INDUSTRIAL AND MANUFACTURING ENGINEERING

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Contents

Summary

The following sections describe the needs and expectations of manufacturing service industry and the engineering and management challenges for industrial and manufacturing engineers. There follows a description of the fundamentals of industrial and manufacturing engineering, new engineering and management approaches to the design of manufacturing/service systems.

1. Introduction

Industrial and Manufacturing Engineering is a profession that can help any manufacturing service or government organization become competitive by being aware of the needs and expectations of global economy, quality and flexibility-minded internal and external customers, partners, and aware citizens.

The purpose of this theme is to describe Industrial and Manufacturing Engineering, its dynamic history and potential future. The rapid development of technologies in the last 100 years contributed a vast amount to the engineering profession. “Lack of efficiency and productivity," being the primary bottleneck, was tackled first, followed by dealing with "lack of integration" of the elements and factoring them into an effective total system.

Industrial and Manufacturing Engineering first emerged as a profession as early as the 1920s to meet the growing need for systems integration in all types of organizations, although it was recognized as critical in 1960s.

In 1989, the Institute of Industrial Engineers prepared the following definition to reflect what the profession would be in 2000:

Industrial Engineering will be recognized as the leading profession whose practitioners plan, design, implement and manage integrated production and service delivery systems that assure performance, reliability, maintainability, schedule adherence and cost control. These systems may be sociotechnical in nature, and will integrate people, information, material, equipment, processes, and energy throughout the life-cycle of the product, service or program.

The profession will adapt as its goals profitability, effectiveness, efficiency, adaptability, responsiveness, quality and the continuous improvement of products and services throughout their life-cycles. The humanities and social sciences, including economics, computer sciences, basic sciences, management sciences, highly developed communications skills along with physical, mathematical, statistical, organizational, and ethical concepts will be used to achieve these ends.

(Nadler, 1992)

The key ingredients that make industrial and manufacturing engineers unique in the above definition concern the human and organizational perspectives as bodies of knowledge to be used in developing the desired systems.

There are three ways in which industrial and manufacturing engineers deal with human and organizational perspectives. The first concerns the systems that result from planning and design. The interfacing of people with machines, where the design of the total system must include not only the physical elements of the machines but also the vital human links of behavioral stress-strain, load carrying, energy expenditure, and motivational responses, is what differentiates industrial and manufacturing engineers from the other engineering disciplines.

The second aspect concerns the operation of the system when it is installed. Internal and external customers of the system will have an impact on its operations.

The third is probably the most important. It concerns both the people who take part in developing the specifications of a system and those who deal with system operations. So the main role of industrial and manufacturing engineers is effectively bringing together the necessary people, organizations, and resources for developing the system specifications and operating arrangements to increase significantly the likelihood that the most effective recommendations will be adopted and implemented (Nadler, 1992).

Thus, Industrial and Manufacturing Engineering is a broad professional discipline concerned with designing effective systems and developing robust processes with the purpose of integrating people, technology, information, and material resources for improved overall effectiveness. It is a systems integrator: a big picture thinker in other words.

Therefore, the areas of responsibility of Industrial and Manufacturing Engineering are very diverse. One of these is to achieve the optimal balance of all assets in the supply chain or business system. Assets include people, materials, buildings, equipment, time, information, and technology. This balance could be as narrowly focused as developing a work method on the plant floor, or as broad as developing a manufacturing and distribution strategy for an entire company. Industrial and manufacturing engineers must understand the choices available, and the inherent trade-offs, as they strive to optimize the system rather than maximize any single component. Industrial and Manufacturing Engineering brings an expertise that provides a system perspective and skills that allow us to identify and measure system dynamics. Once we have designed a balanced system, the next responsibility is to make sure that the assets are efficiently used. We all live in a changing environment and must be able to accommodate change effectively—new products, technology, volume swings, changes in management philosophies, tools—and continually improve all work processes so that we are maintaining highly efficient, flexible and cost effective operations.

2. Background

Industrial and Manufacturing Engineering has gone through five phases that will be covered briefly now and in depth in the topic and article contributions.

The first focused mainly on achieving productivity improvements in terms of efficiency in manufacturing plant operations. People were needed to co-ordinate the products, equipment, and processes developed by mechanical, electrical, and chemical engineers. The lack of "people" orientation or knowledge of human performance capabilities among engineers stimulated the work of the pioneers of industrial and manufacturing engineering, even though their perspective inclined them to treat people like "machines." The tools and techniques developed were gathered under the term "scientific management." F. W. Taylor (1856–1915) was one of the first to investigate human performance and organization in work. His question was: "What is a fair day's work for a fair day's pay?"

Focusing on efficiency and productivity, Taylor made dramatic increases to the amount of work a worker would perform in a day. He achieved this by analyzing and improving work methods and evaluating improvements by time studies.

The results of scientific management were that:

- Emphasis was placed on planning and controlling.
- The number of white-collar workers increased sharply, leading to a management hierarchy.
- The focus on production lines caused workers to become de-skilled and greatly

narrowed their job functions.

- Increases in efficiency led both to worker resistance to being treated as machines, and to redundancies.

Taylor's scientific management tended to dehumanize workers but nonetheless established the profession because it offered much greater productivity than alternative methods. In due course Gantt, Frank, and Lillian Gilbreth further developed Taylor's ideas and made some progress towards making them more socially acceptable. The principles of scientific management were implemented in automobile manufacturing, reducing the assembly time of the Ford Model T: from 728 hours to ninety minutes! The rapid assembly rate allowed the Model T to be produced in high volumes, giving birth to the name "mass production." The human relations movement of the 1930s, led by Elton Mayo and the Hawthorne studies, introduced the idea that worker motivation, as well as the technical aspects of work, affected productivity. The primary contributors were H. Fayol, L. Urwick, M. Weber, and C. Barnard, who developed the administrative management approach (Nadler, 1992).

Both scientific management and administrative management approaches are considered to be part of the "classical management" perspective, which laid the foundation for later developments in management philosophies that industrial and manufacturing engineers have applied.

