1 Progression of Product Manufacturing Technologies

The progression of product manufacturing goals and technologies is introduced through summaries of major product manufacturing developments over approximately the past century. The relationships between produced products and the customers who use them are then discussed. At present, the design scale of sophisticated products ranges from the atomic level and nanotechnology realm (billionths of a meter) to global dimensions, but the importance of preserving a central awareness of human scales is emphasized in the discussion. Next, the changes in product manufacturing paradigms that have occurred during the past century are described and the various forces driving this evolution are explained. The discussion also indicates promising directions for future development of product manufacturing features, particularly the concepts, methodologies, and technologies that enable more preferable product manufacturing scenarios.

1.1 Introduction to Product Manufacturing

The primary goals of advanced product manufacturing are to develop and manufacture essential products that fulfill lifestyle needs to the highest degree possible, as well as auxiliary products that make our living more comfortable, efficient and satisfying. Figure 1.1 illustrates examples of products associated with high standards of living. The manufacturing of all products depends on various levels of technologies.

In the Stone Age, early people crafted spears and stone tools so that they could kill and process game, gather edible plants, and live as securely as they were able. Such items were developed to fit human hands and operated on a correspondingly human scale.

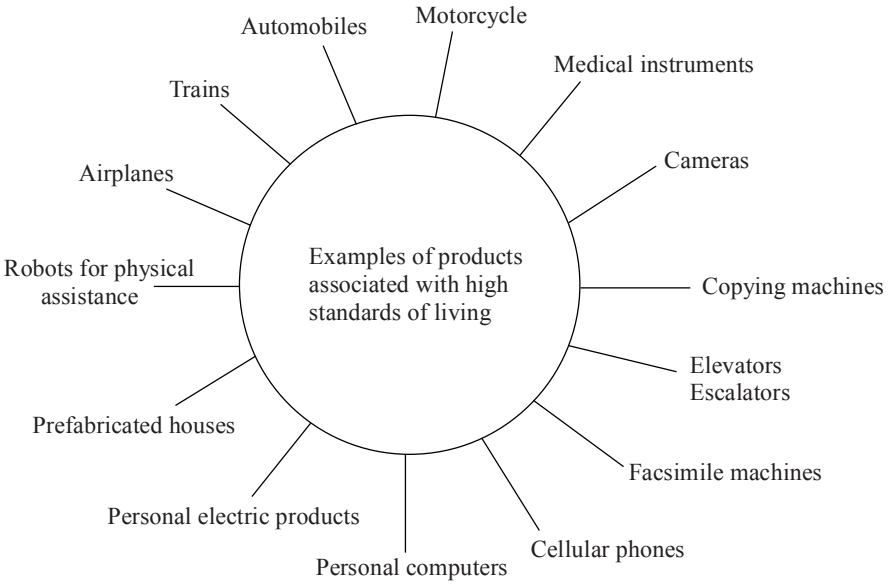

Fig. 1.1 Examples of products associated with high standards of living

Over centuries and millennia of gradual human progress, innumerable kinds of products have been manufactured. The most advanced consumer products of today are associated with high standards of living, such as vehicles for transportation, electronic equipment for communication, business and leisure, and products for recreation and amusement. This tremendous variety of products and their associated technologies encompass a wide range of scales, from manipulation on an atomic scale, exploiting quantum effects, to monumental enterprises such as the creation of dams or a megalopolis, with the scale of the human body roughly at the center. In the course of progress, more efficient airplanes and trains are designed and built to transport increasing numbers of people to their destinations in shorter times, advanced power plants distribution grids aim to provide a more stable infrastructure, and buildings of increasing scale that incorporate more sophisticated control of materials and climate aim to provide higher levels of comfort.

When considering the impact of human activity upon the natural environment and planet as a whole, it is clear that an awareness of issues pertaining to this global scale should be integrated into product design and development processes. On the other hand, it appears that most attention is focused on smaller scales, as products for personal use are increasingly miniaturized to provide greater convenience, utility, and comfort. The realm of nanotechnology is receiving increasing publicity, as researchers uncover ways to incorporate features at the scale of billionths of a meter in practical, everyday products that aim to satisfy requirements for lighter weight, superior functionality, and higher density of parts. On an even smaller scale, some areas of research focus on the atomic and molecular realms,

and certain discoveries have already led to important breakthroughs that will soon have profound social impact.

