becomes difficult to make further improvements without some form of external input; for example, new educational experience.



Learning curve

LED. Light emitting diode.

LIFO. Last In First Out. Quasi-principle in employment that the newest employees have the least right to retain their position in the event of a laying-off of labour.

lift truck (fork-lift truck). An industrial vehicle which is designed to lift heavy or bulky materials.

limit switch. A sensor device in electro-mechanical control systems. When a moving part of a machine tool reaches the limit of its travel, it activates a limit switch which then sends a signal to the control system.

linear programming. Operational research technique used for estimating the best use of resources, operating within practical constraints. It enables different solutions to be developed for different outcomes. It is based upon identifying an objective variable and then finding solutions which maximize or minimize this factor; for example, finding the least cost or shortest route solution to a problem.

line balancing. Technique aimed at achieving equal CYCLE TIMES in all the stages or operations within a process. The principle is that if equal cycle times can be achieved (by reapportioning activities between the stages) then idle time can be minimized or removed. It is generally accepted that limits apply to this process, since work activities cannot be broken down infinitely and capacity is not infinitely variable in its nature (i.e. it cannot be assumed that an activity can be reallocated from one stage to another). For a full explanation *see* K. Lockyer, A. Muhlemann and J. Oakland, *Production and Operations Management*, Pitman (London, 1988) (fifth edition). *See also* HEIJUNKA.

line management. Term used to describe any management function which is directly concerned with an operating area – not simply production, but some linked department such as marketing.

line of balance. A LINE BALANCING technique, similar in many respects to CRITICAL PATH ANALYSIS, in which the stages of a production process are taken as the elements in a linear programme. For a full explanation *see* K. Lockyer, A. Muhlemann and J. Oakland, *Production and Operations Management*, Pitman (London, 1988) (fifth edition).

line stop. A concept contained in JAPANESE TECHNIQUES which is based upon the principle that if there is a problem with a process, it should be stopped so that the process may be corrected. In theory, any operator should be able to stop the production line and point out a problem (e.g. a reduction in quality shown up by STATISTICAL PROCESS CONTROL results). At this point, all the nearby operators join in the problem-solving exercise. Once the problem is solved, the line may restart. In practice, this is too much of an interruption (and in the early stages of introducing line stop, or a new process, there would be little production output), and a moderated version of the concept is generally used. *See* ANDON LIGHTS.

LISP. A high-level computer language used particularly in expert systems and ARTIFICIAL INTELLIGENCE. It takes its name from LISt

Processing language, since it is designed to handle text statements rather than numerical processing.

liquid nitrogen. Often used in micro electronics production in CRYOGENIC equipment. Liquid gas is normally piped into insulated taps within a CLEAN ROOM.

load. The work apportioned to a particular WORKSTATION or operator.

loading chart. PRODUCTION SCHEDULING device which indicates the LOADS applied to the various pieces of equipment within a production facility.

local area network (LAN). A computer network which allows communication of data within a local area (e.g. a building) between all nodes (operating stations) in the network. A number of different configurations exist, including the star, the wheel, and the ring. In theory, each allows any item of information technology to be connected – computers, printers, fax machines, etc. *See also* VALUE ADDING NETWORK (VAN).

local content. Measure of the extent to which an assembled product may be considered to be 'made' in a country on the basis of the VALUE ADDED there. For example, a Japanese automobile manufacturer who assembles cars in the USA may purchase components and materials locally and claim as a result that a certain percentage of the value of the car is 'local'. If this percentage is significant, then the car may be termed an American-made vehicle. This may have major implications for trade issues. The problem with local content is definition – what may be included in local spend. A car which is 60 percent local content may in fact contain very little actual local materials or componentry if the manufacturer is allowed to include such items of spend as catering services, cleaning, transport, etc. Alternatively, a company may prove that it is spending 60 percent of its materials/components bill in the host country, in which case a more substantial case for national origin can be made. It is a political issue, not a technical matter. There are seldom clear rules for definition; indeed the GATT rules are vague, saying that a product may be said to originate in a country if 'the last significant transformation' (e.g. assembly) occurs there. There is no definition of this term, however, and it is likely that local content will remain a matter of heated international political debate.

lockout. Extreme management tactic in industrial disputes, whereby employees are prevented from entering their place of work by the management locking gates or doors. This might be done to prevent an occupation of the premises by a disgruntled workforce, or as an attempt by management to force an issue of disagreement by preventing operators from working and thus earning wages. In either case, the lockout is rarely used, and is considered a more extreme tactic than, say, a strike on the part of the workforce.

lost wax process. A CASTING process in which, rather than using a retrievable model (possibly made of wood), the model for the mold is made of wax (or similar substance) and burned out of the mold once it is made. The process is particularly suitable for high value precision work, such as in jewellery or instrument manufacture.

lot. BATCH.

LSI. Large-scale integration of electronic circuitry in order to minimize physical size of products.

lump labour. Labour which offers itself for hire on a LABOUR-ONLY SUBCONTRACTING basis; it is particularly common in the building industry.

M

machine ancillary time. Non-productive time when a machine is being serviced, cleaned, set-up etc. It differs from DOWNTIME in that it is a planned stoppage of the machine.

machine code. The operating-level set of instructions of a computer, expressed in binary numbers. This is the lowest-level computer language.

machine tool. General name for any piece of manufacturing equipment which carries out physical operations on materials with the aid of machine power; for example, LATHE, MACHINING CENTRE, MILLING MACHINE.

machining centre. Multi-purpose, flexible machine tool. The machining centre has replaced the LATHE and MILLING MACHINE in many applications, providing the benefits of CNC with the ability to machine in several planes or AXES. The machining centre has developed into the heart of FLEXIBLE MANUFACTURING SYSTEMS in many cases.

magnetic chuck. A CHUCK which holds the workpiece by magnetic force, rather than a physical grip. Used mainly on grinders and other horizontal machines, where sheer forces on the workpiece are not too great, the magnetic chuck provides a quick-change facility since the magnetism (electromagnetic) can be turned on and off quickly, releasing the workpiece in a negligible time.

mainframe. Large computer for multi-user applications or very complex problems which require large amounts of processing power. Many traditional mainframe applications are now undertaken using mini computers, or even NETWORKED personal computers.

maintenance. The care and repair of equipment. There are several approaches to maintenance in manufacturing but in each case, a more strategic view is generally taken today than previously. Many of the new techniques (e.g. JUST-IN-TIME) depend upon totally reliable equipment, and the term 'TOTAL PLANNED MAINTENANCE' has been coined to cover this. *See* R.J. Schonberger, *Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity*, Free Press (New York, 1987). Maintenance may be PLANNED or PREVENTIVE, but some production plant is best maintained on a REACTIVE basis – having the ability

to respond very quickly to plant failure.

make to order. Production in which every item manufactured is destined for a specific customer: nothing is made to pure forecasting. This is only possible if demand for the product is constant and in advance of the supply.

make to stock. Production in which the items are manufactured in accordance with a forecast demand, rather than actual order. Once made, sales orders are filled from FINISHED GOODS STOCKS. This can be a risky strategy if the forecasting is not always right, but it is deemed necessary where the customer is not prepared to wait for a product, and the production LEAD TIME cannot be reduced sufficiently to satisfy demand by MAKING TO ORDER.

malleability. Ability of a material to be altered in its physical form without damage. A malleable metal is one which may be bent or forged without breaking.

manufactured quality. The degree to which the manufacture of a product renders it in accordance with the design specification. It is not possible to produce total quality through excellent manufacturing if the DESIGN QUALITY is inadequate. In achieving PRODUCT MANUFACTURED QUALITY, however, all the manufacturing can do is to follow the specification perfectly. There are many other roles for manufacturing personnel in achieving TOTAL QUALITY, however: *see* DESIGN FOR MANUFACTURE, QUALITY CIRCLES, and EMPLOYEE DEVELOPMENT.

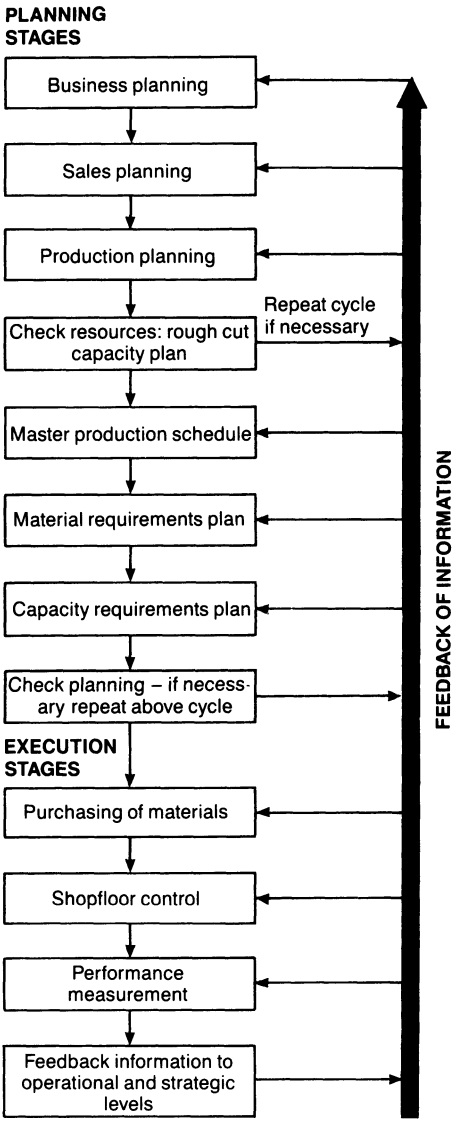
manufacturing. Used synonymously with PRODUCTION, manufacturing strictly refers to the actual processes and techniques involved in making a product. Use of the term in many contexts has led to it becoming interchangeable with PRODUCTION in both study of the subject and management titles.

manufacturing automation protocol (MAP). A standard protocol for communication between different pieces of computerized manufacturing technology within a company or group of companies. The system was developed in the mid 1980s by General Motors Corp. in the USA, under the INTERNATIONAL STANDARDS ORGANISATION seven-layer model for OPEN SYSTEMS INTERCONNECTION. GM had to find a way to link up all the robots and CNC machine tools which they had installed, and MAP was the result. It was subsequently launched as a general system for international manufacturing industry, in conjunction with the TECHNICAL AND OFFICE PROTOCOL (TOP), developed by Boeing Corp. Its attraction was that equipment made by any supplier could be made to communicate, and it became very popular, as the de facto standard. After an initial period of great interest, however, many observers felt that MAP contained too much sophistication for most manufacturing applications, and it lost

popularity. *See* OPEN SYSTEMS INTERCONNECTION.

manufacturing resource planning (MRP II or MRP 2). A system of computerized manufacturing management, developed from MATERIALS REQUIREMENT PLANNING (MRP) by Oliver Wight, in the late 1970s. MRP II differs from MRP in its strategic approach to manufacturing – insisting on the involvement of the production CAPACITY and SCHEDULING activities in the development of a company's business plan. The basis of MRP II is thus much more than controlling production materials; the resources in its title include people, plant, and finance.

Specific techniques within MRP II include ROUGH-CUT CAPACITY PLANNING, CAPACITY RESOURCES PLANNING, and the development of high levels of DATA INTEGRITY. Latterly presented as a 'philosophy' for manufacturing (c.f. JUST-IN-TIME), MRP II gained a great deal of acceptance – even amongst those who had experienced failure in implementing it. It was never tied to one supplier, despite its origins in the Oliver Wight company, and became the predominant technology for production management in the 1980s. Debate continued on the compatibility of MRP II – a BATCH MANUFACTURING technique – and JUST-IN-TIME, without conclusion. Towards the end of the 1980s efforts turned to combining the two approaches. *See* MATERIALS REQUIREMENT PLANNING, BILL OF MATERIALS, DATA INTEGRITY.



Manufacturing Resources Planning

manufacturing strategy. In his influential book, *Manufacturing Strategy*, Macmillan Education (1985), Professor Terry Hill describes two major roles which manufacturing can play in company strategy: (1) to provide

manufacturing processes which will give the company a distinct advantage in the marketplace; (2) to provide coordinated manufacturing support for the essential ways in which products win orders in the marketplace at a level which is better than competitors are able to do. The concept of manufacturing strategy *per se* came to popularity only in the 1980s in the West, even though it is generally recognized that this had been a major reason for the success of Japan as an international trading nation for 30 years previously. The work of Hill in the UK, and Hayes, Wheelright and Clark at Harvard University – *see* their *Dynamic Manufacturing*, Free Press (New York, 1988) was fundamental in inspiring companies in creating manufacturing strategies for competition.

MAP. MANUFACTURING AUTOMATION PROTOCOL.

mass production. Production of goods in which capacity is designed to meet demand for one product. Using an ASSEMBLY LINE and employing the principles of ECONOMIES OF SCALE and HENRY FORD, mass production is used to make high-volume DISCRETE PRODUCTS. *See* FORD.

master production scheduling (MPS). Technique involved in MANUFACTURING RESOURCES PLANNING, and developed forms of MATERIALS REQUIREMENT PLANNING. The master production schedule combines actual orders for products with forecast or planned orders.

Mass production and productivity improvements from Fordism: Ford Assembly Hall 1913/1914

Minutes of effort to assemble	*Late craft production, Autumn 1913*	*Mass production, Spring 1914*	*Percent reduction in effort:*
Engine	594	226	62
Magneto	20	5	75
Axle	150	26.5	83
Major components into a complete vehicle	750	93	88

From: 'From the American System to Mass Production, 1800–1932', David A. Hounshell, Baltimore, 1984.

Mass production

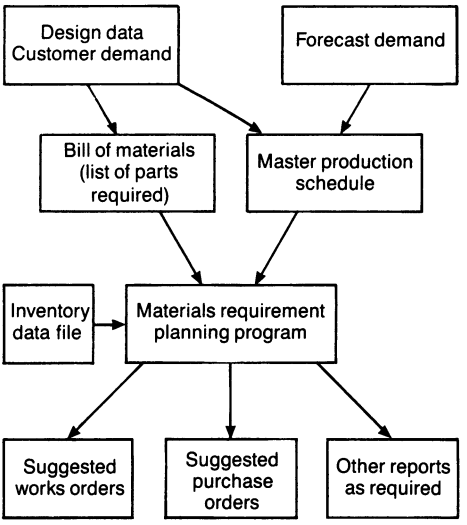
materials control. The production department responsible for efficient provision of materials for manufacturing, in accordance with planned requirements. Materials control is often linked to PURCHASING – following up the requirements of PURCHASE ORDERS, with components or materials suppliers.

materials management. An 'umbrella' term used to incorporate all the functions connected with the flow of materials through a company: PURCHASING, STORES, MATERIALS CONTROL, PRODUCTION CONTROL and SCHEDULING, WAREHOUSING, DISTRIBUTION, etc. This may not be formally installed in the organization structure (although, increasingly, companies are appointing Materials Managers), but it is a natural combination of functions in any company using materials (not only manufacturers).

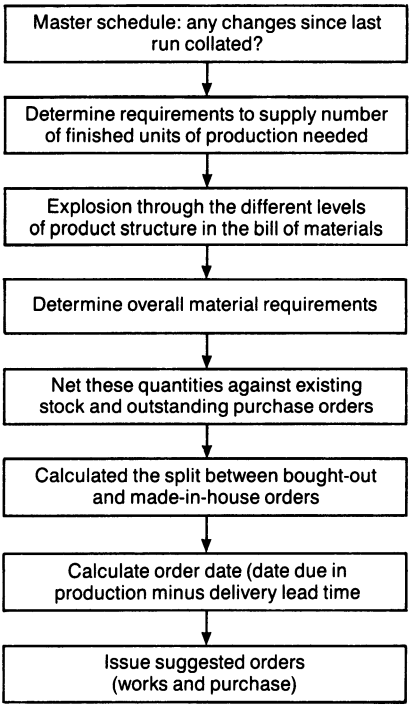
materials requirement planning (MRP). Computerized production and materials planning and control technique developed in the USA in the 1950s and 1960s. MRP became generally popular in the 1970s, with many manufacturers seeing it as a 'technological fix' – a chance to overcome the traditional problems of controlling materials and production, through the use of a computer. In practice, MRP suffered almost everywhere from poor implementation, as a result of being perceived as simply another computer program, and subsequent poor performance. With the development of MRP II, MANUFACTURING RESOURCES PLANNING in the 1970s, the concept of computerization of these functions gained more credibility.

MRP starts with the sales forecast for products, and then breaks those products down into the subassemblies, components, and materials required to manufacture them (*see* BILL OF MATERIALS and PRODUCT STRUCTURE), taking into account the quantities and timescales, common requirements, IN-HOUSE or BOUGHT-OUT sourcing, etc. The principle is simple and sound; the practice suffered from inadequate attention to details such as FEEDBACK in the system to correct for faulty performance, and DATA INTEGRITY. Latterly (during the 1980s), MRP systems have been greatly improved, and understanding about the importance of careful implementation has increased. As with MANUFACTURING RESOURCES PLANNING, there is heated debate

1: Simple Material Requirements Planning system



2: Simple MRP process sequence



Materials requirement planning

over the compatibility of MRP and techniques such as JUST-IN-TIME.

maturity. Final stage of a PRODUCT LIFE CYCLE, in which the product's profitability and popularity go into decline.

mean time between/before failures (MTBF). A measure of the reliability of a system, expressed as the time taken before an average example of it fails in a test run. For components, the same measure can be applied, and determined statistically as the average time between components failing a test in the production process.

measured day. (Measured day work/ controlled day work.) A payment system based on a fixed regular wage rather than on PAYMENT BY RESULTS. The wage is paid on the basis of a daily target rate of productivity, which is usually set by some form of WORK MEASUREMENT technique.

measured variable sampling. ACCEPTANCE SAMPLING technique in QUALITY CONTROL, in which some dimension of the part (length, weight, diameter, volume, etc.) is measured in a sampling process. The sample size is determined using the statistical methods chosen by the firm for the specific process. It is expected that the various measurements in the sample will differ, within TOLERANCE. The mean of these sample measurements and the range (e.g. largest minus smallest) are used in CONTROL CHARTS, based upon assumed statistical distributions.

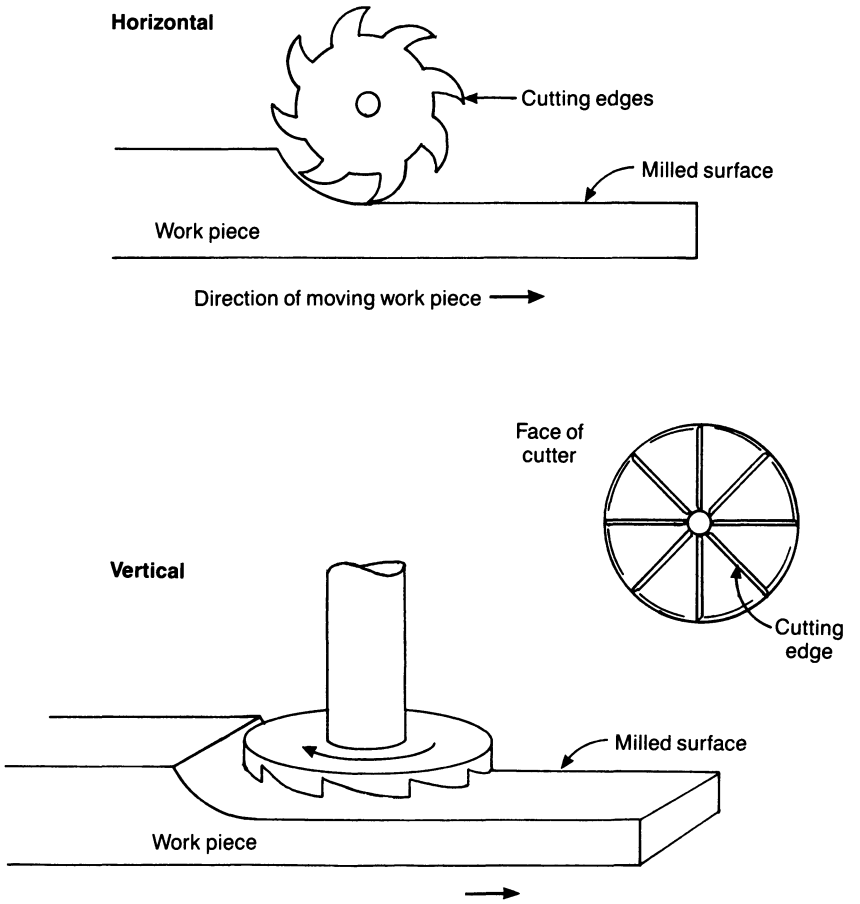
mechanization. The application of mechanical devices to a manufacturing process in order to remove the need for human effort in a physical and control sense. Thus, a series of CAM-operated controllers, using LEADSCREWS, and FEEDBACK devices, is mechanization. The mechanized machine still requires human operation to activate it, whereas the AUTOMATED machine will activate itself.

merit rating. Payment scheme used in conjunction with JOB EVALUATION, to provide individual recognition for employees within job grades. Merit rating assesses factors such as length of service, qualifications, skill, success, etc.

Metal In Inert Gas Welding (MIG). WELDING process in which the metal to be joined is protected from corrosion during the process by a shield of inert gas (e.g. argon). The welding electrode is metallic. *See also* TUNGSTEN in INERT GAS WELDING (TIG).

metrology. The study of measuring techniques and tools.

micrometer. Precision measuring device which employs a linear rod and screw mechanism. Micrometers range from simple hand-held devices for measuring outside diameters or lengths (C-shaped instruments with rotating thimble-type scales) to complicated equipment integrated into machine tools.



Horizontal and vertical milling operations

MIG. METAL in INERT GAS WELDING.

mill – horizontal. A MILLING machine in which the axis of the milling cutter is horizontal, so that the cutting action also takes place in a horizontal plane, parallel to the axis and below it. It is the circumferential edge of the milling cutter which contains the cutting edges.

mill – vertical. A MILLING machine in which the axis of the milling cutter is vertical, so that the cutting action takes place in a horizontal plane, perpendicular to the axis and below it. It is the face of the milling cutter which contains the radial cutting edges.

million instructions per second (MIPS). Measure of the speed with which a computer is able to transmit or receive BITS of information.

minimum stock points. A concept contained in JUST-IN-TIME manufacturing: BEST PRACTICE manufacturing systems contain the minimum necessary points in the process at which work-in-progress may be kept. Ideally, this is none. In practice, there are usually a few. Best practice requires removal of all stock points – a gradual process, involving observation of the effect. *See* ABSOLUTE PHYSICAL PARTS CONTROL.

MIPS. MILLIONS OF INSTRUCTIONS PER SECOND.

MIT. The Massachusetts Institute of Technology. The leading technological university, situated in Cambridge, Massachusetts in the USA.

Mitrafanov. Influential engineer from the Massachusetts Institute of Technology, generally credited with developing the early NUMERICAL CONTROL machine tools.

mock-up. A pre-production, experimental simulation of a product, used to try out ideas for their feasibility. The mock-up may bear little resemblance to the finished item, or it may be designed to resemble it closely (for purposes of visual assessment). *See also* BREADBOARD.

modularity. The concept of building a system or product from discrete units or modules, each of which is considered a stand alone sub-system. The idea is that such modules may then be used again, elsewhere, in different systems or products, thereby benefiting from the previous development work.

Monden, Yasuhiro. Author of the influential *Toyota Production System*, US Institution of Industrial Engineers (1983) (ISBN 0–89806–034–6), he is Professor of Accounting at the University of Tsukuba, in Sakura, Japan. Taichi OHNO (Vice President of Toyota Motor Corp. and originator of the JUST-IN-TIME techniques) credited Monden with developing the theories of the approach from observing the purely practical nature which existed previously.

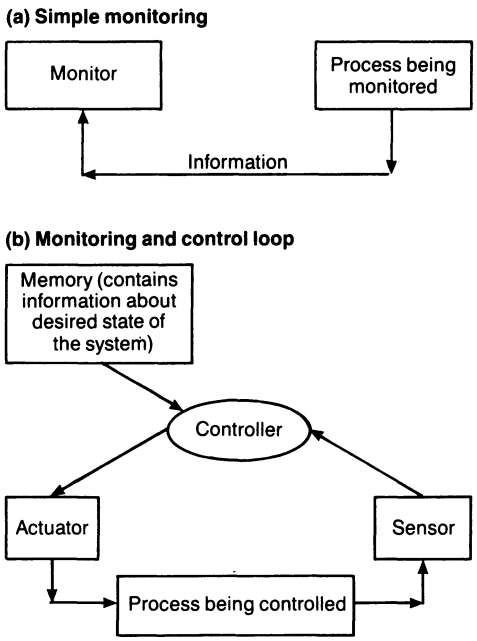
monitoring and control loop. Feature of control systems which build in FEEDBACK – *see* diagram.

motion study. A technique in WORK STUDY in which the movements carried out by a worker are analysed systematically, with the aim of optimizing the performance of the task. The field was pioneered during the 1920s by Frank and Lilian Gilbreth (inventors of the THERBLIG) in the USA.

MRP. MATERIALS REQUIREMENT PLANNING.

MRP II. MANUFACTURING RESOURCES PLANNING.

MRP III. A developed application of MRPII, JUST IN TIME operation, EXPERT SYSTEMS, a high degree of involvement of operators and other people, and SIMULTANEOUS ENGINEERING. MRPIII was developed by



Monitoring and control loops

the British computer manufacturer, ICL, and published in April 1990 (Computerised Manufacturing Magazine, April 1990). Unlike MRP and MRPII, this is not a packaged solution to manufacturing management problems, but a combination of existing ideas, developed by a practitioner. Its significance to manufacturing management has yet to be seen.

MSDOS. OPERATING SYSTEM developed by Microsoft Corp. in the USA, for use on IBM-compatible PERSONAL COMPUTERS.

MTBF. MEAN TIME BETWEEN/BEFORE FAILURES.

muda. ('moo-dah'.) Japanese word meaning waste. This concept is at the heart of the PERPETUAL IMPROVEMENT techniques (KAIZEN) contained in JUST-IN-TIME operation. Anything which does not directly add value to the product can be considered as muda, and therefore a target for removal. Thus, an operator standing idle or waiting for a machine to finish its cycle is muda; so is excessive WORK IN PROGRESS. Other example are: over-engineering in design, too many levels of management, over-specification of technology in manufacturing, scrap materials, poor quality, any RECTIFICATION work (however it may be justified). The identification and elimination of muda is the basis of BEST PRACTICE.

multi-cycle systems. Production control systems which have different order quantities for each part, often based upon EBQ formula calculations. Multi-cycle systems are prone to instability because the peaks and troughs in demand for the various parts are seldom in phase with one another. In contrast, single-cycle systems work on a fixed BUCKET or time period, and on one standard ordering schedule. For a comprehensive analysis and explanation see John Burbidge *Production Flow Analysis*, Oxford University Press (Oxford, 1989).

multi-layer pcb. A printed circuit board in which several circuit boards are sandwiched together in a solid block, with interlinking in a three-dimensional sense between them. A very complicated production process

is required to make such items, but the benefits in space saving and ruggedness of design are great.

multistage tool. PRESS tool which has several operations arranged in series, and a separate press for each, all contained within one piece of plant. Automatic transfer of the workpiece from one operation to the next is usually employed to remove the need for stoppage or work in WORK IN PROGRESS between stages. Thus, one piece of plant may take raw material (metal sheet) right through to finished component (bent, formed, pierced, blanked and cropped, etc.). Inevitably, such press tools are highly expensive.

mura, muri. Japanese word, associated with waste in the manufacturing process (a similar concept to MUDA). Muri is overburden, overload, as a result of a poorly balanced process. Muri thus represents wasteful inefficiency, since the overload results in stoppages, poor quality, demotivation, etc. Mura is unevenness in the process, which results in similar wastefulness.