Behavioral management and human relations approaches evolved in the second phase of development, and provided important insights into motivation, group dynamics, and other interpersonal processes in organizations. Prominent contributors to this movement were E. Mayo, A. Maslow and D. McGregor. In 1943, Maslow advanced a theory suggesting that people are motivated by a hierarchy of needs, including monetary incentives and social acceptance (Keats and Hitti, 1988). Meanwhile, McGregor's Theory X and Theory Y model best represents the essence of the human relations approach. Theory X takes a relatively negative view of workers and is consistent with the views of scientific management. Theory Y is more positive, and is a more appropriate philosophy for managers to adhere to. The primary contribution of behavioral management relates to ways in which this approach has changed managerial thinking (Miller, 1987).

The third phase, which started in the early thirties but did not develop fully until the Second World War, lasted until the mid-1980s. This phase, known variously as the quantitative management approach or management science, extended the efficiency concept with mathematical, statistical, and computational tools. Sophisticated quantitative techniques were developed to assist in decision-making, and application of models increased the awareness and understanding of complex organizational processes and situations. These tools, in conjunction with the qualitative ones from the first phase, diversified the activities of industrial and manufacturing engineers into numerous areas outside manufacturing: education, hospitals, offices, transportation, distribution, military logistics, and government, among others. However, the quantitative management approach suffers from a number of limitations:

- It cannot fully explain or predict the behavior of people in organizations.

- Mathematical sophistication may come at the expense of other important skills.
- Models may require unrealistic or unfounded assumptions.

This third phase effected a transition from efficiency to effectiveness and quality, from relatively small systems to large or macro systems, from analysis and modeling to integration of all the elements of a system. Thus, systems integration is the hallmark of modern industrial and manufacturing engineering.

The fourth phase was the quality revolution. Both manufacturing and service manufacturers realized that a business organization must produce goods and services that meet its customers' needs. Quality rapidly became the crucial factor in a customer's choice of products and service. Several pioneers such as Deming (1986), Juran (1991), Feigenbaum (1991), Crosby (1979), and Taguchi (1986) discussed the concept of quality from three viewpoints: the customer, the producer, and society

Continuous improvement, minimization of variance, and focus on the process (*Kaizen*) itself rather than on the output or results of the process were emphasized in detail. Several manufacturing concepts emerged as a result. These include just-in-time processes, agile manufacturing, total quality management, concurrent engineering, cellular manufacturing, business process re-engineering, design for assembly/disassembly, and lean manufacturing, to name but a few (Kayis, 1997). Today's consumer market is characterized by product proliferation, shorter product life-cycles, shortened development times, changes in technology, more customized products, and segmented markets. The just-in-time (JIT) concept changed the rules of manufacturing from mass production to lean production (Monden, 1992). The basic principle of JIT is the total elimination of waste in all its forms. This concerns reserve stocks of raw materials, work in progress and finished goods, excess capacity, returned items, unnecessary operations, poor design, over production, and excessive waiting, among other matters. Thus, JIT is a production strategy for continuous improvement built around two fundamental ideas; the total elimination of waste and an emphasis on a high-quality workforce to achieve "quality at the source." Quality at the source is produced by the person on the shop floor who adds value to the product. Thus, lean production considers value adding processes designed to flourish while consuming less space, less inventory, fewer people, less investment and ever-decreasing waste in general. The essence of industrial and manufacturing engineering is to achieve and maintain highly efficient, flexible, and cost effective operations, as defined in the first chapters of this theme, which in fact emphasizes that all operational systems are concerned with transformations of inputs to outputs which add value (Hines et al., 2000). Paying attention to what the customer says is one of the most important factors in providing value. Manufacturers cannot provide value unless they are very clear about how the customer perceives value when a product is purchased, and equally importantly, in the service which accompanies it.

Efficient value adding stems from two main areas: the design of the product itself, and the design of processes and support activities that are required to manufacture it.

In the past, manufacturers tended to emphasize the design of the product, and so emphasized the importance of innovative design aimed at demonstrating excellence to the customer. This resulted in less efficient value adding processes. The direct value adding process of physical production can often be made much more efficient if the product is designed in the first place with a view not only to satisfying the customer, but also for ease of manufacturing. In view of the trends in competitive strategy towards the provision of greater product variety, and the advent of time based competition, the time to market of new products (measured from the point of product conception to the point when the first models are shipped to the customer) is becoming an increasingly important measure of performance. Product lead times need to be dramatically reduced, not only for standard products for which the design and production specifications already exist, but also for tailor-made products where many companies are having to reduce their design and product engineering cycle times from several months to a matter of weeks or even days and hours if they are to remain competitive.

Usually 80 or 90 percent of the time to market is taken up by the design phase. However, a disproportionate amount of value adding effort tends to be concentrated on improving the efficiency of the manufacturing phase of a product that has a predetermined design; relatively little effort is put into the design itself, though this will in fact usually have a dominant influence on the final product cost.

The terms concurrent engineering or simultaneous engineering describe a new approach to product design that involves the active participation and input of all interested parties—manufacturing, design, purchasing, finance, suppliers, and customers—in the design process. These parties, using a common database, share information and ideas wherever necessary to reduce territorialism and focus their energies on the common goal of developing timely and cost effective designs that are easy to produce and that meet the customers' needs. Effective implementation of a concurrent engineering approach can allow the supply of greatly increased product variety or products designed specifically to suit individual customers (mass customization) at little or no more cost than mass production. The term agile manufacturing has been coined to describe this scenario (Profozich, 1998).

Thus, concurrent engineering has been a key concept of the fourth phase, aiming to achieve:

- Concurrence: simultaneous development of both new product and process design.
- Integration: ensuring that all the organizational elements associated with the product life-cycle—management, marketing, design, manufacturing engineering, quality control, production planning and scheduling, and so on—are fully integrated with and actually participate in the product development process (Kaebernick, 2001).