Thus, as shown in Fig. 1.2, the scale of current product manufacturing covers a range from atoms and molecules, to household products, and then to cars, trains and planes, skyscrapers, space stations, and even monumental earthworks. Since the design, manufacturing, sale, and use over time of consumer products is almost always associated with rising standards of living, it is vital to preserve a strong awareness of human scales, which lie approximately at the center between the very large and the very small. Product manufacturing that ignores human needs and desires, that is, manufacturing that concentrates too strongly on one particular scale at the expense of the human scale, may turn out to have significant drawbacks or be manifestly harmful. The design and production of successful products almost always depend on a sensitive examination of the relationships of scale between these objects, the surroundings in which they are used, and the people who make them a part of their lives.

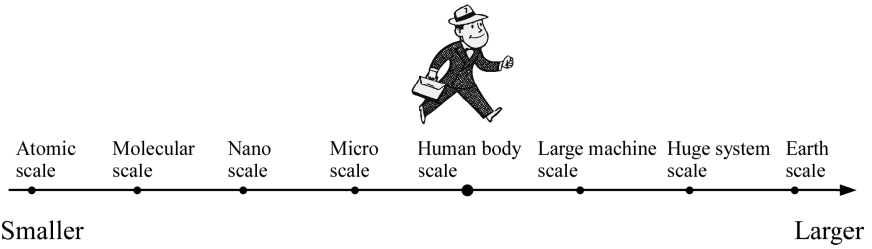

Fig. 1.2 Scale range in current product manufacturing

There are the following two major types of products:

1. Products that consumers buy and use
2. Industrial products used to manufacture the products belonging to 1 above

Figure 1.3 shows the relationship between customers and the manufacturers of consumer products and the industrial machines used to produce these products. The behavior of customers as they "vote with their wallets" naturally influences the demand for certain products, which in turn affects product manufacturers and supporting industries. As retail sales increase, certain manufacturers flourish and business activity radiates to other manufacturers and business sectors according to the specifics required for the production of the given products. The need to design and develop increasingly useful, attractive, and sophisticated consumer products provides a fundamental stimulus for development and improvement in the manufacturing realm.

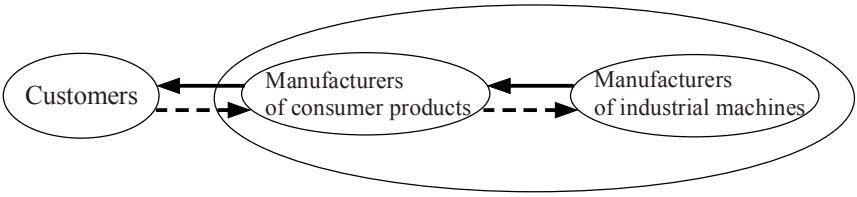

Fig. 1.3 Relationship between customers and manufacturers of consumer products and industrial machines

Figure 1.4 shows a generalized manufacturing flow, which is usually the same for both consumer products and industrial machines. This flow begins with market research and proceeds through product development, product design, product manufacturing, and ends with the sale of the product.

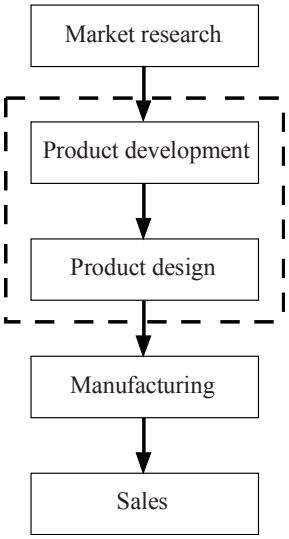

Fig. 1.4 Conventional product manufacturing flow

1.2 Historical Changes in Product Manufacturing Methodology Paradigms

Modern methods for manufacturing machine products have been evolving in accord with industrial development. Historical changes in product manufacturing paradigms are shown in Fig.1.5. Figure 1.6 shows the changes in manufacturing methodologies.

