Chapter **1**

Globalization and Manufacturing Paradigms

Globalization is the integration and interdependency of world markets and resources in producing consumer goods and services

Globalization has created a new, unprecedented landscape for the manufacturing industry, one of fierce competition, short windows of market opportunity, frequent product introductions, and rapid changes in product demand. Indeed, globalization is challenging, but it presents both threats and opportunities. To capitalize on the opportunities, industry needs to offer products that are innovative and also can be made to appeal to buyers from many cultures so they can be sold all over the globe. The challenge, however, is to succeed in a turbulent business environment where all competitors have similar opportunities.

Success in such a turbulent environment requires a global enterprise structure that can rapidly respond to changing markets and customer's needs. This enterprise should be equipped with a manufacturing system that can be rapidly changed and reconfigured to respond to volatile demand. This new generation of manufacturing systems will need to be reconfigured within two categories: product quantities (changed capacity) and product mix (changed functionality). Capacity reconfiguration is needed to produce exactly the product quantities required by the market at any given time. Manufacturing system and supply-chain functionality must also be reconfigured to support an accelerated pace of product innovation, and to produce the right mix of products required by various regions around the globe.

The Global Manufacturing Revolution: Product-Process-Business Integration and Reconfigurable Systems
By Yoram Koren

In short, a new global manufacturing revolution is needed to succeed in the new global economy; it must be a revolution based on responsive manufacturing systems and responsive business models. Responsive business models should aim at expanding into global markets by developing products that fit the culture of those markets and can be sold there. The business model must encompass not only selling, but also the international buying of components, and establishing global supply chains. The global enterprise should more closely integrate product design with its manufacturing systems and its global business model.

> Charles R. Darwin's statement in his book *On the Origin of Species**: "It is not the strongest species that survive, nor the most intelligent, but the ones most **responsive** to change," is now valid for global manufacturing enterprises.

1.1 THE IMPORTANCE OF MANUFACTURING TO SOCIETY

Why are we worried about manufacturing in the twenty-first century? Isn't manufacturing an "old-economy" profession that should be relegated to only poor countries? Is manufacturing really so important for a fully developed nation in the global economy?

Manufacturing is today, as it always has been, a cornerstone of the U.S. economy as it is for other developed nations. Having a strong base of manufacturing is important to any advanced country because it impels and stimulates all the other sectors of the economy. It provides a wide variety of jobs, both blue- and white-collar jobs, which bring higher standards of living to many sectors in society, and builds a strong middle class. Simply put, its most important benefit to society is that **manufacturing creates wealth**.

Think about this:

> ***Only art, agriculture, construction, and manufacturing, and more recently the software industry, create something of value from nothing.***

However, there is a big difference in the types of jobs that each industry creates.

> **An important advantage of manufacturing is that it creates a whole range of diverse jobs. Whereas agriculture and construction generate lots of low-skilled jobs, and art and software create a few jobs for higher-skilled elites, manufacturing calls on the skills of everyone from entry-level factory workers to scientists, engineers, and business professionals.**

*Charles R. Darwin (1809–1882) developed in England the theory of evolution. His most known book is *On the Origin of Species*, in which he describes the evolution of life on earth and includes this famous quote: "It is not the strongest species that survive, nor the most intelligent, but the ones most responsive to change."

To meet its far-ranging needs, manufacturing stimulates employment in other sectors of the economy. It has been calculated in 2001 by the Association of Manufacturing Technology (AMT) that each $1 million in sales of manufacturing goods produced in the United States supports eight jobs in the manufacturing sector and an additional six jobs in other sectors, such as information technology (IT), transportation, and construction. That means an average of 14 jobs are created by the U.S. manufacturing industry for each $1 million in sales. No other sector comes even close.

American manufacturing has been a strong contributor to the U.S. national economy for generations. In addition, gains in manufacturing productivity pass down to other sectors, building wealth and generating employment through the whole economy. The finished goods amount to only a portion of manufacturing's value. Production of intermediate-level goods (parts included in other products like engines, compressors, pumps, etc.) contributes significantly to the economy. Further, the design and production of manufacturing infrastructure, tooling, and equipment are industries of their own. And this says nothing of the high levels of transportation, information, and communications infrastructure that are all required to support world-class manufacturing. Because of its scale and volume, no other industry can replace manufacturing industry in any nation's economy. While the products America builds may and must change over time, domestic manufacturing continues to play a critical role in U.S. prosperity.

Manufacturing was, is, and shall remain the foundation of a strong economy. No other sector can replace it. Without a solid manufacturing base, the service and finance sectors will collapse.

As shown in Figure 1.1, the percentage of GDP of the U.S. private manufacturing sector has been gradually declining from 32% in 1950 to 13.4% in 2007.* From 1950, the manufacturing sector was constantly the highest in GDP percentage until 2005. In 2006, the real-estate sector moved ahead (14.9%) with manufacturing second (13.8%), and, as depicted in Figure 1.2, these sectors were 14.3% (real-estate) and 13.4% (manufacturing). However, even 13% is still a huge portion of the economy. In fact, **manufacturing still remains the largest productive sector in the overall U.S. economy**.

The GDP percentages of several sectors of the economy are shown in Table 1.1. In the late 1980s, "information" emerged as a new sector, which gradually increased to 5% in 2000. It is worth noting that, since 1990, investments in IT on behalf of manufacturing enterprises have contributed significantly to development of the information sector.

*Source for Figures 1.1 and 1.2 as well as Table 1.3 is U.S. Department of Commerce, Bureau of Economic Analysis, (http://www.bea.gov).

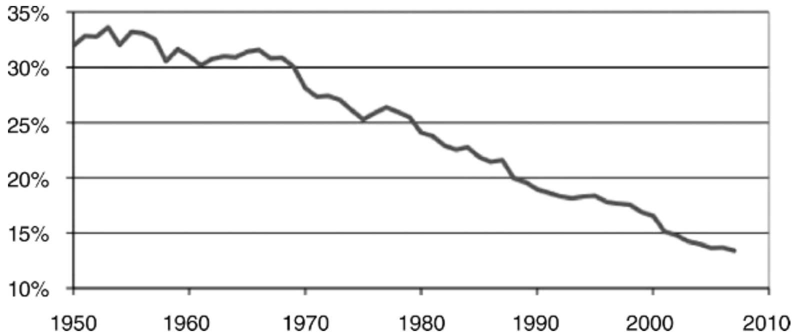

Figure 1.1 Manufacturing share of the U.S. Gross Domestic Product, 1950–2007 (as a percentage of the private industry). *Source*: U.S. Department of Commerce, Bureau of Economic Analysis.

Table 1.1 shows that the productive sectors of the economy halved in 35 years. Simultaneously with the 50% decline in manufacturing in the last 35 years, agriculture also declined at the same percentage. During the same period, the service sectors (including education, health, finance, and insurance) doubled. These data show that the U.S. economy is becoming more of a service economy than an economy that creates tangible wealth. But, is this a healthy trend?

Some renowned economists argue that the future of the United States is in the service industry. However, many portions of the service industry depend on the domestic manufacturing industry—trucking, financing, education, and infrastructure. Furthermore, an export of the service industry is very limited. A balance of export and trade is vital to a nation's economy, and therefore for the economy to thrive, manufacturing must remain healthy.

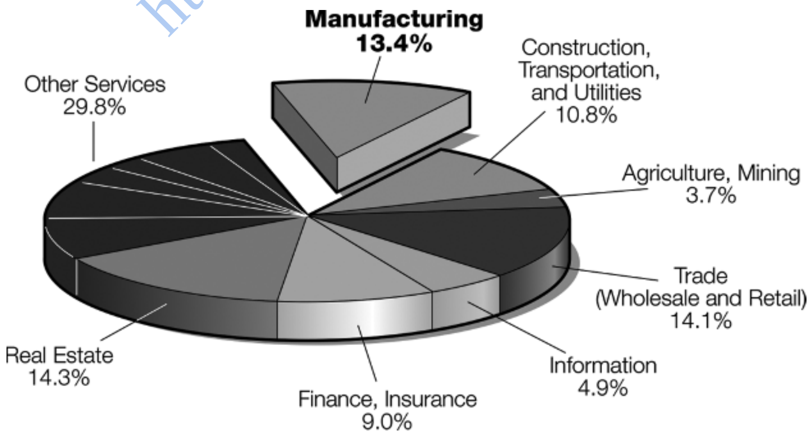

Figure 1.2 Decomposition of private industries in 2007.

TABLE 1.1 Sectors of Private Industries From 1970 to 2006 (in %)

Sector/Year	1970	1980	1990	2000	2007
Manufacturing	28.4	24.5	19.0	16.6	13.4
Agriculture + mining	5.3	4.5	3.6	2.5	3.7
Information	–	–	4.5	5.3	4.9
All services	13.9	16.0	25.9	27.8	29.9
Finance and insurance	5.2	6.1	6.8	8.6	9.0

Advanced industrial countries, including the United States, heavily subsidize agriculture, rendering that sectors benefit to the nation's economy as questionable. And yet, by contrast, manufacturing is not subsidized in the United States, even though its growth directly contributes to the wealth of the country.

Enhancing manufacturing growth depends on increasing productivity and inventing manufacturing technologies. Many major innovations in manufacturing methods originated in the United States—the invention of mass production by Henry Ford at the beginning of the twentieth century, the invention of numerical control (NC) machines of the 1950s, and the invention of reconfigurable manufacturing systems (RMSs) in the late 1990s. Coincidently, these three inventions that contribute to productivity improvements were started in the state of Michigan—the first in Dearborn, the second in Traverse City, and latest in Ann Arbor.

1.2 THE BASICS OF MANUFACTURING IN LARGE QUANTITIES

Manufacturing revolves around the production of quantities of new products. First, the product is developed, then it is manufactured, and finally it is sold to customers. Important factors for product developers to consider include how products look, how they work, and how the user interacts with them. To verify the product design, a product prototype is often constructed and tested to validate the design and product functionality. A prototype is built as a one-of-a-kind, essentially a work of art, and that can take a lot of time and labor. Even so, the prototyping method can be cost-effective when only a handful of copies are ever going to be sold.

When the manufacturer intends to produce large quantities of the product, as in the production of automobiles, refrigerators, or microprocessors, a more economical method is required. If large quantities were produced in the same way as the prototype, each product could be 10–20 times more expensive than the ones produced by a well-designed manufacturing system. For large quantities of products, a manufacturing system capable of mass production has to be developed.