The most important aspect of concurrent engineering is the formation of such multi-disciplinary product development teams. However, this is also often the biggest obstacle to its effective implementation. The formation of such teams, composed of people who may have very different views of product development, requires major cultural change within the organization and the breaking down of organizational and cross-cultural barriers and traditions that in the past may have been very strong. So, although concurrent engineering carries the word "engineering" in its title, it is not an engineering or technology discipline. It is truly an organizational, human resources, and communications discipline which is essential to improve boundaries, structures, relationships and processes.

(US Society of Manufacturing Engineers, 1992)

The emphasis on quality and the strategic importance of operations is especially important today as continuing advances in information technology have further increased competition and customer expectations of new products (Traver, 1995).

New products enhance an organization's image, motivate employees, and help a firm to grow and prosper. Product design and development, however, can be long and tedious, especially with a serial design process. Concurrent engineering combines product and process decisions, utilizes design teams and design for manufacture and assembly (DFM/DFA) concepts, and calls for changes. Methods of improving the quality of design include monitoring long-term design quality, quality function deployment, and Taguchi methods for robust design. Technology in the form of computer integrated design (CAD), computer aided engineering (CAE), computer aided manufacturing (CAM), and CAD/CAM allows better quality products to be designed, revised, tested, and produced at much faster pace using appropriate process planning tools (Hoang, 2000; Groover, 1991; Foston, 1991).

Computer numerical controlled (CNC) machines, direct numerical control (DNC) machines, flexible manufacturing system (FMS), robots and automated material handling systems are part of the collection of technologies referred to as computer aided manufacturing (CAM). The integration of these and other technologies is called computer integrated manufacturing (CIM).

The role of CIM in Industrial and Manufacturing Engineering is very important since it is a strategy for organizing and controlling the organization rather than specific technology that can be purchased. CIM develops linkages between people, machines, databases, and decisions. Each CIM component represents a different type of linkage. CAD can physically link different design components together to create new or modified designs and communicate electronically to other systems. Group technology (GT) classifies existing designs so that new designs can incorporate the expertise of earlier ones. CAE links the functional design of the product to the CAD generated form design. Computer aided process planning (CAPP) converts design specifications from CAD into instructions for manufacture for CAM. CAD/CAM describes the direct physical link between design and manufacturing. Within the manufacturing function, CAM technologies facilitate remote control and integration of operations.

The CIM environment was made possible by the development of shared databases, standards, and networking within the manufacturing function. For example, the manufacturing automation protocol (MAP), and technical and office protocol (TOP) set standards for communication between work places/departments for manufacturing and office environments. Initial graphics exchange specification (IGES) translates graphics data between different CAD systems. Standards for the exchange of product model data (STEP) can represent all critical product specifications, such as shape, material, tolerances, behavior, function, and structure, and consider the entire product life-cycle, from development to manufacture, through use and disposal by specifying process sequences for specific production systems (Russel and Taylor, 2000).

In the process of manufacturing a product, materials need to be ordered, workers scheduled, demand forecast, customer orders received and entered into the manufacturing system, production planned, progress reports issued, costs and quality documented, and customers billed. Computerized manufacturing control systems developed to collect, store, and display this information are an integral part of CIM. Manufacturing resource planning (MRPII) and enterprise resource planning (ERP) are examples of such systems.

Just-in-time processes and total quality management (TQM) systems require the collection, sharing, and exchange of information as well (Foster, 2001; Besterfield et al., 1999).

Process planning is concerned with connecting product designs into workable instructions for manufacture. Process planning on a broader scale involves decisions such as process selection, equipment purchase, and whether to outsource components or services. Process analysis drives the continuous improvement of operations, and process re-engineering may lead manufacturers to breakthrough improvements. Technology and information advances are very rapidly introducing changes to manufacturing and service organizations. Decision support systems (DSS), management information systems (MIS), expert systems, and artificial intelligence (AI) help managers make decisions based on data, knowledge, and experience. The Internet, intranets, and extranets increase the speed and nature of communication.

The fifth phase of development has centered upon globalization and flexibility. Technology and increased information channels, together with changing political and economic conditions, have prompted an era of industrial globalization in which companies compete worldwide for both market access and production resources. Although both products and services are becoming more customized in wider global markets, services, in many cases, are the key to competitiveness. International competition for goods and services has gone far beyond national boundaries. The impact of the changing world on the management of manufacturing operations is immense. Three main issues need to be addressed in order to cope with the global market. The first is to understand the changes in international markets and their effect on the manufacturing operations now and in the future. The second is the range of global challenges that businesses face, and the need to prepare to meet these challenges. The third issue is how to prepare qualified individuals who can understand and deal with the changes taking place in the global market. The development of the international arena has thus created many challenges for business managers. Companies have to deal with a variety of economic, political, and cultural conditions, along with the different laws and attitudes toward business, in a way that will allow them to retain their competitive advantages in the international market.

Adapting to the globalization of the world economy and to the related shift from domestic to global business requires adopting new strategies as well as new managerial skills and philosophies (Alkhafagi, 1995).

An analysis of evolving manufacturing strategies (Ferdows et al., 1985) revealed that the new competitive edge is the one which combines flexibility with low cost manufacture: "low cost flexible manufacturing." The 1970s was the decade of productivity, the 1980s of total quality management, and from the 1990s onwards, the key has been flexibility. Flexibility involves restructuring, re-engineering, reinventing, and simply developing methods to make a company flexible enough to respond to the ever-increasing and faster-changing needs of the customers from industrial and manufacturing engineering point of view; it means the ability to meet the needs of the markets without too much cost, time, effort, performance, or organizational disruption. It involves making small changes in operations to meet needs that originate from the customers. As market competition heats up, customers demand customized products, and this calls for quick design change, broader and changing product lines, fluctuating order sizes, multiple quality levels, quick delivery response, and a variety of price levels. Organizations can make use of a large variety of flexibilities: layout flexibility, process/technology flexibility, development flexibility, routing flexibility, and so on to enhance the capability of manufacturing processes (Kara and Kayis, 2002; Thomke and Reinertsen, 2000).