N

nagare. In the Toyota production system, a conveyor-based approach, similar to a series of linked U-LINES, which balances the cycle time for producing a finished automobile with all other operations on the line; so that every time a unit is produced, every other part-finished automobile is moved along to the next stage. This production flow is called *Ikko nagare* in Japanese, which roughly translates as 'single unit production and conveyance'.

natural language processing. Branch of ARTIFICIAL INTELLIGENCE concerned with the analysis, simulation and reproduction of human language. It is of particular importance in designing new human-computer interaction arrangements which permit the use of natural (human) languages rather than computer languages in input and output.

NC. NUMERICAL CONTROL.

NDT. NON-DESTRUCTIVE TESTING.

nearest neighbour. Algorithm in storage systems.

need pull. In models of technological innovation, one of the two forces which bring about change (the other being TECHNOLOGY PUSH). Need pull refers to the process whereby an innovation is brought into being in response to a need – whether in the marketplace, as a demand for new products or services – or in the factory, where improvements are needed to existing plant or equipment. The essence of need pull is that 'necessity is the mother of invention'. Further discussion of the concept, and a more sophisticated analysis of different types of needs and their relationship to the innovation process can be found in Roy Rothwell and Walter Zegveld, *Reindustrialisation and Technology*, Longman (London, 1986).

nesting. (1) In computer programming, the location of a section of a larger program within a loop which can only be left when a certain condition is met. In this way several nested loops can be built up. (2) In NUMERICAL CONTROL, a program often used in sheet metal and other flat material-cutting work which calculates the optimum use of a piece of material by nesting the various shapes which could be cut from that material as closely together as possible.

network. (1) A schematic diagram used to explain and plan a series of

events in a PROJECT or complex activity. The diagram consists of standard symbols denoting work items (activities) with details (e.g. time required, etc.), and specific points (events) linking activities. The plan is related to resources required for the operation, the time scale, and the order in which activities must be carried out or events reached. A popular use of networks is in CRITICAL PATH ANALYSIS. (2) A grouping of computers enabling communication of data between them and the sharing of resources such as memory, printers and other peripheral devices. In doing so it combines some of the power of mainframe computing with the flexibility of microcomputers. *See* LOCAL AREA NETWORK.

network analysis. The use of a NETWORK to plan a series of activities (a PROJECT) to make best use of RESOURCES and ensure that control may be maintained over progress.

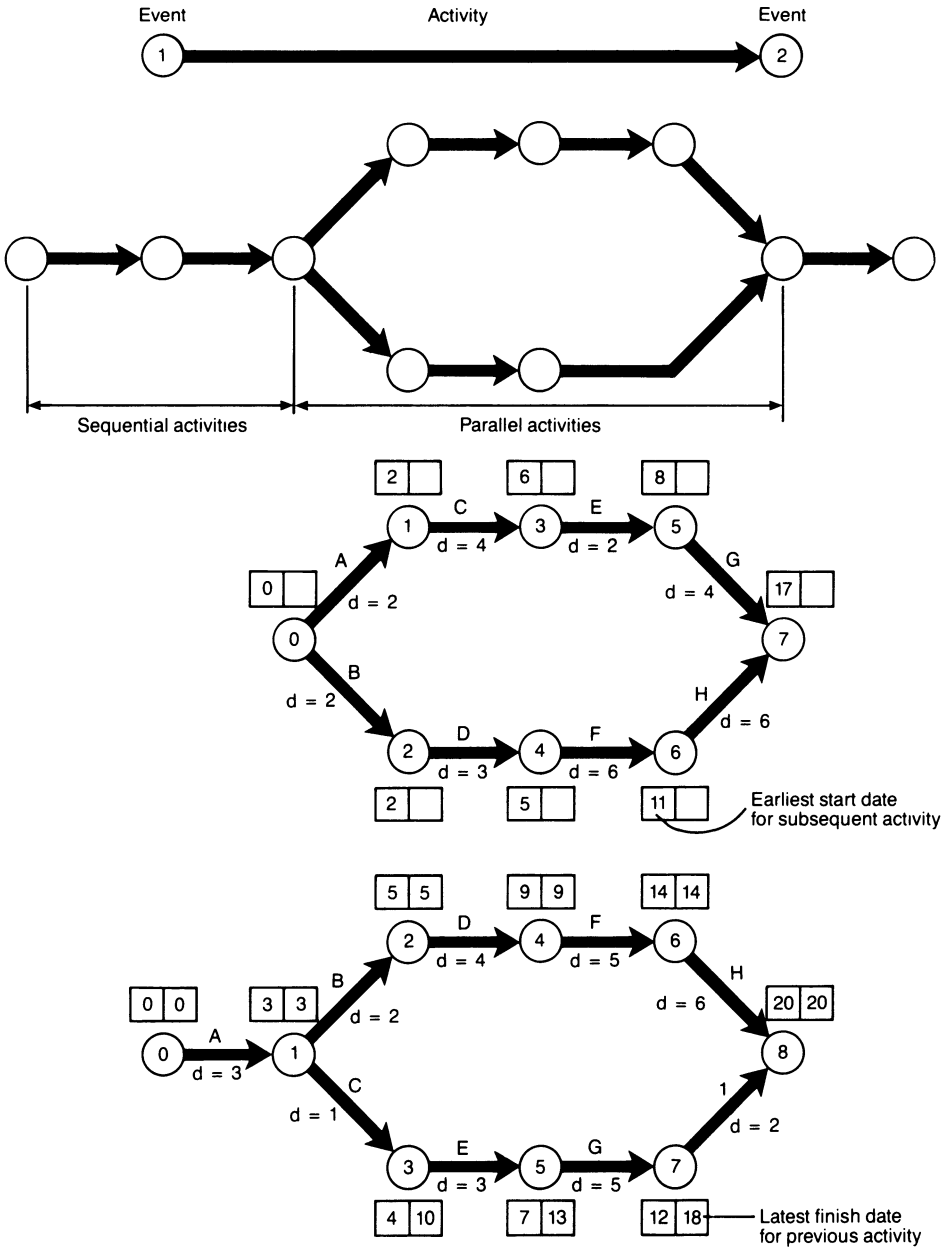
It may be used to determine the chain of events which has the tightest time requirements – the critical path – through the network. Networks are also used, for example, in planning layouts for manufacturing facilities to ensure optimum use of resources and smooth flow through the facility.

net present value (NPV). A method of applying the DISCOUNTED CASH FLOW principle to future income or expenditure by estimating the value of future amounts at the present time, using discounting factors applied to envisaged amounts to allow for inflation, etc. The net present value of an investment or income is the sum of positive cash flows minus the sum of negative cash flows over a period.

net requirements. In a MATERIALS REQUIREMENTS PLANNING (MRP) system, the amount of material required after taking into account ON-HAND STOCK, ORDERS DUE and the required level of SAFETY STOCK. *See* GROSS REQUIREMENTS.

newly-industrializing country (NIC). Country which is emerging from a predominantly agriculture-based national economy, to one in which manufacturing and industry in general plays a major part. Examples are: South East Asian countries (e.g. Singapore and Malaysia) in the 1960s and some Latin American states in the 1980s.

new technology agreement (NTA). An agreement between a TRADE UNION and an employer on the introduction of new technology, containing details of implications and impacts on such factors as employment levels, working practices, status differentials, training and development, etc. With increasing emphasis on technology in manufacturing has come a recognition that industrial relations negotiations need to focus more centrally on this issue. Introducing such change is seen as involving more than simply payment for operating new machines or accepting redundancies; it extends to other areas like health and safety, and the agreement of new working practices to ensure greater flexibility. The idea originated in Scandinavia and has



Network analysis

been widely applied in Europe and the USA where a number of trade unions and employee representative bodies have put forward models for new technology agreements which provide a broad framework within which negotiations over the general introduction of new technology can be conducted. Sample guidelines for the negotiation of NTAs can be found in the Trades Union Congress pamphlet *Employment and new technology*, TUC (London, 1979).

nibble. Machining process in the metalworking industry which involves removal of metal in very small amounts, in order to arrive at the desired shape.

NIC. NEWLY-INDUSTRIALIZING COUNTRY.

nitriding. Metal treatment/finishing process which provides a stronger steel or alloy surface finish by exposing the metal in an atmosphere rich in nitrogen (such as ammonia) so as to form various metal nitrides on the surface.

node. Intersection point in a NETWORK. *See* ACTIVITY ON NODE.

node diagram. *See* ACTIVITY ON NODE.

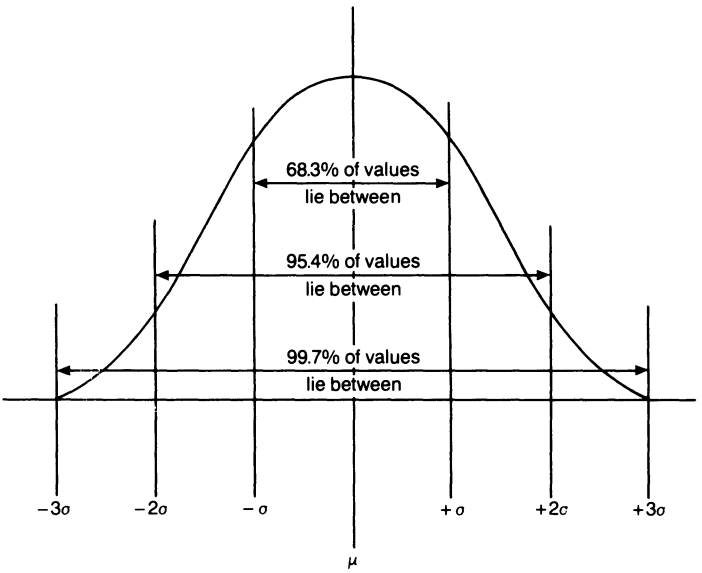
noise. (1) Any unwanted sound or disturbance which may affect efficiency by inducing stress, disrupting communications, etc. Various codes of practice and regulatory frameworks now exist setting out the maximum permitted levels of noise in production environments; for example, the UK Department of Employment *Code of Practice for Reducing the Exposure of Employed Persons to Noise*, HMSO Books (London). (2) In INFORMATION THEORY, any disturbance and interference with a clear signal which inhibits its effective communication.

non-assignable variables. Observed departures from expected performance which cannot be attributed to known causes. They are used in PROCESS CONTROL.

non-destructive testing (NDT). Form of testing in which the object in question is tested in some way which does not involve damage. NDT is often applied to expensive products which cannot be fully tested prior to operation by the manufacturer; for example, pressure vessels. An example of NDT in the latter case would be X-ray inspection of welding.

non-linear programming. Mathematical modelling techniques for solving problems in which non-linear relationships exist; for example, quadratic programming. *See* LINEAR PROGRAMMING.

normal distribution (Gaussian distribution). A PROBABILITY DISTRIBUTION of randomly occurring events or values, such as the weights of components or the dimensions of products, or the life expectancy of a product. A distribution is 'normal' if 68.3 percent of the population are



Alternatively: 2.5% of the values lie above $\mu + 1.96\sigma$
2.5% of the values lie below $\mu - 1.96\sigma$

Similarly: 0.2% of the values lie outside $\mu \pm 3.09\sigma$

Normal distribution

within one STANDARD DEVIATION of the mean value, 95.4 percent are within two standard deviations and if 99.7 percent are within three standard deviations.

normal life. In RELIABILITY studies, the normal life which can be expected of a component or piece of equipment before it requires replacement. This is calculated using a variety of statistical techniques aimed at predicting the probability of failure. *See* WEIBULL PARAMETERS, BATH TUB CURVE and MEAN TIME BETWEEN FAILURES (MTBF).

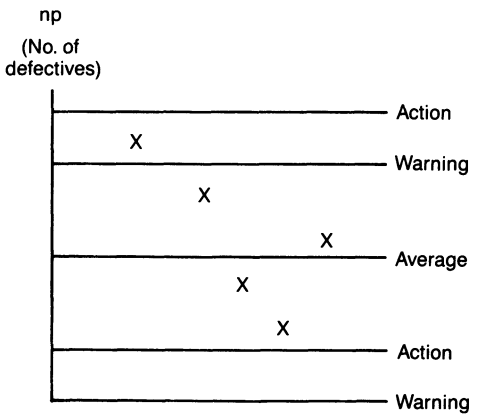
normal population. A collection of recordings (population) of a random variable which has a NORMAL DISTRIBUTION.

NPV. NET PRESENT VALUE.

number defective (np) charts. In ACCEPTANCE SAMPLING, a CONTROL CHART used where the number of defective products is being counted. It has warning and action lines set related to the average and standard deviation of the number of detectives in the sample.
These lines are calculated in the following way:

$$\text{Action lines} = np \pm 3\sqrt{np(1-p)}$$

$$\text{Warning lines} = np \pm 2\sqrt{np(1-p)}$$



Number defective chart

where p is the proportion unacceptable, n is the size of the sample, and np is the expected number defective in a batch.

See STATISTICAL QUALITY CONTROL.

number of defects chart (c chart). In ACCEPTANCE SAMPLING, a CONTROL CHART used to monitor the number of defects or flaws in a product or service. The probability (p) of finding x defects in a unit will be given by a formula derived from the POISSON DISTRIBUTION:

$$p(x) = e^{-\bar{c}}(c^{-x}/x!)$$

where e = an exponential constant, 2.7183, and $\bar{c}$ = average number of defects per unit being produced by the process.

Action lines and warning lines are calculated on the control chart as

$$\bar{c} \pm 3\sqrt{\bar{c}}$$

$$\bar{c} \pm 2\sqrt{\bar{c}}$$

respectively.

See STATISTICAL QUALITY CONTROL, CUSUM CHART.

numerical control (NC). Technology based upon digital/analogue numerical information which may be generated, stored, manipulated and retrieved for purposes of controlling the operation of machine tools and other electro-mechanical equipment. Originating in such early items as music boxes, pianolas and the JACQUARD punch-card loom of the 1800s, NC was extensively developed in the 1960s following early work in the USA. It subsequently led to developments in COMPUTER NUMERICAL CONTROL (CNC) and DIRECT NUMERICAL CONTROL (DNC), and paved the way for current generations of FLEXIBLE MANUFACTURING SYSTEMS.

Early numerical control relied upon codes carried in punched paper tape, or similar medium. In the 1960s, NC machine tools were developed with PLUGBOARD controllers. The most significant development was the move to solid state electronics, and codes generated, retained and implemented by computers.

O

O and M. ORGANIZATION AND METHODS.

OD. ORGANIZATIONAL DEVELOPMENT.

observed time. In WORK MEASUREMENT by TIME STUDY, the time observed for a task to be performed. This figure is based upon observation of an operator (rated for ability, effort, etc.) completing a given task. Complex tasks are normally broken down into discrete elements and an observed time for each is taken. By taking a number of observed time figures for different operators it is possible to derive a basic or STANDARD TIME for the task to be performed by a qualified operator. *See* RATING.

obsolescence. The loss in the intrinsic value of an asset or process owing to its supersession by other technologies, changes in market demand or other factors which cause it to become 'out of date'. This differs from DEPRECIATION, in which the intrinsic value of the asset reduces through normal use, wear and tear over time.

ODETTE. ELECTRONIC DATA INTERCHANGE standard covering activities in the automobile and components industries.

offer up. When a part is to be assembled it is offered up to see that it fits correctly before final assembly takes place.

off-line. In computing, work which is done at a remote WORKSTATION while it is not connected to a central processor.

off-the-job training. Training or retraining for which the individual is absent from the workplace for a period of time (e.g. day release for attendance at a technical college). It is usually combined with ON-THE-JOB TRAINING for best effect.

ogive. Graphical representation of a distribution function.

Ohno, Taichi. One of the founder figures behind JUST-IN-TIME manufacturing, Ohno was Vice-President of the Toyota Motor Corp. He is particularly associated with the development of KANBAN, the idea for which is said to have come to him whilst observing activity in a US supermarket. *See* SHINGO.

OMS. *See* OUTPUT PER MAN SHIFT.

one-touch set-up. In the TOYOTA PRODUCTION SYSTEM, considerable

experience has been gained in set-up time reduction, especially through the work of SHINGO. The short times now achieved in many set-ups (which can be less than one minute) are referred to as one touch set-up. *See* SINGLE MINUTE EXCHANGE OF DIE.

on-hand stock. In MATERIAL REQUIREMENTS PLANNING (MRP) systems, the amount of stock or INVENTORY already held by the company. When a customer order is to be manufactured, the GROSS REQUIREMENTS for this task will be met by using on-hand stock and by ordering new stock. *See* NET REQUIREMENTS.

on-line. (1) In computing, when peripherals are directly connected to the central processor of a computer. (2) A computer system in which it is possible to access a central processor directly for the purposes of multiple immediate operations. This is not necessarily the same as interactive or real-time operation.

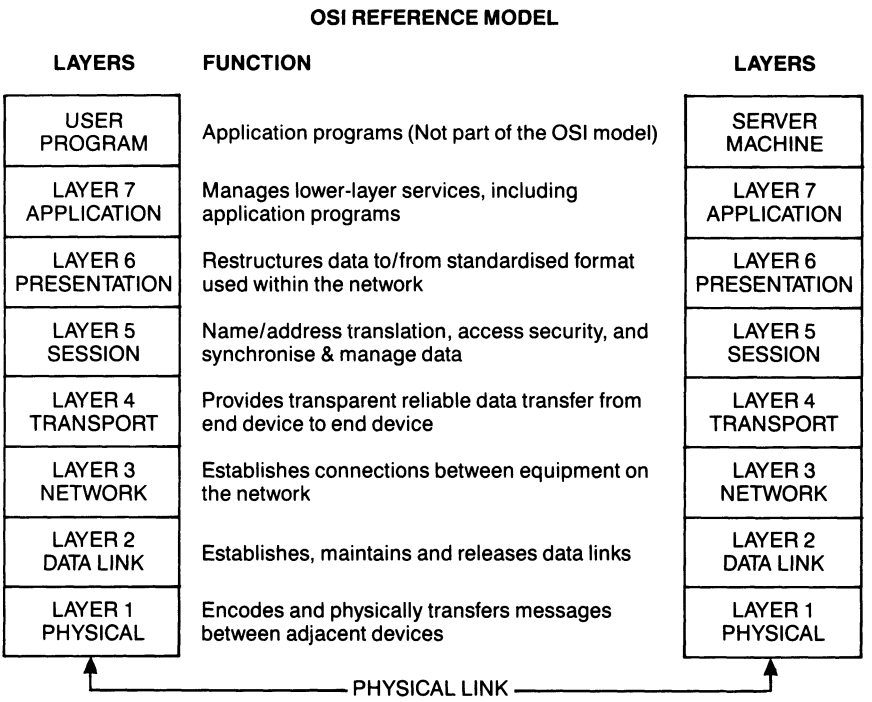
OOQ. Optimum order quantity. *See* ECONOMIC ORDER QUANTITY.

open loop. (1) In control theory, a system which does not have FEEDBACK circuits driven by error signals in order to modify output and thus modify input. (2) Any system in which it is assumed that a given instruction will lead to a predicted result and no account is taken of possible error.

open shop. A workplace in which no one trade union is recognized as representative of all employees and in which membership of a trade union is not compulsory. *See* CLOSED SHOP.

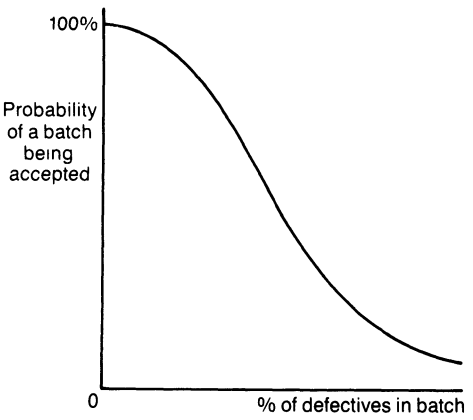
open system. A collection of interrelated activities which combine to form a system capable of receiving inputs and producing outputs. Open systems theory is used to analyse management information and operating systems by analogy with natural systems (organisms).

open systems interconnection (OSI). Blueprint and philosophy for connecting different items of IT-based equipment so that they can communicate effectively in some form of network. OSI is, in effect, a highway code for electronic data traffic, providing rules covering the way in which data moves and is packaged, which message gives priority to which, etc. Fundamental to OSI is the principle that any item of IT-based equipment can be connected to a network irrespective of its supplier – and the network used is thus open rather than based upon a proprietary technology. The INTERNATIONAL STANDARDS ORGANISATION has produced a detailed standard for OSI protocols in the form of a seven-layer reference model which sets out the full specification for open systems. In practice a number of PROTOCOLS are emerging for factory automation including the MANUFACTURING AUTOMATIQN PROTOCOL (MAP) – originally developed by General Motors – and the TECHNICAL AND OFFICE PROTOCOL (TOP), covering design and related work and originally developed by Boeing.



7-layer OSI diagram

operating characteristic curve. In STATISTICAL QUALITY CONTROL, the efficiency of any SAMPLING PLAN as a detector of acceptable or unacceptable batches can be highlighted by its operating characteristic curve. This is constructed by plotting the probability of a batch being accepted against the quality dimension being inspected – for example, the percentage defective. *See* PROCESS AVERAGE PERCENTAGE DEFECTIVE (PAPD).



Operating characteristic curve

operating characteristic chart. *See* OPERATING CHARACTERISTIC CURVE.

operating curve. *See* OPERATING CHARACTERISTIC CURVE.

operating system. (1) The mechanism of interaction and communication within an organization. (2) In computing, a set of supervisory and utility PROGRAMS which perform routine functions within a computer to connect the user with the machine operating level. Examples of operating systems include MSDOS and UNIX.

operational (operations) research (OR) Branch of MANAGEMENT SCIENCE which deals with the application of mathematical theories and models to problems of operations and control, especially in the area of optimization. OR grew out of wartime attempts to bring to bear experience in various branches of science on major problems such as logistics.

operations management. The management of the central value-adding function of a business organization, whether in manufacturing or services. Operations management covers the management of people, materials, equipment, plant, with the objective of matching the activity of the enterprise to its market operations research. *See* OPERATIONAL RESEARCH.

operations sequence analysis. A tool used in PROCESS LAYOUT planning to optimize the design of a production facility. This is usually carried out by taking a measurable objective – for example, minimizing travel costs between different stages of the process – and then using NETWORK ANALYSIS techniques to determine the optimum location of each operation in the sequence.

operator. (1) An individual who operates a piece of equipment. (2) A skilled or semi-skilled worker.

operator performance. The ratio (expressed as a percentage) of the amount of work carried out, expressed in STANDARD HOURS to the number 1of hours actually worked. It is a measure of working efficiency used in WORK STUDY. *See* CONTROLLED WORK.

Opitz classification. A PRODUCTION ENGINEERING coding system for classifying TOOLING items and components, using primary and secondary numerical codes.

opportunity cost. Essentially the cost of a lost opportunity. In pursuing one alternative, the cost is not just that directly associated with that alternative but also the cost of not pursuing the other options.

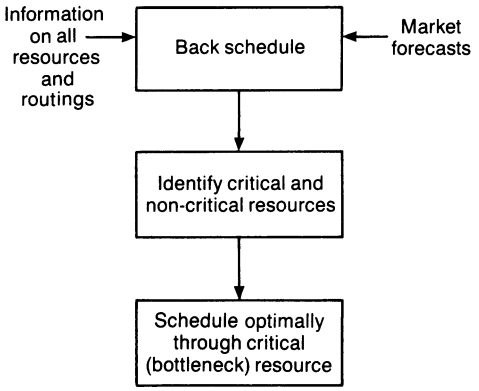
opportunity-based maintenance. *See* PREVENTIVE MAINTENANCE.

optimal solution. *See* LINEAR PROGRAMMING.

OPT. OPTIMIZED PRODUCTION TECHNOLOGY.

optimization. Techniques for calculating the best allocation of resources for a given set of objectives and constraints.

optimized production technology. Production scheduling system, originally developed by Eli Goldratt, an Israeli mathematician based in the USA. OPT is based on the premise that all scheduling should be tied to the speed of the slowest resource – the 'bottleneck' – and uses a complex algorithm to permit scheduling of resources upstream and downstream of that bottleneck. Information relating to all stages of production is stored in network form and then the system schedules back against market forecasts. This highlights critical and non-critical RESOURCES, the former being called 'bottlenecks'. Production is then tied to the speed of the bottleneck resources and a sophisticated algorithm is used to optimize production within these constraints. The principles behind OPT are described in E. Goldratt and J. Cox, *The Goal*, Creative Output (New York, 1985).



Optimised Production Technology

opto-electronics. Technology combining electronic circuitry and optical circuitry for control, information and communication systems. Examples include applications of lasers and the use of fibre optics in network communications.

OR. *See* OPERATIONAL RESEARCH.

order picking. The selection of goods from stock in a sequence designed to fill customer orders in accordance with a predetermined priority.

order point generation. Generation of material requirements for the manufacture of a particular customer order. *See* MATERIAL REQUIREMENTS PLANNING.

order processing (sales order processing). The acceptance, acknowledgement and initiation of a response to sales orders. A typical output of order processing is an internal or works order.

orders due. In a MATERIAL REQUIRE1MENTS PLANNING system, the planning of which orders are needed will have to take account of what is already in stock (ON-HAND STOCK) and what is currently on order from suppliers – the orders due. *See* MATERIAL REQUIREMENTS PLANNING, NET REQUIREMENTS.

organization and methods (O and M). Broad term to describe analytical approaches to improve all aspects of production on the shop floor and in administrative areas. A somewhat

more specific use of the term is the application of WORK STUDY to the office and administrative activities within a business.

organizational development (OD). Planned and systematic approach to improve overall organizational performance through changes to its structure, function and processes. Often involves a change agent to catalyse and manage the change process. A full discussion of the approach and of many of the common tools used can be found in W. Fench and O. Bell, *Organisational Development*, Addison-Wesley (Reading, Mass., 1982) (2nd edition).

orientation programme. Induction training for a new task or set of working conditions.