The goal of a manufacturing system is to produce high-quality products at a fraction of what it took to build the prototype, so they can be sold at a marketable price. The manufacturing system achieves "economies of scale" that the prototype shop cannot, neither in output nor in consistency. In a globally competitive environment, designing a cost-effective manufacturing system and operating it efficiently is a key

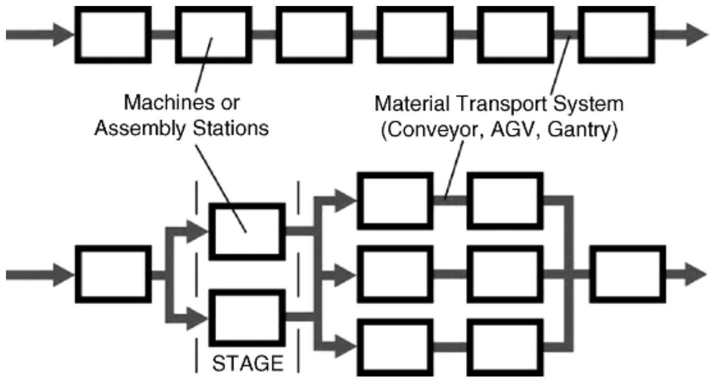

Figure 1.3 Examples of multi-stage manufacturing systems: six stages (top) and five stages (bottom).

competitive challenge especially when competitors have an advantage in countries where labor costs are substantially smaller.

Manufacturing systems typically consist of multiple stages, where each stage contains a machine or an assembly station to perform a given set of operations, as is illustrated in Figure 1.3. The machines are connected with a material transport system.

When the operations in one stage are completed, the raw product is transferred to the next stage, and so forth until all needed operations are completed and the product is finished. When especially large quantities are needed, multiple machines (or assembly stations) can be installed in parallel to perform the same operations at the same time on each machine (Figure 1.3, bottom), which increases the system throughput but makes the system design and operation more complex.

Most manufacturing is applied in multi-stage systems including assembly, such as those used to build automobiles, office chairs, or personal computers from given parts; or they may be systems with chemical processes, such as those on which semiconductor wafers are produced; or they may be machining systems for products that have to be machined, such as engine blocks, motors, pumps, and compressors. In machining systems, the products start out as rough castings that have to be drilled, milled, shaped, and polished using computerized numerically controlled (CNC) machine tools.

1.2.1 Dedicated and Flexible Systems

At the dawn of the twenty-first century, industries around the world used two basic types of manufacturing systems: dedicated manufacturing lines (DMLs) and flexible manufacturing systems (FMSs). Dedicated lines (often referred to as “transfer lines”) are designed to produce very large quantities of just one product, and they operate at very high productivity because the machines are simple and robustly designed. For example, engine blocks for cars can be machined on dedicated machining lines at a cycle time of 30 seconds (two engines are produced every minute). Therefore, once the line is properly tuned and calibrated, and as long as the dedicated line operates at its planned high-volume capacity, it produces products very quickly at very attractive prices (but it is only able to produce that one single product per line).

So what happens when there is no longer a need for that many engines, and demand is reduced to say one engine every 3 minutes (1/6 of the line designed capacity)? When that happens the dedicated line is underutilized, and therefore, the cost per product becomes higher. A report published in Italy[1] in 1998 indicated that the average utilization of the surveyed DMLs in the European auto-industry was only 53%. That means that barely half of the potential capacity was being utilized and the lines stood idle for long periods.

Furthermore, DMLs cannot be easily converted to produce new products even if they are similar and of the same product family. In the new global manufacturing paradigm, this is the main drawback of DMLs. With globalization, the marketable life of products is becoming shorter and shorter, and new products are being introduced faster and faster. These realities make DMLs uneconomical, and in fact they are vanishing in many manufacturing industries.

On the other end of the product volume versus variety spectrum (Figure 1.4) are FMSs. Unlike DMLs where each machine does a few simple operations, FMSs include machines that are capable of performing a variety of operations, and by extension can produce a large range of different products. FMSs, however, fit the factory portfolio only when relatively small product volumes are needed because they are slow and expensive (compared to DMLs).

FMS systems are expensive most particularly because the equipment possesses features enabling general flexibility that are expensive to build and maintain. Obtaining general flexibility requires added degrees of freedom, motors, mechanical components, and complex control. They are also expensive in the sense that companies typically purchase machines with more functionality than they really need, because they think they may use them in the future. However, the extra flexibility and functionality that the general-purpose FMS can offer is in many cases

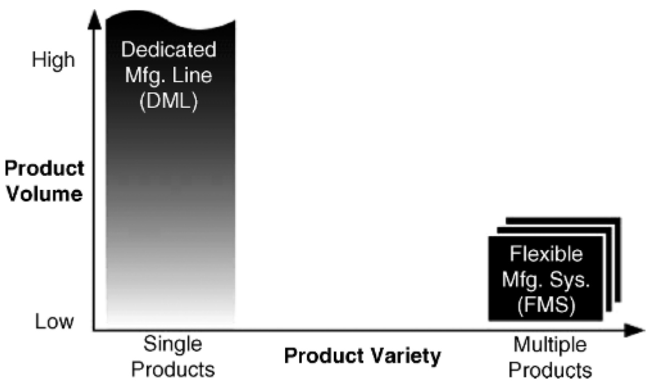

Figure 1.4 Volume–variety spectrum.

a waste of resources, since the extra cost paid for this general functionality equals unrealized capital investment until the extra functionality is actually used. Experience shows these extra resources are rarely utilized.*

The spectrum of products that are produced with FMS is quite large, and includes optical parts, missiles, aircrafts, automotive engines, integrated circuit boards, and even shoes. There are even applications in which the FMS is not built for multi-stage operations. In these cases, the FMS consists of a group of identical CNC machines that are arranged in parallel and each machine does the whole set of operations.

1.2.2 Business Models

Products are developed, then manufactured, and finally sold. The business unit of the manufacturing enterprise is in charge of marketing and selling, and the business model actually drives the whole enterprise. Our definition of a business model is:

> A business model is a strategic approach for creating economic value for the company by utilizing the competitive advantage of the company, for enhancing the product value to its customers

A business model considers three essential elements: (1) economic value (e.g., profit from selling products); (2) competitive advantage (over competitors); and (3) value to the customer. The business model should define who the customer is and how to create economic value for the company by providing customers with a product or service from which they can derive benefit.

For some products it is not so easy to define who is the customer, and a thorough understanding of the market may be required. Suppose a manufacturer tries to market a mechanical mini-robot that aids in orthopedic surgery. The customers of this technology are, in the order of importance: (1) orthopedic surgeons, (2) hospitals, (3) insurance companies, and (4) the patients. Yes, the patients come last. If the surgeons don't like the device, it will not be bought; if they do like it, they will recommend it to the hospitals. But only when the hospitals are convinced of the usefulness of the robot for improving surgery results, will they ask for an approval from their insurance companies. Finally, the patients must be convinced that a robotic-aided surgery enhances the success of their surgery. Each one of these four customer groups represents a necessary, but in themselves insufficient condition for the product success. Note that insurance coverage procedures are country-dependent, which makes the global marketing of this device more challenging.

In the business model of the surgery-aid robot, the product (i.e., the robot) may not necessarily generate the full economic value for the manufacturer. It's the consumables! In particular the disposable clamps that connect the mini-robot to the patient's

*See industry survey in Section 6.5.

spine generate the main economic value. Because of contamination this clamp must be thrown away after every use. Since a sole supplier (a monopoly) provides this clamp at non-competitive prices, it is the primary economic value for the robot manufacturer. Computer printer manufacturers utilize a similar business model: they sell inexpensive printers that consume very expensive ink cartridges.

In many cases, inventing a new business model rather than a new product can generate success. Tom Monaghan, for example, became a billionaire by starting a new firm in Ann Arbor, Michigan—Domino's Pizza. This firm created an economic value not by inventing a new product (the pizza was invented in Italy hundreds of years ago) and not by inventing the process of making the pizza, but rather by inventing a business model of home delivery of his pizza. Home delivery added benefits for the customer, and none of the competition had pizza home delivery when Domino Pizza started. Dominos' competitive advantage was its delivery system and transportation fleet.

Michael Dell also became a billionaire by creating a new business model. By integrating online communication with simple assembly factories for Dell Computers, he created a combination that generates huge economic value. His business model—exactly the computer that you need—benefits the customer, although it required a substantially complex IT infrastructure that Dell built into a competitive advantage.

1.2.3 The Traditional Sequence—Product, Process, Business

Traditionally, the marketing, product design, and manufacturing units work successively on the development of new products. First, the marketing unit conducts research and furnishes the design team with requirements and specifications for a new product, together with its target price and forecasted sales. The product design team must develop a product that includes all the features given by marketing, no matter how much it costs to produce each feature. The real production cost of each feature is not a parameter when marketing makes decisions. The product design team then optimizes for performance versus cost tradeoffs, where material cost is given. Only then is a manufacturing system built to produce the product. This routine substantially increases the product time-to-market, often by many months. By the time the product is manufactured, and the business unit tries to sell it, the customer's requirements and interest may have moved on or been fulfilled by a competitor. In the globalization era, this routine must be changed to speed up the product time-to-market.

1.3 THE 1990s: A DECADE OF INTENSIFIED GLOBALIZATION

Modern globalization means the integration and interdependency of world markets in producing consumer goods and services. But when did the era of globalization begin? Goods have been traded globally for thousands of years; for example, the Silk Road between China and Europe spanned the whole Eurasian supercontinent. And before that, some 4000 years ago, King Solomon in Jerusalem traded with Queen Sheba of Ethiopia in Africa. Nevertheless, globalization, as we know it today, emerged in just the last decade of the twentieth century.

The globalization revolution was shaped mainly by the events that occurred during the 10 years from 1991 to 2001. This decade started with the economic liberalization of India in 1991 that was initiated by Dr. M. Singh, then Indian finance minister, and allowed automatic approval of foreign investment in India. The last landmark in this decade was the inclusion of China as a member of the World Trade Organization (WTO) on December 11, 2001. To do so, China agreed to undertake a series of commitments to open and liberalize its market to foreign products. The WTO, which developed to its current structure in 1995, is a multi-governmental entity (as of July 2008 it had 153 countries as members) that facilitates doing business internationally by (1) formulating rules to govern global trade and capital flows through member consensus and (2) supervising member countries to ensure that the trade rules are implemented.

During that same decade the European Union (EU) and the North America Free Trade Agreement (NAFTA) were also created. The EU was established on November 1, 1993 along with the European Economic Community. The EU is not only a free trade zone, but also an economic and political union of 27 countries, with 500 million people (in 2007), that has its own parliament. NAFTA is a trilateral trade bloc created by the governments of the United States, Canada, and Mexico, which came into effect on January 1, 1994. It is one of the most powerful, wide-reaching treaties in the world.

In addition to these four government initiatives, Russian president Yeltsin initiated changes in 1993 that started to privatize industries in that country that were government controlled prior to that time. These five governmental initiatives are marked **1–5** in Table 1.2.