The variety of customer demands is the primary reason for the focus on flexibility. A focus on people, structures, and information that are the major constituents of organizations is essential to achieve flexibility. Humans are the most flexible resource due to their special attributes of social motivation and emotional needs, as well as their ability to learn, feel, and adapt. All complex tasks must be performed by humans. People provide flexibility through their alertness and analyzing capabilities. Humans can greatly add to flexibility if they are cross-trained, trained, skilled, creative, and motivated.

Organizational design can also be used effectively to promote flexibility. To be successful, the structure must be molded to meet on-going problems. Team-based designs have been proven to enhance flexibility. Organizations are constantly engaged in varied, non-repetitive, and challenging tasks that require discretion, evaluation, and judgment. In the course of time, their responsiveness to vendors, customers, suppliers, distributors, and others improves. In addition, flexibility requires not only that relationships between an organization and its external stakeholders (financial institutions, distribution networks, markets, and shareholders) are simplified, but also that its policies and procedures are made transparent and communicated to all concerned. In this way, new business opportunities and ways to utilize shared resources are made possible. It was for such reasons that, towards the end of the 1990s, organizations searched for even further competencies, working with broad networks of suppliers and distributors in the process known as supply-chain management. Over time, "extended enterprises" consisting of central firms supported by global networks of suppliers were formed, where partners are both collaborators and competitors for value.

The current emphasis on customer value goes a step further, to establish the reasons a customer chooses one company's product over another's and look at the entire range of product, services, and intangibles that constitute the company's product and image. The more knowledgeable and skilled companies become, with their willingness to learn and experiment their ability to engage in an active dialogue, the more they will help create enhanced networks where the customer is both collaborator and competitor for value.

Information resources can provide great support in achieving flexibility. Fast data collection, storage, and analysis of information help companies arrive at faster decisions and quicker action. To achieve greater flexibility through information, organizations must eliminate redundant data and minimize the total number of interface points within the company's information system (Aggarwal, 1997).

Table 1 summarizes some of the historical events/concepts mentioned in the phases of purpose of Industrial and Manufacturing Engineering.

Phase	**Events/concepts**	**Dates**	**Originator**
1. Scientific management	Productivity and efficiency	1910	F. W. Taylor
	Time and motion studies	1911	F. & L. Gilbreth
	Activity scheduling chart	1912	H. Gantt
	Moving assembly line	1913	H. Ford
	Systematic practice management	1920	H. Fayol, M. Weber, C. Barnard
2. Human relations and behavioural management	Hawthorne studies	1930	E. Mayo
	Motivation studies	1940s	A. Maslow
		1950s	F. Herzberg
		1960s	D. McGregor
3. Management science	Linear programming	1947	G. Dantzig
	Simulation, waiting line theory,	1950s	Operations research groups
	Decision theory		
	Project evaluation review		
	technique (PERT)		
	Critical path method (PM)		
	Material requirement planning (MRP)		J. Orlicky
		1960s	
4. Quality revolution and information age	Just-in-time (JIT)	1970s	T. Ohno
	Total quality management (TQM)	1980s	E. Deming
	Lean manufacturing		J. Duran
			A. Feigenbaum

	Strategy and operations		W. Skinner
	Computer integrated manufacturing (CIM), PCs	1980s	R. Hayes Numerous individuals and companies
	Business process re-engineering, Internet, World Wide Web	1990s	M. Hammer, J. Champy, T. Berners-Lee
5. Globalization and flexibility	Worldwide markets and operations Supply chain management Electronic commerce Mass customisation Flexibility Enhanced networks	1990s 2000	Numerous companies and nations

Table 1. Some historical events/concepts

The sciences that are relevant to Industrial and Manufacturing Engineering are diverse, as noted in the definition of the subject in the year 2000, and tend to be less quantitative than those supporting other engineering branches. The social sciences, to which industry and manufacturing look for information about the behavior of the human elements of their systems, are still not sufficiently developed to support an engineering discipline in a scientific sense. Some relevant mathematical areas—discrete mathematics and the mathematics of uncertainty—are still not well developed, although significant advances have been made in the last thirty years. Statistics are close to being fairly well developed as one of the bases of Industrial and Manufacturing Engineering. The emergence of a “science of operations” and a “science of management” have been very promising. It appears likely that different types of management and operating systems can be identified, defined, and described. These system types seem to exist independently of the era of application. They can be studied in general terms to determine their fundamental properties, which can then be used to understand and design new and more complex systems.

It is this last notion, the concept of sciences of operations and management and the ability to apply them to any type of operating system that has enabled Industrial and Manufacturing Engineering to expand its horizons and opportunities for practitioners almost limitlessly. The systems to which the sciences are being applied and from which practitioners have diversified from manufacturing alone have been impressive.

Thus, Industrial and Manufacturing Engineering helps us develop new or modified systems that capture the whole scenario of needs for a specific organization. These could be inventory systems in a manufacturing company, a hospital, a bank, a department store, an educational institution, an airline or a retail store. Similarly, quality monitoring, scheduling, personnel evaluation and staffing, production and other key dimensions of operating systems can be integrated, modeled, evaluated, and synthesized by industrial and manufacturing engineers (Nadler, 1992).

Business competition used to be a lot like a traditional theatre: on stage, the actors had clearly defined roles, and the customers paid for their tickets, sat back, and watched passively. In business, companies, distributors, and suppliers understood and adhered to their well-defined roles in a corporate relationship. Now the scene has changed, and business competition seems more like experimental theatre; everyone and anyone can be part of the action. The shift away from formal, defined roles is already occurring in business-to-business relationships. Major business discontinuities such as deregulation, globalization, technological convergence, and the rapid evolution of information technology have blurred the roles that companies play in their dealings with each other.

The earlier discussion of the five phases of Industrial and Manufacturing Engineering reveals this change clearly. The changing dynamics of business have been the focus of managerial debate especially during the last decade. Practitioners and scholars talk about "competing as a family." They talk about alliances, networks, and collaboration among companies. But the end customers, the consumers, have largely been ignored by many professionals. Consumers have increasingly been engaging in an active and explicit dialogue with manufacturers of products and services, and can now imitate the dialogue; they have moved out of the audience and onto the stage (Prahalad and Ramaswamy, 2000).