OS/2. OPERATING SYSTEM developed by Microsoft Corp. for IBM for their 1987 series of personal computers – the PS/2.

outgoing average quality. *See* AVERAGE OUTGOING QUALITY.

outgoing average quality limit. *See* AVERAGE OUTGOING QUALITY LIMIT.

output device. Item of computer-related equipment designed to provide information produced by the system in a usable form – for example, a printer or plotter.

output per man shift (OMS). A unit of efficiency, mainly used in the coal mining industry, to measure the productivity of an operation. The total output for the shift is divided by the number of men working during that period to give the OMS.

out-source. To obtain materials or services from another company or individual. *See* SUBCONTRACTING.

overhead. *See* INDIRECT COST.

overhead absorption. The spreading of overhead costs across the whole range of a company's operations. *See* ABSORPTION COSTING.

overhead structure. The areas of an organization which do not contribute directly to the production of value; for example, the administrative support, the sales, the technical and research departments.

overtime. Work done outside normal working hours, usually at an agreed special rate of pay.

overtime ban. A RESTRICTIVE PRACTICE designed to expose the extent to which a company is reliant upon overtime (i.e. how under-resourced it is in labour) and to create operating difficulties which will bring pressure to bear on the company towards some resolution of an INDUSTRIAL RELATIONS issue.

P

PABLA. Problem Analysis By Logical Approach. System of problem solving used in improving design processes, using progress cards which must be completed at planned stages.

pacer. A fast worker used by management in time-setting activities to arrive at an unfairly low time allowance for a job. *See* OBSERVED TIME.

pacing. Allowing time for operations, especially on a moving assembly line. The rate or pace of work is controlled by the machinery set by the supervisor.

package. Computer SOFTWARE consisting of a set of PROGRAMS written for a common purpose.

pallet. A carrying platform or container of standard size and shape designed for a specific purpose or product to enable more efficient materials handling and storage; for example, by robot or machine tool or in HIGH BAY WAREHOUSING.

palletized. (1) System of materials handling designed to incorporate the use of PALLETS. (2) The goods handled by such a system.

paradigm. Set of norms and values associated with an operation or environment, which becomes the accepted 'way of doing things'. Thus the manufacturing paradigm of the early Twentieth Century might be said to have been MASS PRODUCTION, whereas that of the late Twentieth Century, it could be argued, is JUST-IN-TIME. The move from one paradigm to another is called a paradigm shift or risky shift: it is often a difficult time for those involved in the industry which undergoes the change.

paradigm shift. *See* PARADIGM.

parallel interface. Computer connection (for example, between a computer and a printer) which carries parallel electronic signals. One of the most commonly used is the CENTRONICS interface.

parallel systems. In RELIABILITY engineering, a system in which two or more components operate in parallel. This means that if either component fails the system continues to operate, although this may be at a reduced performance level. By contrast, SERIES SYSTEMS are those in which components are linked in series or sequence, and thus a failure in any one will cause the whole system to fail.

Pareto analysis. A method of determining the relative importance of certain items within a population in terms of their contribution to the overall effect, named after the Italian economist, Vilfredo Pareto. It is chiefly used in INVENTORY CONTROL to determine the stock items which account for the major proportion of overall stock value, and in sales and marketing to identify those products which provide the majority of sales value. It is also used as a problem identification tool in QUALITY CIRCLES. It is often referred to as the '80:20 rule' since it is usually found that 20 percent of items account for 80 percent of overall value. *See* ABC ANALYSIS.

parity. (1) Means of checking the accuracy of DATA COMMUNICATION between computers. It operates by monitoring whether or not the sum of all the binary digits is either even or odd, depending on which convention is in use. If the result is not what was expected, the transmission has lost data somewhere and should be repeated. *See* PARITY BIT. (2) The equality (real or perceived) of fairness in pay of two or more groups of employees.

parity bit. In DATA COMMUNICATION within a computer network, or between two computers, an additional BIT which carries no data but is used to make the sum of the other bits sent equal to either one or zero, and hence to provide a means of checking the accuracy of transmission.

part. A component or product which is not itself an ASSEMBLY of other items.

part program. In NUMERICAL CONTROL, the control program which gives instructions (via paper tape, magnetic tape or directly from a microprocessor) to a machine tool for the production of a part.

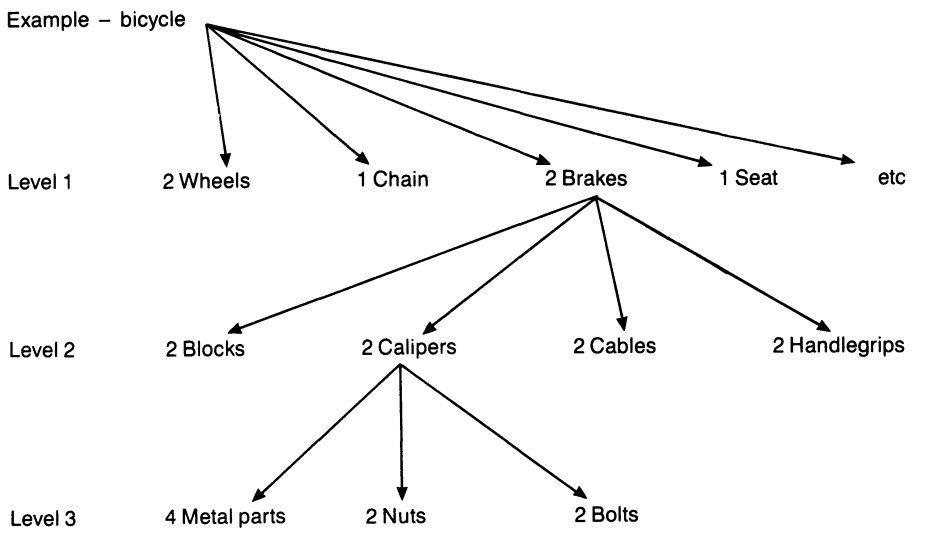
part programming. Activities involved in the production of a PART PROGRAM.

part number. Identifier for spares, fault-tracing, etc.

partial failure. In RELIABILITY engineering, a type of failure in which the product fails to perform as well as expected but has not completely failed. *See* TOTAL FAILURE; GRADUAL FAILURE; SUDDEN FAILURE.

parts explosion. In a MATERIAL REQUIREMENTS PLANNING system, the determination of what materials are needed to manufacture a product is made by breaking the product down into its component elements and then breaking these down further into their component parts. This multi-level analytical process is also called a PRODUCT STRUCTURE DIAGRAM, and is used to generate a BILL OF MATERIALS. The multiplication of the quantities required throughout the PRODUCT STRUCTURE is called the parts explosion.

parts family. Similar parts which bear a similarity to each other (for



Parts explosion

example, size or shape) and which can be grouped together for manufacturing so as to minimize the resetting of machines. Parts family analysis is an important pre-requisite for a PRODUCT LAYOUT and in GROUP TECHNOLOGY.

parts list. List of all the components and parts in an assembly, product or range.

Pascal. High-level computer language, named after the French mathematician Blaise Pascal and used for dealing with alphabetic data.

passivation. *See* ACTIVATION.

password. A unique, secret individual code used to enable an authorized user to enter a computer system or other protected device or area.

patent. An official record of specific rights awarded to an individual or group to prevent others from copying a design for goods or a manner of procedure (e.g. a manufacturing process) invented by that individual or group for a specified time. In the UK this is 20 years, dependent upon payment of fees, although it is sometimes possible to extend this period after the first 16 years. Patents may be exchanged by firms or individuals as part of licensing agreements, particularly between different countries. Protection is normally national and thus must be obtained in every country in the world to be truly effective. Reciprocal arrangements exist to which most countries subscribe through the International Convention for the Protection of Industrial Property.

Paterson method. A JOB EVALUATION technique based on the degree of decision-making required in a job, devised by Thomas T. Paterson. For a full explanation, *see* D. Torrington and J. Chapman, *Personnel Management*, Prentice-Hall (Englewood Cliffs, 1983) (2nd edition).

pay-for-knowledge system. Alternative form of payment system to traditional incentives based upon PAYMENT BY RESULTS. Payment for knowledge encourages employees to acquire new skills and knowledge and this, in turn, facilitates greater flexibility through MULTI-SKILLING.

payment by results (PBR). A payment system which links the level of remuneration to the quantity of OUTPUT. *See* PIECEWORK and WORK STUDY.

payroll. (1) A list of all employees who must be paid by a company. (2) The total amount of money required per period to pay a workforce.

pay scheme. Formal arrangement of pay within a company, explaining grading levels, SALARY ranges, MERIT RATINGS, etc.

PBC. PERIOD BATCH CONTROL.

PBR. PAYMENT BY RESULTS.

PC. PERSONAL COMPUTER.

PCB. PRINTED CIRCUIT BOARD.

PC/DOS. OPERATING SYSTEM for IBM PERSONAL COMPUTERS. A special version of MSDOS, written for IBM by Microsoft Corp.

PDM. PHYSICAL DISTRIBUTION MANAGEMENT.

pecker. Probe or pin which reads the code carried by a punched paper tape or card in a NUMERICAL CONTROL system. The pecker senses the presence of a hole and activates the system accordingly.

pegboard. (1) In control performance appraisal, a technique for measuring or assessing performance with regard to a standard (e.g. in physical tasks). *See* WORK STUDY. (2) *See* PLUGBOARD LATHE.

percussion welding. RESISTANCE WELDING in which the metal parts which are to be joined are repeatedly pressed together – 'percussively' – after or during the heating process.

perishable. Goods which may not be retained long before they become useless through degradation. Term used mainly for food products, but the principle is applicable to many other materials, e.g. raw rubber. *See* SHELF LIFE.

period batch control. System for PRODUCTION SCHEDULING often likened to MATERIALS REQUIREMENTS PLANNING. PBC schedules parts for manufacture in precise quantities to match the requirements for assembly or further use in the next period. Thus a batch of assembly operations is directly connected to

one of parts production and thus no waste is created. In this it is similar to JUST-IN-TIME except that JIT operates on a 'pull' message from assembly to trigger production, whereas PBC plans production and assembly together. The LEAD TIME for all parts in the system is one period. For a comprehensive explanation see John Burbidge's *Production Flow Analysis*, Oxford University Press, (Oxford, 1989).

peripheral. Piece of equipment in a computer system other than the central processor unit; for example, printers, plotters or disk drives.

perpetual improvement. (Also known as continuous improvement.) Approach to problem-solving which is based upon the belief that solutions to problems can only be improved upon since they are never perfect. The approach can be summarized in the phrase 'best is the enemy of better'. It is particularly associated with Japanese manufacturing methods and used extensively in process and product improvement within programmes of JUST-IN-TIME and TOTAL QUALITY MANAGEMENT. *See* KAIZEN.

perpetual inventory. (Also known as PERPETUAL STOCKTAKING.) System of STOCK CONTROL involving a periodic physical check on the contents of a store. Usually a number of different items are checked every day so that by the end of the year the whole stock will have been checked several times.

perpetual stocktaking. *See* PERPETUAL INVENTORY.

personal computer (PC). A microcomputer designed to be used by one person as opposed to a shared facility.

PERT. Programme Evaluation and Review Technique. A technique originally developed in the USA by the US Navy to aid planning, monitoring and control of resources and project progress. The term has been broadened to include almost any use of a formal technique; for example, GANTT CHARTS. PERT covers CRITICAL PATH ANALYSIS and other approaches based upon NETWORK ANALYSIS.

physical distribution management (PDM). The planning, monitoring and control of distribution and delivery of manufactured goods, including the use of transport, warehousing, agents and retail outlets.

physical life. The length of time over which an item of equipment can be usefully and economically used. It will depend upon patterns of use and degree of maintenance. *See* TECHNOLOGICAL LIFE; PRODUCT LIFE.

pick. To locate an item in stores and withdraw it for issue.

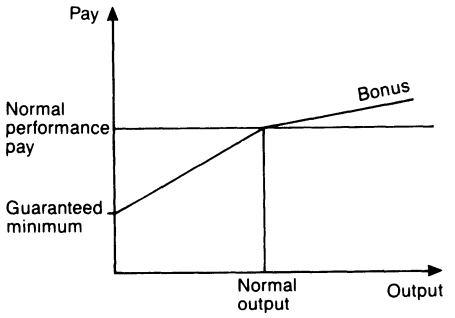
pick and place. Simple form of handling/manipulation equipment which picks an item up and places it; for example, insertion of components in electronic assembly. Usually designed for specific repetitive operations but some pick and place devices employ more sophisticated robotic techniques and are reprogrammable for different operations.

picking list. Computer-generated list which indicates specific items needed and the order in which they should be picked for maximum efficiency.

PIDM. PROPORTIONAL INTEGRAL DERIVATIVE MODULE.

piece rate. Agreed rate of pay for the production of one unit of output in a PIECEWORK system. The rate is based on agreed estimates of time required for the work and targets for overall (weekly) pay levels.

piecework. Payment system derived from F. W. Taylor's SCIENTIFIC MANAGEMENT theory which links pay to output using an agreed rate and method. Development of the idea has led to a variety of systems including those which set minimum wages and BONUS levels for extra output above a fixed level.



Piecework

Pittler system. Coding system for classifying components, using a nine-digit code.

planned maintenance. A routine and regular maintenance programme which uses forecasts of performance and reliability with the objective of reducing unexpected DOWNTIME by preemptive action. A complete planned maintenance system specifies the range of tasks required, identifies who should perform them, lays down performance standards and documents the process. *See* PREVENTIVE MAINTENANCE.

planned orders. In a MATERIAL REQUIREMENTS PLANNING system, the new orders which are placed upon a supplier. These are determined by subtracting from the GROSS REQUIREMENTS the ORDERS DUE and ONHAND STOCK (plus the required level of SAFETY STOCK) to obtain the NET REQUIREMENTS. They are usually phased to allow for DELIVERY LEAD TIME.

plant. General term covering premises and equipment used in manufacturing.

plant engineering (plant layout). The function of applying structured management to the acquisition, planning, maintenance and replacement of plant.

plant layout. *See* PLANT ENGINEERING.

plasma arc machining. Non-traditional machining process which

may be used instead of MILLING, TURNING, etc. An electric arc is set up between a torch and the workpiece, which heats it within the protection of a plasma (gas) shield. The metal is melted away, leaving a desired shape. The plasma, which is swirling, may consist of nitrogen, argon-hydrogen, or air.

plasma arc welding. Process in which the heat required to WELD two pieces of metal together is provided within a plasma gas shield. The plasma, which is swirling, may consist of nitrogen, argon-hydrogen, or air.

PLC. *See* PROGRAMMABLE LOGIC CONTROLLER.

plugboard (pegboard) lathe. A type of NUMERICALLY CONTROLLED machine tool in which the parameters are controlled by inserting pins into a matrix of values. For each parameter (e.g. spindle speed) listed down the left-hand side of the matrix, the value may be set by inserting the pin, or peg, into a hole along the line: further to the right might be a higher speed, etc. Largely superseded by more advanced COMPUTER NUMERICAL CONTROL.

plug compatible. Computer equipment designed to connect to other items by means of standard plugs and interfaces.

PMTS. *See* PRE-DETERMINED MOTION-TIME SYSTEM.

point of manufacture. An identifiable point at which a certain proportion of a product's ADDED VALUE may be said to have accrued.

point of manufacture system. DATA CAPTURE system which records transactions at the POINT OF MANUFACTURE, rather than subsequently. The idea is that such a system should provide REAL TIME information and thus control.

points ranking (points rating). JOB EVALUATION system based upon awarding points to specific job functions for responsibility, training, degree of autonomy, dexterity, decision-making, etc. Jobs are ranked according to their points and grade for pay-level decisions.

points rating. *See* POINTS RANKING.

Poisson distribution. A PROBABILITY DISTRIBUTION, named after the French mathematician, S.D. Poisson, in which the VARIANCE equals the average. It is widely used as a model for random events. For example, in the production of polythene sheeting there may be a constant probability of a blemish which makes the film opaque; the number of blemishes per square metre would give a Poisson distribution. It is used to forecast the likelihood of a rare event happening a specified number of times when there are many opportunities for it to occur.

Poka-yoke (baka-yoke). Japanese word, literally meaning 'fool-proof'. An extension of the PERPETUAL IMPROVEMENT approach applied to machinery and processes is that of

foolproofing them – making sure that mistakes cannot be made – through various simple devices. Many of these result from employee suggestions and individually they may make little difference. Grouped together, however, they can make a big difference in reducing SET-UP times or increasing QUALITY. Poka yoke ideas might include getting engineering to make up a special fixture on which it is impossible to locate a part wrongly, or something to eliminate the need for judgement in adjustment of a press die. Templates, limit switches, colour coding and so on, are all typical examples of poka yoke. Associated with poka yoke is the idea of simplification – of constantly challenging the complexity of existing solutions in search of simpler ways of doing the same job. In many cases the simpler methods are more reliable and less wasteful.

POPLOG. Computer programming language, a version of PROLOG, used extensively in the development of EXPERT SYSTEMS.

population. In statistical analysis, a group of items about which information is obtained. Sometimes known as 'sample population'.

porosity. A problem in castings caused by air within the metal as it cools in the mold. The resultant casting will leak when pressure is applied to liquid or gas/vapour inside it. Casting processes are designed to reduce porosity. *See* COSWORTH PROCESS.

post-entry closed shop. A CLOSED SHOP which accepts new employees on the condition that they join the union immediately upon appointment.

post-factory system/management. Umbrella term for the control of everything that happens to a product after manufacture: warehousing, distribution, retailing, etc.

post Fordism. The powerful influence of Henry Ford in establishing a blueprint for subsequent manufacturing organization is reflected in the label given by some economic historians to the approach – FORDISM. They recognize that Fordism was about much more than just building cars; it represented a coming together of several ideas dating back over the previous two centuries regarding not just the organization and management of production but the basis of political economy.

As a consequence of its dramatic impact on productivity in an era of demand for high volumes of new products, Fordism became the dominant institutional form with which the early Twentieth Century system operated. Fordism was a response to an era of MASS PRODUCTION and mass consumption, and survived well for the first half of this century. However, by the mid-1970s there was what many commentators have called a 'crisis of Fordism' in which the model seemed increasingly inappropriate. Amongst features of the environment which had changed were the saturation of

mass markets, the emergence of rigidities in the labour process (especially a wage explosion resulting from strong unions and non-compliant labour) and the rise of newly-industrializing countries bringing more competitive actors into the picture. In the 1980s emerged what are sometimes called neo- or post-Fordist models, suggesting that the mismatch between system and environment has reached the point where a new model is needed. Such models for BEST PRACTICE are by no means clearly defined but they are likely to be characterized by common elements such as market fragmentation, flexible specialization and an emphasis on flexibility – in production, in labour, in inter-institutional relationships and beyond.

post processor. Computer interfacing program which links the general processor in a control system to the specific needs of the controller on a MACHINE TOOL, or other piece of process equipment.

potential capacity. Production CAPACITY which a factory or process could have if some moderate capital investment were made, i.e. to extend it slightly. The implication is, however, that such investment is not currently within budget, and thus senior management decisions are required to realize potential capacity. *See also* IMMEDIATE CAPACITY and EFFECTIVE CAPACITY.

potting. *See* ENCAPSULATING.

powder metallurgy. *See* SINTERING.

power press. A PRESS which uses electrical power, as opposed to hydraulic power, to produce its active force.

precedence constraint. In LINE BALANCING calculations, precedence constraints are imposed as a consequence of the nature of the technological relationship between different WORK ELEMENTS. These dictate the order in which certain activities proceed. *See* PRECEDENCE DIAGRAM.

precedence diagram. In LINE BALANCING, a diagram indicating the order in which different WORK ELEMENTS are carried out.

precision. In STATISTICAL PROCESS CONTROL (SPC) a process is ACCURATE if the average of readings of control parameters are equal to the TARGET VALUE and precise if the standard deviation around that value is narrowly spread. *See* ACCURACY.

predetermined motion-time system (PMTS). Basic technique used in WORK STUDY to estimate the time required for a complex activity (e.g. a subassembly task) by breaking it down into basic elements of movement for which accurate times have previously been determined.

predictive maintenance. The anticipation of problems on plant and equipment through the use of monitoring and forecasting tools which give warning of impending failure. Such information provides a valuable input to PREVENTIVE MAINTENANCE programmes.

press. A MACHINE TOOL which uses great physical force, usually downwards, and specially-made shaped metal blocks (press tools) to alter the shape and form of sheet metal by bending, cutting, piercing and flattening it. The force may be several hundred tonnes, created by electrical rotary motors or hydraulics on larger presses, or by hand-activated mechanical devices in smaller models (*see* FLY PRESS). Modern, large presses may have several stages in line, with automatic handling between stages. At each stage, the tools which stamp the metal add the effect of the last stage. Thus a piece of flat steel sheet may be fed into one end and a fully formed side panel for a car delivered from the other – complete with window/door spaces, body shape curves, holes for locks and fuel filler caps, etc.

presintering. *See* SINTERING.

press brake. *See* BRAKE PRESS.

press forging. (Also known as squeeze forging.) FORGING in which the stamping action of the hammer is enhanced by subsequent pressure upon the closed mold.

pressure die casting. Form of metal casting used for non-ferrous alloys which involves injecting molten metal into a die under high or low pressure.

pressure gas welding. Gas welding in which physical pressure is added to the heating process in order to make a good joint. No filler material is necessary.

preventive (preventative) maintenance. Approach to MAINTENANCE which seeks to prevent problems and breakdowns occurring, as opposed to reactive maintenance which deals with repair or replacement owing to failure of plant or equipment. There are four basic approaches to preventive maintenance: (1) TIME-BASED, which involves checking at regular intervals and is suited to equipment which deteriorates on the basis of time elapsed rather than level of use; (2) WORK-BASED, which involves checking after a certain amount of usage (e.g. a number of hours of operation) and is suited to equipment which deteriorates on the basis of how often it is used (e.g. tool wear); (3) OPPORTUNITY-BASED, which involves checking, repair and replacement when suitable opportunities occur such as annual shutdowns or holidays. This is suitable for equipment which is heavily used and difficult to maintain under normal circumstances; (4) CONDITION-BASED, which involves setting conditions under which action should be taken and then monitoring on a continuous basis to detect when these conditions are reached. This is the most effective but is costly in terms of monitoring equipment and procedures.

price breaks. In calculating the ECONOMIC BATCH QUANTITY, consideration needs to be given to the effects of any special offers or price breaks which a manufacturer may

offer as an incentive for bulk purchasing. For example, if a customer is prepared to buy a minimum of 1000 units he may be offered a reduction of 5 percent per unit; this will have the effect of decreasing the overall cost to the manufacturer by making a larger batch size possible.

Priestman scheme. A PAYMENT-BY-RESULTS scheme based on a group bonus. All employees are paid a guaranteed basic wage, and in addition, have their wages increased by a certain percentage which is related to improved output performance of the factory or unit as a whole. For example, if a target output is exceeded by 10 percent, the wage increase would also be 10 percent. *See* SCANLON PLAN.

primary standard data (PSD). WORK MEASUREMENT techniques employing a synthesis of activity times from predetermined element times.

prime cost. *See* DIRECT COST.

print. *See* DX.

probability. The likelihood of an event occurring, usually expressed as a decimal number between one and zero. Probability theory is a branch of mathematics concerned with the concepts of prediction on a numerical assessment basis. Where there are two or more possible events out of which one is certain to occur (e.g. whether it will rain or not), the arithmetic sum of their probabilities is one. *See* BAYES THEOREM.

probability distribution. The pattern of PROBABILITIES for a specific POPULATION mathematically expressed as a function. The function may refer to the items in the population (e.g. the number of women in the armed services over a period of time), or some random variable (e.g. the height of women in the army), in which case it is termed a frequency function. Probability distributions may compare with well-known phenomena which have been expressed as functions (e.g. NORMAL DISTRIBUTION, BINOMIAL DISTRIBUTION, POISSON DISTRIBUTION, etc.), and are used for testing the significance of a result by comparing it to an expected norm. This is known as STATISTICAL INFERENCE.

problem analysis by logical approach. *See* PABLA.

problem display boards. In JUST-IN-TIME manufacturing and in TOTAL QUALITY CONTROL applications a key principle is VISUAL CONTROL. Problem display boards provide a clear indication of where problems have been located and the status regarding solving them, and are a powerful mechanism for developing a problem-solving rather than a problem-hiding approach in manufacturing. *See also* ANDON.

process. A series of events which takes place to alter the nature of material or information for subsequent use. Manufacturing processes range from FLOW PRODUCTION through to BATCH MODE processing.

process capability. In STATISTICAL PROCESS CONTROL, the limits to the level of QUALITY which can be achieved will be imposed by the actual capability of the process itself. Inevitably there will be some degree of variation in performance owing to wear and tear, lack of adjustment and so on, and this will affect the quality of products leaving the process. For example, in a machine cutting lengths of metal there may be variations around the required standard length. Providing these variations are small enough to be acceptable the process does not need adjustment, but when they consistently fall outside the specified target range then action must be taken. A process is said to be in control when only random causes of variation are present and a PROCESS CAPABILITY INDEX can be calculated which provides a measure of how well the process actually performs relative to the specified requirements.

One example of such an index is given by the formula

$$C_p = \frac{\text{Upper Specified Limited} - \text{Lower Specified Limit}}{6\sigma}$$

where C_p is the process capability index and σ is the standard deviation from the specified average.

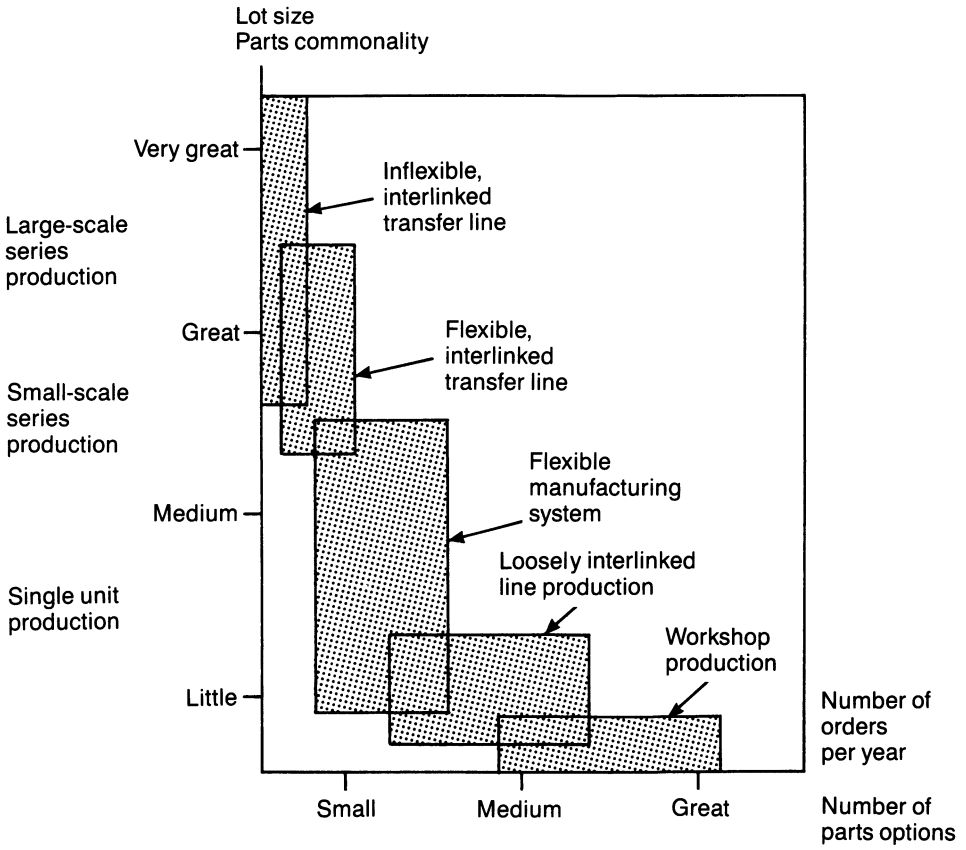
When the value of C_p is high, there is a wide tolerance allowed but when it is less than 1 the process is incapable of achieving the requirements.

process capability index. *See* PROCESS CAPABILITY.

