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Factories and Manufacturing

Themes likely to dominate manufacturing through the first decade of the twenty-first century include a continued emphasis on quality, concurrent approaches to *everything* (especially design, processing, and distribution), and globalization (especially marketing, distribution, and customer support). Quality will continue to be a major driver, including statistical process control (SPC), quality function deployment (QFD), design of experiments (DoE), "re-engineering" of operating processes, and other quality improvement efforts.

Concurrent engineering will grow and become the standard for development of new products and processes. New products will be configured in a manner that is most "producible" based on existing or planned manufacturing processes, a significant departure from today's standard approach, which involves designing the product and worrying later about how to build it.

Globalization will be a major change agent over the next two or three decades. Led by globalization in markets and distribution activity, mainstream manufacturers from all major industrialized countries will find themselves drawn into multinational status. This will dramatically affect management training and skills, as well as the cultural make-up of multinational manufacturing work forces, particularly in management and technical areas.

Locations for production operations are selected today based on such criteria as the availability of skilled labor, adequate distribution modes, tax breaks, and other political-economic incentives. Over the next ten to twenty years, domestic production facilities will shift from the Midwest to the Sun Belt states and especially to second-tier cities and large-city suburbs. Internationally, fabrication in general (particularly low-tech fabrication operations—metal bending, sewing, etc.) will move from industrialized countries to less developed, industrializing countries. This will allow companies to take advantage of lower labor rates, looser environmental and other regulations, and trade offsets.

Actual factory size is likely to diminish generally as equipment becomes more compact, materials become more adaptable to final fabricated shapes, and efficiency improves, and also as large manufacturers move away from vertical integration. Average factories by the year 2000 will employ half the number of a decade earlier.

Human resources, the most critical aspect of any company's operations, will face new challenges as a result of two primary factors. First, the work force will not have all the education, skills, and training required to operate the increasingly complex manufacturing and information-processing equipment. Educational levels, both in the United States and in most other industrialized nations, are woefully inadequate and may not improve quickly enough to keep pace with future workplace

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demands. The shortages may be acute in engineering, product and process research, physical sciences, and computer sciences. Secondly, the values of tomorrow's workers will be quite different. People entering the manufacturing work force are less eager for overtime pay and for job stability at any cost, and likely to be more interested in free time and personal fulfillment. As a result, the most talented people will be far less responsive to the deadlines and other regimens imposed regularly in today's manufacturing settings. This will mean rapid expansion of temporary workers contracted for specific assignments, free-lance management specialists and technical people, and telecommuting from distant locations in job categories not requiring face-to-face dealings.

Automation levels through 2010 will grow exponentially. Rather than earlier images of an army of humanoid robots moving up and down aisles and assembling manufactured goods in the place of people, the robotics applications in factories will stem from initial successes in redundant operations, hazardous processes (such as welding and spray painting), in areas requiring precision and high levels of accurate repeatability (such as data entry and mixing of chemical compounds), and in areas where human strength is inadequate (such as the continuous lifting of heavy loads).

2010-2030

Themes that will dominate the manufacturing world between 2010 and 2030 are likely to include knowledge-based systems development and deployment, the development of product and service infrastructures, and the integration of technologies into "seamless" process development activities.

Knowledge-based systems will be used to determine optimum product configurations and availability; to allow materials management professionals to calculate optimum inventory investment levels and procurement timing; to enable finance departments to take maximum advantage of lending rates, tax laws, and other financial opportunities; to allow transportation/distribution professionals to identify the lowest-fare carriers and shortest-time distribution channels; and to let production departments schedule optimum production flow rates so as to maximize direct labor efficiency. These systems will grow out of the converging technologies of expert systems, natural language processors, telecommunications, and computers.

Infrastructure building will likely be recognized as critical for success. Infrastructures, environ-

mental factors, and systems required for support include sales and distribution networks, legislation, and even cultural factors that influence product "demand."

Technology integration will be a distinguishing characteristic as lines blur between materials sciences and manufacturing engineering, between sales and distribution, and between design and production. Cross-training will enhance the breadth of individual expertise levels. Single workstations operated by one or two individuals may be able to take the "design" process from concept through (simulated) testing, (simulated) marketing, production process development and scheduling, packaging development, and distribution channel selection.