How then can we integrate different components of a business for the purpose of conforming to customer needs and requirements, and thus provide value? One answer lies in Industrial and Manufacturing Engineering education, since it is a good "liberal arts" engineering education. Although the other engineering branches impart specific professional skills, their graduates are qualified only in limited bodies of knowledge and thus restrict themselves to standard industrial classification (SIC) groupings or codes in which they might obtain work. The broad preparation of industrial and manufacturing engineers is one of the main reasons so many organizations use them to integrate all the resources needed in a system and to facilitate communications among management, engineering, vendors, and very importantly, customers.

Industrial and manufacturing engineering skills are applicable at all stages of product, service, and process design, development, and implementation. Thus the incorporation of systems thinking concept, methodologies, and techniques into education could greatly enhance the service education offers to industry. Many of us have experienced the disappointing results of sub-optimization: trying to optimize one aspect of an organization, only to achieve no change in the desired metrics, or—worse—to witness adverse effects elsewhere, as in other engineering disciplines.

An industrial and manufacturing engineer who can view an organization as a whole—as a system of interdependent components—and who can help others within the organization do the same has tremendous potential.

Some of the unique characteristics of the profession are as outlined below.

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Bibliography

Abdel-Malek, L.; Wolf, C. 1991. Evaluating Flexibility of Alternative FMS Designs: A Comparative Measure. *International Journal of Production Economics*, Vol. 23, Nos. 1–3, Oct, pp. 3–10.

Aggarwal, S. 1997. Flexibility Management: The Ultimate Strategy. *Industrial Management*, Vol. 37, No. 6, pp. 20–6.

Alkhafagi, A. 1995. *Competitive Global Management*. St Lucie Press, Florida, pp. 113–17.

Association of Manufacturing Excellence (AME). 1990. *Flexibility: Manufacturing Battlefield of the 1990s*. Sponsored by the Association of Manufacturing Excellence and Systems Science Institute. Japan, Waseda University.

Atkinson, J. 1987. Flexibility or Fragmentation? *Labour and Society*, Vol. 12, No. 1, January, pp. 5–9.

Barad, M.; Kayis, B. 1994. Quality Teams as Improvement Support Systems (ISS), Management Decision, Vol. 32, pp. 49–57.

Barad, M. 1996. Total Quality Management. In: *International Encyclopedia of Business and Management*, Vol. 5, 4884–902, England, Thomson Business.

Beckett, R. 2000. From Research to Reality Through Global Partnerships. In: Proceedings of the Eighth International Conference on Manufacturing Engineering, Sydney, Australia, pp. 78–83.

Benjaafar, S. 1992. *Modelling and Analysis of Flexibility in Manufacturing Systems*. Unpublished Ph.D. Thesis, School of Industrial Engineering, Purdue University, West Lafayette, Ind.

Bennett, F. L. 1995. The Management of Engineering. Canada, Wiley, pp. 22–49.

Berger, A. 1994. Balancing Technological, Organizational and Human Aspects in Manufacturing Development. *International Journal of Human Factors in Manufacturing*, Vol. 4, No. 3, pp. 261–80.

Berkel, R. V.; Willems, E.; Lafleur, M. 1997. Development of an Industrial Ecology Toolbox for the Introduction of Industrial Ecology in Enterprises: 1. *Journal of Cleaner Production*, Vol. 5, No. 1–2, pp. 11–25.

Bessant, J. 1990. Organization Adaptation and Manufacturing Technology. In: Proceedings of the Final IIASA Conference on Computer Integrated Manufacturing, Austria, pp. 351–60.

Besterfield, D. H.; Michna, B. C.; Besterfield, G. H.; Sacre, M. B. 1999. *Total Quality Management.* New Jersey, Prentice Hall, pp. 47–69.

Boer, H. 1990. *Organizing for Manufacturing Innovation; The Case of Flexible Manufacturing Systems*. Dissertation, University of Twente, The Netherlands.

Broström, A. 1991. Arbets organization och produktivitet. In: A. Broström SOU1991: 82, *Arbetsorganization och produktivitet, Expertrapport Nr. 5,* pp. 9–43. Stockholm, Almänna Förlaget.

Buckley, J. V. 1998. *Going for the Growth: Realising the Value of Technology*. New York, McGraw Hill, pp. 34–55.

Buzacott, J. A.; Shanthikumar, J. G. 1991. Models of Production Systems. In: G. Salvendy, *Handbook of Industrial Engineering*, 2nd Edn, pp. 1989–2024. New York, Wiley.

Chapanis, A. 1985. Some Reflections on Progress. Proceedings of the Twenty-ninth Annual Meeting of the Human Factors Society, Santa Monica, Calif. Human Factors Society, pp. 1–8.

——. 1995. Ergonomics in Product Development: A Personal View. *Ergonomics*, No. 38, pp. 1625–38.

Chatterjee, A.; Cohen, M. A.; Maxwell, W. L. 1987. *A Planning Framework for Flexible Manufacturing Systems*, WP #87-07-04. Philadelphia, University of Pennsylvania, July.

Chatterjee, A.; Cohen, M. A.; Maxwell, W. L.; Miller, L. W. 1984. Manufacturing Flexibility: Models and Measurements. In: Stecke, K. E. and Suri, R. Proceedings of the First ORSA/TIMS Special Interest Conference on FMS, pp. 49–64. Amsterdam, The Netherlands.

Christopher, M.; Towell, D. R. 2000. Supply Chain Migration from Lean and Functional to Agile and Customized. *Supply Chain Management. International Journal*, Vol. 5, No. 4, pp. 206–13.

Chung, C. H.; Chen, I. J. 1989. A Systematic Assessment of the Value of Flexibility from FMS. In: K. E. Stecke, and R. Suri, Proceedings of the Third ORSA/TIMS Special Interest Conference on FMS, pp. 27–34. Amsterdam, The Netherlands.