In parallel to these governmental initiatives, U.S. and European manufacturing industries started to take advantage of the new global conditions. The manufacturing world was shocked when in 1994 GM announced its plan to open factories in China "to penetrate Asia's growing market and to save money by using low-cost Chinese labor."[2] Before then, no one had imagined the fierce competition that was to come across the ocean from China. At the same time, U.S. manufacturing industry, and especially the automotive industry, started to migrate abroad, first to Mexico and later to other parts of Asia as well.

All through that decade, high-capacity fiber-optic cables were laid across the oceans. These cables serve as the information highways of the world and enable Western companies to utilize brainpower in countries where talented professionals can work while we sleep; for example, because of the time difference, GM R&D in Warren, Michigan can send a problem in the late afternoon, to GM R&D in Bangalore, India, and get an answer the next morning; and there are no language barriers. These fiber-optics cables are the blood vessels of globalization, enabling integration of the world's knowledge and markets.

On January 1, 2002, **the Euro currency** was adopted in 12 countries of the EU and stands as a symbolic milestone at the end of this decade of intensified globalization.

TABLE 1.2 Significant Events Marking a Decade of Intensified Globalization

1	1991	**India** was opened to foreign investments by "economic liberalization package," initiated by Dr. Singh, at that time India Finance Minister (he later became Prime Minister)
2	1992	The **European Union** was created
3	1992	**Russia**'s prices were freed and President Yeltsin started enterprise privatization
	1993	**Boeing** Design Center was established in Moscow with 350 engineers
4	1994	**NAFTA** (North America Free Trade Agreement—US, Canada, Mexico) was formed
	1994	**GM** decided to build engine parts in China
	1995	**Ford** India was established as a joint venture with Mahindra to assemble the Ford Escort
	1995	**Delphi** Automotive opened its first factory in China (producing batteries)
	1997	**General Motors Shanghai** (GMS) was established as a 50–50 joint venture partnership with Shanghai Automotive Industry Corp. In 2005, GMS sold 325,000 vehicles in China
	1998	**DaimlerChrysler** was formed by a merger of Daimler–Benz (the manufacturer of Mercedes–Benz, Germany) and the Chrysler Corp. (USA)
	1999	**Ford** India bought out a majority stake from Mahindra and started to produce the Ikon, Fusion, and Fiesta
5	2001	**China** joined the World Trade Organization
a–h	1992–2001	**High-capacity Transoceanic fiber-optic cable** deployments around the world (see Table 1.3)

From that point forward, globalization rolled like a tsunami, engulfing the entire world economy.

Table 1.2 and Figure 1.5 describe the main events that intensified globalization in the years 1991–2001. Three forces generated these events: governments (marked

Figure 1.5 The major government initiatives in five global regions that created the modern globalization era (**1–5** on the map) occurred during a single decade (1991–2001); at the same time, high-capacity fiber-optic cables were laid across the oceans (**a–h** on the map).

1–5), manufacturing enterprises (e.g., Boeing, General Motors), and new technology (undersea fiber-optic cables, **a–h**). The synergy among these three forces intensified globalization in an unprecedentedly short period of just 10 years.

Table 1.3 shows examples of fiber-optic cables that were laid across the oceans (**a–h** on the map and in Table 1.3). **The transoceanic bandwidth frequency (in bit/second) grew by a factor of 1000 in just 10 years**, dramatically increasing overall communication speed over global distances. (Brazil and South America were connected to the United States in 2002.)

TABLE 1.3 Examples of Transoceanic Fiber-optics Cables; Frequency × 1000 Within 10 Years

	Year	Cable	Frequency
a	1992	PC-4 (Trans-Pacific cable 4), connecting United States with Japan	0.56 Gb/second
b	1993	SAT-2 connecting South Africa with West Africa Portugal, and Spain	2 Gb/second
c	1996	Trans-Atlantic (TAT) cable utilizing new fiber-optic technology	20 Gb/second
d	1998	Connecting Australia and Singapore with Germany through the Suez canal	60 Gb/second
e	1999	China–United States cable network (CUCN), over 12,000 km, connecting the U.S. West coast with China, Taiwan, Korea, and Japan	120 Gb/second
f	1999	AC-1 (Atlantic Crossing) new ring-cable, connecting New York with the UK, the Netherlands, Germany, and back to NY	160 Gb/second
g	2000	MAYA-1 connecting Costa Rica and Panama to Mexico and Florida	
h	2001	PC-1 (Pacific Crossing) Japan—U.S. West Coast	640 Gb/second

1.4 THE GLOBAL MANUFACTURING REVOLUTION

The global manufacturing revolution started in the last decade of the twentieth century with evolutionary, and largely independent, developments in three important areas: (1) Governmental policy changed in several regions around the globe opened India, China, and Russia to free trade, and created new multi-country free-trade zones including NAFTA and the EU. (2) Global expansions of the manufacturing industry exponentially increased the potential manufacturing capacity available to all. (3) The laying of a huge network of transoceanic fiber-optics cables increased the volume of inexpensive information flow around the world. The synergy of these fundamental changes has created the global manufacturing revolution (Figure 1.6) and the new global manufacturing paradigm, which erupted at full strength in the first years of the twenty-first century.

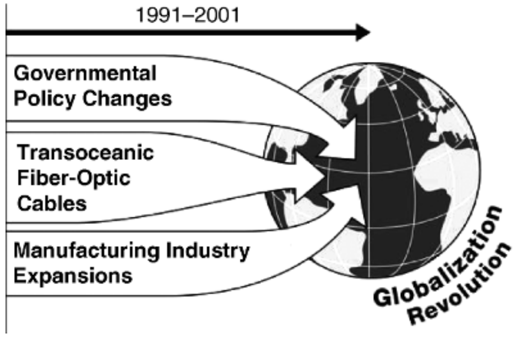

Figure 1.6 The global manufacturing revolution emerged due to changes in governmental policies, global expansion of manufacturing industry, and the development of transoceanic fiber-optics cable networks around the world. The synergy between these three independent forces has created the global manufacturing revolution.

Globalization created a new type of market dynamic driven by fierce worldwide competition among companies that are located in different countries and produce similar products (e.g., cars, furniture, refrigerators, and shoes). When many large corporations produce similar products, a global excess capacity is created. In 2002, the total world automobile production capacity was 80 million units, and actual worldwide sale was 55 million vehicles (69% capacity utilization[3]). A large global excess capacity, with supply much greater than demand, destabilized the market with large fluctuations in product sales per company.

In addition to over-capacity, global enterprises must carefully monitor currency exchange rates. A company's profit margin, say 9%, in one country can be completely wiped out by an equal fluctuation of 9% in the exchange rate of the country in which products are sold. When exchange rates are volatile, this can also have an impact on complex global supply chains that take years to establish.

The fortunes of global manufacturing enterprises are also strongly impacted by changing oil prices, and we are not just talking about the type of cars that people buy. Domestic manufacturers benefit from a rise in oil prices ($140 per barrel in April 2008), because rising ocean freight costs are affected by the cost of fuel, making imports more expensive compared with domestic products. From 2000 to April 2008, the cost of shipping a 40-foot container from East Asia to the United States rose from $3000 to $8000, making the manufacturing of some products in the United States cheaper than importing them. In anticipation of this, global enterprises often build factories in the local markets to minimize transportation costs. For example, IKEA, the world's leading home furnishings retailer, opened its first furniture factory in the United States (in Virginia) in May 2008.

But what happens when shipping prices drop back down to their previous levels? Won't imported cars and other products be suddenly less expensive? This points to the heart of our argument that manufacturing needs to be responsive to such change. Domestic production should be positioned so that it can (a) scale back on excess production volume and (b) introduce new innovations to compete with a resurgent importation. This second tactic includes offering **personalized products**, produced for individual designs and built by domestic manufacturers in closer proximity to these high-end customers who are less willing to wait for products designed and made just for them.*

Globalization has created many new opportunities and becoming a global manufacturing enterprise has several benefits:

- Globalization reduces manufacturing costs by utilizing low labor-cost countries.
- Globalization reduces business risk and filters currency exchange fluctuations.
- Globalization is a source for enterprise growth, achieved by accessing new markets.

Globalization means not only that large companies are becoming global in terms of their world-wide sales and the location of their production facilities, but also that they can offer innovative products to satisfy specific customer culture and preferences in different countries and different world regions. A global market with a large number of competing suppliers increases the customer's purchasing power, and these potential consumers now live all over the world. China, for example, now has 1 million millionaires and a large middle class. Many countries in South America also have a strong new middle class with increased purchasing power, and some countries in Eastern Europe (not a part of the EU and economically repressed for decades) have been prospering.

Markets are now global; but competing successfully in the global production paradigm requires reconsideration of the three components of the enterprise: product development, manufacturing system, and business model. These three components have always been in a precarious balance, especially when responding to unanticipated market events, and now these events occur in a much larger arena.

1.4.1 The Way We Are Heading

Increased responsiveness to changing market conditions is crucial for manufacturing enterprises to flourish in a global market and sustain continuous growth. Product development, the manufacturing system, and the business model must all be designed to rapidly respond to unpredictable changes, and be planned by a global strategy that determines issues such as which products to develop, for which regions on the globe, where to locate factories, and how to integrate global supply chains. These issues are the essence of the global manufacturing revolution.

*See Sections 3.3 and 14.4 for description of personalized products.

1.4.1.1 Product Development In addition to product development for traditional mass-customization markets, product development in the global manufacturing paradigm will have two new aspects:

1. Producing **regionalized products** that fit customer's culture in different world regions
2. Producing **personalized products** that fit individual needs (aiming at a market of one).

Designers of global products must be responsive to customers who live in different cultures and in dissimilar climate zones, and who have a wide range of purchasing power. To compete in those regional markets their products must be designed for regional customization in mind. To allow cost-effective regionalization and personalization, products should be highly modular, and be designed with changeable functionality within product families.

1.4.1.2 Manufacturing Systems For global manufacturing systems, responsiveness is an essential feature that can be achieved by developing **RMSs** that have a production capacity that is highly adaptable to market demand. Possession of RMSs enables companies to adjust their capacity (i.e., volume per product variant) to quickly match market demand, rapidly retool for new products, and upgrade with new functionality to produce different product variety. They provide...

...exactly the capacity and functionality needed, exactly when needed.

1.4.1.3 Business Models In the global manufacturing paradigm, the enterprise must be responsive to volatile markets and capable of rapidly taking advantage of market opportunities. The business model should be of a pull-type, encouraging customers to send their product preferences to the manufacturer via the Internet and receive their products in a timely manner. Industry's marketing must coordinate its actions with the product development team and consider manufacturing costs and constraints earlier in the product development.

As said above, traditionally, the marketing, product design, and manufacturing units work successively on the development of new products. With this approach marketing would often ask for a list of desirable product features to maximize sales, even though manufacturing of these features is very expensive. Marketing is traditionally disconnected from manufacturing and often sets target prices without consideration of the manufacturing costs and capabilities. With globalization this approach must be changed—marketing should consider the manufacturing costs and the capabilities of existing manufacturing systems when deciding upon new product requirements.

