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Evolving Paradigms of Manufacturing: From Mass Production to Mass Customization and Personalization

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Abstract

This paper reviews the development of the paradigms of manufacturing, including mass production, mass customization and the emerging paradigm of personalization. In each paradigm, we discuss the contributions of scientific principles, manufacturing technologies and systems operations and how they are integrated together to achieve quality, productivity and responsiveness in manufacturing. We also compare the roles of the consumer in each paradigm.

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1. Introduction

Manufacturing is essential to a nation's economic well-being and quality of life for its citizens because manufacturing creates lasting wealth while also distributes wealth through high-paying jobs. Since its birth two centuries ago, the manufacturing industry has evolved through several paradigms [1]. The first paradigm was "Craft Production", which created the product the customer requested but at a high cost. There were no manufacturing systems associated with this paradigm. In addition, the providers of craft products were confined to localized geographical regions hence such production was not scalable. Interchangeability and the moving assembly lines enabled the development of "Mass Production" which provided low-cost products through large scale manufacturing. However, the number of varieties offered by such production was very limited, as evidenced by the famous statement from Henry Ford, "Any customer can have a car painted any color that he wants so long as it is black" [2]. In the late 1980s, global competition and consumer demands for high product variety led to the development of "Mass Customization" [3]. Manufacturers designed the basic product architecture and options while customers are allowed to select the assembly combination that they prefer most. Product family planning enabled manufacturers to share certain common components across the products in the family so that economy of scale is achieved at the component level. Flexible and reconfigurable manufacturing systems are utilized to create high variety in the final assembly through combinational assembly, thus achieving the economy of scope. For example, BMW claims that the number of possible combinations for the 7 Series alone could reach 10^{17} (www.bmwgroup.com). Many companies are offering high variety through such an approach.

What is the next manufacturing paradigm? For the past three decades, the governing premise of many corporations has been to maximize shareholder value. However, in an article published in the *Harvard Business Review*, Martin [4] shows that corporations that focused on the consumers have been considerably out-performing companies that focused on the shareholders. Hence, Martin advocates a shift from focusing on shareholder value to focusing on the consumer. In their widely read book, "The Game Changer" [5], former CEO of Proctor & Gamble A.G. Lafley and management consultant Ram Charan advocate a core business practice centered on the idea of the "customer as boss". They advocate "Actually getting her involved in co-creation and co-design. At its foundation is clarifying, segmenting, and precisely targeting the who before engineering and formulating new-product innovations. This means involving her in the iterative, two-way creation and design of innovation, right from the start."

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Consumers' desire to influence and participate in the design of products is the key driver leading to the new emerging manufacturing paradigm – which we call *Personalization* or *Personalized Production*.

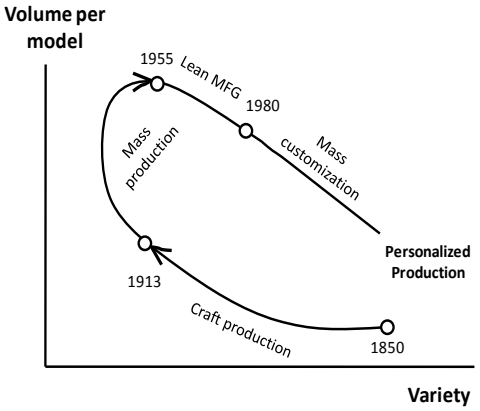

Fig. 1. Volume variety relationship in manufacturing paradigms [1].

The evolution of the manufacturing paradigms is illustrated in Fig. 1 using a volume-variety relationship. In the remainder of the paper, we review the development of mass production and mass customization and the enabling technologies associated with each. Then we discuss the emerging paradigm of personalization and the enabling technologies required to realize such a new paradigm.

2. Mass Production

Mass production, or the American system of production, began with the introduction of the Henry Ford moving assembly line at Highland Park near Detroit, Michigan and reached its peak after the end of the World War II when demands for products were very high. Interchangeability, moving assembly lines, and scientific management are the key science, technology, and systems enablers for mass production. While mass production created tremendous wealth for the U.S. and many individuals, it also had several weaknesses as we will see later.

Interchangeability: The ability to randomly select parts and assemble them together was crucial to the introduction of assembly lines at the beginning of the 20th century. Individual parts were made in large volumes but controlled within tolerance. Products can be assembled in a random order to desired specification and performance. The concept of interchangeable parts began in Europe, but Eli Whitney was credited with experimenting with interchangeable parts in 1801 when he built 10 guns using the same exact parts and mechanisms and then disassembled and reassembled them in front of the U.S. Congress [6]. While Whitney actively promoted the concept of interchangeability, he was not able to successfully implement it in his production. Henry Leland, founder of Cadillac automobiles, later successfully adapted interchangeable parts for automobile manufacturing. Interchangeable parts enabled the economic production of components parts in large volumes. Subsequently, economy of scale was achieved when all these came together on the assembly line.

Moving Assembly Line: The first modern version of an assembly system was the moving assembly line introduced by Henry Ford in 1913 at Highland Park, Michigan for producing the Model T automobiles (see Fig. 2). Prior to the introduction of the assembly line, cars were individually crafted at fixed locations by a group of workers who traveled from car to car. The process was slow and expensive. The moving assembly line where the cars came to the worker who performed the same tasks again and again was able to significantly improve the speed and reduce the cost of assembly [7]. Table 1 illustrates the productivity gains achieved through moving assembly lines. This technology is still being used today.

Fig. 2. Henry Ford assembly line at Highland Park [7].

Table 1 Productivity gains due to the moving assembly line at Highland Park.

Pre-1912	20-30 per day
1913	100 per day
1914	1000 per day
1915	3000 per day

Division of Labor: The production of volumes of individualized parts and the moving assembly lines led to specialization in the tasks of the workers. While division of labor was not a new concept in society, the moving assembly line and production systems further divided work with much finer granularity by having each worker focus on some specialized repetitive tasks. Adam Smith predicted very early that division of labor represented a qualitative increase in productivity [8], but