Clarke, T.; Clegg, S. 1998. *Changing Paradigms: The Transformation of Management Knowledge for the Twenty-first Century*. London, Harper Collins Business, pp. 41–60.

Cleveland, G.; Schroeder, R. G.; Anderson, J. C. 1989. A Theory of Production Competence. *Decision Sciences,* Vol. 8–9, No. 2, April, pp. 655–68.

Connock, S. 1985. Workforce Flexibility: Juggling Time and Task. *Personnel Management*, Vol. 17, No. 10, October, pp. 38–44.

Cox, T. 1989. Toward the Measurement of Manufacturing Flexibility. *Production and Inventory Management Journal*, Vol. 30, No. 4, first quarter, pp. 68–72.

Crosby, P. B. 1979. *Quality is Free*. New York, McGraw Hill. pp. 19–25.

Deming, W. B. 1986. *Out of the Crisis*. Cambridge, Mass., MIT Press, pp. 168–9.

Ellesmere, S. 1995. *Distribution and Logistics: Transforming the Supply Chain*. United Kingdom, Prime Marketing Publications, pp. 38–56.

Erengüç, S.; Simpson, N. C.; Vakharia, A. J. 1999. Integrated Production/Distribution Planning in Supply Chains: An Invited Review. *European Journal of Operations Research*, No. 115, pp. 219–36.

Falkner, C. H. 1986. Flexibility in Manufacturing Plants. In: K. E. Stecke and R. Suri, Proceedings of the second ORSA/TIMS Conference on Flexible Manufacturing Systems, pp. 95–106. Amsterdam, The Netherlands.

Feigenbaum, A. V. 1991. *Total Quality Control*. 3rd Edn. New York, McGraw Hill, pp. 11–18.

Ferdows, K.; Miller, J. K.; Nakane, J.; Vollmann, T. E. 1989. Evolving Global Manufacturing Strategies: Projection into the 1990s. In: J. Sheth and G. Eshghi, *Global Operations Perspectives*, pp. 5–14. Cincinnati, South-Western.

Fisher, M. L. 1997. What Is The Right Supply Chain For Your Product? *Harvard Business Review*, Vol. 75, No. 2, March/April, pp. 105–16.

Forsythe, C.; Karwowski, W. 1995. Human Factors in Agile Manufcturing, In: Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, Human Factors and Ergonomics Society, pp 538–40. Santa Monica, Calif.

Foster, S. T. 2001. *Managing Quality: An Integrative Approach*. Prentice Hall, New Jersey, pp. 176–82.

Foston, L. 1991. *Fundamentals of Computer Integrated Manufacturing*. Upper Saddle River, N.J., Prentice Hall, pp. 176–208.

Frazelle, E. H. 1986. Flexibility: A Strategic Response in Changing Times. *Industrial Engineering*, Vol. 20, No. 3, March, pp. 17–20.

Garvin, D. A. 1992. *Operations Strategy; Text and Cases*. New York, Prentice-Hall, pp. 33–51.

Gilmour, P. 1993. *Operations Management in Australia*. Cheshire, Longman, pp. 25–40.

Goetsch, D. L.; Davis, S. B. 2000. *Quality Management: Introduction to Total Quality Management for Production Processing and Services*. Prentice Hall, New Jersey, pp. 54–68.

Groover, M. P. 1991. CAD/CAE: Computer Aided Design and Engineering. In. G. Salvendy, *Handbook of Industrial Engineering*, pp. 563–86. Canada, Wiley.

Harrison, M. 1993. Operations Management Strategy. London, Pitman, pp. 21–34.

Hauser, J. R.; Clausing, D. 1988. The House of Quality. *Harvard Business Review*, May–June, pp. 63–73.

Heisel, V. 2000. New Approaches in Australian Technologies for Manufacturing Systems. In: Proceedings of the Eighth International Conference on Manufacturing Engineering, Sydney, Australia, pp. 33–55.

Helander, M. G. 1995. *A Guide to the Ergonomics of Manufacturing*. London, Taylor and Francis, pp. 3–16.

Helander, M. G.; Domas, K. 1985. Task Allocation between Humans and Robots in Manufacturing. *Material Flow*, No.3, pp. 175–205.

Hines, P.; Lamming, R.; Jones, D.; Cousins, P.; Rich, N. 2000. *Value Stream Management*. Prentice Hall, London, pp. 102–19.

Hoang, K. 2000. *Computer Integrated Manufacturing*. Sydney, University of New South Wales, pp. 2.5–7.

Hörte, S. A.; Lindberg, P. 1994. Performance Effects of Human and Organizational Development and Technological Development. *International Journal of Human Factors in Manufacturing*, Vol. 4, No. 3, pp. 243–59.

Huse, E. F.; Cummings, T. G. 1985. *Organization Development and Change*. St Paul, West Publishing, pp. 12–33.

Jarvis, J. J.; Ratliff, H. D. 1991. Distribution and Logistics. In: G. Salvendy, *Handbook of Industrial Engineering*, pp. 2199–218. New York, Wiley.

Johnston, R.; Chambers, S.; Harland, C.; Harrison, A.; Slack, N. 1993. *Cases in Operations Management*. London, Pitman, pp. 88–107.

Juran, J. N. 1991. Strategies for World-class Quality. *Quality Progress*, March, pp. 81–5.

Kaebernick, H. 2001. *Concurrent Product and Process Design*. Sydney, University of New South Wales, pp. 1.3–25.

Kals, J.; Brinke, E.; Lutters, D. 2000. *Effective Support of Design and Engineering Through Information Management: Cost Control Revised*. Proceedings of the Eighth International Conference on Manufacturing Engineering, Sydney, Australia, pp. 64–77.

Kara, S.; Kayis, B. 2002. The Role of Human Factors in Flexibility Management: A Survey. *Human Factors and Ergonomics in Manufacturing*, Vol. 12, No. 1, pp. 1–45.

Kayis, B. 1997. *Managing Manufacturing Operations*. Sydney, University of New South Wales, pp. 2.1–17.