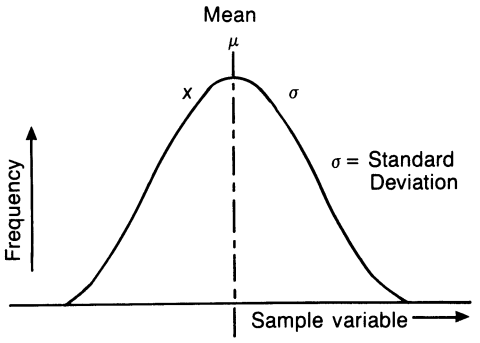
process capability study. A study carried out to determine PROCESS CAPABILITY by taking a series of readings over a period of time with no adjustment to the process. These are plotted as a DISTRIBUTION and the mean and standard deviation are calculated to give an indication of the extent of variation. An alternative, more suited when fewer readings are taken, is to use the mean and sample range, i.e. the difference between the largest and smallest values in the sample. *See* STATISTICAL PROCESS CONTROL.

process characteristics. Characteristics associated with a particular form of manufacturing – for example, JOBBING – which differentiate it from other forms such as CONTINUOUS FLOW or MASS PRODUCTION systems.

process charts (process control charts). In STATISTICAL PROCESS CONTROL two kinds of chart are used: MEAN CHARTS and RANGE CHARTS. These provide a visual indication of the performance of a process with respect to previously set quality limits, so that early warning of a drift outside the acceptable range can be given and action be taken to bring the process back under control. In constructing a mean chart, samples of a given size are taken at intervals of time from a process which is believed to be under control. For each sample a mean and standard deviation is calculated.



Process characteristics



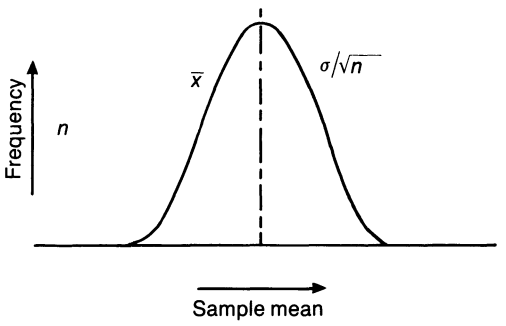
Process charts – 1

The means are then plotted to produce a second distribution which should be normal.

The standard deviation of this distribution is called the STANDARD ERROR. This should be less than the standard deviation of the original population and can be calculated from the formula

$$\text{Standard Error} = \frac{\sigma}{\sqrt{n}}$$

where n is the sample size.



Process charts – 2

The mean chart can then be used to construct a process control chart for the sample mean. If the process is in control, then one can expect that almost all the means of samples taken will lie in an area between two lines – the upper and lower ACTION LINES. These are plotted as in the figure below at a distance of ± 3 standard errors.

The PROBABILITY of a mean falling outside these lines is low – 1 in 1000 – so if points repeatedly fall outside these limits the cause(s) should be investigated. A second set of lines, called WARNING LINES, can also be calculated at a distance of ± 2 standard errors.

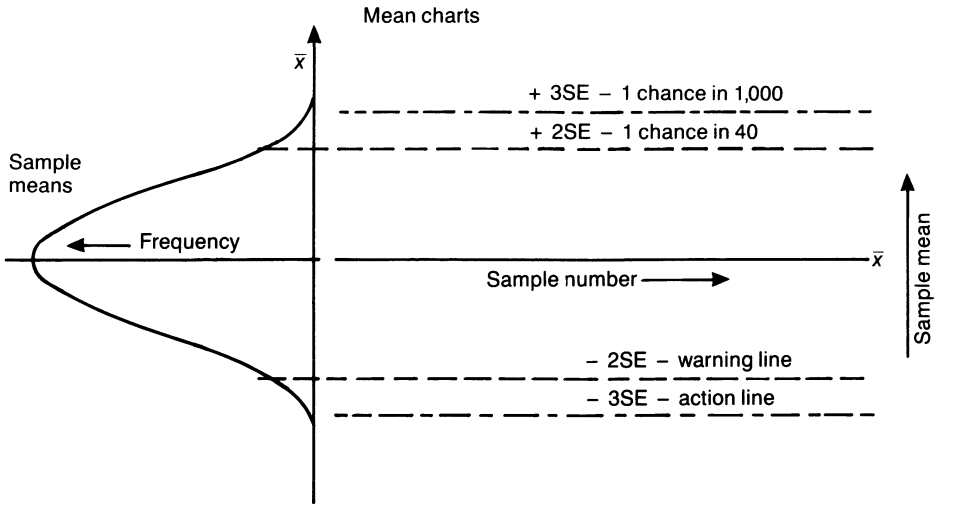
Here, the probability of a point falling outside this range is higher: 1 in 40. If this happens repeatedly, it gives a warning that the process is drifting out of control and action should be taken. RANGE CHARTS are an alternative to mean charts where a smaller sample (usually less than 12) is involved. Here an alternative measure of spread of the process is used: the mean range. This is calculated by taking the highest and lowest values of the sample means.

process control. (1) *See* STATISTICAL PROCESS CONTROL. (2) Control of manufacturing processes. *See* CONTROL LOOP.

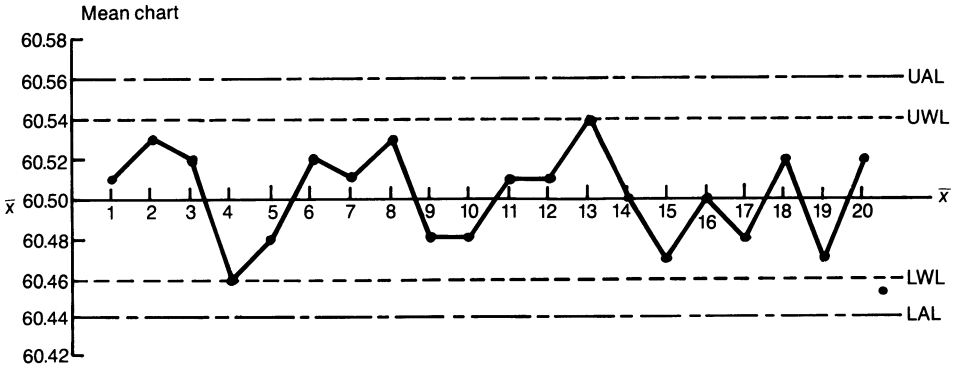
process industries. Industries concerned with the bulk transformation of materials – for example, commodity processing, petrochemicals or steelmaking. Such industries often make use of FLOW PROCESSES.

process layout. Production LAYOUT in which similar processes and equipment for the manufacture of products are grouped together in the same areas. For example, in an engineering firm a process layout would put all the drilling, all the grinding, all the painting and all the inspection activities in groups, and products would visit them in sequence. *See* PRODUCT LAYOUT.

process life cycle. Similar concept to PRODUCT LIFE CYCLE. A process or technique, when in the early stages of its adoption, is like to be problematic: of unknown potential and benefit. Once it has been learned, the user should be able to make very profitable use of it. As other processes emerge, however, the competitive position of the older technique may decline, until it is finally considered inappropriate. Most process innovation is incremental however, since there are few radically new ways of manufacturing products.



Process charts – 3

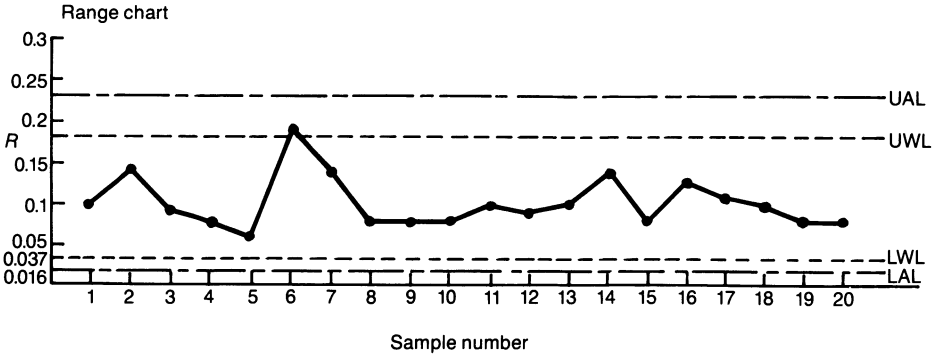


Process charts – 4

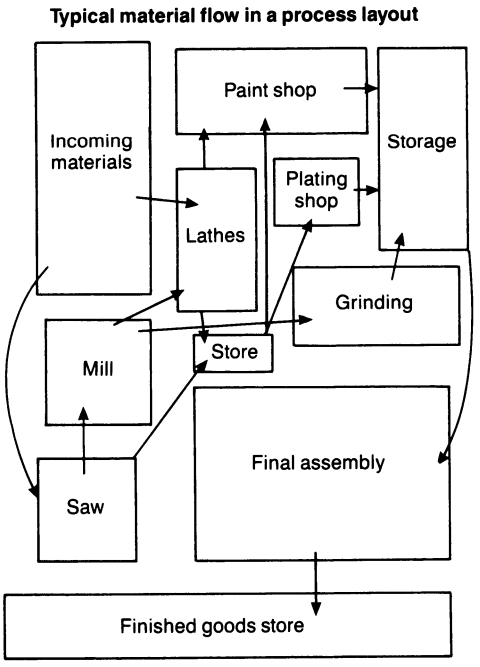
process planning. The function of preparing facilities and resources for a necessary process, usually on a long-term basis.

procurement. *See* PURCHASING.

producer's risk. In STATISTICAL QUALITY CONTROL there are two types of risk associated with any SAMPLING PLAN which reflect the fact that the samples taken may not be representative of the whole batch or production run. The first is where the decision is taken to reject a batch which should have been accepted; this is termed producer's risk. The second is where a customer accepts



Process charts – 5



Process layout

a batch the quality of which is, in fact, unacceptable; this is termed CUSTOMER'S RISK. The efficiency of any sampling plan as a detector of acceptable or unacceptable batches is given by its OPERATING CHARACTERISTIC CURVE, and a highly efficient plan will minimize both producer's risk and customer's risk.

product development. Activities involved in converting a design concept into a physical product and matching it to its market requirement, manufacturability, etc. *See* RUGBY TEAM and RELAY RACE.

product differentiation. The designing of interdependent products to have related but clearly differing specifications, in order to appeal to specific sections of the target markets. For example, the standard model of a saloon car, the deluxe, the estate, and the sports model are all differentiated products within a range.

production. *See* MANUFACTURING.

production control. The function of balancing output with demand, with reference to information on sales, capacity and other factors affecting production performance. *See* MATERIALS REQUIREMENTS PLANNING.

production engineering. The application of engineering principles and techniques to design, planning and provision of facilities and resources required in a production process.

production flow analysis. A technique for cost reduction through improving the logic of a work path through a production process.

production schedule. The detailed specification of which work will be carried out in which sequence by which function over which time periods in a manufacturing facility. Preparation of a production schedule is a complex balancing process which needs to take account of factors including the availability of plant, dates on which products are required, capacity, maintenance schedules, materials availability, etc.

production kanban. A KANBAN which is issued to authorize production of a quantity of a part at the supplier WORKSTATION.

production layout. Arrangement of production facilities to suit the manufacture of particular products. *See* PROCESS LAYOUT; PRODUCT LAYOUT; GROUP TECHNOLOGY.

production line. Linear workplace designed to enable sequential operations to be interrelated during the course of manufacturing. *See* ASSEMBLY LINE.

production scheduling. Process of generating a PRODUCTION SCHEDULE.

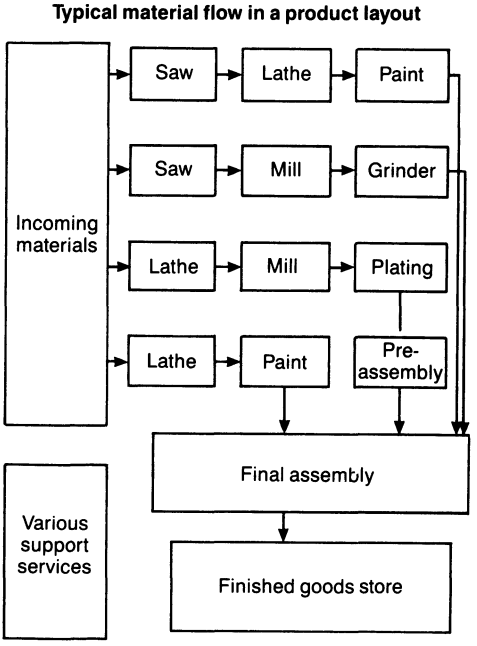
production standards. Standard methods to be used in a manufacturing process, and the times taken for each of them. Derived by WORK STUDY from the ideas of SCIENTIFIC MANAGEMENT. Fundamentally important data in the costing of manufactured products.

productivity. General term relating the efficiency with which inputs to the production process are used in converting them to outputs. Inputs include labour, energy, materials and capital although emphasis is often placed on measures of labour productivity such as output per worker or added value per direct employee. A broader definition, known as TOTAL FACTOR PRODUCTIVITY, takes account of changes in the efficiency of use of all inputs to the process and provides a more useful measure of performance in industries where there is increasing use of CAPITAL EQUIPMENT and less reliance on direct labour. *See* TOTAL FACTOR PRODUCTIVITY and SINGLE FACTOR PRODUCTIVITY.

productivity agreement. Form of wage deal which links increases in pay to those in PRODUCTIVITY rather than output alone.

productivity growth. The rate at which PRODUCTIVITY increases over time for a particular firm, industrial sector or nation.

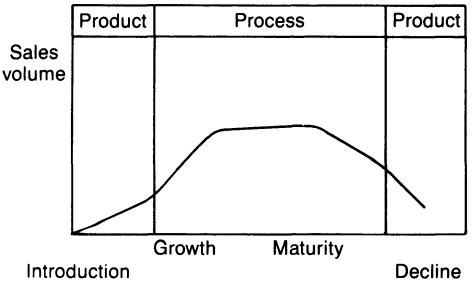
product layout. Production LAYOUT



Product layout

which groups together all those processes and activities associated with the manufacture of a particular product (or family of products with similar features). *See* GROUP TECHNOLOGY.

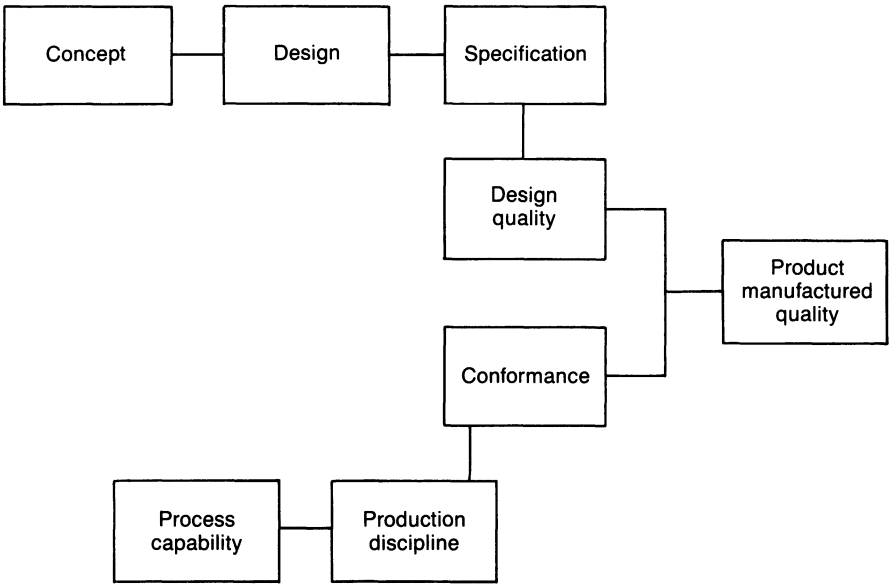
product life cycle. The concept of four discrete stages in a product's life. The first is development, before the launch; the second is growth of sales following the launch; the third is maturity, once the product has become established and sales have reached their maximum rate; the fourth is decline, when the rate of sales begins to reduce and the product approaches withdrawal from the market. Matching production processes to the relative stages in the product life cycle is an important element of MANUFACTURING STRATEGY. For a full discussion of this, *see* R. Hayes, S. Wheelright and K. Clark, *Dynamic Manufacturing*, Free Press (New York, 1988).



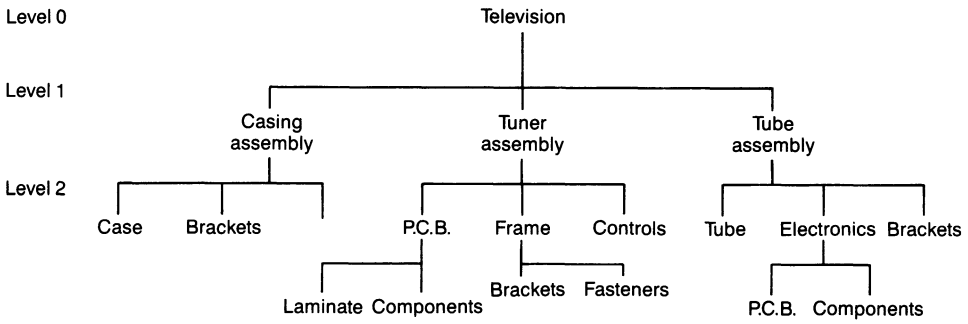
Product life cycle

product manufactured quality. The QUALITY which a product has as a result of the combination of quality in its design and its manufacture.

product structure. The arrangement of components, sub-assemblies and assemblies which go into making a particular product. Their relationship to one another can be expressed diagrammatically in a PRODUCT STRUCTURE DIAGRAM or PARTS



Product manufactured quality



Product structure diagram

EXPLOSION. *See also* BILL OF MATERIALS.

product structure diagram. See PARTS EXPLOSION and BILL OF MATERIALS.

profiling systems. A JOB EVALUATION technique which uses profiles of specific factors in jobs (e.g. responsibility, degree of experience needed, etc.) to compare one with another for the purposes of RANKING.

profit centres. Areas of a factory (or organization in general) that are identified for accounting purposes as

collection points for all costs and value adding items. Each profit centre is treated like a small firm, having the costs it attracts set against the revenue it generates.

profit sharing schemes. Form of incentive in which employees receive, in addition to a basic wage, some element of the profit generated by a company.

profit/volume chart (P/V chart). A diagram which shows the level of profit to be expected from different volumes of production. *See* BREAK-EVEN CHART.

program. A computer command sequence written in a formal language to direct the computer to carry out certain activities. When several programs are combined for complex multi-functioning, it is often referred to as a suite or package.

programmable logic controller (PLC). A general purpose controller (usually based on a microprocessor) which can be used for a variety of monitoring and control tasks in manufacturing. PLCs are usually used at the lowest levels of control hierarchies – for example, controlling individual parameters in a complex system or single machines in a manufacturing cell – and often provide information to a more powerful host computer which optimizes control of the larger system.

programmable read only memory (PROM). Type of computer memory which can be read but not written to. It is particularly useful for storing instructions such as the control program for a machine tool.

Programme Evaluation and Review Technique. *See* PERT.

progress chaser. *See* PROGRESS CHASING.

progress chasing. (Also known as EXPEDITING.) Activity carried out by staff in a PROGRESS DEPARTMENT whose responsibility is ensuring that current performance of a manufacturing facility keeps as closely as possible to the production plan. Progress chasers are responsible for trouble-shooting when deviations from the plan occur and the activity involves considerable interaction with other functions, often literally chasing up the progress of a particular order. It is generally recognized now that progress chasing is MUDA – a wasteful exercise which has become built-in to manufacturing systems to allow for things going wrong. As such it is a target for removal under such concepts as JUST-IN-TIME, and LEAN MANUFACTURING.

progress department. *See* PROGRESS CHASING.

progressive part method. A training technique in which the operator learns a task one part at a time, mastering each part on its own and then in conjunction with the subsequent part before going on to the next.

project. A specific, discrete operation with defined start and finish points

which requires special management to ensure completion on time and within budget.

project management (project planning). A special type of management activity chiefly concerned with the planning, execution and consolidation of a project of any type within the constraints set by the company and the environment. For a full description *see* D. Lock, *Project management*, Wildwood House (London, 1986) (3rd edition).

project network techniques. The application of NETWORK ANALYSIS for controlling a PROJECT.

project planning. *See* PROJECT MANAGEMENT.

PROLOG. High-level computer language used extensively in applications involving ARTIFICIAL INTELLIGENCE.

PROM. *See* PROGRAMMABLE READ ONLY MEMORY.

proportional integral derivative module (PIDM). A processor in a machine control system which provides three types of control, to convert input voltages into control signals, and thus into physical conditions or movements. Proportional control causes the signal to change in direct proportion to the input voltage. Integral control causes the output signal to change in relation to the input voltage and other sampled signals. Derivative control causes the signal voltage to change in proportion to the rate at which the input voltage is changing (i.e. in line with the differential of the signal input).

proportion defective (p) chart. In STATISTICAL QUALITY CONTROL, a CONTROL CHART which indicates the proportion of defective items in a sample. *See* NUMBER OF DEFECTS CHART.

protocol. Formal rules for communication between two computers within a communications NETWORK. Protocols define how data should be formatted and transmitted, together with conventions used for error checking and the order and priority in which messages will be transmitted within the network. In effect, protocols provide the 'Highway Code' for electronic traffic within the network.

PSD. *See* PRIMARY STANDARD DATA.

pull system. Materials management in manufacturing can take one of two approaches to ensuring material is available at the right time and in the right place. A PUSH SYSTEM works back from the forecast of what is to be made, procures the relevant supplies (from in-house stores and from external suppliers) and then issues them to the shop floor at the start of the manufacturing period. In effect it operates by pushing INVENTORY into the system from the supply side. The alternative is a pull system, in which the release and the procurement are triggered by some form of signal about

demand. STOCK CONTROL systems based upon replenishment of stock at certain points are pull systems. However, they all accept a lag in the system – the LEAD TIME of the component or material. Modern pull systems do not work in this way. The lead time is a form of MUDA. Pull systems which have eliminated lead times are at the heart of KANBAN and JUST-IN-TIME manufacturing.

push system. *See* PULL SYSTEM.

purchase order. An official order placed on a supplier by a buyer for specified items of material. It may employ a BLANKET ORDER format, supported by MATERIAL CONTROL schedules, for VENDOR SCHEDULING of production items.

purchase requisition. Request to a BUYER originating from any function in the business to procure items of material. *See* STORES REQUISITION.

purchasing (procurement). The MATERIALS MANAGEMENT function responsible for buying all items of material required by a company. Purchasing denotes a strategic, planned approach to the procurement of materials and services, rather than the tactical nature of 'buying'. Companies can create and sustain competitive advantage by employing the correct purchasing and supply strategies in order to reduce operating costs, and by building alliances with important suppliers (*see* CUSTOMER-VENDOR RELATIONSHIPS). Much as the importance of MANUFACTURING STRATEGY has only been recognized in the last decade in the West, so purchasing strategy remains, in many industries, an area in which advanced thinking has yet to be properly formulated.

Q

QA. *See* QUALITY ASSURANCE.

QC. *See* QUALITY CONTROL.

quality. The whole set of features of a product or service which relate to its being able to satisfy the needs of the user. It is a complex concept, involving a variety of dimensions. In general, it involves some perception of excellence and reliability, and often an association with higher cost – 'you pay for what you get'. It is also important to see quality as a perceived characteristic which varies between individuals. A commonly used definition is that quality is 'fitness for purpose', i.e. the extent to which a product possesses characteristics which suit the users' purposes. It also includes some consideration of reliability as an indicator of the long-term continuation of this state of fitness for purpose.

This user-oriented approach is helpful in focusing attention on the customer rather than the producer, but it can be argued that it needs some modification. In particular, it fails to deal with two key problems: (1) how to aggregate what may be widely varying individual perceptions of quality in order to provide something meaningful at the level of the market; (2) how to identify the key product attributes which connote quality.

An alternative set of definitions emerge from considering the producer's side, which are concerned with establishing standards and measuring against them. The quality of design represents the intentional quality which the designer wishes to see produced in order to meet his interpretation of the customer's needs. It is a multi-attribute definition but has the advantages of permitting measurement against each of these attributes to assess whether or not the intentional quality level has been achieved.

Associated with this is the quality of conformance which represents the degree to which the product, when made, conforms to the original design specifications. The extent to which this can be achieved will depend in turn on the various elements of manufacturing: people, processes, equipment, incoming raw materials quality, and so on. This equates to CROSBY's idea of quality as 'conformance to requirements'.

GARVIN identifies five categories of quality definitions, ranging from the 'transcendental' (which define quality as an innate property of 'excellence' which is also timeless and beyond short-term fashions), through product

attribute definitions and the above user and producer views, to definitions which try and put a value or cost on quality or its absence. This last group of views attempt to link quality to the price people are prepared to pay for it, and the expectations which follow from that.

But quality is not just about satisfying the customer in the marketplace; it also has an impact within the firm. With material costs often representing 40–50 percent of total manufacturing costs, any scrap made will have a major impact. Scrap and rework arise from a variety of quality related factors: poor and defective incoming supplies, problems built in at one stage in the process which are not detected until later, problems in handling and transport within the works which lead to damage and so on. Furthermore, anything which 'escapes' the notice of the quality inspectors and is passed on to the customer may result in warranty claims, complaints and other public relations problems.

TAGUCHI takes this approach in his definition of quality, which he relates to the loss to society as a whole as a consequence of not paying attention to quality improvement. His 'loss function' approach takes into account definitions relevant to both producers and users and helps provide some kind of cost/benefit accounting for quality improvement activities.