Factory locations are expected to follow patterns exhibited in the previous decade. The size of the factories is likely to continue to shrink as personnel are cross-trained, knowledge-based systems provide technical "expertise" as needed, and new materials technologies reduce floor space requirements.

Human resources will continue to be a critical aspect, as more heavily cross-trained and broadly skilled and educated personnel are required. Strategic alliances between manufacturers and trade schools, universities, and community colleges are likely to proliferate.

Automation will continue to grow as a percentage of the value-adding component of manufacturing. Interchangeable "plug-and-play" process component equipment should be available for most standard manufacturing processes during this period, assuming that we have dealt with these interface communications issues.

2030-2050

The period from 2030 through the 2050s in manufacturing will likely be typified by the developments of microfabrication, virtual marketing and testing, and biocomputing. Microfabrication will be the most exciting development for manufacturing since the advent of the computer. It will allow the fabrication of materials and parts at the molecular level, building them with the features we desire (strength, weight, flexibility, and so forth). Left behind will be the era of excavating ore from the ground, refining it, and beating it into the forms we want. Common materials such as sand (silica) will require minor modification to configure them into extremely property-rich materials.

Virtual marketing will move to the forefront of marketing, sales, and distribution activity. Based

on enormous volumes of information available through accessible on-line services and data bases, "virtual" markets may be accurately evaluated without major cost.

Biocomputers promise staggering computational power and memory capabilities. Combined with nanotechnology, prodigious information processing capability will easily support "virtual marketing."

Location will begin to wane in importance as microfabrication becomes possible, and the possibility of "portable manufacturing" emerges. Since face-to-face labor requirements will be virtually eliminated, and "pollution" or other environmental side effects will be effectively eliminated, there will be very little restriction as to appropriateness of such "factory" sites.

Factory size will at this point become a function of manufacturing equipment size, which will gradually become smaller just as computers did. Automation will be at the heart of most microfabrication operations, since handling molecules and monitoring molecular construction are not activities for which humans are well suited.

Beyond 2050

Themes likely to dominate include the balance of nanotechnology operations (namely microassembly, disassembly, replication, and altered replication) and the return to space exploration.

Nanotechnology will continue to supplant traditional manufacturing processes, replacing not only fabrication but assembly processes as well. Disassemblers may be constructed that allow virtually any substance to be broken down into its molecular components. We may be able to disassemble just about anything, and reconstruct it molecule by molecule, replicating it over and over again, even with alterations. Manufacturing will most closely resemble today's pharmaceutical industry, with vats and pipes and mixing slurries of chemicals.

As nanotechnology opens new vistas of economy and power for manufacturing, the lure of space exploration will likely become irresistible. New industries supporting space exploration will spring up to expand Earth's domain without ruining our existing habitat. This will also perhaps enable us to do space-based manufacturing of substances that can only be readily generated in gravity-free environments.

In the years ahead, factory size will be gradually reduced as manufacturing processes become encoded in robotic microfabricators and microassemblers. Eventually, as they are catalogued and

made available "over the counter," an entire "factory" may well be comprised of a handful of individuals dedicated primarily to conceiving of, developing, and selling products.

See also APPROPRIATE TECHNOLOGY; BUSINESS STRUCTURE; FORMS; IMPACTS; GLOBAL BUSINESS; DOMINANT ORGANATIONAL FORMS; MANAGEMENT; MATERIALS; RESEARCH AND DEVELOPMENT; NANOTECHNOLOGY; ROBOTICS; SCIENCE CITIES; WORK; QUALITY OF; WORK ETHIC; WORKFORCE REDISTRIBUTION; WORKING CONDITIONS.

BIBLIOGRAPHY

- BOYETT, JOSEPH, and CONN, HENRY. *Workplace 2000*. New York: Dutton, 1991.
- CETRON, MARVIN, and DAVIES, OWEN. *American Renaissance*. New York: St. Martin's Press, 1989.
- DREXLER, K. ERIC, et al. *Unbounding the Future*. New York: Morrow, 1991.
- DUNCAN, WILLIAM L. *Manufacturing 2000*. New York: AMACOM, 1994.

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