1.4.1.4 Globalization Fundamentals In summary, the three components of the global manufacturing enterprise must adapt to a new age, **age of rapid responsiveness**.

The global manufacturing revolution should stand on four fundamentals:

1. Innovative products for global markets and for personalization in domestic markets
2. Reconfigurable manufacturing systems
3. Global business strategies with rapid responsiveness to customers and markets
4. A solid integration between product, process (i.e., manufacturing system), and business

We will elaborate on these topics below.

1.4.2 Innovative Products for Global Markets

In an increasingly competitive global economy, establishing cost leadership over industrial competitors, by itself, is not sufficient to gain prosperity and revenue growth. Leadership in product innovation and in frequent introduction of innovative products is also critical to success in a global economy.

Manufacturing companies must create an environment for creating innovations in existing products and strategies for inventing new products. Inventing products that do not exist today gives one the potential of developing new markets. Past examples include refrigeration, which opened new markets for food, and air conditioning, which enabled increases in population in places like Nevada. New markets of new products will create far more jobs and generate more new wealth in the global economy than simply building things cheaper.

A survey conducted in 2005 by the Deloitte's Global Benchmark Study program[4] of 650 of the world's leading manufacturers revealed that:

- Manufacturers cite launching new products as the No. 1 driver of revenue growth, yet admit that supporting product innovation is one of their least important priorities.
- This is largely because 50–70% of all new product introductions fail.
- And yet, products representing more than 70% of 2005 sales will be obsolete by 2010 due to changing customer demands and competitive offerings.

If new, innovative products are the main source of a company's growth, why is the support of innovation so low, and why do new products fail so frequently? The report shows that many manufacturers were unable to bring new products to market profitably because of several key reasons including:

- Insufficient information on customer needs
- Inferior suppliers unable to provide quality parts on time
- A disjointed approach to innovation across product and supply chain operations.

To capitalize on new products as the main source of revenue and produce them at lowmanufacturing cost, global companies should pay attention to the following points:

New Products—There is a compelling need for developing company strategies aimed at product innovations and, in particular, at new products with global markets in mind. As such, these products will be the main source of growth and revenues.

Shorten Lead time by Developing Supplier Capabilities—New product development must be done simultaneously with developing global supply chains and enhancing supplier capabilities. This will further guarantee low-cost, high-quality products that will generate growth in sales of new products and in new markets.

Product Architecture—Competing within the global manufacturing paradigm requires developing a product platform architecture onto which modular products can be built, each designed to fit a region or a particular culture. This strategy enables the design of products that can be customized and regionalized to fit those sectors and cultures, and still be manufactured at low cost. That same architecture enables manufacturers to produce personalized products at reasonable cost for domestic markets.

Product's Regional Fit—Besides culture and market, regionalization must take into account additional limitations: purchasing power, climate, and legal regulations (e.g., safety, environmental limitations, and driving on the left side of the road). Market research that collects and analyzes information about the habits and needs of customers in the target country is a necessity for the product's success.

Product Personalization—Products that are manufactured to fit the buyer's exact needs are likely to become a new source of revenue in developed countries.

New product release timing is always critical and made more so because of the short windows of opportunity for new products due to global competition. Therefore, a competitive advantage exists for manufacturers who can use existing manufacturing systems that can be rapidly reconfigured to produce new products. To accomplish this, it is essential to add constraints on new product design so they can be made on existing manufacturing systems that currently produce other products. These requirements go well beyond those of existing product design for manufacturability (DFM) methods.

1.4.3 Reconfigurable Manufacturing System (RMS)

The RMS is a modern system that bridges the gap between the DML and the FMS. RMS design is focused on producing a particular family of parts rather than an infinite range of parts limited only by the machine's geometric and operational envelope, as is the case with FMS. The RMS trades a bit of flexibility for higher throughput. While an

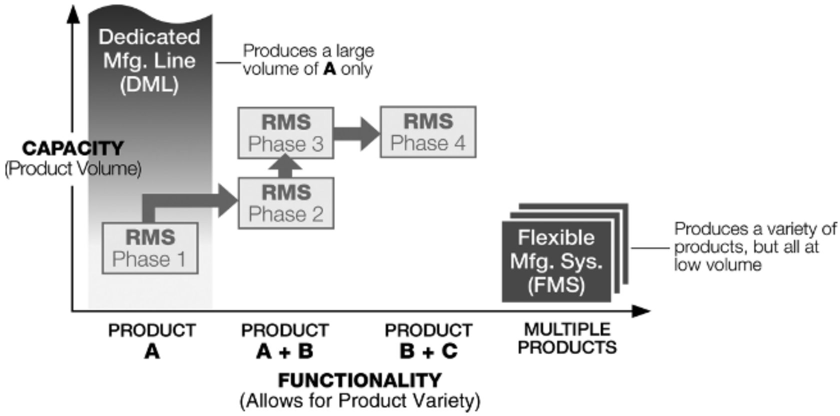

Figure 1.7 Changes in an RMS during its lifetime in response to new products.

RMS does not provide the general flexibility that FMS offers, it can have just enough flexibility (i.e., functionality) to produce the whole part family for which it was designed. Therefore, the RMS has the advantages of both FMS and DMLs without their drawbacks.

More importantly, an RMS includes added advantages that neither of the others possesses. An RMS is designed to "reconfigure" to grow and change within the scope of its lifetime, and so it can respond to market changes quickly. In other words, the RMS is designed for changes in its production capacity (the number of products it can produce) and in its functionality (which provides the capability to produce new parts and products) in ways that do not affect its overall robustness or reliability. Reconfiguration allows an RMS to achieve throughput approaching that of a DML but allows it to produce simultaneously several products.

Figure 1.7 shows the advantages that RMS represents. In this example, the RMS is initially built to produce only Product A. After some time, the system is reconfigured to produce Product B as well. However, since this requires overall higher production output, the system capacity must be higher (phase 2). As the market for Product B grows, more production units are added to the RMS (phase 3). Finally, after a few years, Product A is phased out completely but a new Product C is introduced; the RMS can fulfill all these requirements (phase 4 in Figure 1.7) without a major redesign of the system. The RMS is designed at the outset so that adding capacity can be done cost-effectively, and the system alterations needed to produce new products are done just as easily.

Our definition of an RMS:

A reconfigurable manufacturing system (RMS) is one designed for rapid adjustment of production capacity and functionality, across a product family, by rearrangement or change of its components (hardware and software)

The following anecdote illustrates the risks of fixed production-volume systems and the potential economic benefit of an RMS. In the winter of 1996, the manufacturing lines of Cadillac (a luxury car produced by General Motors Corp.) sat half-idle because of low demand for Cadillac cars. At the same time, an unexpected increase in demand for GM trucks exceeded supply by some 20%. GM considered building new truck manufacturing lines to meet the additional demand but viewed it as a high-risk investment and declined. So, overall, GM lost on both ends. The company lost a portion of their truck market share (for those they could not build), and lost money on their underutilized Cadillac assembly lines (for the capacity they could not use). One solution would be to have the Cadillac manufacturing lines reconfigured for production of small trucks for a few months. However, this required a reconfigurable assembly line, a technology that did not exist in 1996. Imagine the huge economic benefits that a company could gain by being able to build exactly the product needed, at exactly the time that the market demands. That is the manufacturing ideal and the goal of RMS.

1.4.4 Global Business Models

Dell Computers is a global company. The parts for Dell computers (memory, hard disks, etc.) are manufactured in China and Taiwan and shipped to assembly plants in Nashville, TN and Austin, TX in the United States. The company utilizes its mastery of IT (in the early 2000s) to coordinate its complex global supply chain, as well as its customer's orders.

Although the orders of Dell computers are stochastic (customers order computers at random through the Internet), the company avoids both overproduction and shortage by quite accurately forecasting the part quantities that will be needed in the assembly plants, and organizing their shipment exactly on time. This cost-effective global supply chain model is a competitive advantage for Dell. In fact, like Dell, many types of companies are now restructuring their supply chains to take advantage of globalization. It is difficult, however, to adapt Dell's business model, with its complex information infrastructure, to, for example, the automotive industry, because of the differences in scale and product complexity. In general, a global business model must fit the industry type.

The business model of a manufacturing enterprise must be supported by the company's production capability. With the globalization of manufacturing, hardly a single company, if any, makes their entire product. The successful global manufacturing company focuses on its core competency and shifts production of modules and sub-assemblies to suppliers whose own core competency is to manufacture these sub-assemblies and give them value. Another tier of suppliers produces parts for these sub-assemblies, thus forming a supply chain. Managing the information and material flow within supply chains has become an integral part of the enterprise organization and its business model. Supply chains are now a worldwide operation, since suppliers are globally spread and domestic and international logistics became variables that are critical to success.

1.4.5 Integration of the Global Enterprise—Product–Process–Business

Strategic planning of a global enterprise means not only global production facilities and global sales, but also that the enterprise should:

- Design **products that can be regionalized** to address customers' requirements in several world regions. For example, cars designed for India do not need the luxury and safety features required in the United States, but the chassis and engine may be the same. Global enterprises must be responsive to a diverse customer base—customers with different habits, in dissimilar climate zones, with a wide range of purchasing power.
- Operate **RMS** that have a production capacity **adaptable** to market demand, and thereby are responsive to fluctuations in product demand caused by the global excess production capacity.
- Develop **responsive business models** that take advantage of market opportunities to enhance sales and rapidly penetrate new markets.

These refinements of the three domains are equally important, as illustrated in Figure 1.8.

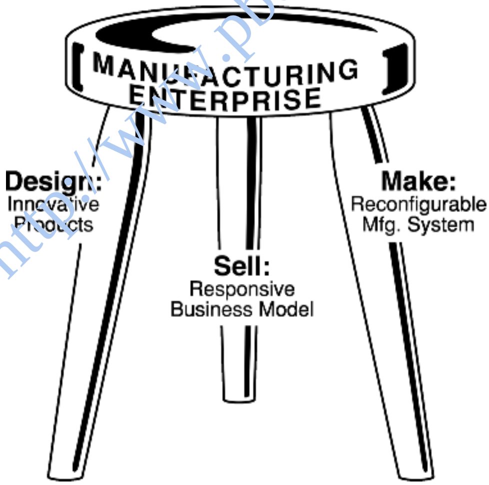

Figure 1.8 The manufacturing enterprise is like a three-legged stool—to be stable, it needs three equally strong legs:

- Innovative, customizable products
- Reconfigurable manufacturing systems, whose capacity and functionality are rapidly adaptable to changing market demands
- Responsive business models to sell, distribute, and maintain a variety of products, as well as form global alliances for new products

It is increasingly important to offer customers as much variety as can be economically justified, and to be able to introduce new goods quickly as technology and customer's demand change. In other words, such enterprises have to achieve **rapid responsiveness** to customers and markets wherever they are on the globe. This responsiveness must encompass all three domains: product design, manufacturing, and the business model.