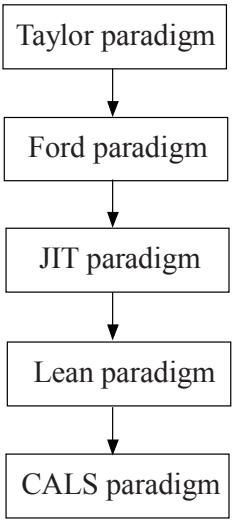

Fig. 1.5 Changes in manufacturing paradigms

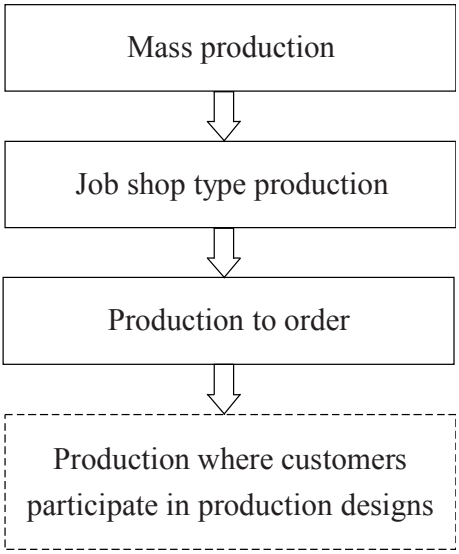

Fig. 1.6 Changes in product manufacturing methodologies

At the end of the nineteenth century, Frederick Winslow Taylor (1856−1915) devised management methods that paid special attention to the efficiency of manufacturing operations. These methods based on the Taylor paradigm were incorporated by US automobile companies of the period as the Ford paradigm so that large numbers of products could be produced at lower manufacturing costs,

which made them more accessible to the general populace and brought about the first step toward more affluent lifestyles. Henceforth, economies of scale were increasingly appreciated and taken advantage of by companies improving their manufacturing methodologies.

Once people became familiar with mass-produced items, there was an increasing demand for more suitable and more highly developed products that would better fit evolving lifestyles. In order to meet the needs of increasingly prosperous customers, product makers were forced to change manufacturing methods from limited variety mass production to a job shop type of production, where a variety of products could be created to satisfy a range of preferences. The following requirements had to be met:

1. Prompt response to customer needs, development of products having high performance, high quality, and low cost, with as short as possible product development time, while avoiding dead-ends or oversights that waste time, energy, and materials
2. Development of new products that customers want to buy, not simply incremental improvements applied to existing products

These requirements imply a change in the product manufacturing paradigm from one of "selling products that are produced," common when mass production was the norm, to one of "producing products that will sell," with a focus on fulfilling customer desires. A production method that could cope with such problems was the so-called Just In Time (JIT) method of production in which required quantities of parts are supplied to each process exactly when needed, a production method that can be effectively applied to job shop production. (This approach is explained in detail in Sec. 2.1.) The method was systematized in the United States of America in the latter half of the 1980s as a lean production method that could efficiently cope with demand fluctuations while maintaining production and fiscal efficiency. The JIT and lean production methods are now widely used around the world. In the latter half of the 1990s, a production method based on the CALS paradigm (Continuous Acquisition and Lifecycle Support) was developed, where all data pertaining to a product's entire lifecycle are processed by computers so that real-time data exchange and decision-making becomes possible, facilitated by increasingly powerful information technology. The original meaning of CALS was replaced by the current meaning, Commerce at Light Speed.

At present, the age of job shop manufacturing, in which customers select the most preferable products from a variety of products that makers prepare in advance, is giving way to a manufacturing paradigm that supports making products to order, where specific and detailed customer needs and desires can be economically dealt with at a relatively fine-grained level. Furthermore, we can envision the possibility that manufacturing in the future will eventually integrate some form of customer participation in the product design process, to maximize customer satisfaction, enabling scenarios of customer-maker collaborative manufacturing to some degree.

In addition to the above two basic requirements concerning response to customer needs and development of novel products, the importance of the following additional points has been growing:

3. Increasing public awareness of adverse effects upon natural environments and depletion of natural resources has made mandatory the consideration of product lifecycle and recycling of parts or raw materials
4. The pursuit of mental as well as physical satisfaction requires design and manufacturing methodologies whose products ultimately suit the emotional and mental aspects of customer needs more closely

Modern product manufacturing should, ideally, satisfy all of the foregoing factors, namely, 1−4. To achieve these requirements, criteria for evaluating the satisfaction level for each factor are required.

Figure 1.6 illustrates changes in product manufacturing paradigms during approximately a 100-year interval, where inter-company competition concerning product development was conducted according to particular criteria relevant during those times. Reflecting progress over time on a number of fronts, criteria for product manufacturing have evolved and become increasingly complex. Below are the main points of product design criteria trends over roughly the past half century:

1. Optimization of a single objective function, such as minimization of the operational time and minimization of the cost under the constraints of product performances and qualities
2. Recognition of the importance of conflicting relationships among characteristics, and use of more flexible optimizations from wider viewpoints, since improvement of a single objective function may cause another characteristic to be degraded
3. Inclusion in product criteria of influence levels of factors pertaining to natural environments, and factors pertaining to resources and recycling
4. Recognition of an increasing need in product design evaluation for inclusion of requirements pertaining to comfort and aesthetic factors when products are used.

Exercises

1.1 Why were mass production methodologies necessary during the early period of modern product manufacturing? How were these mass production methodologies carried out?

1.2 Discuss the problematic aspects of product manufacturing that is based on job shop type production, and methodologies that aim to resolve these problems.

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