Kayis, B. 1998. Assessing the Differences in Total Quality Management in Implementation: Behaviour of the Australian Manufacturing Industry. *Total Quality Management*, Vol. 9, No. 8, pp. 741–51.

Karwowski, W.; Warnecke, H. J.; Hueer, M.; Salvendy, G. 1997. Human Factors in Manufacturing, in Handbook of Human Factors and Ergonomics, ed. G. Salvendy, pp. 1865-–925. Canada, Wiley.

Karwowski, W.; Salvendy, G.; Badham, G.; Brodner, P.; Clegg, C.; Hwang, S.; L. Iwasawa, J.; Kidd, P. T.; Kobayashi, N.; Koubek, R.; Marsch, J.; Nagamachi, M.; Salzman, H.; Seppala, P.; Schallock, B.; Seridan, T.; Warschat, J. 1994, Integrating People, Organizations and Technology in Advanced Manufacturing: A Position Paper Based on the Joint View of Industrial Managers, Engineers, Consultants and Researchers. International Journal of Human Factors in Manufacturing, Vol. 4, No. 1, pp. 1–19.

Keats, B. W.; Hitt, M. A. 1988. A Casual Model of Linkages Among Environmental Dimensions: Macro Organizational Characteristics and Performance. *Academy of Management Journal*, September, pp. 570–98.

Kerr, R. 1996. Management of Business Technology. Sydney, University of New South Wales, pp. 1.6–19.

Kidd, P. T. 1991. Research Policy Review; Organization, People and Technology in European Manufacturing: Interdisciplinary Research for the 1990s. *International Journal of Human Factors in Manufacturin*g, Vol. 1, No. 3, pp. 257–79.

Knudsen, D. C. 1996. *The Transition to Flexibility*. Boston, Mass., Kluwer Academic, pp. 18–23.

Kochan, T. A. 1988. On the Human Side of Technology. *ICL Technical Journal*, November, pp. 391–400.

Konz, K. 1998. *Work Design, Industrial Ergonomics*. 2nd Edn. Columbus, Ohio, Grid Publishing, pp. 23–35.

Krajewski, L. J.; Ritzman, L. P. 1996. *Operations Management*. USA, Addison-Wesley, pp. 27–34.

Krajewski, L. J.; Wei, J. C. 1998. Supply Chain Flexibility. Proceedings of the Annual Meeting of the Decision Sciences Institute, 3, pp. 1278–80.

Kumar, V.; Kumar, U. 1987. Manufacturing Flexibility: A New Approach to its Flexibility. In: Proceedings of the Second International Industrial Engineering Conference, London, UK, pp. 469–75.

Levi, D.; Kaminsky, E.; Levi, E. 2000. *Designing and Managing the Supply Chain*. Singapore, McGraw Hill, pp. 197–208.

Licht, D. M.; Polzella, D. J.; Boff, K. R. 1991. *Human Factors, Ergonomics and Human Factors Engineering: An Analysis of Definitions*. Report No. 89–01, Wright-Paterson, AFB, OH: CSERIAC Program Office.

Lieberman, M. B.; Montgomery, D. B. 1998. First-mover Disadvantages. *Strategic Management Journal*, Vol. 19, No. 12, December, pp. 1111–25.

Ludema, K. C.; Caddell, R. M.; Atkins, A. 1987. *Manufacturing Engineering: Economics and Processes*. New Jersey, Prentice Hall, pp. 4–18.

McKeown, P. 2000. High Precision Manufacturing in the Twenty-first Century: from Macro through Micro to Nanotechnologies. In: Proceedings of the Eighth International Conference on Manufacturing Engineering, Sydney, Australia, pp. 20–32.

Magretta, J. 1998. The Power of Virtual Integration: An Interview with Dell Computer's Michael Dell. *Harvard Business Review*, March–April, pp. 72–84.

Mandelbaum, M. 1978. *Flexibility in Decision Making: An Exploration and Unification*. Unpublished Ph.D. Thesis, Department of Industrial Engineering, University of Toronto, Toronto, Canada.

Miller, D. 1987. The Structural and Environmental Correlates of Business Strategy. *Strategic Management Journal*, Vol. 8, pp. 55–76.

Monden, Y. 1992. Just-in-Time Production System. In: G. Salvendy, *Handbook of Industrial Engineering*, pp. 2116–30. New York, Wiley.

Monezka, R.; Morgan, J. P. 1996. Supplier Integration: A New Level of Supply Chain Management. *Purchasing*, Vol. 121, No. 7, pp. 15–18.

Nadler, G. 1992. The Role and Scope of Industrial Engineering. In G. Salvendy, *Handbook of Industrial Engineering*, pp. 3–27. New York, Wiley.

Narasimhan, R.; Das, A. 1999. Manufacturing Agility and Supply Chain Management Practices. Production and Inventory Management Journal, Vol. 40, No. 1, First Quarter, pp. 4–10.

Newman, W. E. Jr. 1986. Models to Evaluate the Benefits of FMS Pallet Flexibility. In: Stecke, K. E. and

Suri, R. Proceedings of the Second ORSA/TIMS Conference on Flexible Manufacturing Systems, Amsterda, The Netherlands, pp. 209–20.

O'Kane, S. 2000. *Flexibility Management: Analysis of the Impact of Flexibility Management in the Total Chain of Acquisition, Processing, Distribution Function of Australian Manufacturing Companies*. Unpublished B.E. Thesis, School of Mechanical and Manufacturing Engineering, The University of New South Wales, Sydney, Australia.

Osterman, P. 1991. New Technology and Work Organization. Paper presented at the Conference on Technology and Investment: Crucial Issues for the 1990, January, Stockholm, pp. 21–4.

Pezzoli, K. 1997. Sustainable Development: A Transdisciplinary Overview of the Literature. *Journal of Environmental Planning and Management*, Vol. 40, No. 5, pp. 549–74.

Pinedo, M. 1991. Scheduling. In: G. Salvendy, *Handbook of Industrial Engineering*, 2nd Edn, pp. 2116–30. New York, Wiley.