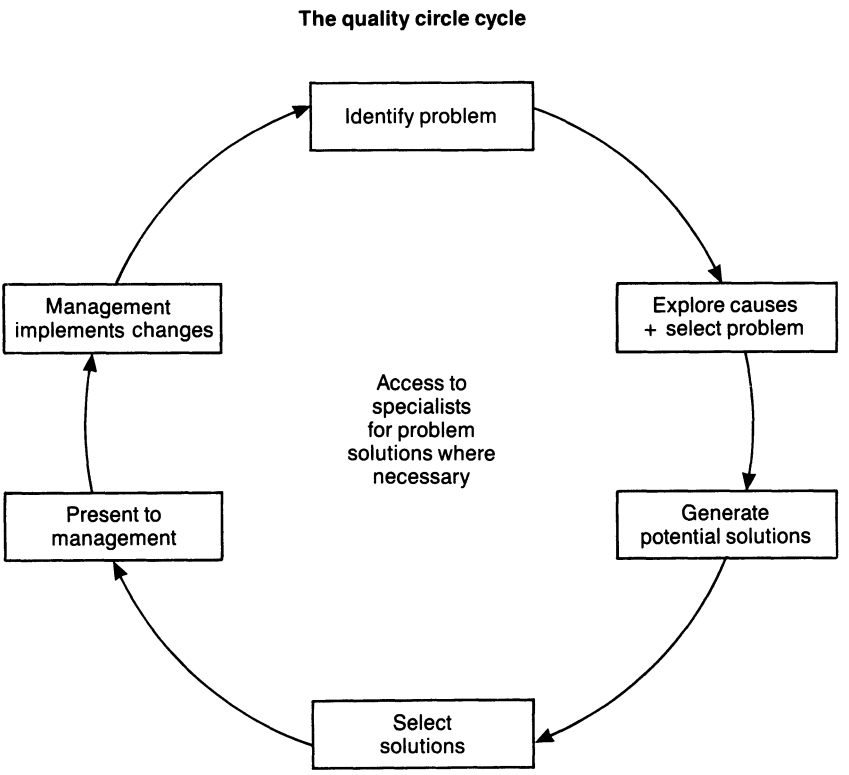
A final point about quality: it is hard to put limits on the term, but it refers to much more than simply the physical attributes of a product. The phrase 'a quality organization' implies a great deal about the approach taken to dealing with all sorts of other issues; for example, customer care, product design, interpersonal relations, financial management and so on. So improving quality management may not simply reflect a change in the way product manufacture is treated – it may result in development of the whole organization.

quality assurance (QA). Umbrella term for all activities associated with the creation and maintenance of the overall QUALITY SYSTEM within a business.

quality audit. Set of procedures designed to monitor and check that the QUALITY SYSTEM is functioning correctly.

quality circles (quality control circles). Quality circles are based on ideas originating in Japan in the 1960s, where they extended from the work of ISHIKAWA. They were not applied in the West until a decade later, with the Lockheed Company in the USA being the first to introduce a circle in 1974. The concept extended ideas which had been applied in early work on COMPANY WIDE QUALITY CONTROL, especially in the areas of EMPLOYEE INVOLVEMENT and CONTINUOUS IMPROVEMENT.

The core elements of a quality circle are simple. A small group (5 to 10 people) gather regularly in the firm's time and examine problems and discuss solutions to quality problems. They are usually drawn from the same area of the factory and participate voluntarily in the circle. The circle is



Quality circles

usually chaired by a foreman or deputy and uses SQC methods and problem-solving aids as the basis of its activity. An important feature, often neglected in considering quality circles, is that there is an element of personal development involved, through formal training but also through having the opportunity to exercise individual creativity in contributing to improvements in the area in which participants work.

The basic activity cycle of a quality circle goes from selection of a problem through analysis, solution generation, and presentation to management and implementation by management.

Once the problem is analysed and the root problem identified, ways of dealing with it can be identified. Amongst valuable techniques here are brainstorming (in its many forms) and goal orientation. However, it is important that the structure and operation of the group supports suggestions from anyone (irrespective of levels in the organization, functional

or craft skills background, etc.) and allows for high levels of creativity – even if some of the ideas appear wild and impractical at the time. The principles of brainstorming, especially regarding expert facilitation and enforcement of a 'no criticism' rule during idea generation sessions – are important.

The circle does not have to confine itself exclusively to current problems – it can also become involved in forecasting. Here the possible future problems resulting from each stage can be anticipated and explored. Finally the group presents its solution to management, which is expected to implement it. A key success factor in quality circles' survival and effectiveness is the willingness of management to be seen to be committed to the principles of CWQC and to act on suggestions for improvement.

Quality circles have been in operation for nearly 30 years and many variants exist. There is, for example, considerable overlap between these groups and continuous improvement groups. A number of factors associated with success have been identified, including the need to ensure clear roles and to demonstrate top management commitment; for example, by allowing meetings to be held on company time. But there is no fixed model for establishing a circle, nor a perfect recipe for success.

Studies of success and failure in quality circles often make the point that, whilst relatively easy to establish, they are often difficult to sustain and thus the prospects of creating a PERPETUAL IMPROVEMENT climate are diminished. Much appears to depend upon commitment and support, from senior management, to a change in the culture of the company.

quality control circle. *See* QUALITY CIRCLE.

quality costs (costs of quality). The total costs associated with ensuring product QUALITY. These are made up of a number of components including: (1) costs associated with the operation of the QUALITY SYSTEM; (2) failure costs, which represent the costs of failing to achieve quality in some aspect of the system. These costs can be broken down into *internal* and *external* failure costs.

Internal costs include: scrap – defects which cannot be repaired; REWORK/RECTIFICATION – the correction of defective output to meet specifications; RE-INSPECTION – re-examination after rework; DOWN-GRADING – where the product is still usable but has a lower than specified quality level and is thus sold at a lower price; failure analysis costs associated with tracking back failures to find their cause.

External failure costs are those incurred when products with quality problems get through to the customer. These include: repair costs; costs arising from WARRANTY claims (products replaced under guarantee); costs associated with handling and responding to complaints; costs associated with administering the return and replacement of rejected products; costs arising from legal liability.

These can be summarized as the costs of 'getting it wrong'. The costs of operating the quality system break down into those associated with *prevention* and those associated with *checking* – the costs of 'getting it right'.

Prevention costs include: determining and specifying standards for all elements; materials, processes, etc.; quality planning; QUALITY ASSURANCE; costs of specialist equipment to assist in the quality system; training costs.

Checking costs include: inspection and test costs such as DOWNTIME of production; costs of quality audits; inspection equipment; vendor appraisal and rating.

Quality costs are often wrongly defined as simply the internal costs of checking and prevention, whereas the true cost of quality includes the various failure costs outlined above. The total costs viewed in this way can often be between 10 and 40 percent of total revenue. *See* TAGUCHI METHODS.

quality function deployment (QFD). Approach which sees the development of quality in all its aspects as something which can be designed into the product. Consequently it mobilizes all relevant information – from customer and DOWNSTREAM manufacturing processes – in providing input to design. The problems identified in use of the product are linked directly back to points in the manufacturing process, in attempts at reducing their number. *See* TAGUCHI METHODS.

quality level acceptable. *See* ACCEPTABLE QUALITY LEVEL.

quality manual. Documentation of aspects of a QUALITY SYSTEM, including: a statement of QUALITY POLICY; identification of who is responsible for quality functions; records required; functions to be controlled; control procedures for processes and equipment; control procedures on purchased materials; sampling procedures. *See* BS5750.

quality of conformance to design. A measure of how well a product meets the QUALITY OF DESIGN once it has been manufactured.

quality of design. A measure of how well a product is designed to meet its purpose. This purpose is described in the SPECIFICATIONS which represent a detailed statement defining the product and how it will meet customer requirements.

quality policy. A comprehensive statement issued by senior management which sets out a company's approach to, and procedures for, ensuring quality in both its products/services and also in the processes whereby they are created.

Amongst features of such a policy would be: creation of an organization for quality; identification and monitoring of customer needs; education and training for quality; regular audit and review of quality systems.

quality system. The total system developed to quality management and

involving a number of contributing elements, including: marketing (determining customer requirements, providing knowledge of competitor quality levels, setting product specifications, analysis of complaints, handling downgrading, etc.); design and product development; production engineering (design and development of inspection and monitoring equipment); production operations (agreeing specifications, training); purchasing (vendor appraisal and rating); quality assurance.

Quality management systems should include clear procedures set out in a QUALITY MANUAL identifying the role and contribution of different functions.

quarantine. In MATERIALS MANAGEMENT, some items of incoming stock are placed in 'quarantine' and can only be released for use after certain tests or procedures have been successfully completed; for example, incoming quality checks on critical items.

quenching. Rapid cooling after heating, by immersing the workpiece in liquid, gas, or by contact with a cold solid item. This process alters the physical structure of some metals, providing desired physical properties such as different hardness, MALLEABILITY, etc.

R

R and D. RESEARCH AND DEVELOPMENT.

RAM. RANDOM ACCESS MEMORY.

random access memory (RAM). That part of a computer system's memory which is made available to the user for short-term storage of data and application programs. The size of the RAM is measured in KILOBYTES, often referred to simply as K. The larger the RAM, the more powerful the programs a computer can operate.

random access storage. Storage in a WAREHOUSE in which a non-traditional placing order technique is used. A computerized system allocates parts to whichever bay or space is empty, rather than to the same bay every time (as conventionally done); i.e. random placing. The system, which is used to remember where each item is kept may also use other data – such as the likelihood of those parts being required frequently, etc. – in deciding in which bay to place them. This system can provide a quicker access to frequently used parts than the traditional method of fixed locations.

random cause. *See* STATISTICAL PROCESS CONTROL.

random sample. A SAMPLE of a specific size taken from a POPULATION which has been chosen so that any sample of items has the same PROBABILITY of being taken. This is important in STATISTICAL INFERENCE because it means that the sample upon which the observations are based may be accepted as fair and unbiased.

range. The difference between the largest and smallest values of an observed factor in the items in a SAMPLE.

range charts. *See* PROCESS CONTROL CHARTS.

rank positional weights (RPW). A technique used in LINE BALANCING to determine the order in which WORK ELEMENTS are considered for allocation to WORKSTATIONS. It gives an indication of the importance of a particular work element in the overall production sequence under examination. Using a PRECEDENCE DIAGRAM, the positional weight (PW) of an element (x) can be calculated by summing the WORK CONTENT values of all elements along all connected paths back from the final product to the work element (x).

These work elements are then ranked in order of decreasing values of PW.

rate buster. In the USA, an operator paid on a PIECEWORK system who works faster than the standard rate in order to earn more money. The rate for the job may be altered as a result, and thus the rate buster is frequently unpopular with TRADE UNIONS.

rate fixing (rate setting). A fixed rate of pay for a job (especially in PIECEWORK), usually arranged by a process of discussion rather than by formal measurement.

rate setting. *See* RATE FIXING.

rating. In TIME STUDY the technique used for compensating for varying effort and ability by comparing an operator to a qualified operator working at standard performance. There are a variety of RATING SCALES which differ in terms of the STANDARD RATING point value – i.e. the average rate at which a qualified worker will naturally work. *See* OBSERVED TIME; WORK STUDY.

rating film. Films of operations used to train TIME STUDY practitioners to assign consistent RATINGS to tasks.

rating scale. *See* RATING.

raw data. Data which has not been processed (e.g by statistical inference methods), such as smoothing.

raw materials. That part of INVENTORY which consists of items bought for use in a company's operation. This may consist of bulk materials, components, sub-assemblies and complete products. The categorization depends on the nature of the operation.

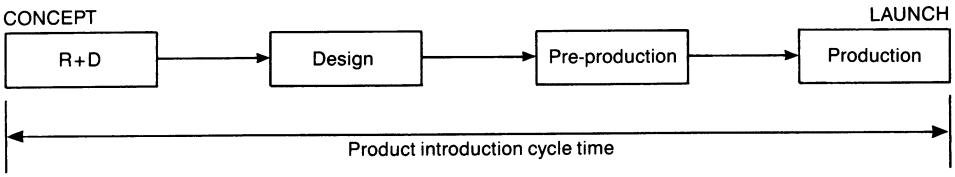
reactive maintenance. Policy of servicing or repairing items of plant only when a fault or breakdown occurs. *See* PREVENTIVE MAINTENANCE.

read only memory (ROM). Data storage device in a computer system which cannot be overwritten (as distinct from a RANDOM ACCESS MEMORY which can). Often used to contain the relevant control programs for industrial automation equipment.

real time. In computing, operations which involve the processor acting on information as it relates to changes in the environment in real time. The alternative is batch mode processing, in which information to be input is first brought together and then processed at a later stage. In industrial automation, real-time process control involves direct control of variables and thus requires very fast processing software in order that the computer controller can react fast enough to changes in process conditions.

reaming. Internal MILLING process used to produce smooth surface finish in a drilled hole. A reamer is similar to a drill in appearance, without a pointed end. It is the spiral cutting edges on the sides of the reamer which produce the milling effect.

receiving inspection. *See* GOODS INWARDS INSPECTION.



Relay race product development

rectification. *See* REWORK.

record. In WORK STUDY the documentary evidence of observations. A number of recording methods are available including the use of PROCESS CHARTS, TIME SCALE CHARTS and MOVEMENT CHARTS.

red post. Form of express KANBAN used for situations where there is a shortage of parts.

red-ringing. The practice of ringing an employee's name in red ink on a printed list when the employee has reached the top of a payment range. An employee who is red-ringed may not be included in a general annual increase for merit but only for basic rate increases.

redundancy. (1) In employment, the legally provable state of being surplus to requirement. Redundancy may come about as a result of company circumstances, personal situation (such as loss of skills), or by changing technology. If legally proved, redundancy can provide the basis for dismissal. (2) In systems RELIABILITY, the replication of key functions so that if failure were to occur, the system can continue to operate until repairs or replacement to the faulty function can be carried out.

regression analysis. A statistical technique used primarily in FORECASTING. The principle is to find a pattern of correlation between a 'dependent' variable (a factor which is being forecast) and one or more 'independent' variables which affect it.

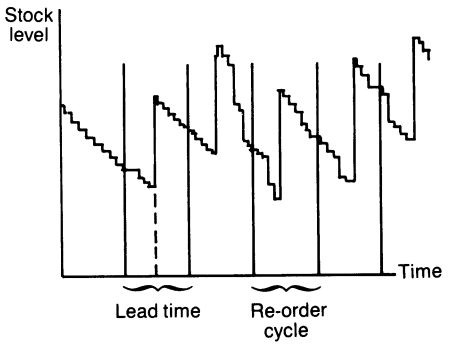
re-inspection. Checking of REWORK to ensure that it meets the desired specification.

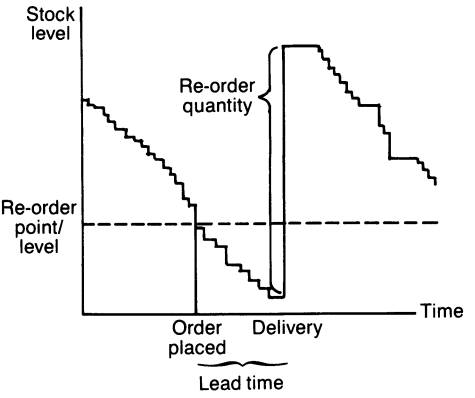
relaxation allowance. (Also known as compensating rest.) An allowance made to basic time in WORK MEASUREMENT to allow for the incidental use of time over prolonged periods, depending on the nature of the job.

relay. Switching device used to interface electronic equipment to the wider environment. Relays take a small current input and convert it to some form of physical movement.

relay logic. Logical system – such as a controller or computer – based upon linked RELAYS.

relay-race product development. Popular analogy for traditional PRODUCT DEVELOPMENT in which each department carries out its work on the product and then passes it to the next (like the baton in a relay





Re-order quantity

race). This tends to lengthen the process since problems in one stage may necessitate a return to an earlier stage, presenting problems for the departments which are not accustomed to good communications. *See* PRODUCT DEVELOPMENT, SIMULTANEOUS ENGINEERING and RUGBY TEAM PRODUCT DEVELOPMENT.

reliability. (1) The degree to which information gathered in a survey might be regenerated in an identical form if a similar survey were carried out at another time. (2) The ability of a product or item of equipment to be fit for the purpose for which it was intended over a continuing period. In statistical terms the reliability ($R(t)$) of a product is the probability that it will still be functioning at time t

$$R(t) = \frac{\text{Number surviving at time } t = t}{\text{Number existing at time } t = 0}$$

Alternatively, the CUMULATIVE DISTRIBUTION OF FAILURE is used, where

$$F(t) = \frac{\text{Cumulative number of failures by time } t = t}{\text{Number existing at time } t = 0}$$

Two other measures are sometimes used: (i) the PROBABILITY DENSITY FUNCTION OF FAILURE, where

$$f(t) = \frac{\text{Number failing in unit time at } t = t}{\text{Number existing at time } t = 0}$$

(ii) the FAILURE RATE (or HAZARD RATE)

$$f(t) = \frac{\text{Number failing in unit time at time } t = t}{\text{Number surviving at time } t = 0}$$

reorder cycle. The period between replenishment orders in STOCK CONTROL.

re-order point (ROP). Level in a stock control system which triggers the authorization of PURCHASE ORDERS for new stock. *See* STOCK POINT GENERATION.

re-order quantity. Amount of new stock ordered when the RE-ORDER

POINT is reached or at the appropriate point in the RE-ORDER CYCLE. This is often fixed at a particular level to minimize stockholding whilst ensuring sufficient availability of stock.

repair limit. Within a PREVENTIVE MAINTENANCE programme, equipment which is defective or worn may be repaired or parts replaced. The repair limit is the point at which such repair work becomes uneconomical and it is a better option to replace the equipment.

repeatability. The ability of a machine to produce exactly the same dimensions repeatedly. This is often quoted as a measure of PRECISION in the machine tool specification.

replacement analysis. An OPERATIONAL RESEARCH technique designed to predict life cycles of plant and equipment in order to provide information for updating, renovation and maintenance policies.

replacement theory. Technique in discounted cash flow analysis of investments which aims to predict the best time (in financial terms) to replace items (allowing for inflation, second-hand prices, maintenance costs, etc.).

replenishment system. STOCK CONTROL system based on estimated usage rate and delivery lead time for each item. The principle is to avoid running out of stock of an item by ordering a replenishment delivery at a predetermined point, in order to use up a SAFETY STOCK amount during the time it takes for the delivery of the items. The replenishment point may be a stock level or a point in time depending on the policy in use. In either case (and more complex systems have been developed which combine elements of both), the system requires safety stock and relies upon accurate standard LEAD TIMES and usage rates. *See* RE-ORDER CYCLE; RE-ORDER POINT; RE-ORDER QUANTITY.

report generator (report writer). In a computer system, a program which allows the user to configure information held within the database into a usable form for output. Report generators can be used, for example, to prepare reports highlighting different aspects of the information relevant to different functional areas and hierarchical levels in the business.

report writer. *See* REPORT GENERATOR.

research and development (R and D). The function within a company which is responsible for the development and progression of new ideas which might be of commercial advantage to the business. Ideas can be for products, processes or services and extend from radical new departures to incremental improvements on existing applications. A company's strategy will tend to limit the scope of R and D to those areas which are deemed feasible in the shorter term, but some degree of long-term speculative work is also an important element. *See* BLUE

SKY, RUGBY TEAM, RELAY-RACE PRODUCT DEVELOPMENT.

research associations. Organizations set up to encourage research activities, often between industrial and academic partners. Trade and industry sector organizations often collaborate to set up research associations for the benefit of all firms in a sector and make their services available on a subscription basis. Examples include the Science and Engineering Research Council (SERC), the Economic and Social Research Council (ESRC), etc.

residual stress. Stresses which exist in a metal product as a result of the manner in which is has been formed; for example, by temperature and cooling rate differences, or presswork operations. Panel beating is used to remove residual stress from SHEET-METAL WORK, since residual stresses may render a metal part more likely to corrode.

resistance welding. Welding process in which an electrical current is passed through the metal parts to be joined. The resistance to the electrical current which is set up by the metal parts causes them to heat up, and thus to weld together.

resolution. Measure of the degree of definition with which computer-generated pictures can be displayed on a monitor or other VISUAL DISPLAY UNIT. Resolution is usually expressed in pixels.

resource. Anything which is available to a company or individual to achieve its purposes. Resources are usually categorized into finance, property, premises, plant/equipment, personnel and materials.

resource allocation. The use of NETWORK ANALYSIS techniques such as CRITICAL PATH ANALYSIS to ensure the optimum use of RESOURCES within a project.

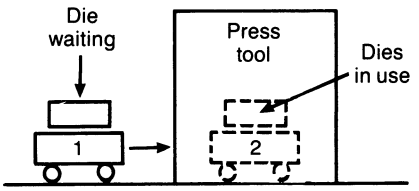
resource smoothing. The planning and scheduling of resource use to avoid periods of very high or very low utilization.

response time. In computing, the time taken for a multi-user system to respond to instructions input by a user.

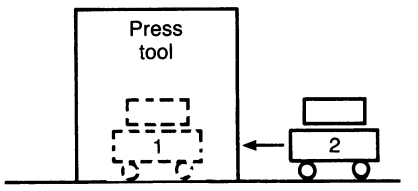
rest period. In BATCH PRODUCTION the time which a unit of a BATCH will spend waiting while work is being carried out on other units in the batch. An important task in PRODUCTION SCHEDULING in batch manufacturing is to ensure that rest periods are kept to a minimum so as to minimize the build-up of WORK-IN-PROGRESS inventory. Another source of rest time is in queuing for bottleneck resources which may require batches to be temporarily stored in a BUFFER STOCK.

rest time. *See* REST PERIOD.

retrofitting. The fitting of advanced control systems – such as microprocessors – to upgrade old but still serviceable equipment, used as an alternative to total replacement.



The next die can be prepared while the current one is being used.



Press tool need not stop operation for long: die change (automatic) takes less than one minute.

Roll in roll out dies

returns. Goods which have been sold but sent back by the customer because of quality problems.

revision (revised version). In computing, an update on a standard piece of application software. *See* VERSION NUMBER.

rework (rectification). Correction of defective output to a required specification. This is a prime example of MUDA.

risk. Probability of failure. *See* PRODUCER'S RISK.

risk analysis. OPERATIONAL RESEARCH technique employed in decision-making to estimate the probabilities of forecasts being wrong at various points in the future and to explore the implications of such errors.

risky shift. *See* PARADIGM.

robot. A programmable, computer-controlled mechanical handling device used in various manufacturing environments. Early robots were characterized by a relative lack of sensitivity and manipulative flexibility, but recent developments have seen increases in sensory capability (vision, touch, speech recognition, artificial intelligence) and in dexterity through advanced drive technology. Robots can be used in stand-alone mode or as part of a larger FLEXIBLE MANUFACTURING SYSTEM.

robotics. The study of the development and application of robots.

robust design. Design which can be developed and built upon for an extended period of time; for example, by stretching, shrinking and other variations. Robust designs have a long PRODUCT LIFE CYCLE because so many variants on the same basic designs can be made. By contrast, lean designs have limited, narrowly defined characteristics, suited for a specific purpose. For a detailed discussion of the concept, *see* R. Rothwell and W. Zegveld, *Reindustrialisation and Technology*, Longman (London, 1986).

robust manufacturing. *See* LEAN MANUFACTURING.

roll in, roll out dies. In the development of the SINGLE MINUTE

EXCHANGE OF DIE approach for set-up time reduction, a key contribution was made by the development of dies used in large press shops which could be pre-set and adjusted ready for a changeover and then exchanged by rolling out the old and rolling in the new die. Their development also involved considerable work on standardizing fixtures and applying POKA-YOKE principles to ensure that the time taken for final adjustment was minimized. *See* INTERNAL SET-UP and EXTERNAL SET-UP.

ROM. READ ONLY MEMORY.

rotational parts. Parts produced on MACHINE TOOLS which hold them in some form of chuck and rotate them at high speed, bringing tools up to shape them. The turning of a shaft in a LATHE is a typical operation.

rough cut capacity planning. In a MANUFACTURING RESOURCES PLANNING system, the process of CAPACITY PLANNING at the aggregate level to determine whether or not sufficient resources will be available to meet an order in the MASTER PRODUCTION SCHEDULE (MPS). If this stage indicates problems, the MPS must be recalculated; but if sufficient resources are available, then more detailed capacity planning can take place.

Rowan scheme. PAYMENT BY RESULTS scheme, similar to the HALSEY scheme in which total earnings for a period of time are calculated as:

$$\text{Time taken} \times \text{Basic rate of pay}$$

plus a bonus based on

$$\frac{(\text{Time taken} \times \text{Time saved}) \times \text{Basic rate}}{\text{Time allowed}}$$

It allows attention to focus on time savings on a particular operation.

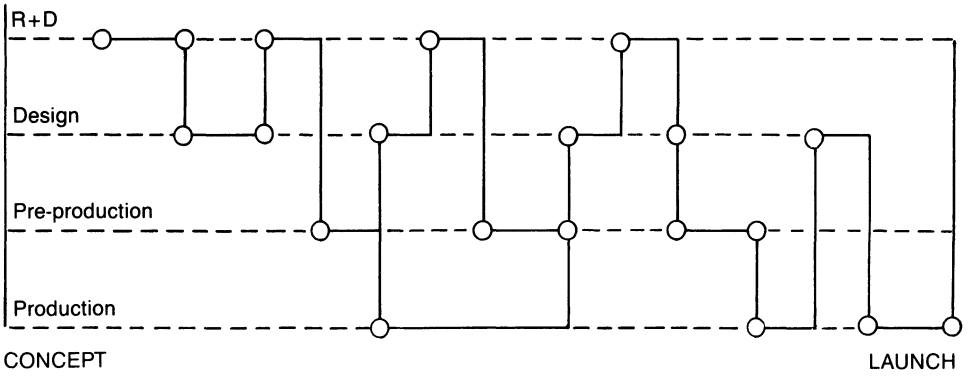
RS232. A standard SERIAL INTERFACE for computer and peripheral interconnection.

Rucker plan. Incentive scheme similar to the SCANLON PLAN.

rugby team product development. Non-traditional approach to PRODUCT DEVELOPMENT in which the product remains the joint responsibility of all departments from concept to launch. As modifications to design are required by practical constraints (e.g. in production), communication between the departments is such that problems can be sorted out quickly. This tends to shorten the cycle for introduction of new products. *See also* RELAY-RACE PRODUCT DEVELOPMENT and SIMULTANEOUS ENGINEERING.

rules. In EXPERT SYSTEMS, the logical rules by which a system makes judgments.

rule-based system. EXPERT SYSTEM which operates on the basis of RULES.



