Manufacturing Operations: Process Technology Selection, Facility Design, and Production Systems

Natalie Park
University of Toronto, Canada

ABSTRACT

This paper is investigating how manufacturing works make process technology, facility design and production system consistent with product characteristics and competitive priorities. Introduce the product-process matrix, and explain the differences among job shop, batch production, assembly line and content flow system. He also talked about how the flexible manufacturing system balances the efficiency and the balance between various products, and the role of configuring facilities in improving material flow, production efficiency and work flexibility. In addition, he also stressed that in order to achieve complex, customized and low-volume production, the importance of additive manufacturing is increasing. This research has changed the manufacturing work, including the digital technologies related to Industry 4.0-smart sensors, AI, robotics, additive manufacturing, but more flexible.

Keywords: Manufacturing Operations; Process Technology; Facility Layout; Product-Process Matrix; Job Shop; Flexible Manufacturing; Additive Manufacturing; Industry 4.0

1. INTRODUCTION

Manufacturing operations management, which is the design plan management of the product system that converts materials into finished products. These decisions include: production process technology (what kind of production process or equipment to use), facility layout (how to arrange the flow of equipment and materials in the factory) and production scheduling, capacity management, which determine the form of production system, as well as the cost management, quality, flexibility and speed of the company. Therefore, the decision of Manufacturing operations is one of the most important strategic choices made by production companies.

2. PRODUCT-PROCESS MATRIX

2.1 Hayes and Wheelwright's Framework

The Product-Process Matrix of Hayes and Wheelwright(1979) shows the quantity and types of product on one axis and the manufacturing methods (job shop, batch, line flow, continuous) on the other axis. Job shops (low volume, high variety: custom machine shops, shipyards) use general-purpose equipment arranged by function (process layout) to accommodate diverse product requirements; batch manufacturing (moderate volume, moderate variety: electronics assembly, food processing) uses partially dedicated equipment with moderate setup times; assembly lines (high volume, low variety: automotive final assembly, appliance production) use highly dedicated, specialized equipment arranged in product flow sequence; continuous flow processes (very high volume, commodity products: chemical plants, paper mills, oil refineries) operate without interruption with fully dedicated equipment.

2.2 Flexible Manufacturing

Flexible Manufacturing Systems (FMS)—computer-controlled manufacturing cells that can produce a family of similar parts or products with minimal changeover time—represent a technological response to the traditional trade-off between efficiency (mass production) and flexibility (job shop customization). FMS achieves both through programmable computer numerical control (CNC) machinery, automated material handling, and real-time production control software that enable rapid product changeover and simultaneous production of different products in the same facility. Jaikumar's (1986) Harvard Business Review analysis of FMS adoption found that American manufacturers used FMS primarily to reduce cost (producing fewer different parts than Japanese manufacturers), while Japanese manufacturers used FMS to achieve flexibility (producing more product variants)—illustrating how the same technology can be applied to achieve different competitive priorities.

Table 1. Manufacturing process types with volume/variety characteristics and examples.

Process Type	Volume/Variety	Examples
Job shop	Low volume; high variety; custom	Aircraft manufacturing; custom furniture; prototype development
Batch production	Medium volume; medium variety	Pharmaceutical manufacturing; food processing; electronics
Assembly line	High volume; low variety	Automotive assembly; consumer appliances; fast food
Continuous flow	Very high volume; commodity product	Oil refinery; paper mill; chemical plant; cement
Additive manufacturing	Low-medium volume; high complexity/customization	Medical implants; aerospace components; rapid prototyping

3. FACILITY LAYOUT AND FLOW

Facility layout—the spatial arrangement of equipment, workstations, material storage, and support functions within a manufacturing facility—determines material flow efficiency, worker productivity, quality visibility, and production flexibility. Four fundamental layout types correspond to the product-process matrix: fixed-position layout (large products assembled in place: aircraft, ships); process layout (equipment grouped by function: job shops); product layout (equipment arranged in production sequence: assembly lines); and cellular layout (equipment grouped to produce a family of similar products: manufacturing cells that achieve job shop flexibility with line flow efficiency). Value stream mapping—a lean tool that visualizes material and information flow through a facility—identifies layout inefficiencies that create waste in transportation, motion, and waiting.

4. ADDITIVE MANUFACTURING

Additive manufacturing (AM/3D printing)—building parts layer by layer from digital design files rather than subtracting material from solid stock (traditional machining) or forcing material into molds (casting, forming)—is transforming manufacturing capabilities for complex geometries, customized products, and low-volume production. AM enables part geometries that are impossible to manufacture conventionally (internal lattice structures for weight reduction, conformal cooling channels in injection molds), eliminating tooling lead times for low-volume production and enabling mass customization (individually tailored medical implants, hearing aids, dental aligners). General Electric's LEAP engine fuel nozzle—AM-produced from nickel alloy in one piece vs. 20 welded parts previously—achieved 25% weight reduction and 5x longer life while reducing production cost: demonstrating AM's potential to change manufacturing economics for appropriate applications.

5. CONCLUSION

Manufacturing operations management has developed robust frameworks for matching production process to product characteristics, designing efficient facility layouts, and deploying production technologies that achieve cost, quality, flexibility, and speed objectives. Industry 4.0's integration of digital technology into manufacturing—through smart sensors, additive manufacturing, collaborative robots, and AI-powered process optimization—is expanding what is achievable in manufacturing operations while creating new design, planning, and control challenges. Future research should examine how the combination of additive manufacturing (eliminating tooling and enabling local production) with AI-powered design (generative design algorithms creating optimal structures) and autonomous robots (reducing labor content) transforms the economics and geography of manufacturing—potentially enabling localized, flexible manufacturing that reverses some of the globalization that has characterized manufacturing since the 1980s.

REFERENCES

[1] Hayes, R. H., & Wheelwright, S. C. (1979). Link manufacturing process and product life cycles. Harvard Business Review, 57(1), 133–140.
[2] Jaikumar, R. (1986). Postindustrial manufacturing. Harvard Business Review, 64(6), 69–76.
[3] Slack, N., Jones, A. B., & Johnston, R. (2016). Operations management (8th ed.). Pearson.
[4] Wohlers, T., Campbell, R. I., Diegel, O., Kowen, J., & Mostow, N. (2022). Wohlers report 2022: 3D printing and additive manufacturing global state of the industry. Wohlers Associates.