Prahalad, C. K.; Ramaswamy, V. 2000. Co-opting Customer Competence. *Harvard Business Review*, Vol. 78, No. 1, January–February, pp. 79–87.

Preece, D. A. 1986. Organizations, Flexibility and New Technology. In: C. A. Voss, *Managing Advanced Manufacturing Technology*, pp. 367–82. London, IFS.

Profozich, D. 1998. *Managing Change with Business Process Simulation*. Prentice Hall, New Jersey pp. 12–22.

Robinson, W.; Fornell, C. 1985. The Sources of Market Pioneer Advantages: The Core Industrial Goods Industries. *Journal of Marketing Research*, Vol. 22, No. 2, August, pp. 87–94.

Robinson, W.; Fornell, C.; Sullivan, M. W. 1992. Are Market Pioneers Intrinsically Stronger Than Late Entrants? *Strategic Management Journal*, November, pp. 609–24.

Rogers, G.; Bottaci, L. 1997. Modular Production Systems; A New Manufacturing Paradigm. *Journal of Intelligent Manufacturing*, Vol. 8, pp. 147–56.

Russell, R. S.; Taylor III, B. W. 2000. *Operations Management*. 3rd Edn. Prentice Hall, New Jersey, pp. 3–27.

Shackel, B. 1991. Ergonomics from Past to Future: An Overview. In: M. Kumashiro and E. D. Megaw, *Towards Human Work: Solutions to Problems in Occupational Health and Safety*, pp. 152–8. London: Taylor and Francis.

Schroeder, R. G. 1989. *Operations Management*. McGraw Hill, New York, pp. 12–31.

Skinner, W. 1985. *Manufacturing: The Formidable Competitive Weapon*. New York, Wiley, pp. 18–25.

Suarez, F. F.; Cusumano, M. A.; Fine, C. H. 1994. Empirical Study of Manufacturing Flexibility in Printed Circuit Board Assembly. *Operations Research*, Vol. 44, No. 1, January–February, pp. 223–40.

Taguchi, G. 1986. *Introduction to Quality Engineering*. Tokyo, Asian Productivity Organization, pp. 245–55.

Talavage, J.; Hannan, R. G. 1991. Flexible Manufacturing Systems and Cellular Manufacturing. In: G. Salvendy, *Handbook of Industrial Engineering*, Wiley, New York, pp. 612–46.

Thomke, S.; Reinertsen, D. 2000. Agile Product Development: Managing Development Flexibility In Uncertain Environments. *IEEE Engineering Management Review*, Vol. 28, No. 1, first quarter, pp. 37–50.

Tipnis, V. A. 1993. Evolving Issues in Product Life-Cycle Design. *Annals of the CIRP*, Vol. 4 2/1/1993, pp. 169–73.

——. 1988. Process and Economic Models for Manufacturing Operations. In: W. D. Compton, *Design and Manufacturing of Integrated Manufacturing Systems*. National Academy Press, Washington, pp. 92–117.

——. 1994. Towards a Comprehensive Methodology for Competing on Ecology. *IEEE* International Symposium on Electronics and the Environment, pp. 139–48.

Toyoda, S. 1999. Manufacturing in the New Global Economy. Keynote speech at the Second Annual California–Japan Forum, December.

Traver, R. W. 1995. *Manufacturing Solutions for Consistent Quality and Reliability*. Amacom, New York, pp. 7–17.

Upton, D. M. 1995a. Flexibility As Process Mobility: The Management of Plant Capabilities for Quick Response Manufacturing. *Journal of Operations Management*, Vol. 12, No. 4, June, pp. 205–24.

——. 1995b. What Really Makes Factories Flexible? *Harvard Business Review*, Vol. 73, No. 4, July–August, pp. 74–84.

US Society of Manufacturing Engineers. 1992. *Technical Report*. USA.

Vickery, S.; Calantone, R. 1999. Supply Chain Flexibility: An Empirical Study. *The Journal of Supply Chain Management*, *National Association of Purchasing Management*, Vol. 35, No. 3, August, pp. 25–33.

Vokurka, R. J.; Fliedner, G. 1998. The Journey Towards Agility: Industrial Management and Data Systems, MCB University Press, London. Vol. 4, pp. 165–71.

Vonderembse, M. A.; White, G. P. 1991. *Operations Management*. West St Paul, USA pp. 41–52.

Voss, C. A. 1986. Flexibility in Flexible Manufacturing Systems: A Comparative Study of Three Systems: Managing Advance Manufacturing Technology. In: C. A. Voss, Proceedings of the UK Operations Management Association Conference, University of Warwick, Coventry, UK, pp. 111–19.

Warnecke, H. J.; Steinhilper, R. 1982. Flexible Manufacturing Systems: EDP-Supported Planning: Application Examples. Proceedings of the First International Conference on Flexible Manufacturing Systems by IFS Conferences Ltd, Bedford, UK, pp. 345–56.

Wheelwright, S. C. 1978. Reflecting Corporate Strategy in Manufacturing Decisions. *Business Horizons*, Vol. 21, No. 1, pp. 57–66.

World Commission on Environment and Development 1987. *Our Common Future*. Oxford, Oxford University Press, 43 pp.

Yamashina, H.; Okamura, K.; Matsumoto, K. 1986. Flexible Manufacturing Systems in Japan: An Overview. In: Proceedings of the Fifth International Conference on Flexible Manufacturing Systems by IFS Conferences Ltd, London, pp. 405–16.

Young, A. R.; Murray, J. 1986. Performance and Evaluation of FMS. In: C. A. Voss, Proceedings of the UK Operations Management Association Conference, Managing Advanced Manufacturing Technology, University of Warwick, Coventry, UK, pp. 291–301.

Yusuf, Y. Y.; Sarhadi, M.; Gunesakaran, A. 1999. Agile Manufacturing: The Drivers, Concepts and Attributes, International Journal of Production Econmics, Vol. 62, No. 1, pp. 33–43.

Zelonovic, D. M. 1982. Flexibility: A Condition For Effective Production Systems. *International Journal of Production Research*, Vol. 20, No. 3, May/June, pp. 319–39.

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