Manufacturing companies must develop tools in all three components of the manufacturing enterprise to compete under the emerging **global manufacturing paradigm:**

Products designed for regional customization in different market segments, and for personalization for domestic high-end customers.

Manufacturing systems (i.e., **process**) designed for reconfiguration to produce products at volumes needed by the market.

Business models are responsive to volatile markets and to customers.

Globalization has brought a revolution to the enterprise organization as well. The three components are now more interdependent than ever before, as shown in Figure 1.9, and therefore their integration (the ring in Figure 1.9) is essential for an enterprise to succeed. If a company makes products with modular structure, for example, the manufacturing system must be designed to be able to produce the whole family of products based on those modules, and the business model should support personal orders of products that have a modular structure.

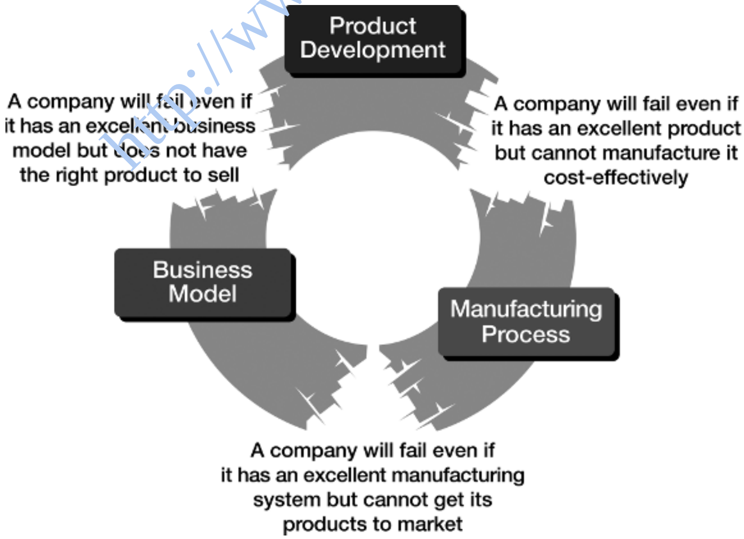

Figure 1.9 To be successful, the global enterprise must integrate its innovative products with its manufacturing system capabilities and a flexible business model.

In globalization, cooperative efforts between marketing, design, and manufacturing should begin during product development. The design team should analyze the product features and determine which specifications are not realistic and must be modified given a business target. This is feedback to the business unit, which must review the product price in response to the new specifications. The new price and modified product features may also change the projected demand and production volume targets, which, in turn, will impact the configuration and reconfiguration plan of the manufacturing system.

This way capacity allocation and manufacturing costs are coordinated with marketing targets during product development. Furthermore, in order to reduce time-to-market and decrease costs, every new product must be produced on available machines and on existing manufacturing systems that can be reconfigured for the new product production.

Remedying a major problem in one component of the enterprise necessitates changes in the other two. Changes in product design affects manufacturing and vice versa; plant productivity relates to the product selling rate, and vice versa. If one of these three components fails, the enterprise will fail.

1.5 THE MANUFACTURING PARADIGM MODEL

Since its birth some two centuries ago*, manufacturing industry has undergone several revolutionary paradigms induced by (1) new market and economy conditions and (2) emerging societal imperatives driven by customers (Figure 1.10).[5]

Societal needs may arise from the desire to have more products to choose from to satisfy individual tastes and preferences, small purchasing power of a certain population that drives a decrease in product prices, or environmental concerns. Market depends on the economy and may change, for example, because of substantial increase in product supply—making more products than customers buy—or the emergence of new economic powers, like China and India, that change global product prices.

Industry has responded to these market and societal imperatives by developing new types of manufacturing systems to produce products, and new business models to sell them. The integration of the new manufacturing system with the new business model and with the product architecture creates a new manufacturing paradigm. For example, the societal need to reduce automobile cost was realized by the invention of the moving assembly line (which, in 1913, was a new type of manufacturing system). The moving assembly line combined with the technology of interchangeable parts enabled the creation of the mass production paradigm.

*In the late eighteenth and early nineteenth centuries (two centuries ago), major changes in manufacturing took place, in Britain first, and in all Europe and North America later. In this period, which is called the Industrial Revolution, a move from manual-labor-based economy towards machine-based manufacturing occurred. The introduction of power-driven machinery and the parallel development of factory organization (see Chapter 12) created an enormous increase in the production of many kinds of goods, and is regarded as the birth of modern manufacturing.

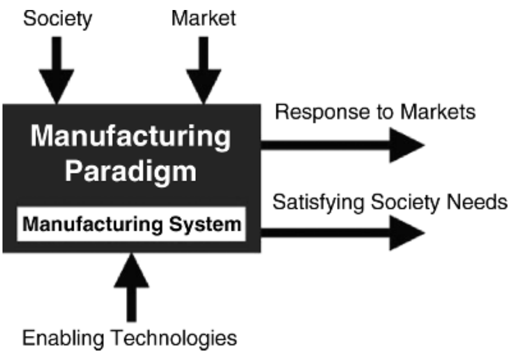

Figure 1.10 The manufacturing paradigm.

We define a manufacturing paradigm as:

> ***A Manufacturing Paradigm***
> A revolutionary integrated production model that arises in response to changing societal and market imperatives, and is enabled by the creation of a new type of manufacturing system

Figure 1.11 depicts our manufacturing paradigm generic model. As we said, the goal of each paradigm is driven by new market conditions or by emerging societal needs. Each new manufacturing paradigm is composed of a new type of manufacturing system, a new business model, and appropriate product architecture.

New paradigms become possible as new technology enablers are introduced and subsequently used to create new types of manufacturing systems. For each new paradigm, a new type of manufacturing system is developed—a system that is based on a new technology enabler and addresses the paradigm imperatives. For example, the emergence of the mass customization paradigm was driven by society's demand for expanded product variety. Producing a wider product variety became possible with

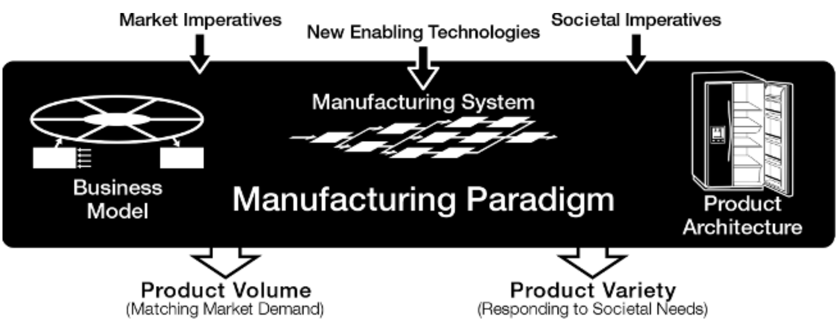

Figure 1.11 Manufacturing paradigm model.

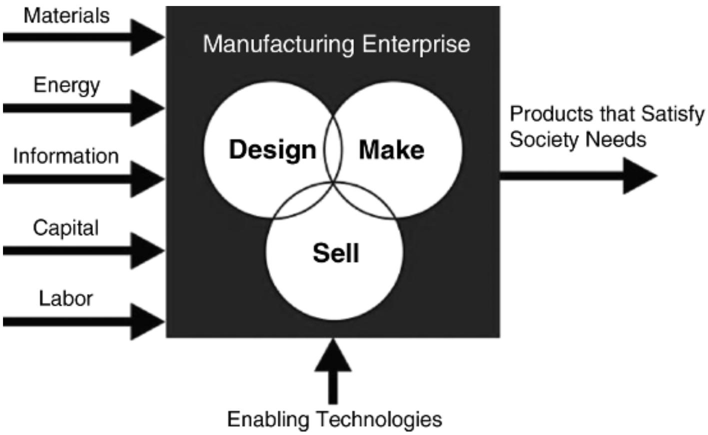

Figure 1.12 A manufacturing enterprise has three basic elements: *Design, Make,* and *Sell.*

the invention of the FMS. The new enabling technology of FMS was the mini-computer that was first integrated in the 1970s into controllers of CNC and industrial automation devices (see Appendix A). Thus, the mass customization paradigm became possible with the invention of the minicomputer.

The **product architecture** also transforms with the paradigm change. As product variety further expanded, product architecture became more and more modular. Each paradigm has its own **business model** that fits its nature and addresses its imperatives—society's needs and market conditions.

Each manufacturing paradigm addresses three basic elements: Design, Make, and Sell, as shown in Figure 1.12.

Design: Designing the product and its functions to satisfy particular societal requirements.

Make: Making the product by a manufacturing system that can quickly respond to the market's needs and opportunities.

Sell: Selling products to customers in order to satisfy their needs and to make a profit for the enterprise.

Is the sequence of these three elements always the same? It turns out that each manufacturing paradigm has a unique business model sequence of the three elements {**Design; Make; Sell**}, a sequence that has changed in each of the four major paradigms in modern manufacturing history.

1.6 FOUR MAJOR MANUFACTURING PARADIGMS

In order to understand the principles of the emerging **global manufacturing paradigm**, one must first understand the imperatives, enablers, and principles of the previous manufacturing paradigms, as well as their basic business-model principles. Today, one may identify four major paradigms in consumer goods manufacturing: (1) craft production, (2) mass production, (3) mass customization, and, most recently, (4) global manufacturing, which points in two directions at once: regionalized and personalized production.

1.6.1 The Craft Production Paradigm

We define craft production as creating exactly the product the customer asks for, on demand, and usually one unique product at a time. Highly customized craft products have been produced since time immemorial but this paradigm reached its zenith both in scale and in complexity with the hand building of coaches and carriages, and then automobiles starting around 1850. By the late 1800s and early 1900s, there were many craft producers of carriages that later turned to automobiles. Like the carriages, each part of an automobile was produced separately in a small machine shop that had general-purpose machine tools. Highly skilled workers that knew how to operate machine tools (such as lathes, drills, and milling machines) took great pains to produce precision parts, especially the complex mechanism like engines and drive trains. These workers also did all the bodywork and assembly.

The principle of the craft production paradigm may be summarized as:

> Skilled workers, using general-purpose machines, make exactly the product that the customer paid for; one product at a time.

Key enablers of this paradigm were:

- Low barriers to entry for new companies.
- A highly skilled work force that was able to produce precision products even with simple machine tools.
- Milling machines, necessary for precision finishing of metal parts, were invented in 1876.
- Development of the electric power station, in 1882 by Thomas Edison, supplied electricity to power the machine tools, making them safer and more reliable, as well as allowing the production of critical parts to take place in many more places, far away from traditional water-powered mills.

To a small but very exclusive market, craft production is still used today to produce exotic sport cars, custom furniture, and other single products. Each of them is literally a work of art.