Rugby team product development

S

safety advisor. An individual assigned the responsibility for advising an organization on all aspects of SAFETY POLICY.

safety audit. A systematic, critical examination of safety in all areas of an organization's activities. The process, which should be regular, is designed to identify strengths and weaknesses in the existing system and to highlight potential areas of risk.

safety officer. An individual within the company who monitors adherence to codes of practice and laws relating to safety at work. In the UK the HEALTH AND SAFETY AT WORK ACT 1974 requires the safety officer to report on accidents, etc. also, and to make employees aware of their obligations and rights with respect to themselves and others.

safety policy. Company statement which sets out all aspects of policy with respect to safety, including provisions for monitoring and audit to ensure conformance to relevant safety legislation, and to ensure safe working conditions in all aspects of plant operation.

safety representative. An honorary position instituted in the UK by the HEALTH AND SAFETY AT WORK ACT 1974. The safety representative is an employee (often a trade union official) with particular powers and responsibilities under the Act to ensure that SAFE WORKING CONDITIONS and practices are maintained.

safety stock. *See* BUFFER STOCK.

safe working conditions. Legal definitions guaranteeing the availability of a working environment. For example, in the UK under the HEALTH AND SAFETY ACT 1974, the FACTORIES ACT 1961 and the Offices, Shops and Railway Premises Act 1963, an employer must provide conditions of work which all parties (employer, employee and authority) agree to be safe. Once these conditions are provided, the employee shares responsibility for correct use of facilities and thus safe working.

sample. A small number of items chosen at random from a POPULATION which are subject to some form of analysis. Observations may subsequently be made about the population from which the sample was drawn on the basis of results obtained from inspecting the sample.

sampling distribution. The PROBABILITY DISTRIBUTION of a RANDOM VARIABLE characteristic or statistic of a sample showing the occurrence pattern for that statistic in any sample that may be chosen from the given population.

sampling error. The degree to which a sample does not actually represent the POPULATION from which it is drawn.

sampling plan. In STATISTICAL QUALITY CONTROL the approach taken to ACCEPTANCE SAMPLING to ensure a high statistical probability of control. A variety of plans can be used; the simplest is one where a single SAMPLE of size n is taken from a batch of size N and the batch is accepted if the number of defects found is less than an acceptance number, c – the ACCEPTABLE QUALITY LEVEL. Under ideal conditions, all batches which pass this test would be accepted, but in practice this approach is limited since no sampling plan will offer perfect discrimination across all batches.

sand blasting. Metal-finishing process in which the workpiece is placed in a totally enclosed chamber and subjected to a blast of abrasive sand. The action of the sand removes rough edges on the workpiece. *See also* SHOT BLASTING.

sand casting. Metal casting process which involves pouring molten metal into molds made of sand plus various forms of binder to maintain the shape whilst pouring is taking place.

SCADA systems. SUPERVISORY CONTROL AND DATA ACQUISITION SYSTEMS.

scale economies. *See* ECONOMIES OF SCALE.

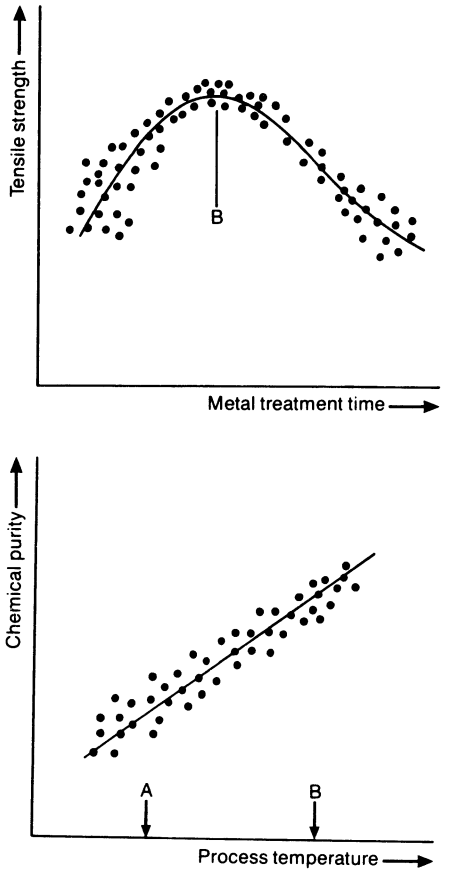
scaling parameter. *See* WEIBULL PARAMETERS.

Scanlon plan. A group bonus scheme originally developed by the US trade unionist Joseph Scanlon, in which all employees receive a basic guaranteed wage plus a bonus calculated from the effective reduction in total labour cost which any improved performance makes possible. Various measures are used to calculate this; for example, a ratio of labour cost to total sales value. The nature and extent of improvements and cost savings are decided by a committee, comprising labour and management representatives. *See* PRIESTMAN SCHEME.

scattergram. A graph on which the points are not connected by lines in the usual manner. The main purpose is to show how the points represent groupings. See diagram overleaf.

schedule. (1) A plan of events with respect to time. (2) In MATERIALS MANAGEMENT a list of the raw materials required and the sequence in which they will be needed. (3) Plan covering the sequence of activities in manufacturing required to produce a particular order. *See* SCHEDULING AND LOADING.

scheduling and loading. Process of planning the production of an order,



Scattergram

taking into account the time required, available resources, levels of work already committed, and so on, and thus arriving at a SCHEDULE of times by which activities are expected to be completed. From this master schedule more detailed schedules can be calculated relating individual activity to the broader picture. *See* MASTER PRODUCTION SCHEDULE; SCHEDULING CRITERIA; SCHEDULING RULES.

scheduling criteria. SCHEDULING AND LOADING needs to take account of a variety of different and often conflicting factors; for example, shortest time, minimum production costs, minimum storage costs, maximum machine utilization. Defining the criteria relevant to a particular scheduling activity is an important first stage in production planning.

scheduling rules. (Also known as loading/despatching rules.) Rules to simplify the SCHEDULING AND LOADING problem which involve examining particular characteristics of tasks within the manufacturing process and evaluating them against established SCHEDULING CRITERIA such as least cost or shortest processing time.

scientific management. A theory relating to worker motivation and work measurement based largely on the work of the US engineer Frederick Taylor. The principle tenet is that managers should define the one best way of doing any particular job, using scientific methods, and that the selected and trained operators should then follow instructions without deviation. In this way the operator becomes an extension of the mechanical task and may be measured as such, while the manager's task is to derive the greatest benefit for both company and employees from the overall operation. Motivation in such a system is based on the belief that workers would work harder if offered greater extrinsic incentives (e.g. more money). This gave rise to the idea of

PIECEWORK and formed the basis of most Twentieth Century payment systems.

scrap. (1) Defective product which cannot be restored to specification. (2) Material which becomes unusable excess as a result of a particular production process.

scrap costs. *See* QUALITY COSTS.

scrap note. A MATERIALS CONTROL DOCUMENT which records that an item of scrap has been generated, which can be exchanged at the stores for replacement good material.

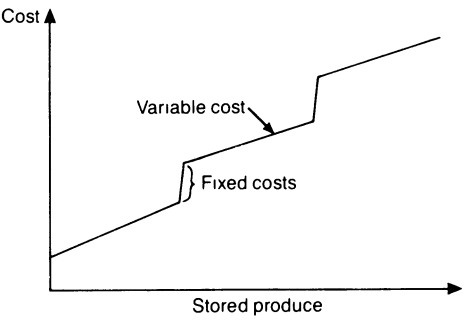
screwdriver plant. Assembly plant set up to take advantage of low labour costs or other incentives generally in a country other than the home of the company. The actual activities carried out in the plant do not require a high level of skills or complex equipment, and such plants can quickly be closed down and relocated to exploit new advantages in other places.

seasonality. Influence on demand for products or services which varies during the year; for example, surges before Christmas or quiet periods during the summer. FORECASTING models need to take account of such variations. The effects of seasonality can be very difficult and costly for manufacturers. To some extent they may be offset by mixing products which have different seasons, or by selling at discount out of season.

self-optimizing control. *See* ADAPTIVE CONTROL.

semi-manufactures. Items which consist of RAW MATERIALS, partly processed towards being end products and which are subsequently supplied to manufacturers for completion.

semi-variable cost. (Also known as mixed or semi-fixed cost.) An operating cost which will increase with a rise in output but not in strict proportion. For example, labour cost is variable in proportion to production output, but the cost of supervision will only increase with a substantial increase in output. The cost of supervision is thus semi-variable. In the diagram, the amount of produce in the warehouse increases, and as it does so the cost of holding it (insurance, capital, extra staff, etc.) increases proportionally. At certain points it is necessary to open a new warehouse, hence incurring extra fixed costs. *See* BREAK-EVEN CHART.



Semi-variable cost

sensitivity analysis. Tool used in FORECASTING to assess the impact on desired outcomes of a variety of different conditions – essentially exploring questions of the 'what if?' variety.

sensors. Devices in control systems which measure and relate changes in physical variables to the controller.

sequence arrow. Part of a NETWORK diagram showing the sequence of events within a network.

serial interface. A computer connection device through which data is transmitted and received in serial mode (i.e. one BIT at a time). *See* RS232.

series systems. *See* PARALLEL SYSTEMS.

service time. In LINE BALANCING calculations, the time required to complete the work assigned to a given WORKSTATION.

setting (setting-up). The preparation of a piece of equipment for the next operation.

setting-up. *See* SETTING.

setting-up cost (set-up cost). The cost of setting up equipment, especially in BATCH PRODUCTION. It is an important factor in decisions concerning batch size and ECONOMIES OF SCALE.

set up. To prepare a piece of equipment for an operation.

set-up time. The time taken to SET UP a machine or to change it from making one product to another.

set-up time reduction. Reducing set-up times is crucial to JUST-IN-TIME production since it offers increases in flexibility, shorter lead times and reduced inventories. It also offers firms the chance to compete effectively in markets characterized by demands for greater product variety or more rapid product innovation.

Set-up time is made up of four basic components which apply to all types of machine. These are:

(1) preparation and finishing; getting parts, fixtures and tools ready, delivering them to the machine, and the reverse of the process – taking the old ones away (together with any necessary cleaning or maintenance). This component represents about 30 percent of set-up time;

(2) mounting and removal of tools and fittings. This component represents around 5 percent of set-up time;

(3) measuring, calibrating and adjustment so as to ensure the correct positioning, speed, temperature, or other conditions are fulfilled. This component accounts for around 15 percent of time;

(4) trial runs and adjustment, to ensure the machine is now set-up correctly. This accounts for around 50 percent of set-up time.

Clearly, the better the adjustment the less time required for this stage. Reducing set-up times was one of the major breakthroughs of the original JIT efforts within Toyota and owes

much to the work of Shigeo Shingo. His approach, which has become known as the SMED – Single Minute Exchange of Die – system led to massive reductions in set-up times on a range of equipment, not only in the large pressworking machinery area but across the manufacturing board.

In essence, Shingo's system evolved through a classical piece of work study, watching how changeovers were effected and constantly trying to improve on them. His observations took place in the 1950s in a variety of factories, and the system was refined during the 1960s in his work with Toyota. The process made extensive use of the principles outlined above of involving all the workforce and never accepting that the problem had been solved, simply that it had been improved upon. Indeed, the momentum was maintained at times by senior management setting apparently impossible goals. For example, as Shingo comments '. . . in 1969 Toyota wanted the set-up time of a 1000 tonne press – which had already been reduced from four hours to an hour and a half – further reduced to three minutes!'

The consequence of this is that the system is basically simple and can be applied to any changeover operation. It relies on observation, analysis and creative problem-solving. There are four basic steps:

(i) separate out the work that has to be done while the machine is stopped (called internal set-up) from that which can be done away from the machine while it is still operating (external set-up). For example, typical external set-up activities include the preparation of dies and fixtures and the actual movement of dies in and out of stores and to and from the machine in question. Typical internal tasks are attaching/detaching dies, adjustment and testing. Shingo estimates that between 30 and 50% of set-up time can be saved by doing external set-ups rather than including these operations as part of internal set-up.

(ii) reduce the internal set-up time by doing more of the set-up externally. This can be done, for example, through the use of pre-set dies or special easy fit fixtures holding the new dies. External set-up times can themselves be reduced by colour coding, easy access stores of tools, special transport equipment, etc – all designed to minimise the time taken for moving and finding.

(iii) reduce the internal set-up time by simplifying adjustments, simplifying attachments, developing special easy fit connections, devoting extra resources to it at the critical time (making it a team effort with several people leaving their 'normal' jobs to help out with the changeover, etc). Adjustment of dies once in position often accounts for up to 50% of the total internal set-up so finding ways of reducing or eliminating the need for adjustment (for example, through the use of locator pins or grooves) is a rich source of opportunity. Another example is the pre-heating of dies for injection moulding machinery so that the machine is able to start running much earlier.

Another important way of reducing internal set-up is the use of parallel

operations, where extra assistance is provided at the critical time of changeover and the time is reduced by several people working in parallel. This not only improves things by having extra pairs of hands but it cuts time out which a single operator would spend moving around fetching carrying and fitting.

(iv) reduce the total time for both internal and external set-up. Implicit in this is the concept of continuous improvement, of constantly monitoring, analysing and developing new attacks on the problem.

Changing over set-up is thus a precision, team-based activity in which everything is to hand, special purpose tools and fixtures are used and everyone knows what he/she has to do. A very close and effective analogy can be seen in motor racing when a car makes a pit-stop for tyres to be changed. This is also accomplished in seconds – as a result of a very similar process.

Evolving the ideas for reducing set-up time is a classic demonstration of the waste elimination principles of JUST-IN-TIME manufacturing and the concept of CONTINUOUS IMPROVEMENT. Various techniques are available to identify and highlight wasteful practices including the use of video cameras to focus attention on the problem (sometimes called 'watching with new eyes') and the use of analytical techniques (including PERT networks to determine CRITICAL PATHs). Once identified, problem solving techniques involving the whole work group are brought into play to try and generate ideas for reducing the time taken. These are followed by a sequence of experiment and evaluation, repeatedly attacking the core problem and then moving on to the next in a continuous improvement cycle. Recording progress in reducing set-up time (e.g. on a downward sloping graph over time) and making it visible to all those involved is an important source of motivation for the long-term maintenance of improvement momentum. Finally, demonstrations of success in one area of set-up time reduction can motivate workers in other areas who may be able to transfer some of the solutions developed, thus spreading the benefits of the programme. For further information, *see* S. Shingo, *SMED – A Revolution in Manufacturing,* Productivity Press.

SFP. SINGLE FACTOR PRODUCTIVITY.

shaper. MACHINE TOOL which forms a shaped profile or groove in a part by drawing a tool linearly across its surface repeatedly, moving back and forth, cutting in one direction only.

shaping parameter. *See* WEIBULL PARAMETERS.

share of production plan. A plant wide incentive scheme, similar to the SCANLON PLAN based upon linking an employee's rewards to overall achievement in a production facility.

sheetmetal work. FABRICATION process using large areas of thin sheet steel to construct such items as

ventilation ducting, etc. Manual and automated processes are used. Differs from PRESS work because the strength of the sheet-metal product lies in its construction rather than its position in a final welded assembly.

shelf life. The time for which an item or material may be retained in storage before use without deteriorating.

Shewart, Walter. Influential US writer who is generally credited with having developed the concept of STATISTICAL QUALITY CONTROL as a result of his work in Bell Laboratories in the 1920s. In 1931 he wrote an influential book based on his experience, entitled *The Economic control of manufactured products*. This study of methods for monitoring and measuring quality marked the emergence of the concept of statistical quality control as a sophisticated replacement for the simple inspection procedures of the 1920s. Two of his staff in the QUALITY ASSURANCE department at Bell Laboratories were W. Edwards DEMING and Joseph JURAN, both of whom went on to influence Japanese thinking on quality management.

shift. A period or portion of the day during which a section of the workforce is in operation. Normal shift refers to a 'normal' working day somewhere between 8 am and 5 pm. Double shift usually means one shift from early morning to mid-afternoon and another from then until late evening. The maximum is usually three shifts, covering 24 hours between them. Shifts need not run to eight hours, however, and special arrangements are often made to suit particular requirements of the business.

shift bonus. *See* SHIFT PREMIUM.

shift premium (shift bonus). An extra payment made to an employee in return for working a shift other than normal hours, especially 'unsocial hours'. The amount is usually linked in some way to the normal rate of pay, in a similar manner to OVERTIME payments.

Shingo, Shigeo. Influential Japanese engineer who is credited, along with Taichi OHNO with the development of many of the key features of JUST-IN-TIME manufacturing. In particular Shingo is associated with the SINGLE MINUTE EXCHANGE OF DIE approach to set-up time reduction. A full discussion of his work can be found in *The Sayings of Shigeo Shingo* and *A Revolution in Manufacture – the SMED System*, both published by the Productivity Press.

shojinka. Approach within the TOYOTA PRODUCTION SYSTEM to developing flexibility in the face of changes in demand volume and variety, through changing the numbers of workers involved.

shopfloor data collection (SFDC). The process of recording information from shopfloor activities and equipment for the purposes of feedback into PRODUCTION CONTROL systems, either computerized or otherwise. This is increasingly being carried

out automatically by process plant control systems but the term applies equally well to manual systems of collecting readings and measurements.

shortage. The absence of component parts from an otherwise finished product, resulting from a lack of supply or quality problems.

shortage costs. Costs arising from a SHORTAGE. These range from simple REWORK costs (e.g. post-completion fitting of parts) to substantial penalties (e.g. stopping a moving mass production line, holding unfinished products, etc.).

shortage note. A MATERIALS CONTROL DOCUMENT issued from the stores to the person making a requisition stating that the material in question is not available.

short-interval scheduling (SIS). A method of WORK MEASUREMENT and control based on dividing routine work into small groups of tasks which can be covered by an operator in a short interval (often one hour), during which time performance ratings can be made and feedback data obtained.

short-time working. The practice of employees agreeing, or being required, to reduce the working week (and thus the weekly wage) to relieve difficulties for the company during a period of recession.

shot blasting/shot peening. Similar to SANDBLASTING, but with a heavier abrasive – lead shot, not sand. Removes more metal than sand, and can also be used to give special-effect finishes.

shusa. Japanese word: the title of the Project Manager for a new automobile or other major product, during the development and introduction stages. The status of the shusa (pronounced shoo-sha) is paramount. The use of cross functional teams in the development of a new product under the shusa system is more fundamental than in the West. The individuals align themselves with the product team more strongly than with their line department. This fact alone means that fewer people are required to bring new products to market in Japan than in the West. The ability of the shusa to override other management decisions, in the interests of bringing the product to market on time is a key competitive factor.

shutdown. A period of closure of plant or parts thereof, usually for common holiday arrangements, which is planned so as to minimize disruption to production. The shutdown period can be used for maintenance and other activities which are difficult or impossible when the plant is running.

SIC. STANDARD INDUSTRIAL CLASSIFICATION. *See* ISIC.

SIMO. *See* SIMULTANEOUS MOVEMENT CHART.

simple steel. *See* CARBON STEEL.

Simplex method. Commonly used approach in the solution of LINEAR PROGRAMMING problems.

simulation. Techniques for replicating a system of activities or functions in another, more convenient form for the purposes of design, development, experiment, training, etc. For example, new facilities in production such as FLEXIBLE MANUFACTURING SYSTEMS can be simulated to explore the implications of different layout arrangements, scheduling activities, etc.

simultaneous engineering. An approach to design management as a means to ensure more rapid time to market for new product developments. Estimates suggest that being first into the market means a firm obtains a 50 percent market share for that product or service, and other benefits include reduced costs (of work hours and inventories) and improved customer relationships because of better, more rapid service. 'Cycle compression' is another phrase which is beginning to emerge, especially in the context of long development cycle products like military equipment and aircraft.

Simultaneous engineering aims at four key targets: reduce the time lag between different stages in the traditional sequence of product development, marketing and sales; minimize development and final product costs; increase product quality; increase market share through early entry.

It is based on a simple principle which involves moving away from what might be termed the traditional RELAY-RACE approach, with each player in the process of passing the baton (the new product) on to the next, but seldom discussing the overall progress until after the race. Instead, in simultaneous engineering, teams representing all disciplines work through in parallel.

The main advantage in such an approach comes from the early identification and resolution of conflicts – it stops the problems being thrown over the fence and demands a co-operative solution. The improved information flow also brings in new inputs to design at a stage where they can be used to improve the design – as distinct from the traditional practice of apportioning blame to different areas because they failed to pass on information which could have helped avoid costly design faults.

Such a teamwork and co-operative approach needs to be set against the traditional structure of design which often sees it as a distant function, pursuing goals very different to those of the rest of the organization. Successful teams stress mutual learning – indeed, some companies prefer to make continuing use of such teams since the investment in group development is so valuable. They need a clear goal towards which they can all work, and the leadership needs full authority to challenge what has traditionally been done. *See* RELAY-RACE and RUGBY TEAM PRODUCT DEVELOPMENT.

simultaneous motion-cycle chart. *See* SIMULTANEOUS MOVEMENT CHART.

simultaneous movement chart (SIMO). (Also known as simultaneous motion-cycle chart.) PROCESS CHART which records the movement of two or more parts of a worker's body. Preparing a SIMO chart is normally carried out through analysis of film of an activity. Work elements are recorded in THERBLIGS, a name derived from the surname of Frank and Lilian Gilbreth who pioneered the technique in their early work on WORK STUDY.

single-cycle systems. *See* MULTI CYCLE SYSTEMS.

single digit set-up. The Japanese concept of reducing any set-up time to less than ten minutes (single digit – number of minutes). Once set-ups reach this level they begin to become negligible. Naturally the Japanese worker who achieves a single digit set-up time will not be satisfied, but will try instead to reduce the time even further. *See* KAIZEN.

single factor productivity. Method of describing the productivity for a specific product in terms of a specific resource, thus the sfp for Product A in terms of resource No. 2 is:

$$sfp_{A,2} = \frac{\text{output of product A}}{\text{amount of Resource 2 used}}$$

For a full explanation *see* Hayes, Wheelright and Clark, *Dynamic Manufacturing*, Free Press (New York, 1988). *See also* TOTAL FACTOR PRODUCTIVITY.

single minute exchange of die (SMED). Technique for set-up time reduction, originally developed by SHINGO in Toyota and other Japanese firms. It relies on observation, analysis and creative problem-solving.

There are four basic steps: (1) separate out the work that has to be done while the machine is stopped (called 'internal set-up') from that which can be done away from the machine while it is still operating ('external set-up'); (2) reduce the internal set-up time by doing more of the set-up externally. This can be done, for example, through the use of pre-set dies or special easy-fit fixtures holding the new dies; (3) reduce the internal set-up time by simplifying adjustments, simplifying attachments, developing special easy-fit connections, devoting extra resources to it at the critical time (making it a team effort with several people leaving their 'normal' jobs to help out with the changeover, etc.); (4) reduce the total time for both internal and external set-up. Implicit in this is the concept of continuous improvement, of constantly monitoring, analysing and developing new attacks on the problem.

SMED changeover set-up is thus a precision, team-based activity in which everything is to hand, special purpose tools and fixtures are used and everyone knows what he/she has to do.

single set-up. *See* SINGLE MINUTE EXCHANGE OF DIE; ONE TOUCH SET-UP.

single status. The concept, originating in Japan, of all employees having the same status in non-functional roles within a company. For example, all employees from the most menial to the most senior wear the same company uniform, use the same canteen, share the same car park, etc.

sintering. Metal forming process in which powdered metal is placed in a mold and heated under pressure. The metal solidifies into the part, without wastage of metal as might be the case in a forging process. The sintered part is also often usable without finishing/machining since the surfaces thus formed are smooth, and there is no 'flash' of metal around joins, etc. Sintering is used for gears, etc. but has not proven as popular as was first imagined (during its development in the 1940s/1950s). The science of materials in sintering is called powder metallurgy. Presintering is the heating of the metal before sintering (to a lower temperature) in order to prepare it, and to make it easier to handle at that stage.

SIS. SINGLE INTERVAL SCHEDULING.

SI units. An internationally agreed, monitored and controlled system of units of measurement, the Systeme Internationale.

six sigma quality. A term, derived from SPC, which is used to denote products which are manufactured to a defect level of 3.4 parts per million, at the process step level. For a comprehensive explanation see Mikel J. Harry, *The Nature of Six Sigma Quality*, Government Electronics Group, Motorola Inc. Schaumberg, IL. USA.

skewness. The degree to which the results of a statistical analysis, based upon sampling, show a bias or imbalance.

skill. The ability to perform a certain task.

skilled operator. An individual who has specific SKILLS in relation to particular types of work.

skilled work. Tasks which require a SKILLED OPERATOR.

skills analysis. Techniques for analysing specific tasks to develop training programmes to develop suitable skills.

slack. The available time within a PROJECT which may be employed to cover for slippage in performance against the schedule. A series of events within the programme which contains no slack is a critical path. *See* CRITICAL PATH ANALYSIS.

slip chart. A graphical method of representing the SLIPPAGE in a project. The chart plots planned times for the sequence of events on a vertical axis against actual times on a horizontal axis. A line at 45 degrees is thus the perfect position. A steeper gradient means the project is being completed in less time than planned – and vice versa.

slippage. The falling behind in a programme or project.

Sloan, Alfred. Generally credited with having built up the General Motors Corporation in the early part of this century, Sloan introduced a number of innovations in product, process and organization which improved upon those developed by HENRY FORD. In particular, he recognized that the rapidly developing market for motor cars would not be satisfied forever by a product such as the Model T Ford which was famously available in 'any colour you like, as long as it's black'. Instead Sloan implemented a strategy based on PRODUCT DIFFERENTIATION, tailoring different models of car for different market segments, and through this approach General Motors was able to challenge successfully the dominance of the Ford Motor Company in the early 1920s. For a detailed description of the strategies and innovations implemented by Sloan, see W. Abernathy, *The Productivity Dilemma; Roadblock to Innovation in the Automobile Industry*, Johns Hopkins University Press (Baltimore, 1977).

SMED. SINGLE MINUTE EXCHANGE OF DIE.

smoothing. Statistical technique for interpreting graphical data by lessening the effects of atypical data on an overall result (smoothing out a bumpy line, for example). A variety of mathematical methods, including exponential smoothing, can be employed for this task.

SMT. SURFACE MOUNTING TECHNOLOGY.

socio-technical system. Concept which evolved in the 1950s particularly as a result of the work of members of the Tavistock Institute in London such as Trist, Rice and Bamforth. In work on industries like coal mining and textile manufacturing, research showed that productivity could be significantly enhanced if people were organized into groups or teams and the technology in use designed with such arrangements in mind, often with the participation of the team members. This differs from the traditional Ford/Taylor type of approach which sees technology and people as interchangeable elements which should be organized in a single 'best' way for maximum productivity. Socio-technical systems design has been extensively used in a variety of industries (for example, it influenced the Volvo experiments in teamworking at the Kalmar car plants in Sweden, and has many echoes in the AUTONOMOUS WORKING GROUPS in Japan and elsewhere) and forms a useful blueprint for organization in CELLULAR MANUFACTURING.

software. Computer programs designed for specific functions.

software engineering. The process of developing software to suit specific purposes and perform specific functions.

soikufu. Japanese term for 'creative thinking' or 'inventive ideas' which represent an important component of the TOYOTA PRODUCTION SYSTEM. Much of the success of the system

depends upon the idea of employee involvement in problem identification and solution.

solid modelling. In COMPUTER-AIDED DESIGN, a technique for constructing an apparently solid three-dimensional picture on a computer screen. The solid model is constructed by a detailed mathematical analysis of each constituent element, through a process called FINITE ELEMENT ANALYSIS, and then built up by adding together each of these elements. The value of such models is that detailed simulations can be performed on the model to explore its reaction to a variety of changes – stresses, environmental changes, etc. *See* SURFACE MODELLING.

source code. The original code in which a computer program was specified by the analyst or programmer.

spark erosion. Metal cutting technique based on removing metal by a series of rapidly recurring electrical discharges which use the workpiece as one electrode and a cutting tool as the other. The metal is vaporized and removed by a continuously flowing stream of coolant. *See* ELECTRICAL DISCHARGE MACHINING.

spatter. Metal particles which are formed during a welding operation but spread out in a spray rather than forming part of the join.

