Holonic Manufacturing Systems for Agile Manufacturing

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Executive Summary

Bedford Innovations is a multinational manufacturing enterprise based in the US. To place Bedford Innovations as a successful, high technological global design and manufacturing enterprise in the year 2035, the company needs to be committed to transformation in order to be sustainable in the future of manufacturing. The goal of this report is to provide a framework for Bedford Innovations to continue the growth of the company as technology shifts in the ever changing current of manufacturing technology.

1 High-Tech Global Design and Manufacturing Enterprise in 2035

The changing economics within the manufacturing industry, along with the changes in consumer demands requires a shift in the way companies do business. In the year 2035, the manufacturing industry will have a much broader focus on the production of physical products. With the exponential advancement of technology, including artificial intelligent (AI) and manufacturing processes, there will be shifts in consumer demands for physical products. Consumers already desire smarter personalization as options on all of their products as self expression through consumer customization is becoming the societal norm.

Asian markets for the past five years have been considered an emerging market area in the manufacturing sector [1]. To compete, US based manufacturing industries need to be competitive and develop innovative techniques to gain access to global markets. New business models need to be implemented where the view of the future is considered to adapt with the growth of future market.

Key challenges for the manufacturing in the year 2035 are:

- **Dynamic economics:** Flexibility and adaptability to economic climate uncertainty in order to sustain the market demands as they fluctuate.
- **Smarter product development:** Manufacturing capabilities need to be innovative in the product development process in order to have better, faster, and less expensive end products for the general consumer.
- **Competitive market:** Competitive in the producers market requires the company to be innovative and have high efficiency in the manufacturing capabilities.

Based on the predictions of market trends and the associated key challenges, implementation of holonic manufacturing systems (HMS) for agile manufacturing will be a key component for Bedford Innovations to be an effective competitor in the ever evolving dynamic global economy of 2035.

2 Holonic Manufacturing Systems for Agile Manufacturing

Implementation of a Holonomic Manufacturing System for Agile Manufacturing for Bedford Innovations' business model starts with defining the concept of holonomic manufacturing systems and agile manufacturing.

2.1 Holonic Manufacturing Systems

A Holonic Manufacturing System (HMS) is a method of controlling a manufacturing system. The HMS is based on the concept of autonomous cooperating agents. The holonic concept was originated from Arthur Koestler [2] to explain the concept between wholeness and partness in living organism and social organizations. HMS consists of holons, autonomy, cooperation, and holarchy.

The concepts and characteristics of holonic systems as defined by the HMS consortium are [3]:

- *Holon:* An autonomous and cooperative building block of a manufacturing system for transforming, transporting, storing and/or validating information and physical objects. The holon consists of an information part and often a physical processing part. A holon can be part of another holon.
- *Autonomy:* The capability of an entity to create and control the execution of its plans and/or strategies.
- Cooperation: A process whereby a set of entities develops mutually acceptable plans and executes these plans.
- *Holarchy:* A system of holons that can cooperate to achieve a goal or objective.
- *HMS:* A holarchy that integrates the entire range of manufacturing activities from order booking through design, production, and marketing to realize the agile manufacturing enterprise.

A holon is designed to be an autonomous entity that can operate as a whole and can also have sub-holons. Holons are formed by physical processing and a software controlling unit which operates autonomously. The HMS concept in manufacturing systems consists of autonomous modules (holons) with distributed control where each holon has a level of independence and reacts to disturbances independently [4].

2.2 Agile Manufacturing

Agile Manufacturing (AM) is defined by a manufacturing system that enables quick responses to customer needs and market changes [5].

3 Implementation of HMS Concept

Modern manufacturing systems involve managing large and complex systems. Implementing an HMS system to the manufacturing system could be used to achieve an agile manufacturing system. The structure of the manufacturing organization for Bedford Innovations is shown in Figure 1. The manufacturing organization is designed by a combination of building blocks (holons) with the internal structure inside the building blocks. Each building block is designed to be an autonomous system. This independence allows the system to have a level of autonomy in order to improve the individual manufacturing process as part of the whole manufacturing facility's capabilities.