France was the center of car production by craft methods in the 1880s. By the early 1890s, Panhard et Levassor (P&L) in Paris was building several hundred automobiles per year. Sir Henry Ellis, a member of the English Parliament, was in 1895 the first person in England to drive a car (which was produced by P&L); his car had a maximum speed of 10 miles per hour. In 1896, the first law for a legal speed limit was legislated in England—a maximum speed of 12 miles per hour. We have come a long way since then.

At the end of the nineteenth century, craft production of automobiles flourished in Europe. The total annual production was 1000 automobiles, of which no more than 20–50 were built to the same design. But even those duplicates were not completely identical, since each part was produced separately (not in series). More importantly, each vehicle was customized—it was built to order. By 1905, hundreds of companies existed in Western Europe and the United States, using the craft-production model.[6]

When buying a craft-built product the customer pays in advance, and only then is the product designed (with the customer's input) and produced. Craft production has a **pull-type** business model, with the sequence: Sell – Design – Make. First, the customer decides to purchase the product and "pulls" a product design from a variety of possible concepts offered by the manufacturer. Only when the customer orders the product it is designed in detail and then built from scratch. Craft production has the following characteristics:

- **High product variety** because each product is built to order
- **Very low volume per product**
- **Pull-type business model: Sell–Design–Make**
- **General-purpose machines** to perform all the manufacturing operations
- **Highly skilled work force**

1.6.2 The Mass Production Paradigm

Mass production, which flourished for most of the twentieth century, means producing extremely large quantities of identical products. This paradigm is expressed through the synchronized flow of production lines that produce key precision components and assemble the finished product. The moving production line consists of specialized equipment dedicated to assemble, transport, and finish products, and its operations are optimized to create economies of scale. To maintain high production volumes, machinery must take the place of human skill as much as possible, and machines are dedicated to very specific operations to produce the same product over and over without variation. Because extremely large quantities are involved, products can be produced at low cost and this enables a comparable reduction in the sale price. Reducing the cost of manufacturing, and therefore product price, is the main goal of mass production. Note that the two main characteristics of mass production—low product variety and high volume per product—are exactly the opposite of those in craft production.

In contrast to craft production that requires a highly skilled work force, mass production substitutes machinery for most of the human skills. Therefore, compared to craft and other paradigms, the average work force skill level required of mass production is very low.

The invention of the automobile **moving assembly line** in Dearborn, Michigan, by Henry Ford in 1913 is usually viewed as the starting point of the mass production paradigm. Ford's brilliance was that he understood the societal needs of the market—low-cost automobiles, and he invented the manufacturing system that reduced the cost of making them. The cars produced on Ford's 1913 assembly line were of "Model T." With the aid of the moving assembly line, within just 13 years the number of Ford Model T's produced in Dearborn increased from 40,000 to 2 million units annually.

Nevertheless, the availability of high-quality **interchangeable parts** was a main technological enabler for the success of mass production. Prior to interchangeable parts, each piece of a product had to be individually made and fitted in the product assembly. This involved time-consuming precision labor throughout the entire production process. The availability of interchangeable parts technology dramatically reduced production costs and allowed the use of low-skilled workers to build cars.

Mass production succeeded in lowered production cost, which, in turn, enabled reduction of the unit price. As prices lowered, more people could afford to buy the products, increasing the market for cars and resulting in even more sales, and therefore even greater production. More production created greater economies of scale, which lowered costs further; the lower costs enabled a further reduction in prices, and so on. . .

The business model of mass production is of a **push–type** and the business sequence is: Design – Make – Sell. First, the manufacturers design products they can build efficiently with their mass production system, and then they build them assuming there will be always customers to whom the products can be sold. The manufacturer's sales force "pushes" the products to a lot, and eventually the products are sold.

The mass production business model is based on the following principle:

> Production of a limited variety of products in high volume reduces production cost, which, in turn, allows price reduction for the benefit of customers. Reduced product price increases customer demand and sales.

The dominant characteristics of mass production are:

- **A very limited product variety**
- **A high volume per product** is produced to achieve economies of scale
- **Push-type business model: Design–Make–Sell**
- **Dedicated machinery and moving assembly lines** reduce costs
- **Relatively unskilled work force**

The mass production era continued from 1913 until the 1980s. Its peak in the USA was around 1955, a year in which the product variety was very small and the volume

TABLE 1.4 Annual Volume and Number of Models (variety) of Four Car Manufacturers

	Ford		GM		Chrysler		Toyota	
Year	Volume	Variety	Volume	Variety	Volume	Variety	Volume	Variety
1950	1,500,000	4	2,700,000	9	1,100,000	12		
1980	2,200,000	16	4,400,000	32	900,000	17	2,400,000	16

per product very high (compared to the United States population at that time). In 1955, six models of GM, Ford, and Chrysler accounted for 80% of all cars sold in the United States. A summary of the automotive industry sales in the United States between 1950 and 1980 is shown in the Table 1.4.

1.6.3 The Mass Customization Paradigm

Mass customization is a society-driven paradigm that started in the 1980s. As the market for a product matures and customers become wealthier, they begin to look for a **larger variety** of products to choose from. Society's need for a larger product selection is the imperative of this paradigm. In response to this imperative, manufacturers start to offer product "options," each comprising a number of extra features that constitute a "package" that is added to their standard product. Consequently, the customer is offered a larger variety to choose from. Increasing product variety at low cost is the goal of the mass customization paradigm.

In the mass customization paradigm, the manufacturers decide on the basic product options they can practically offer, and customers select the package that they prefer, buy it, and only then is the product finished. This allows the manufacturer to draw to the strengths of its mass production assets for the lowest cost production of major components while postponing the customization process to the final assembly with optioned accessories.

The penetration of computers into industrial operations has made the development of flexible automation possible. Flexible automation, in turn, enables inexpensive mass customization—the production of an expanded variety of products of the same product family at low cost. The low cost of production permits the sale of a wide variety of "customized" products based on the same product family at prices comparable to those of standard goods built by mass production methods.

With more variety offered, the probability increases that every customer can get the product he/she prefers. Offering options on cars is an example of mass customization. Types of customization may include dimensional, shape, color, taste, special features, etc.

There are two basic strategies for mass customization:

Strategy 1: Off-the-shelf variety of customized products

Strategy 2: Standard options installed on customized products

Strategy 1 is actually a transition stage from mass production to full mass customization. Pairs of jeans offered in a variety of sizes in a department store are a good example. It is, however, very much still a push-type business model, like mass production. The main economic decision here is how much variety (how many sizes) manufacturers should offer in order to maximize their profit.

Strategy 2 is the real mass customization approach. A typical example of Strategy 2 is the ordering of cars and computers (from Dell, for example) in the United States and Europe. Customers are given a set of possible options (now even on the Internet), and they choose the subset that best fits their needs and wants. Note that the manufacturing system must have a relatively high level of sophistication and flexibility in order to efficiently assemble the product with the correct options at a reasonable cost.

The business sequence of Strategy 2 mass customization is:

1. Design a product that can be enhanced by a variety of options
2. Sell the specific options to specific customers
3. Make (assemble) the product with the options that the customer selected

This is a combination of push (design and, to some extent, make by the manufacturer) and pull (final assembly to produce the customer's selected option). Therefore, we define it as a **Push–Pull type business model**, and the business sequence is: Design – Make – Sell.

Mass customization does not mean producing one-of-a-kind products, as in the craft production era. Mass customization develops multiple sets of practical variation (options) that can be produced on a mass production system and offered to potential customers, hoping to satisfy the specific needs of many customers. Therefore, very personalized production does not match with mass customization on one hand, and standard products, produced in the millions, do not fit on the other.

The mass customization business model is, therefore, based on the following principle.

> Production of a wide variety of customized products, at mass production cost, attracts more customers and increases sales.

The key enablers of mass customization are:

- *FMSs* including computerized numerical control (CNC) machine tools and computer-controlled handling equipment as well as welding and assembly robots that can quickly switchover production from one product type to another.
- *Marketing networks and customer–plant direct communications*: The mass customization paradigm started with aggressive direct marketing. The Internet now allows customer's orders that are directly communicated to the manufacturing plant.

Lean Production started around 1960 at Toyota in Japan, with the development of waste reduction methods to reduce product cost and enhance product quality (see Chapter 4). Before implementing "Lean" higher-quality products were produced at a substantially higher cost in effort and investment. Lean proved that high quality could be achieved even at a lower cost to the manufacturer. The principles of lean production started to be implemented in the United States and Europe by the late 1980s, when mass customization was also emerging, and therefore the goal of achieving high-quality products is sometimes associated with the mass customization paradigm. Lean production is not defined here as a new manufacturing paradigm; it just augments the other paradigms—producing higher-quality products at lower cost.

1.6.4 The Global Manufacturing Paradigm

The arrival of manufacturing globalization has intensified worldwide competition to a level not possible anytime in the past. With massive over-capacity in production and the proliferation of advanced communications, the next manufacturing paradigm—global manufacturing—points in two directions at once: regionalized and personalized production. Regionalized production for global markets is stimulated by exactly the same imperatives as mass customization, but directed more by cultural and regional differentiations. Personalized production for domestic markets is stimulated by the desire of customers to have exactly the product that they need (rather than merely settling for options) without paying the price of a craft-built product. Personalized production requires a short delivery time, and therefore fits domestic production that can compete with inexpensive imports.

1.6.4.1 Regionalized Production in the Global Manufacturing Paradigm Global manufacturing enterprises cannot ignore the customers' desire to have products that fit their specific cultural needs and living conditions. For example, the typical large U.S. washing machine cannot fit into the tiny apartments of Paris, Budapest, and Lima. Products should be designed with the world market in mind, and for regional customization in many specific regions. In the global manufacturing paradigm, regionalized products fit the culture, living conditions, and legal regulations of that region. Nevertheless, regionalized production is based on the principles of mass customization—the manufacturer decides the possible options that fit the region and asks the customers who resides in the region to select an option from those offered. The product features fit the culture of a consumer group, but they are not tailored toward value creation at the individual level.

1.6.4.2 Personalized Production in the Global Manufacturing Paradigm The personalized production facet of the global paradigm began to emerge at the close of the twentieth century. In the mass customization paradigm, customers only select from lists of available options. By contrast, in personalized production, customers are actively involved in the design of the products they want to buy. Personalized production is the next logical step in developing consumer products. "We are moving to a world in which value is determined by one consumer-created experience at a time; $N = 1$."[7]

The product design in the personalized production paradigm has two phases:

1. The *Initial Phase*, Design (A), in which the product architecture and module interfaces are designed, and the envelop of product variety and basic modules are established. This design phase is driven by strategic decisions made by the manufacturer to fit their facilities and strengths.
2. The *Personalized Design Phase*, Design (P), in which the final tailored design takes place with close interaction with the customer.