SPC. *See* STATISTICAL PROCESS CONTROL.

specific price. The price actually paid for an item of material.

speed test. A test of manual dexterity in assembly operations. It is used both for assessment of individual operators and for setting performance norms.

split inventory system. *See* ABC ANALYSIS; PARETO ANALYSIS.

spot welding. RESISTANCE WELDING in which a metal fabrication is constructed by the pieces being held together by many small welds, rather than a continuous seam weld. The most common application is automobile bodies.

spreadsheet. Computer-based tool for recording data and simulating 'what if?' projections. Items of information are recorded in rows and columns which can be manipulated in a variety of ways and can be presented in various graphical forms. The concept originated in accountancy but now finds wide application in other areas where information manipulation is required. One of the most common programs was originally developed by the Lotus Corporation and called Lotus 123. See diagram overleaf.

sprue. The channel in a casting mold through which the metal is poured, or air allowed to escape; and the scrap cast metal part, attached to the product, which results from this channel and must be removed.

sputter. Deposition process for precious metals in micro electronics, carried out within an enclosed chamber, often in a vacuum.

	South	North	East	West	Total
January	4.73	2.61	2.62	4.33	14.29
February	5.19	3.00	3.91	5.64	17.74
March	6.20	3.11	3.96	5.61	18.88
April	8.72	4.22	5.00	5.90	23.84
May	10.64	7.41	7.00	6.90	31.95
June	10.64	7.00	7.11	7.00	31.75
July	10.00	4.78	6.21	6.99	27.98
August	9.40	3.61	5.00	4.97	22.98
September	7.43	3.62	4.10	3.97	19.12
October	5.50	2.90	3.00	3.00	14.40
November	5.10	3.00	2.90	2.90	13.80
December	4.99	2.97	3.20	3.20	13.91
Total	88.54	48.23	53.46	60.41	250.64
Sales: figures in £000s					

Spreadsheet

SQA. *See* SUPPLIER QUALITY ASSURANCE.

SQC. STATISTICAL QUALITY CONTROL

squeeze forging. *See* PRESS FORGING.

SSDAM. STRUCTURED SYSTEMS ANALYSIS AND DESIGN METHODOLOGY.

stamping. Large PRESS work, for items such as automobile body panels.

stand alone system. A control system which is designed to operate in isolation from other equipment, and which may be replaced if necessary. The opposite of a fully integrated system. The stand alone system must be INTERFACED with the overall system.

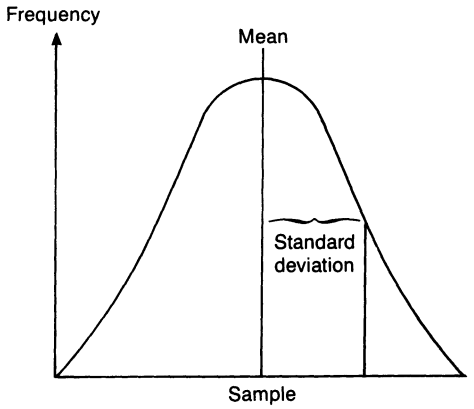
standard cost (direct cost). Approach to cost estimation and control which assigns estimated values to elements such as labour, materials and overheads, and then reports ACTUAL COSTS as a VARIANCE on these standard costs. For example, valuation of WORK-IN-PROGRESS depends upon accounting for value added to each point in the process, and thus needs standard costs for items observed at each stage. Standard costs may also be used to stabilize prices over a forward period by estimating a level of costs which might be reached half-way through the period, and thus fixing a standard cost for the whole period.

standard deviation. Statistical term to describe the spread of values around a MEAN or average. It is calculated by adding together all the squares of the differences between measured values and the mean, and then dividing the sum by the total number of observations and taking the square root; i.e.

$$\sigma = \sqrt{\frac{\Sigma(x - \mu)^2}{N}}$$

where σ = standard deviation, μ = mean of sample, x = variable value, N = number of observations.

For a PROBABILITY distribution this is also called the population standard deviation and is equal to the square root of the variance, usually denoted by σ. For a FREQUENCY DISTRIBUTION the letter 's' is used, and is called the sample standard deviation.



Standard deviation

standard error. Statistical term to describe the spread of mean or average values of a series of samples. It is calculated as:

$$\text{Standard Error} = \frac{\sigma}{\sqrt{n}}$$

where σ is the STANDARD DEVIATION of the means and n is the number of samples.

standard hour. A measure of work, not time. In WORK STUDY a standard hour is the amount of work which may be completed by an operator, working at STANDARD PERFORMANCE for one hour, allowing for all reasonable interferences.

Standard Industrial Classification. *See* ISIC.

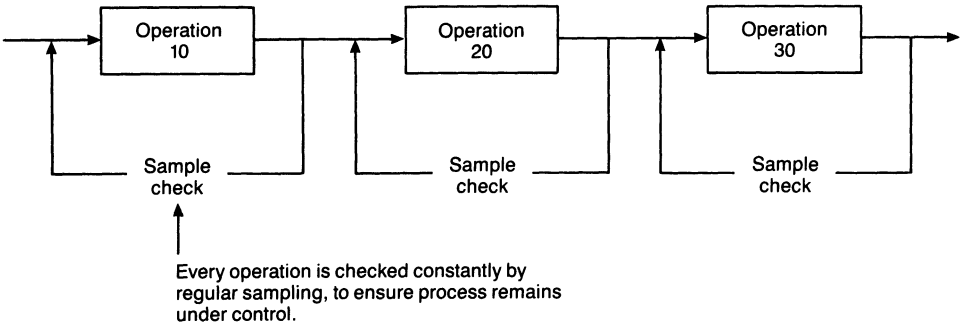
standard minute. A measure of work equivalent to one sixtieth of a STANDARD HOUR.

standard operations. In the TOYOTA PRODUCTION SYSTEM a specification of standard cycle times and standard routines associated with all operations. Such standardization is a key factor in ensuring smooth flow through a JUST-IN-TIME manufacturing facility.

standard performance. Concept used in WORK MEASUREMENT to enable comparisons between the performance of different workers for a given task. The STANDARD TIME for a job is that which a qualified worker (in terms of experience, skills, physical aptitude, etc.) would take if working normally on that job. In the UK it is defined by a BRITISH STANDARD and is equivalent to the effort needed to maintain a walking speed of four miles per hour. *See* WORK STUDY.

standard rating. The WORK STUDY practice of estimating the rate at which a specific operation is being carried out, with reference to STANDARD PERFORMANCE. A rating out of one hundred (but never expressed as a percentage) is estimated for each operation and the time taken for the operation, as measured by the work study engineer, is multiplied by the reciprocal of the rating to arrive at the basic minutes for the job.

standards. (1) Agreed values, practices, conventions etc. for carrying out technical or business activities. Standards are usually set and maintained by national and international organizations such as the BRITISH STANDARDS INSTITUTE or the



Statistical process control

INTERNATIONAL STANDARDS ORGANISATION. (2) In manufacturing, standard times for operations established by WORK STUDY.

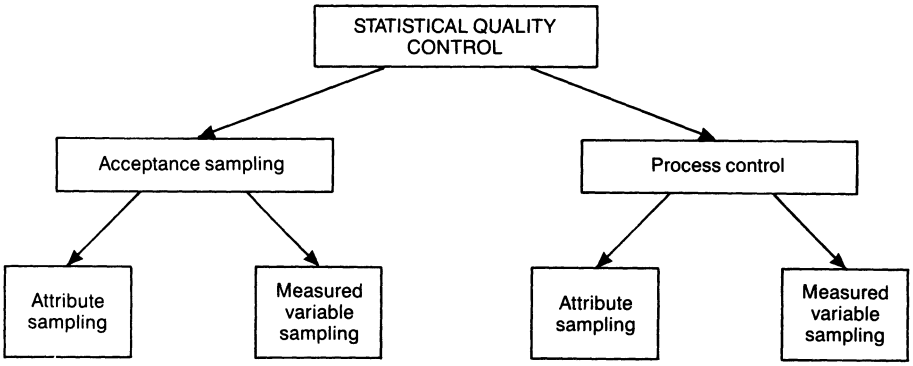
standard time. The amount of work contained in an operation as defined by work study. The standard time is calculated from the observed time, amended by STANDARD RATING to arrive at the basic time which is then augmented by allowances for interruptions, etc. It is used as the basis of cost accounting (for DIRECT LABOUR costing) and often in PAYMENT BY RESULTS schemes (e.g. PIECEWORK). Such a payment system is referred to as a standard time payment system.

standard wire gauge (SWG). UK system for gauging metallic rods and wires in electrical installations. *See* AMERICAN WIRE GAUGE.

statistical inference. The use of PROBABILITY theory to make assumptions and assertions about the behaviour of samples and populations.

statistical process control. (SPC). The discipline of recording observed measurements of process parameters and taking corrective action immediately to maintain the process (and thus the output) within the predetermined limits. STATISTICAL INFERENCE is used to determine the acceptable limits within which such observed parameters should lie to various levels of significance. SPC uses the techniques of STATISTICAL QUALITY CONTROL, coupled with the disciplines of vigilance and problem solving. Thus it is a combination of the scientific, quantitative side of QUALITY and the organic, humanistic side. See PROCESS CAPABILITY.

statistical quality control. (SQC) The general use of STATISTICAL INFERENCE to determine TOLERANCE levels for inspection of process output, upon which an accept or reject decision may be based. A typical application of SQC is the practice of ACCEPTANCE SAMPLING where a sample of a few items from a batch is examined and the batch is accepted or



Statistical quality control

rejected on the basis of the outcome of such inspection.

Much of the initial work on quality has concentrated on the middle two questions – 'are we making it OK?' and 'have we made it OK?' These can be answered in most cases not by checking everything but by the careful and systematic use of various statistical techniques. SQC is a simple concept which has been extensively refined during the past fifty years and is an area where information technology can make an important contribution through its data capture, storage and processing capabilities. There are two main areas – acceptance sampling and process control. Each of these is broken into 2 parts – ATTRIBUTE SAMPLING (which examines some attribute of the product such as its visual attractiveness or its ability to function correctly) and sampling based on MEASUREMENTS OF VARIABLES.

stepped cost. An operating cost which is fixed for a certain range of output and then rises in a step (rather than a gradient) at some level. For example, the cost of supervision is not linked to the level of output until a certain level at which it is necessary to employ an extra supervisor. At this point the cost of supervision increases to reflect the extra wages cost of the new supervisor.

stochastic. Term used to describe behaviour which is essentially random in nature. A stochastic approach to something is usually the reverse of a deterministic approach and is based on the assumption that the situation in question will be affected by random factors and cannot therefore be treated as simply a logical arrangement of input and output.

stochastic PERT. A version of PERT which includes random factors which may affect progress through the project. The forecast and actual effects of such factors are regularly reconsidered in the course of project control stock. (1) INVENTORY – RAW MATERIAL, WORK IN PROGRESS and

FINISHED GOODS contained in a production process.

stock control. (INVENTORY CONTROL; INVENTORY MANAGEMENT). The control of materials used and stored within a company, with the objective of providing exactly what is required, where and when it is required and employing a minimum of residual stock, and thus incurring the least possible cost. Stock may be controlled by monitoring and replenishing individual items on a timed basis or physical check routine, or by employing a computer-based system such as MATERIALS REQUIREMENTS PLANNING.

stockout. (1) The situation when stock of an item has been used up and not yet replenished. (2) Condition when a manufacturing plant is held up due to shortages of raw material.

stock point generation. The signal which triggers re-ordering of stock. Two types of stock order point systems are in common use. In a FIXED QUANTITY SYSTEM and TWO BIN SYSTEM, orders are placed when stock drops to a previously set RE-ORDER POINT or level. By contrast a FIXED INTERVAL SYSTEM operates on the basis of time, with reordering taking place at a predetermined frequency related to known patterns of usage.

stocktake. See STOCKTAKING.

stocktaking. The process of recording the amount of stock held throughout an organization (both in stores and in process) so as to provide up to date information on the level of investment tied up in materials and to update materials management systems. Two common forms of stocktaking are usually employed – annual and PERPETUAL STOCKTAKING.

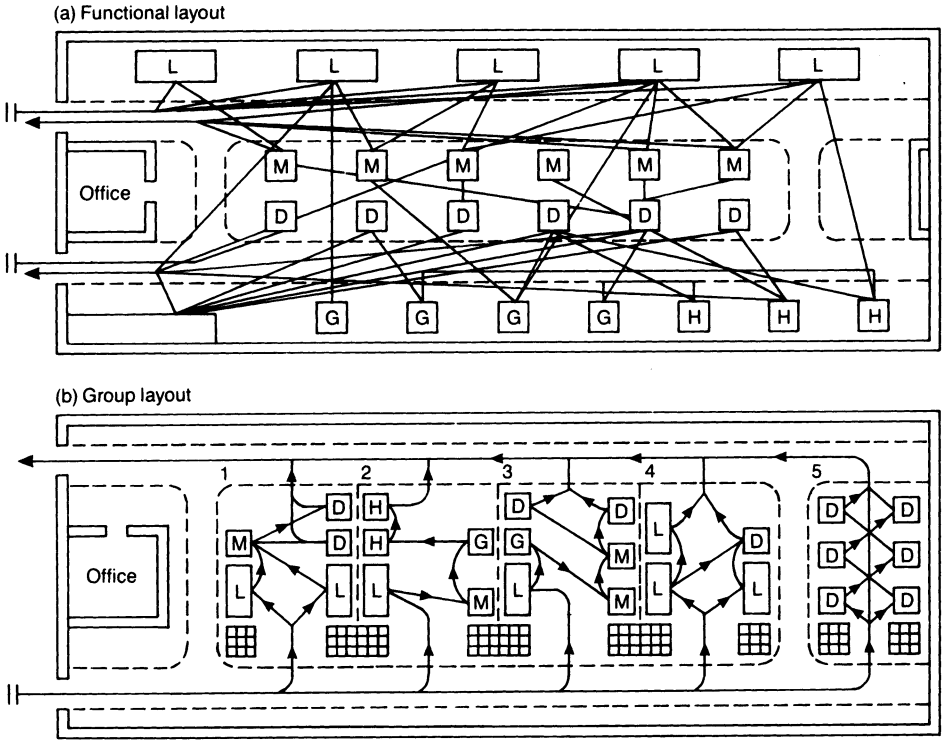
stock turnover (inventory turnover; turnover of stock; stockturn). The number of times the value of material stock is used up and replenished per year. It is calculated by dividing the annual cost of materials bought in by the average value of stocks held at any time during the year and expressed as a 'times' (e.g. 12 times per year), or in a week's or month's worth of usable stock (e.g. 1 month's stock). The higher the figure, the better since it reflects a more efficient manufacturing operation. Traditionally a stock turnover of between 10 and 15 was good for a manufacturing company; however, new techniques such as JUST-IN-TIME manufacturing have increased this target to double, treble or higher figures.

stock turns. See STOCK TURNOVER.

store. Area of a company's premises used to store materials.

stores record. Information on the nature of quantity of material held in stock, often in the form of computer data.

storekeeping. Activities concerned with the efficient management and record-keeping of the stores function in an organization.



Group layout machines grouped for component 'families'; D = drill; H = horizontal borer; G = grinder; L = lathe; M = milling machine.

String diagram

stretchforming. Metal forming process in which a sheet of metal is PRESSED while the edges are retained firmly (whereas in normal presswork they are allowed to pucker and be drawn as necessary for the pressing operation). The resultant form has pre-detemined shape and other required physical characteristics.

strike. The withholding of labour for the purposes of applying pressure to management in the course of an industrial relations dispute. Strikes may be official, which means that they have the full and formal backing of the relevant trade unions, or unofficial which means that they have been entered into without such backing or support (though this may subsequently be given).

string diagram. WORK STUDY technique used to chart movements of people, materials of parts within a facility. A scale drawing is fixed to a wooden base and then pins are placed on this to mark key stages. String wound between pins can be measured to calculate distances moved and to

identify bottlenecks and sub-optimal layouts. This technique is intended to highlight any anomalous distance or movement which might be reduced by some form of reorganization, and thus an improvement in responsiveness.

structured programming. The technique of building up a computer program from basic routines, following an overall structure. This modular approach offers improvements in speed and efficiency in operation and is also easier to test since faults can be located in specific blocks of the structure rather than distributed throughout the entire program.

subroutine. Part of a computer program designed to complete a specific function or operation which may be required several times during the program, or subsequently in other programs.

Structured Systems Analysis and Design Methodology. (SSADM) Standard approach developed in the UK for large government-related systems analysis and software-development projects and promoted subsequently as a model methodology for the development of computer software. It brings together several of the main principles of good systems-analysis practice with lessons borne out of experience of managing large-scale development projects. It has a number of similarities with IDEF, another methodology which emerged out of large-scale project work in the USA.

substantive agreement. An agreement reached between management and trade union representatives as a result of COLLECTIVE BARGAINING, which concerns some substantial reform of working practices, payment systems, etc.

successive approximations. A method of estimating something by beginning with a rough approximation and gradually improving the result by repeating the calculations with more precise input data. It is used in several areas of quantitative decision-making.

sudden failure. Type of failure which occurs rapidly and can not be easily predicted by prior examination or testing.

suggestion scheme. A scheme which encourages all employees in a firm to suggest ways in which any part of the operation might be improved to reduce costs, improve quality, remove anomalies, etc. Financial rewards are often made for suggestions which are implemented. See QUALITY CIRCLES.

sunk cost. The cost incurred in acquiring a fixed asset (e.g. a piece of equipment) which cannot be reclaimed after the event.

supervisor. An individual employed to co-ordinate the activities of others, often at a designated salary position within a company.

supervisory bonus scheme. Bonus scheme aimed at supervisory staff

rather than at DIRECT LABOUR. Various schemes are used, mostly relating a bonus to the aggregated improvement in performance of workers being supervised.

supervisory program. A program (often part of the operating system) in a computer, with responsibility for locating other programs in executive fashion.

supervisory control and data acquisition systems. (SCADA). Computer-based monitoring systems which collect production-related information for the purposes of PRODUCTION CONTROL. See SHOPFLOOR DATA COLLECTION.

supplier. A company to which the supply of materials and components is entrusted. Also, a SUBCONTRACTOR.

supplier development. Process of working with suppliers by major customers to develop their organization, methods, equipment and layout in order that they can provide a better service in terms of quality, delivery, etc. See CUSTOMER-VENDOR RELATIONSHIPS, COMAKER.

supplier quality assurance. (SQA). A QUALITY ASSURANCE technique developed in the 1970s. It is based on the principle that goods used by a manufacturer contribute to the overall quality of the end product and thus the supplier of such goods must be seen as part of the process. Quality assurance engineers from the customer company visit the supplier to ensure that the latter has (and is using) formal systems and procedures which comply with a formal manual of requirements and may thus be accepted as an approved supplier of parts and materials. *See* STATISTICAL PROCESS CONTROL; TOTAL QUALITY CONTROL.

supplier rating. A process whereby customers evaluate suppliers on the basis of quality, delivery and other performance factors, often assigning some form of score. These scores/ratings are used in selecting and to allocate business to particular suppliers.

supply. The discipline and practice of providing materials and components to customers. In a similar way to PURCHASING, strategic planning has yet to be fully applied to the supply function in many industries. However, JUST-IN-TIME operation is pulling this development into being (an example of NEED PULL). *See also* EX-WORKS DELIVERY SYSTEM.

surface mounting technology (SMT). The technique of fitting discrete components and integrated circuits on to printed circuit boards without the need for leads to pass through drilled holes in the LAMINATE. Surface mounting enables the design of more compact board circuitry and simpler assembly operation, both resulting in cost reductions and quality improvements.

SWG. See STANDARD WIRE GAUGE.

swing shift. A flexible working arrangement in which employees cover for fluctuations in workload requirements by working flexibly rather than linked to a SHIFT pattern.

symmetrical movements. In ERGONOMICS, human movements which require the left and right hand to carry out the same action in mirror image to one another.

synchro-MRP. A hybrid production management system which combines features of KANBAN and MATERIALS REQUIREMENTS PLANNING. In essence the MRP capabilities are used to support the planning process and generate the MASTER SCHEDULE and the day-to-day production management to that schedule is carried out JUST-IN-TIME.

synchronous manufacturing. The technique used in JUST-IN-TIME systems for coordinating (synchronizing) the manufacture of component parts in order that they may arrive at the assembly point at the appropriate time. Thus, the schedule for component production is derived from the assembly schedule, etc. *See also* NAGARE SYSTEM.

synthetic data. Data which has been built up from estimated data elements, particularly in a PREDETERMINED MOTION-TIME SYSTEM.

system. A group or series of independent functions which are destined to combine towards one or more common objectives and which may be treated as one entity.

systems analysis. Activity concerned with the analysis of SYSTEMS. Systems analysis is an esssential first step in the design and development of communication and control systems since it identifies the relevant information flows and transformations which can then be converted into computer programs.

systems engineering. The discipline associated with the design, development and implementation of SYSTEMS. In practice this is nearly always concerned with the development of computer hardware and software for specific tasks.

T

tack weld. A weld made to hold two parts in a fixed position, so that they may be welded properly without the danger of their moving relative to one another during the process.

Taguchi. Influential Japanese authority on QUALITY management. Taguchi is particularly associated with the concept of building in quality in the earliest stages of a product's life, and was responsible for the development of the widely-used TAGUCHI METHODS for implementing quality improvements.

Taguchi methods. Taguchi methods for QUALITY improvement were originally developed in Japan in the 1950s by Genichi Taguchi, and the approach is propounded now by his son, Shin.

The central idea is that whilst on-line process control is powerful as a means of monitoring and maintaining quality, it does not help get highest quality at lowest cost. Seventy-five percent of a product's manufacturing costs are determined at the design and planning phase – and many of the quality problem solutions can be dealt with cost effectively at that stage too. It is thus product-centred rather than process-centred.

His definition of a good quality product is one which performs its intended functions without variability, and causes little loss through the cost of using it. His method uses a mathematical expression – the loss function – to measure this loss. This measure gives a basis for comparing different design options and methods for focusing improvement.

The basic idea is quality at source/ quality engineering – a form of off-line control to support on-line methods. The more that can be done off-line to eliminate the possibility of variations occurring, the less the on-line control will be needed.

There are three basic stages: system design – the product and the manufacturing process; parameter design – this involves experimenting with different parameters in the product design to achieve optimum performance and maximum immunity from variations; tolerance design – which involves upgrading the product and the process with better elements – materials, equipment, etc.

The Taguchi method identifies the key control factors which affect performance, but it does so using powerful statistical techniques which helps identify quickly the most important so that redesign efforts can concentrate on these. It provides the basis for the

QUALITY FUNCTION DEPLOYMENT approach, increasingly used in quality management.

tape streamer. Computer data storage device which is used to record back-up (security) copies of information processed and stored on disk. The tape storage mechanism is inherently safer and less vulnerable than disk storage, but slower in access. The streamer is designed to pass tape very quickly, recording the data at high speed. Thus a great deal of data can be 'dumped' onto tape quickly (often at the end of a day's business).

target costing. PURCHASING technique which provides a cost for which each component part should be bought. This begins with the market for the final product, and as assessment of the price which might be charged to the customer. This is then translated into a total product manufactured cost. This is then split down into major component target costs, and then minor component target costs. In this way, the control of product cost can be maintained and cost reductions can be focused on specific parts.

task. A specific activity to be carried out by an individual in accordance with set rules and procedures, to achieve some defined result.

task analysis. The analysis of a TASK into elements for the purposes of improving methods and identifying skill and/or training requirements for an operator.

task-based appraisal. Appraisal based on assessment of performance against set tasks.

task force. A group of individuals, brought together and often representing different skills and experience for the purpose of accomplishing a specific major TASK. Task forces are often used for major projects such as the implementation of new process technology or the re-organization of production layout. Task forces may be established for the duration of the project and then disbanded, or they may be maintained on a longer-term basis.

Taylor, Frederick Winslow. US industrial engineer who established the principles of SCIENTIFIC MANAGEMENT, applying them to a variety of industrial settings and especially in the steel and engineering industries. His doctrine of defining the one 'best' way of accomplishing any production task and his ideas of paying workers in direct proportion to their output level have survived to the present day in the form of PIECEWORK SYSTEMS and PAYMENT-BY-RESULTS schemes, and many of the underlying principles of WORK STUDY owe their origin to Taylor's ideas. In later life Taylor and his ideas fell into disfavour, but his influence on production management thinking and organizational functioning is still apparent in factories throughout the world. For further information, *see* F.W. Taylor, *The Principles of Scientific Management*, Harper and Row (New York, 1947). *See also* FORD.

Taylorism. Approaches to management and organization based on the ideas of Frederick TAYLOR and his principles of SCIENTIFIC MANAGEMENT.

't' distribution. A PROBABILITY distribution of sample statistics similar to a NORMAL DISTRIBUTION. It is commonly used to test whether or not a sample is a reasonable representation of a POPULATION with a characteristic that is normally distributed; for example, to test whether a change in the production method for making electric light bulbs has improved the life expectancy of those bulbs.

Technical office protocol (TOP). Communications PROTOCOL developed originally by the Boeing Corporation to enable the transfer of data along communication networks primarily in the product design and drawing office areas. TOP is compatible with the MANUFACTURING AUTOMATION PROTOCOL and also conforms to the principles of OPEN SYSTEMS INTERCONNECTION.

technological fix. Term used to describe the attitude which sees solutions to complex manufacturing problems as being soluble through the application of a suitable piece of advanced technology – as opposed to a more thorough analysis of the problem and a search for solutions which may involve organizational change, product or process design changes or other routes apart from investment in advanced technology.

technological life. The length of time elapsing before new equipment appears on the market which will make existing plant and equipment obsolete.

technology. Word derived from the Greek 'techne' which refers to the various means of achieving manufacturing tasks through the use of materials, equipment, processes, protocols and people. In a much narrower sense technology is often used to describe equipment or processes. Economists sometimes split technology into two components: that which is embodied in machines and equipment; and that which is disembodied, in the form of programs, work organization, procedures, etc.

technology agreement. *See* NEW TECHNOLOGY AGREEMENT.

technology push. In models of technological innovation, one of the two forces which shape and bring about change, the other being NEED PULL. Technology push refers to the set of opportunities which is created by the discovery and application of new knowledge. For example, the development of micro electronics opened up a huge field of possibilities in both product and process innovations. For a more detailed discussion, see R. Rothwell and W. Zegveld, *Reindustrialisation and Technology,* Longman (London, 1986).

technology transfer. The process of transferring TECHNOLOGY (in embodied and disembodied form) from one

field of application to another. This can be from laboratory to industrial environments, from company to company or from country to country.

terminal. Input/output device for a computer, consisting of a keyboard, VISUAL DISPLAY UNIT and other specialized equipment such as a mouse, a BAR CODE READER, DIGITIZING TABLET, etc. Terminals may be 'dumb' – in which case they are only configured to receive and display information – or 'intelligent' in which case they also contain some information processing capabilities.

terminal industry. In an industrial sector, the terminal industry consists of the companies who actually assemble the final product, from components supplied by others.

terotechnology. General term covering the investment and implementation of practical technology such as a manufacturing plant. All aspects of the investment are taken into account, from financial to maintenance. The idea behind terotechnology is to take an holistic view of the project, balancing factors against each other and exploring potential trade-offs.