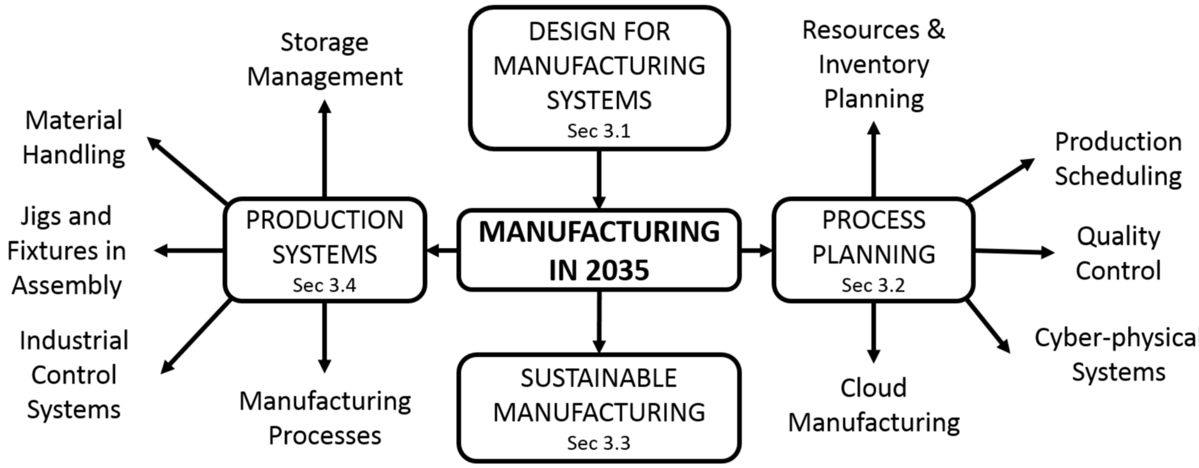

Figure 1: Manufacturing Organization

3.1 Design for Manufacturing Systems

Design for Manufacturing Systems (DFMS) is the combination of the product design process, the process planning production systems, and sustainable manufacturing into one common system. DFMS is different compared to common manufacturing design standard; Design for Manufacturing (DFM) [6], Design for Assembly (DFA) [7, 8], Design for Quality (DFQ) [9], Design for Packaging (DFP) [8], Design for Resilience (DFR) [10], Design for Environment (DFE) [11], Design for Sustainable Manufacturing (DFSM) [12], and Design for Additive Manufacturing (DFAM) [13] where DFMS combines all of the manufacturing design processes together in the early design process. The implementation of DFMS will predict the performance measures of the production processes before it is built. The difficulty to implement the DFMS process is to have software tools, manufacturing facilities and capabilities, human labor, and available production resources to provide enough information to executed the system effectively. The DFMS is imagined to provide simulation of possible methods in production planning to design the best possible system to meet the specified requirements while operating the system in the best possible way to meet those requirements.

3.2 Process Planning

Process planning of manufacturing systems includes business planning, resources and inventory planning, production scheduling, quality control, cyber-physical systems, and cloud manufacturing.

3.2.1 Resources and Inventory Planning

Resources and inventory planning can be defined as finding the available resources (suppliers) for production, production capacity, human labor, and managing the inventory (raw materials) to support the manufacturing processes. The idea is to optimize the available resources to maximize the profits without affecting the product quality specifications. Databases of inventory and resources are needed to monitor and autonomously update in real time for tracking proposes. The inventory and resources are treated as an autonomous module which keeps track of the supply chain process thus improving the process planning optimization of inventory and material storage space. The merit system can be used to identify supplier characteristics in order to check supplier performance.

3.2.2 Production Scheduling

Production scheduling deals with planning a set of tasks to make use of resources and equipment for the production tasks. Real-time monitoring systems can be used to update the production process and equipments status. The equipment is equipped with enough sensors to keep track of the machine status in order to include predictive and preventive maintenance scheduling and unexpected maintenance on a real time basis. All machinery and equipment are connected to a cloud system where the tasks can be distributed directly to the machinery and equipment based on sensor feedback.

3.2.3 Quality Control

Quality control activities need to be automated and monitored where quality related data can be used to correlate with process planning parameters to reduce the quantity of rejected products and predict the source of low quality production processes.

3.2.4 Cyber-physical systems

Cyber-physical systems (CPS) involve the integration of software and embedded intelligence in the equipment [14]. Realization of the HMS concept depends on implementation of CPS on the manufacturing organization's architecture. The CPS enables data analytics processes to be executed. Artificial intelligence (AI) and machine learning (ML) can contribute to the data analytics to create intelligent manufacturing systems (IMS). This will help track and trace possible solutions to improve the production processes.