Although the general product architecture and the basic product modules are designed prior to the sale, the business sequence in this paradigm is such that "Sale" precedes the personal "Design (P)" phase. So, the sequence is Design(A) – Sell – Design(P) – Make and the business model is of a **Pull** type.

A classic example may be the design, construction, and installation of kitchen cabinets. Initially, the manufacturer makes a series of strategic decisions about the number of modules, their shape, functions, stylistic features, color, and the types of material that they can be made from. The customer's role is to design their own kitchen by selecting modules from a given range of available modules and arranging them to fit their own kitchen dimensions as well as convenient access, functionality, etc. None of the cabinetry is constructed until the personalized design phase is completed and the order is paid off. In the end, each kitchen will eventually be unique—a personal design that fits the customer's needs and price range.

The interior of automobiles could be constructed in the same way if a standard architecture and interfaces were available. Even more personalization can be offered when modules that are beyond the standard range are made available and manufactured not by the auto manufacturer, but by another company.

The business model of the personalized production paradigm is based on make-product-to-customer's design, where modules are selected from a pre-designed, given range. It obeys the following principle.

> Cost-effective, timely production of made-to-customer's design products increases sales by exactly tailoring the product's options and features to the customer's needs.

The business model emphasizes timely production. A short delivery time to the customer is an essential component in gaining a competitive advantage in personalized production. Therefore, the personalization paradigm enables shifting production (or at least the product final assembly plants) from low-wage countries to countries in which the product is sold.

1.7 PARADIGM TRANSITIONS OVER TIME

To summarize, we discussed four paradigms:

1. Craft Production, in which each product is designed and made for a particular customer, effectively a "Market-of-One."
2. Mass Production, in which only a few models are made, assuming there will always be enough buyers.
3. Mass Customization, in which customers select a product from a list of available options before production.
4. Personalized Production—a segment of Global Manufacturing—in which product options are designed by the customers, sold, and then produced on advanced manufacturing systems.

As we said, each manufacturing paradigm has had a different set of imperatives that came either from societal needs or from market forces, as seen in Table 1.5. These imperatives change the principle of the business model, such that it creates value for the customer and the company.

Over the past two centuries, manufacturing has come nearly full circle: **From focusing on the individual (Craft) to focusing on the product (Mass Production), to focusing on targeted market groups (Customization), and back to the individual customer (Personalization)**. The main principle of the business model originated from a pure pull system in the craft production paradigm and transitioned to a pure push system in mass production, it then transitioned again to a push–pull type for mass customization. The global manufacturing paradigm suggests that the next shift will go almost a full circle with the introduction of personalized products.

TABLE 1.5 Manufacturing Paradigms and Their Drivers

Paradigm	Craft Production	Mass Production	Mass Customization	Personalized Production
Focus	The individual	The product	Market segments	The individual
Societal new needs	Tailored-made products	Low-cost products	Large product variety	Personal-fit products
Business model principle	Pull	Push	Push–Pull	Pull
	Sell–Design–Make	Design–Make–Sell	Design–Sell–Make	Design (A)–Sell–Design (P)–Make

The author perceives the business model shift as a change in the customer's role in relationship with the enterprise's three main basic functions—Design, Make, Sell—as shown in Figure 1.13.

The customer initiates the Sell–Design–Make sequence in craft production (a pull-type model) and drives the design. In the mass production model, the customer is, however, at the back of the sequence (a push-type model). "The customers will always be there to buy products" is the main assumption of mass production. In mass customization, the manufacturer makes the main strategic decisions about the product basic architecture (a "platform" in the auto industry) as well as the number of variants and options offered based on targeted customer groups. The customer can only select the option that best fits his/her preferences and price. The personalized production paradigm promises customers both the greatest fit to their needs with the greatest cost-effectiveness. It is closest to the craft production model but has a more complex sequence, as shown in Figure 1.13.

Although the goal of both the mass customization and personalized production paradigms is to create a better fit between product offering and customer preference, the manufacturer's strategic decisions in each paradigm are different. In mass customization, the strategic economic decision is how many variations and options will provide the highest economic value for the manufacturer. On one hand, more variations will add complexity and cost, but on the other, more variation increases the number of potential customers, and thereby expands sales and market share.

In personalized production, the product has a modular architecture, and the manufacturer's strategic decisions are (1) the product architecture to which modules

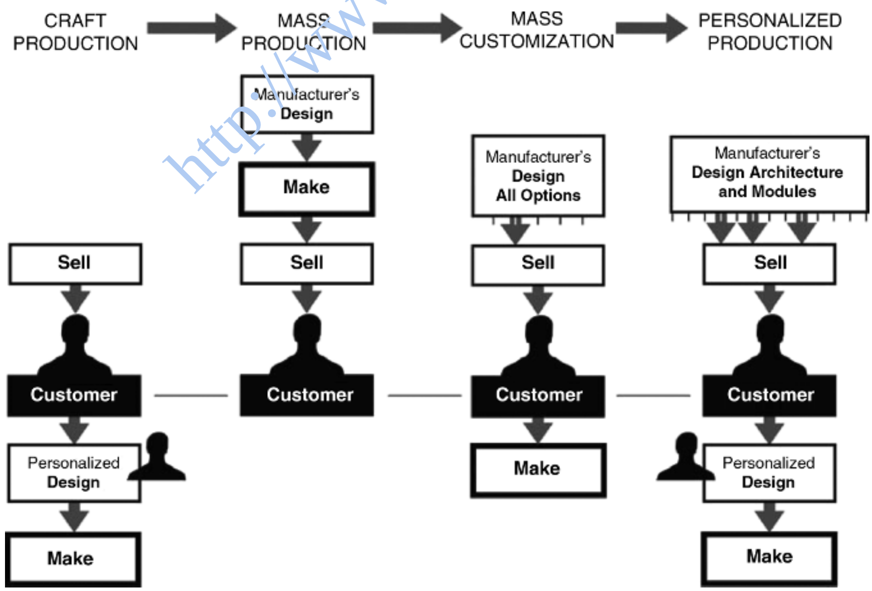

Figure 1.13 The customer role in the four paradigms.

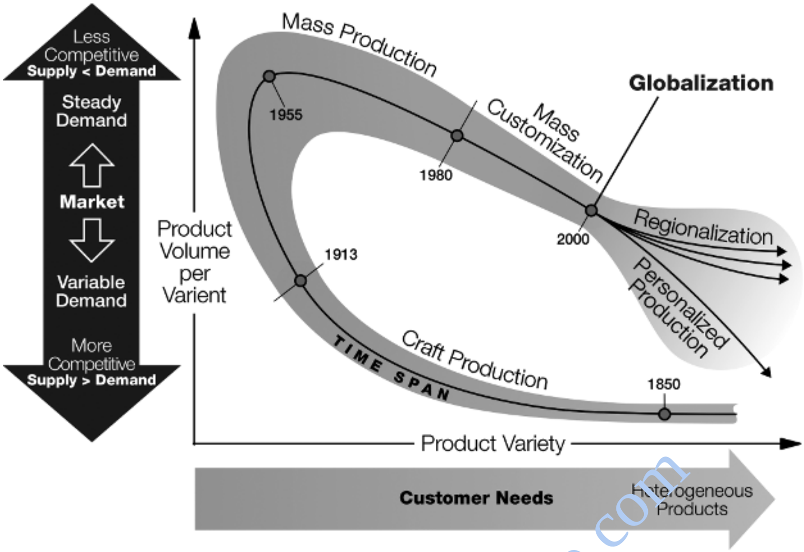

Figure 1.14 The drivers to new paradigms are market and society needs.

will be attached, (2) the type of interfaces to accommodate the modules, and (3) the type and function of modules from which the customers can design their individual product. In the personalized production paradigm, customers are involved in the design of their product, while in mass customization, the customers can only select a best fit to meet their needs.

In a globally competitive world, the customers' role in the Design–Make process is paramount and their involvement is intensified as the paradigm shifts from mass production to mass customization, to the personalized production paradigm. It is maximized in craft production, but there the product cost is highest of all. The personalized production paradigm promises optimal value to the customer when the level of their satisfaction and product price are traded off.

As we have said, new manufacturing paradigms are established by emerging societal needs or by new market conditions. An illustrative model of the four paradigms for automobiles is depicted in Figure 1.14*. The years 1850, 1913, and 1955 on the time line in this figure fit the paradigm shifts in automobile production in the Western world.

The paradigm model's inputs are the market and customer's needs. The model's outputs are the number of variants (i.e., models) offered for products with similar functionalities, and the product volume per variant, which reached its peak

*A different graph that shows the number of products versus the volume per product has been depicted by J. P. Womack, D. T. Jones, and D. Roos in *The Machine that Changed the World*, HaerperPerennials Publishers, New York, 1991, p. 126.

(minimum variants) in automobile production in 1955. From the mid 1950s, the trend in product variety versus volume is toward higher variety and smaller volume per variant, a trend that is applicable not only to automobiles, but also to many consumer goods, such as appliances, office furniture, etc.

The graph shows how changes in the market and consumer's needs propel the paradigm transition. Globalization currently impels regionalization (regional customization) and personalized production, in which society requires a larger variety and smaller volumes per product variant. Market fluctuations, which become larger every day, force manufacturers to produce even smaller volumes per each product variant. This trend in terms of product volume per model is perhaps moving toward those of craft production—a market-of-one.

1.7.1 Paradigms and Types of Manufacturing System

The challenges of each new manufacturing paradigm have always been met by a new type of manufacturing system, which, in turn, was made possible by applying a technological enabler that was new at the time the paradigm started. For example, as depicted in Figure 1.15, the mass customization paradigm was realized by utilizing FMS, since that manufacturing flexibility enabled cost-effective production of a variety of products. And mini-computers (which were a new technology in the 1970s; see Appendix A) enabled the creation of FMS and its basic building blocks—CNC machines and industrial robots.

A wise manufacturer who identifies emerging societal or market needs and knows how to invent a manufacturing system to address these needs will be successful. Henry Ford is a classic example. Ford realized that high product cost was the main obstacle that was keeping people from buying automobiles. He reasoned that if the price could be lowered, many more people could afford to buy cars and the market would flourish. Ford asked himself how product cost could be lowered if the cost of material and labor were constant. His answer was to organize the work differently. He organized the car assembly work sequentially, and later he invented the moving assembly line. The "Ford Method" worked great, but only, as it has been found, in stable markets where demand is greater than supply.

Figure 1.16 shows the relationship between the market and societal needs (e.g., heterogeneous products) on one hand, and the manufacturing systems that work best in responding to these conditions, on the other. In the craft production paradigm, general-purpose machine tools were used. They were replaced in the mass production

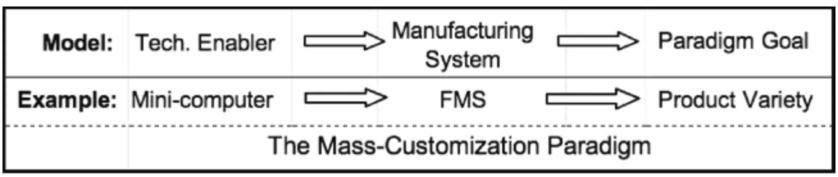

Figure 1.15 The paradigm goal is met by a new manufacturing system.