TFP. TOTAL FACTOR PRODUCTIVITY.

therblig. Unit of measurement used to record WORK ELEMENTS such as grasp, hold or delay when defining SIMULTANEOUS MOVEMENT CHARTS. The name derives from that of Frank Gilbreth who, with his wife Lilian, pioneered the field of motion study. Gilbreth identified 17 basic elements of bodily movement and gave them the name therbligs, derived from reversing his own name. A therblig chart is used to record a series of elements involved in a complex activity, such as working a machine tool.

thermal copy. Low-quality printer output produced from a printing system based on developing an image with heat onto special surfaced paper.

thread milling. Process of generating an external thread on a bar or rod using a special thread-form cutter on a milling machine.

thread rolling. A COLD-FORGING process for forming, rather than cutting, thread on bar or round section WORKPIECES.

three-bin system. STOCK CONTROL method, similar to the TWO-BIN SYSTEM but using an extra third bin for SAFETY STOCK.

threshold limit value (TLV). A measured level of some environmental factor (for example, noise) which must not be exceeded. For example, in some industrial premises the level of ambient noise is not permitted to exceed 80 dBa on a constant basis, although short-duration increases may be allowed. Thus 80 dBa is the TLV for this noise regulation. *See* dB(A).

through kanban. If two or more processes are so closely connected that

they can be viewed as a single process, then in a KANBAN system there is no need to exchange a kanban between each of them but instead a single through or tunnel kanban is used, rather as a through ticket is used in rail travel.

throughput. Production output, often expressed as a rate per unit of time.

TIG. *See* TUNGSTEN IN INERT GAS WELDING.

tight rate. A PIECEWORK rate which is set so that the operator has difficulty in making a reasonable wage.

time and motion study. WORK STUDY technique designed to quantify the labour aspects of a task for the purposes of accounting and method improvement.

time bucket. In a MATERIALS REQUIREMENTS PLANNING system, the interval of time over which a certain quantity of output must be produced. Scheduling of production and procurement of materials is based on such time buckets.

time card. Record of attendance by an individual. Originally the record would often be kept by the employee inserting a card into a clock which would then punch time and other relevant information on the card. Recent years have seen extensive development of electronic systems for such record keeping which offer greater flexibility.

time phasing. In MATERIALS REQUIREMENTS PLANNING the ordering process requires first that the NET REQUIREMENTS should be calculated. PLANNED ORDERS are then placed by calculating these net requirements offset by the order LEAD TIME – and the process is known as time phasing.

time recording. Mechanism in a payment system for establishing the time spent on different jobs or activities. *See* TIME SHEET.

time-scaled charts. Charts used in WORK STUDY for recording movements where two or more activities are occurring concurrently on a common time scale. There are two forms of time-scaled charts: multiple activity charts, which are used to show time relationships between two or more elements (in effect a vertical version of a GANTT CHART) and SIMULTANEOUS MOVEMENT charts.

time sheet. Record of the total time spent on various activities, filled in by employees over a period (often weekly). An alternative is the JOB CARD which records the time spent on each different job.

time study. WORK STUDY technique based on rating operator performance against STANDARD TIMES.

time sharing. Sharing of expensive resources (such as computers) by more than one user.

toggle press. A PRESS in which the slides are activated by a linked mechanism, rather than directly from the drive of the activator (motor or manual).

tolerance. A defined degree to which a dimension may depart from its nominal value.

tooling. Wholly or part-specialized equipment used in conjunction with CAPITAL PLANT in a production process. For example, a power press is a machine tool but the dies used within it to produce a particular pressed shape are referred to as tooling.

tool room. Area of a manufacturing plant which is devoted to the development, production and repair of tools for production work, especially in the field of metalworking. The toolroom is usually characterized by a relatively high level of craftsman skill amongst those working there.

TOP. TECHNICAL AND OFFICE PROTOCOL.

total factor productivity. The productivity of manufacturing a certain part, expressed in terms of all resources used. Thus:

$$\text{total factor productivity for part A} = \frac{\text{output of product A}}{\text{sum of all resource inputs}}$$

See for a full account Hayes, Wheelright and Clark, *Dynamic Manufacturing*, Free Press (New York, 1988).

total failure. In RELIABILITY studies, the complete lack of ability of a product or service to perform the required function.

total quality control (TQC). A term originally used by Armand FEIGENBAUM, but now widely adopted to mean a comprehensive, all-embracing approach to instilling quality consciousness into a company, and to achieving PERPETUAL IMPROVEMENT and ZERO DEFECTS. *See* COMPANY WIDE QUALITY CONTROL, STATISTICAL PROCESS CONTROL, QUALITY CIRCLES, and QUALITY.

total work content. In LINE BALANCING, the sum of the STANDARD TIMES for all WORK ELEMENTS.

touch screen. Type of VISUAL DISPLAY UNIT which permits entry of data and interaction via direct contact with the screen, as opposed to via a keyboard or other device.

Toyota production system. Approach to production organization and management, developed over a 40-year period by the Toyota Motor Corporation in Japan. Under its architects Taichi OHNO and Shigeo SHINGO, the Toyota Production System evolved many of the core techniques which form the basis of JUST-IN-TIME manufacturing. For a detailed review, *see* Y. Monden, *Toyota Production System*, Industrial Engineering and Management Press (Norcross, Ga, 1983).

TQC. *See* TOTAL QUALITY CONTROL.

trade union. An organization of employees formed to represent common viewpoints and interests, and to protect individuals from malpractice in employment, through lobbying from a position of strength.

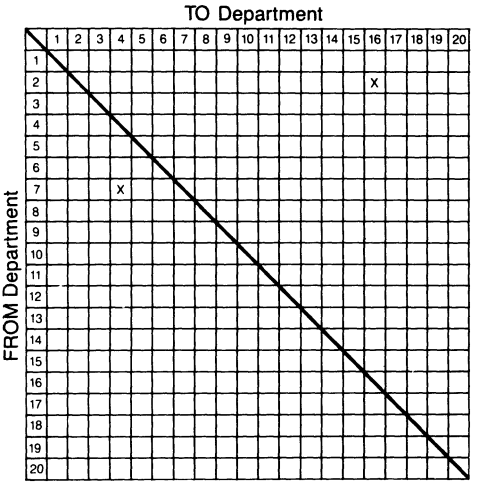
transducer. A device in an electromechanical system which enables a signal, generated in one form, to be relayed in another form; for example, converting physical temperature data into electrical signals for processing in a computer control system.

transfer line. Production equipment designed to carry out several operations in a particular sequence, moving the workpiece from one station to the next automatically.

translation. Process of converting information developed in one computer language (or within one operating system) into another. *See* COMPILER.

transplant. A manufacturing facility set up by a foreign manufacturer, in which the manufacturing processes, organization, techniques and culture are 'transplanted' to the new host country. An example is the transplantation of Japanese manufacturing methods via their overseas plants in the car and machinery industries. The term is sometimes considered derogatory by the company involved. *See also* SCREWDRIVER PLANT, LOCAL CONTENT, and GREENFIELD SITE.

travel chart. In WORK STUDY, a chart for recording movement in which the number of movements over a period of time are monitored.

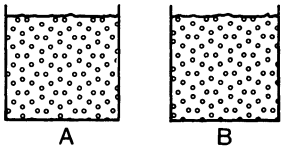


Travel chart

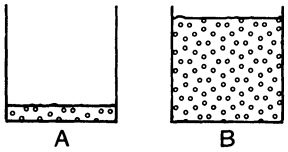
tribology. The study of lubricants and lubrication.

t-score. The ratio of a deviation from the MEAN in a DISTRIBUTION to the STANDARD ERROR. The resultant 'score' is compared with the critical value of the T-DISTRIBUTION.

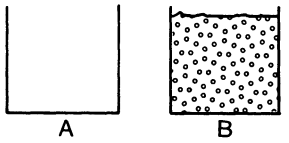
t-test. A test using the T-DISTRIBUTION to test whether a correlation coefficient is significantly different from zero.



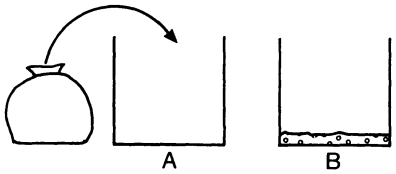
1. Both bins full of stock items



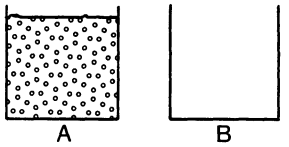
2. Items drawn from one bin only



3. When bin A is empty another load is ordered and stock items are drawn from bin B



4. Just as Bin B is about to runout a new delivery is received to fill bin A.



5. Stock items are on order to fill bin B meanwhile items are drawn from bin A.

Two bin system

tungsten in inert gas welding (TIG). Type of ARC WELDING.

turnbroaching. BROACHING technology in which the teeth of the broach are mounted radially on a centre wheel, instead of linearly along the spine of a straight shaft. The process is thus akin to HORIZONTAL MILLING, except that a form is cut, rather than a flat surface or rectangular groove.

turn-key. Term used to describe projects or contracts in which the contractor or supplier has the responsibility for completing all aspects, so that the user receives a system which he simply has to 'turn the key' to enable full operation.

two-card kanban. *See* KANBAN.

two-bin system. (Also known as last bag system.) A simple STOCK CONTROL method used for low-value items in production. When one bin becomes empty, another bin load is ordered and should arrive before the second bin has been used up. The empty bin itself is the signal to reorder, and the order quantity is fixed at one bin full. *See* STOCK POINT GENERATION; KANBAN.

2-d CAD. *See* COMPUTER-AIDED DESIGN.

3-d CAD. *See* COMPUTER-AIDED DESIGN.

two-machine scheduling. Computer-based technique used in machine shop SCHEDULING for the case where there are only two machines and the target is to minimize the total throughput time.

U

ULA. UNCOMMITTED LOGIC ARRAY.

U-lines (U-shaped lines). Approach to PRODUCTION LAYOUT based on U- shaped rather than linear arrangements. Such U-lines permit a higher degree of employee communication and interaction, and minimize the distance travelled within a facility. They are a common feature of JUST-IN-TIME systems. For a full explanation, *see* K. Suzaki, *The New Manufacturing Challenge: Techniques for Continuous Improvement,* Free Press (New York, 1987); and Y. Monden, *Toyota Production System*, Institute of Industrial Engineers (Georgia, 1983).

ultrasonic machining. Process which shapes metal parts by removing metal in an abrasive slurry which is vibrated by ultrasonic radiations.

unattended time. Time for which a piece of equipment is not being used or serviced.

uncommitted logic array (ULA). Integrated circuit which consists of a large number of logic elements which can be configured to a particular user's program needs through a final production process. ULAs offer a low-cost way of installing programmed functions in hardware which are likely to be needed in medium volumes but which do not justify the expense of developing a dedicated integrated circuit.

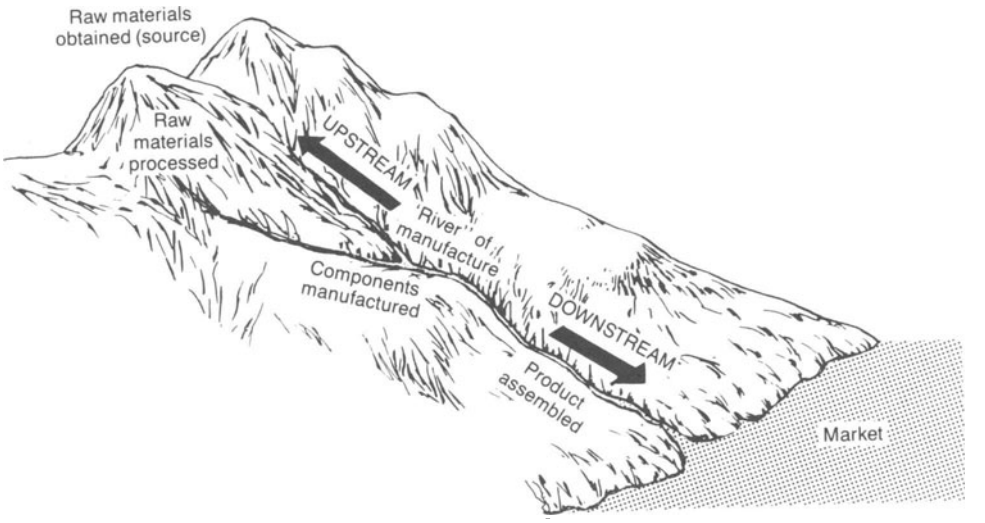
uncontrolled work. Parts of an operating process which cannot (or have not) been measured by WORK STUDY techniques, and which must thus be estimated for the purposes of calculation.

unit cost. The cost involved in producing one unit of a product.

unit production. Producing products one at a time.

unilateral tolerance. A TOLERANCE in which variation is only permitted in one direction away from the specified dimension.

unit cost. The cost of one unit of product. For DISCRETE PRODUCTS this would be 'each' or 'per 100', etc. For DIMENSIONAL PRODUCTS it might be 'per metre' or per litre, etc. Unit cost is a good focus for cost reduction since it is the basis for setting the selling price and represents a combination of all other cost-contributing factors.



Upstream processes – the concept

universal grinding machine. A multi-purpose GRINDING machine, used in TOOL ROOMS, on which any type of grinding may be carried out.

universe. In the context of statistical surveys, the large group about which observations and predictions may be made on the basis of the experimental samples taken.

UNIX. Computer operating system which permits a high degree of interchange between different programs and languages. Originally developed at Bell Laboratories in the USA in 1969, UNIX is now available on a wide range of computer systems and is a useful foundation for network development because of its relative transparency.

unproductive time. Time within a certain OPERATING CYCLE during which no productive work is carried out.

unskilled work. Tasks for which no special ability or training is required.

UPC bar code. BAR CODING system used in the USA and Canada.

upper warning line. *See* STATISTICAL PROCESS CONTROL.

upsetting. A forming process in which the end of a metal piece is pressed into a desired shape. (Also known as heading: *see* COLD HEADING.

upstream process. An operation which is carried out later in the overall process. *See* DOWNSTREAM, and VERTICAL INTEGRATION.

uptime. The time for which a machine is available for operation. *See* UTILIZATION.

usage. The rate at which material is used in a process.

usage classification. An indication of how expensive or important an item is, calculated on the basis of its usage value, usually in terms of class A, B or C. *See* ABC ANALYSIS; PARETO ANALYSIS.

usage value. The value of the amount of an item used during a specific period.

useful life. In RELIABILITY studies, the period of time over which a piece of equipment can be expected to perform without failure. *See* BATHTUB CURVE.

user-friendly. Characteristics of computer systems which make them easy for a new operator to understand and operate them.

utilization. The amount of time which a machine or item of plant is actually used for productive activity, as opposed to waiting, setting, etc. Utilization is usually expressed as a percentage of the time it is available for production.

V

vacuum forming. A forming process for plastics. A plastic sheet is clamped in a frame and formed into a mold by a vacuum which is created between the two.

value added. The contribution made by various activities in manufacturing which make the final product or service worth more than the inputs (energy, labour, materials, etc.) used in its production. *See* ADDED VALUE.

value adding network. Form of computer NETWORK which offers some form of service – for example, on-line information services – for which fees can be charged.

value analysis. A cost reduction and control technique which operates by a regular critical questioning of the basic design of a product or service. Value analysis normally focuses on the function of a product, where function is defined as that property of the product which makes it work or sell. For example, a lightbulb's function is to give light. From this analysis, unnecessary elements can be identified – for example, does the lamp need to be decorative as well? If not, then its design can be modified to one which gives light at the lowest cost.

Estimates suggest that in some cases as much as 80 percent of the final product cost is determined at the design stage, so value analysis can be a powerful cost reduction technique. Similar approaches are used in the quality area: *see* QUALITY FUNCTION DEPLOYMENT; TAGUCHI METHODS. The technique of value analysis is generally attributed to L. Miles who first proposed the ideas in the 1950s, and his text is still a useful introduction: *Techniques of Value Analysis and Engineering*, McGraw-Hill (New York, 1972).

value engineering. The application of VALUE ANALYSIS techniques.

value envelope. A project NETWORK ANALYSIS technique designed to compare actual work done with planned activity in terms of its value to the project. The envelope compares the cumulative value of the work done if all activities are completed by their earliest date with the same calculation for latest dates. Then, during the project, actual work done may be regularly compared with this to monitor progress.

valueless costs. Costs incurred in activities which add no value to a product or service. Examples include

SETTING-UP COSTS, handling and manipulation costs and OPPORTUNITY COSTS due to interruptions and unanticipated changes to smooth flow and SCHEDULING.

VAN. *See* VALUE ADDING NETWORK.

vanilla products. Basic products produced in high volume with minimal variety. *See* PRODUCT DIFFERENTIATION.

variable cost. A production cost which is proportional in size to the level of production – for example, material costs.

variable expense. A production expense which is proportional to the level of production output.

variable working hours. *See* FLEXIBLE WORKING HOURS.

variability. In the theory of STATISTICAL PROCESS CONTROL it is necessary to differentiate between different kinds of variation in quality during production. One class of variations represents the sum of small, random causes which interact to introduce variation; for example, temperature changes, operator emotional and physical state, vibrations, weather conditions, etc. Nothing can be done about these other than to change to process; consequently when only this type of variation is present, a process is said to be in statistical control.

A second source of variations is due to specific causes, termed ASSIGNABLE VARIATIONS. These represent causes about which something can be done – for example, adjustment of machinery – and their presence indicates that the process is out of statistical control. *See* STATISTICAL PROCESS CONTROL.

variable overheads. *See* MARGINAL COSTING.

variance. (1) An expression of the dispersion around the mean of a random variable probability distribution. (2) The square of a STANDARD DEVIATION.

variety. The degree to which a product family contains different designs as a result of product differentiation and the desire to meet customer specifications. Variety is the result of market demand stimulation but it can produce complexity in manufacturing and hence increase costs. It is important to distinguish between real variety – actual differences in product specifications – and apparent variety – apparent differences which can be achieved by minor additions to the specification and thus posing few problems in manufacturing; for example, different colours. Variety reduction is a major objective in cost-saving exercises.

VDU. VISUAL DISPLAY UNIT.

vendor. *See* SUPPLIER.

vendor rating. *See* SUPPLIER RATING.

vendor scheduling. PURCHASING technique of issuing long-term,

BLANKET ORDERS to suppliers, agreeing price, specification and other general supply details, and subsequently requesting delivery quantities and timing by means of a regular delivery schedule.

vertical integration. The strategy of carrying out UPSTREAM and/or DOWNSTREAM processes as well as the main operation traditionally done. For example, a television manufacturer might decide to start making its own tubes rather than buying them from a tube manufacturer; or it might decide to take over the supplier company. In either case, this is vertical integration. The integrating company gains better control over the process. However, it is often less able to carry out the specialist tasks in the integrated processes, and loses competitive position as a result. Im many manufacturing industries, vertical integration has been dropped as a strategy in favour of better SUBCONTRACTING.

very large scale integration (VLSI). The fitting of a large number of electronic components onto an integrated circuit – the basis of powerful micro electronic devices.

visual control. In JUST-IN-TIME and related systems, an approach to production management which requires making flow and operations clearly visible by reducing inventory and other elements likely to obscure a clear overview of what is happening. Under such a system it is possible to see quickly where and when problems occur. Various techniques exist for making things more visible, such as ANDON LIGHTS and PROCESS CONTROL CHARTS which make it clear when a process is drifting out of control. Other indicators include PROBLEM DISPLAY BOARDS and colour coding systems.

visual display unit (VDU). The display part of a computer system which may be a conventional (television-type) cathode ray tube or a plasma or liquid crystal screen.

vitrified wheel. A GRINDING WHEEL made with a vitreous BOND.

W

walk and count. Basic method of PRODUCTION CONTROL which involves a PROGRESS CHASER walking around a production facility and monitoring by visual observation the status of production.

wand. A light-emitting, hand-held device for reading BAR CODES.

warehouse. Literally, a house where a company keeps its wares. Since wares refers to the products which that company has to sell, the warehouse is strictly speaking the storage place for FINISHED GOODS. In common parlance, however, it is used to refer to any storage place – for RAW MATERIALS or finished goods.

warning lines. *See* STATISTICAL PROCESS CONTROL.

warranty. A guarantee that a product will perform in accordance with its specification for at least a certain period after the date of sale, and that corrective action will be taken by or on behalf of the manufacturer should this not be so.

warranty costs. Costs incurred by a manufacturer in fulfilling the terms of a WARRANTY.

wave soldering. Automated soldering process for printed circuit board manufacture. The components are inserted into the board, which is then carried across a bath of molten solder (in an enclosed chamber, fitted with fume extraction). A wave is created in the solder – so that it just touches the connections of the circuit and components – to solder them as the board passes across.

Wear-out period. In RELIABILITY studies, the period in which a product or component can be expected to wear out, following its USEFUL LIFE.

Weibull parameters. In RELIABILITY studies, a generalized mathematical expression which indicates the reliability over time of a product based on the probability of its failing. This is expressed as

$$R(t) = \exp - \left[\frac{t - \gamma}{\alpha} \right]$$

where α is the SCALING PARAMETER, β is the SHAPING PARAMETER and γ is the LOCATING PARAMETER.

These parameters are obtained through plotting the age at which failure occurs against the cumulative percentage of failures at that time.

The familiar BATHTUB CURVE for reliability is essentially a sequence of three Weibull frequency distribution curves which apply over the life of a product. In the early life period $B < 1$, in the USEFUL LIFE period $B = 1$, and in the WEAR OUT period $B > 1$.

weighted points plan. System for SUPPLIER RATING in which points are awarded on the basis of certain factors (e.g. delivery performance, quality) and then a weighting applied for the importance of each factor in the context of the overall buyer/supplier relationship.

whirligig. In the TOYOTA PRODUCTION SYSTEM a term used to describe a regular resupply of small quantities to particular operations in a regular sequence. It takes its name from the whirligig beetle.

whole-job ranking. A technique in JOB EVALUATION which compares one job with another on a total basis (i.e. instead of trying to analyse the function and then award points to each element).

Winchester. A hard-disk storage system for computers.

window. (1) Available space in a schedule within which some extra event may be fitted. (2) In many computer systems it is possible to have more than one activity or set of data in use at the same time; for example, the performance figures of a machine for the past three months. The screens on which these are displayed can be switched between and superimposed on each other, and in this process each screen is termed a window and the switching process is windowing.

wink. In WORK STUDY, a period of .03 seconds.

WIP. WORK IN PROGRESS.

withdrawal kanban. *See* CONVEYANCE KANBAN.

work centre. A physical area arranged for specific work purposes, sometimes treated as one entity for administration purposes.

work element. A distinct part of a production process identified for the purposes of observation and measurement. It is used in LINE BALANCING, WORK MEASUREMENT, PRODUCTION LAYOUT and other applications of INDUSTRIAL ENGINEERING.

work factor system. A WORK STUDY system designed to analyse an operation, similar to a PREDETERMINED MOTION-TIME SYSTEM.

work in process. *See* WORK IN PROGRESS.

work in progress (WIP). Items which are currently being worked upon as opposed to those which have been finished but await despatch. WIP consists of materials to which some value has been added (as distinct from raw materials) but which are not yet finished. As a result WIP is a difficult item to

account for since it is necessary to estimate the extent to which value has been added. Since WIP represents working capital tied up in part-finished products, it is desirable to minimize the levels held in a production facility; however, the problems of batch manufacturing in particular often lead to high levels of WIP building up.

work to rule. A restrictive practice designed to cause disruption to an operation by withdrawal of co-operation between employees and management above and beyond the basic contractual requirement (the 'rules'). Such action may also reveal the extent to which smooth operation is dependent upon the goodwill of the employees involved, since compliance with contractual obligations alone may not suffice to support the operation.

work measurement. The concept of quantifying effort and time required in specific activities for two purposes: cost accounting and payment systems. Even if remuneration is not linked to output (which requires quantitative assessment of work done), effective financial control of a physical process still requires some form of work measurement to provide the basis for cost recovery and pricing policy.

works order. An order for components or sub-assemblies required for production which is to be made up within the factory as opposed to ordered from an outside supplier.

works order raising. Process of raising a WORKS ORDER.

workstation. (1) An identifiable place in the PRODUCTION LAYOUT at which a particular operation or set of operations is carried out by an operator. (2) A powerful computer terminal which is capable of significant stand-alone activity (such as running COMPUTER-AIDED DESIGN or ARTIFICIAL INTELLIGENCE applications) but which can also form part of a wider NETWORK. Workstations are usually based on fast processor chips, advanced screen and interface capabilities, and carry significant memory for storage and for random access work.

world class manufacturing. Global presence and the achievement and sustaining of competitive advantage in delivery of manufactured products. World Class Manufacturing is a term developed in the 1980s and popularized by Richard Schonberger in his 1987 book of that title (Free Press, New York). It refers to BEST PRACTICE in manufacturing. Hayes, Wheelright and Clark, in their 1987 book, *Dynamic Manufacturing* define world class manufacturing as 'being better than almost every other company in your industry in at least one important aspect of manufacturing.'

XYZ

x-axis. The horizontal axis on a graph – often the timescale.

x-bar. Sample mean (where each measurement is termed a value for 'x').

y-axis. The vertical axis on a graph.

yield. The amount of output produced by a production process. Yield is sometimes used to refer to the proportion of usable output and expressed as a percentage of the potential yield if all output was usable. For example, in the production of silicon chips for the electronics industry the process is extremely sensitive so that the yield from a wafer of silicon which has been etched and processed may be less than 50 percent of usable chips.

Yo-i-dan. Literally, 'ready, set, go.' An approach used in the TOYOTA PRODUCTION SYSTEM to balance the synchronization between various processes where there is no conveyor belt to provide the physical linkage.

z chart. Graphical method employed in time series analysis to compare observed periodic values of a variable, their cumulative total and the moving annual total.

zero defects. A QUALITY POLICY which is aimed at removing all defective items from production and to delivering 100 percent correct items. This is in contrast to the tradition of making allowances for poor quality and working with the concept of an 'ACCEPTABLE' QUALITY LEVEL of less than 100 percent.

zero defects day. Part of the CROSBY plan for TOTAL QUALITY. The idea is that the company identifies a day on which the level of defects in production output may be termed zero (negligible). On this day, everyone in the factory enjoys a major social event – a party – to celebrate their joint success. The key point, however, is that anniversaries of Zero Defects Day should be kept as special events too, so that the momentum created early in the total quality drive may be maintained.

zero time activity. A dummy activity on a critical path NETWORK.

zone circles. Type of QUALITY CIRCLE or CONTINUOUS IMPROVEMENT GROUP in which employees from a particular production area are grouped into self-regulatory teams in

order to improve motivation and benefit from a joint approach to problem-solving of operational difficulties.

zone curve chart. Graphical chart which has, for each point, two values, one vertically above the other (e.g. maximum and minimum). When the lower and upper lines are drawn, a zone of varying size is shown between them. It is the nature of this difference, rather than the absolute value of either line, which is of interest.