3.2.5 Cloud Manufacturing

The manufacturing organization's architecture is connected to cloud manufacturing. The connected systems enable resources being controlled by different parties to be available through a centralized cloud service. This will be helpful for globally distributed manufacturing facilities maximizing the use of their equipment and minimizing the waste of both time and materials.

3.3 Sustainable Manufacturing

Sustainable manufacturing is defined by the US Environmental Protection Agency (EPA) as "the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources" [15]. By considering sustainable manufacturing in the business practices, it will help to increase manufacturing operational efficiency by reducing waste and costs.

3.4 Production Systems

Production systems in the manufacturing industry are categories such as storage management, material handling, jigs and fixtures in assembly, industrial control systems, and manufacturing processes.

3.4.1 Storage Management

The handling of inventory and finished products before delivery requires proper storage management systems. The storage management provides tools for businesses to accommodate the customer's demand requirements and distribution channels. There are a few different concepts in storage management such as just-in-time and supply chain management. Proper tools need to be developed to manage and control the operation of storage management.

3.4.2 Material Handling

Automated material handling systems can help in transfer line processes. Warehouse robots can be used as the material handling system to transfer material or product between manufacturing stations during the production processes. The use of the warehouse robots provides flexibility in the production processes compared to the fixed transfer line method currently in use by industry. The production facilities can have a fixed equipment layout, where the autonomous material handling robots can move around the manufacturing facilities to support the transfer line processes. Optimization in the material handling robots traveling route can be done in the process planning activities. The route also can be reconfigured to support new product development and realtime changes to production levels.

3.4.3 Jigs and Fixtures in Assembly

Assembly is one of the most important activities in the production process. Designing suitable jigs and fixtures will help to accelerate the assembly process. For production flexibility, a fixed design jig and fixture is not suitable for the variety of product designs in the customized world of 2035. Complexity in the product design may require human labor assistance in the assembly processes. Integration of industrial robots and adaptable jigs and fixtures design can help to reduce the human labor in the repetitive assembly tasks. Simulation of the assembly process in the product design process will optimize the automation capabilities of the assembly process. The simulated system enables determination of the process layout, material flow, and material handling system to provide the most economical process before actual hardware implementation in the physical world.

3.4.4 Industrial Control Systems

Industrial Control Systems (ICS) are used to gather large scale data in real time from the sensors, machinery, actuators, and other components installed in the manufacturing facilities. Since it requires a large amount of data to be collected and processed, the reliability and robustness of data collection is an important aspect to avoid noise in the processed information. Building blocks in the manufacturing organization architecture can be used as a high level controller and the internal structure as the low level controller. The ICS process enables operations control for the HMS.

3.4.5 Manufacturing Processes

Manufacturing processes involve various processes in product fabrication. The manufacturing processes can be classified as material removal, joining, forming, casting, and additive processes. With suitable DFMS software tools to simulate the manufacturing processes, the capabilities of the production facility can be fully utilized to provide the most economical production processes to fabricate products. Availability, status, and condition of each machinery must be available to be used in the DFMS and process planning activities to improve production efficiency.

4 Mode of Operation

Implementation of the HMS concept for Bedford Innovations from a conventional manufacturing industry to a complex system manufacturing facility requires slow migration to coexist with the existing infrastructures. In the year 2035, Bedford Innovations is expected to have flexible manufacturing systems that enable quick responses to customer needs and market changes with the implementation of the HMS concept. Collaboration with outside entities, for example university research on the case studies from the existing implemented HMS companies, will help the migration process.

4.1 Academia - Industry Collaboration

Education and training is essential to expose the future workforce to the future of manufacturing industries. Education framework is needed to align the course structure, especially in manufacturing specialization students, with future manufacturing tools to prepare the students for the workforce requirements in the near future.

Research and case study analysis will help the manufacturing industry migrate to more complex manufacturing systems.

5 Conclusion

The goal of this report is to develop an HMS framework to be implemented in the manufacturing system to become a successful high tech global design and manufacturing enterprise in the year 2035. The development of the holons to work autonomously under the entire holonic system will allow for the HMS framework to be implemented into Bedford Innovations' business. Remaining competitive in 2035 will require effective implementation of available technology and thus HMS for agile manufacturing is a solution to the complex problem of innovating manufacturing in the 21st century.

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