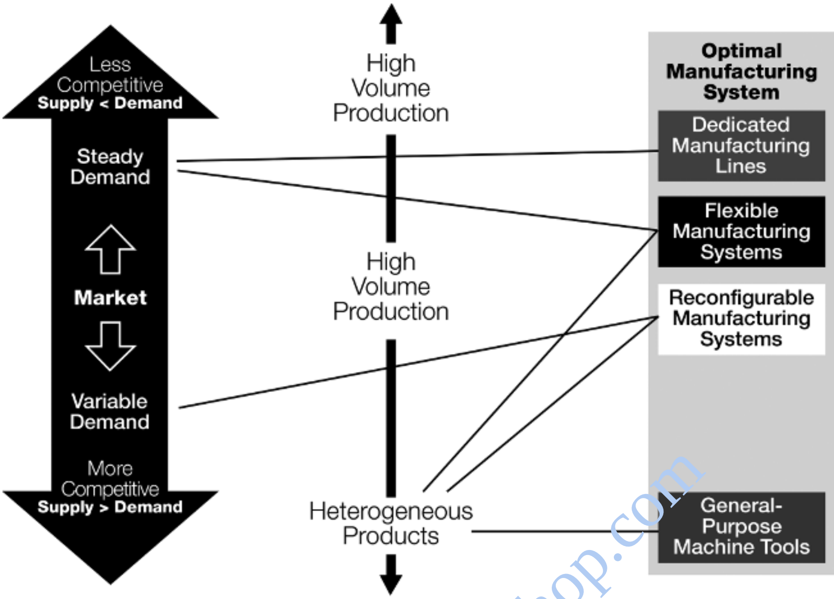

Figure 1.16 Market and society needs are linked to corresponding manufacturing systems.

paradigm by DMLs that utilized fixed automation to manufacture products and parts (e.g., car engines, pump housings, etc.) in very large and stable quantities.

As the balance between supply and demand starts to turn toward Supply > Demand, customers begin to look for products that better fit their preferences, in addition to low prices. The product market gradually stops being homogeneous, and starts to become more and more diverse. In response to this imperative, manufacturing engineers developed the FMS to produce the product mix that the market demands.

The characteristics of FMS perfectly fit markets with stable demand that require systems with fixed capacity. FMS, however, does not fit unstable markets with fluctuations in product demand (rocky markets) as we are witnessing in the globalization era. The engineering response to this new situation is the RMS. The RMS can adjust production capacity (i.e., volume per product) quickly to match market demand, can be rapidly tooled to produce new products, and can be upgraded with new functionalities to produce different varieties of the product. RMS enhances the firm's speed of responsiveness to new market conditions and gives a competitive edge to the enterprise.

Table 1.6 shows how societal needs and market forces have changed over the past two centuries, and the effect this has had on paradigm goals. It shows the corresponding changes in the manufacturing system, the product architecture, and the corresponding business model principle—all aimed at reaching that goal.

TABLE 1.6 Characteristics of Four Manufacturing Paradigms

Paradigm	Craft Production	Mass Production	Mass Customization	Global Manufacturing
Society needs	Unique products	Low-Cost products	Large product variety High quality	Regional products Personalized products
Market demand		Steady	Unstable	Fluctuating
Paradigm goal	Satisfy customer's desire	Product low cost	Wide variety	Rapid speed of responsiveness
Technology enabler	Electricity	Interchangeable parts	Computers	Information tech. and the Internet
Manufacturing system	Electrically powered machine tools	Moving assembly line Dedicated machines	Flexible systems w/Lean operations	Reconfigurable systems
Product architecture		Unified	Modular	Highly modular
Business model principle	Pull	Push	Push–Pull	Pull

The goal of the preceding paradigm is still a goal of the new paradigm, but additional goals divert the paradigm focus. Figure 1.17 conveyed graphically the transition of paradigm goals.

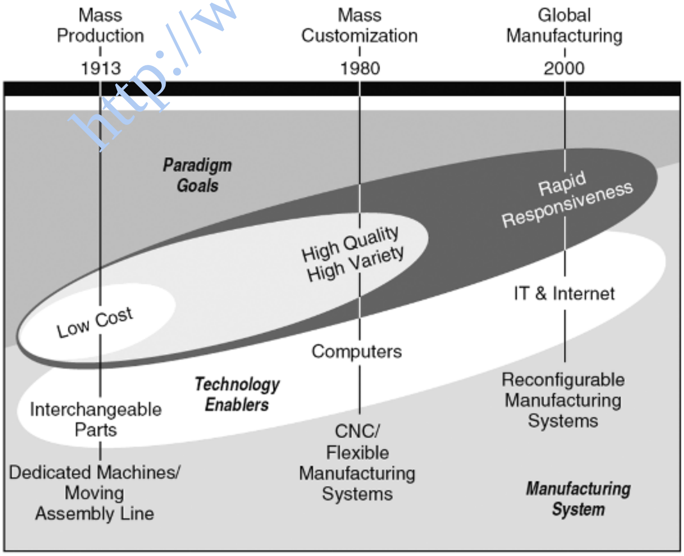

Figure 1.17 Each paradigm was driven by a goal, which was achieved by a new type of manufacturing system, which, in turn, was realized by a technology enabler.

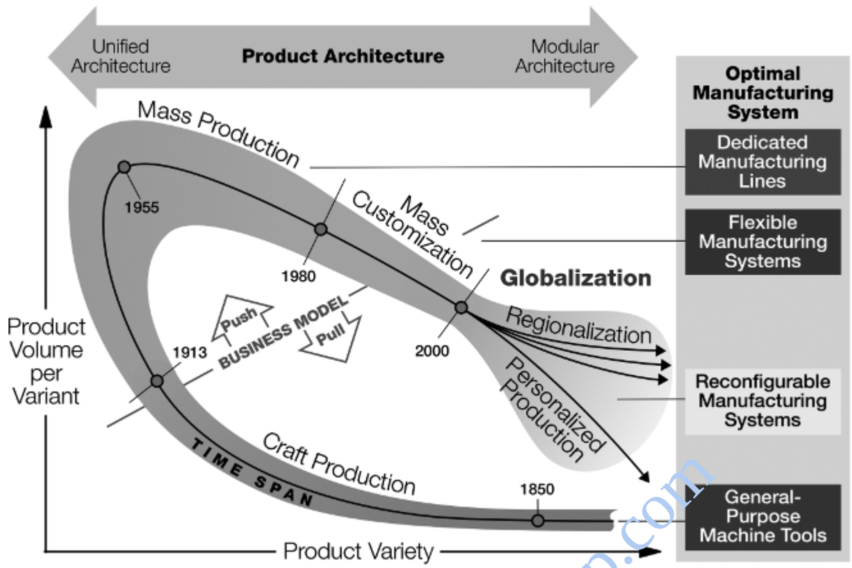

Figure 1.18 The product architecture and the manufacturing system fit the paradigm.

Figure 1.18 illustrates the relationships in the Western world between the type of manufacturing systems, the product architecture, and a simplified business model in four automotive production paradigms. This illustration shows how the paradigms transitioned over time given the changing needs of society, markets, and the emergence of new technological capabilities.

With the emergence of personalized production as an imperative of the global manufacturing paradigm, the time line in Figure 1.18 is moving toward closing the loop with the starting point of the craft production paradigm. The business model of personalized production is again of a pull-type. However, there is some big difference—the manufacturing cost of products in the personalization paradigm is much lower than that in craft production.

The basis of strategic thinking about the future of manufacturing enterprises may be drawn from Table 1.6 and Figure 1.18. Industry leaders must understand the current societal needs and emerging technologies to predict the future direction of manufacturing enterprises. For example, environmental concerns require product's end-of-life solutions, which will impel new life-cycle engineering-business models. For another example—the reduced prices of optical components developed for digital cameras has enabled a new generation of in-line inspection machines that inspect every single mechanical part at the line speed. Integrating these machines into production lines will tremendously increased product quality and reduce warranty costs. Companies have to assess how new technologies can assist in solving burning social imperatives.

Focusing on the marketing of current products may help a company, but only in the short term. Long-term success requires a strategic analysis of business–product–manufacturing relationships as well as an awareness of up and coming technologies that may revolutionize manufacturing operations and product architecture. Studying how past paradigms evolved can also assist in this analysis.

Globalization is causing market fluctuations that have brought serious instability to many manufacturing enterprises that are struggling to survive. Clearly, Darwin's principle—*the species that survive are usually not the smartest or the strongest, but the ones most responsive to change*—is applicable to the twenty-first century manufacturing enterprise! To thrive in the global manufacturing era, manufacturing enterprises must adapt to rapid changes in the new global economic environment. The enterprise's speed of responsiveness is essential to its staying alive in a rapidly changing world.

PROBLEMS

1.1 Compare the manufacturing paradigms in Table 1.5 in terms of (1) work force skills and (2) the level of flexibility of the manufacturing tools.

1.2 We say: "One of the benefits of mass customization is that it has the potential to create a diverse and large customer base. A large and diverse customer base has an advantage beyond market share: the cash flow generated by a large number of customers with diverse tastes is more stable than the cash flow of a large homogeneous customer base." Explain why a diverse customer base provides more stable cash flow relative to a homogenous customer base.

1.3 Is personalized production limited to a certain spectrum of products? Is product complexity a factor in deciding to design a product for personalized production, or is product complexity irrelevant to a product fit to personalized production?

1.4 Do you think customers should be offered as much variety as possible?

1.5 Will the loop in Figure 1.14 be ever closed in terms of variety and volume? What is your prediction?

REFERENCES

1. Y. Koren, F. Jovane, U. Heisel, T. Moriwaki, G. Pritschow, G. Ulsoy, and H. VanBrussel. Reconfigurable manufacturing systems: a keynote paper. *CIRP Annals*, 1999, Vol. 48, No. 2, pp. 6–12.
2. The New York Times, January 7, 1994.
3. http://www.federalreserve.gov/releases/g17/current/default.htm.
4. Deloitte's Global Benchmark Study Program. *3rd Report: Mastering Innovation*, May 2005.

5. F. Jovane, Y. Koren, and C. Boer. Present and future of flexible automation—towards new paradigms: a keynote paper. *CIRP Annals*, November 2003, Vol. **52**, No. 2, pp. 543–560.
6. J. P. Womack, D. T. Jones, and D. Roos. *The Machine that Changed the World*. Harper-Perennials Publishers, New York, 1991, p. 24.
7. C. K. Prahalad and M. S. Krishnan. *The New Age of Innovation*. McGraw Hill, 2008.