Factory-In-a-Box – Mobile Production Capacity on Demand

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Abstract

Change and uncertainty dominate today's business environment. The competition is becoming truly global with fragmented markets and customers expecting to get the best product at the best price with immediate availability. Meeting customer demands require a high degree of flexibility, low-cost/low volume- manufacturing skills, and short delivery times. In this highly competitive environment there is a great need to identify and develop unique manufacturing capabilities in industry. This paper will present an ongoing research project in Sweden called Factory-in-a-Box with the objective to develop unique manufacturing capabilities in a turbulent business environment. The Factory-in-a-Box concept consists of standardized production modules that are installed in a container and transported by e.g. a truck or by train. The modules may rapidly be combined into production systems that can be reconfigured for a new product and/or scaled to handle new volumes. The key features of this futuristic production system concept are thus flexibility, mobility, and speed. In the research project five fully operative demonstrators are developed and implemented in close cooperation between different academic and industrial partners in Sweden.

Introduction

Today's business environment is dominated by change and uncertainty, and global competition is diminishing defined markets. Manufacturing success and survival are becoming more difficult to sustain. It is recognized that low cost and high quality alone are not enough to sustain firm's competitive position in market place. Meeting customer demands require a high degree of flexibility, low-cost/low-volume manufacturing skills, and short delivery times. Success in manufacturing, and indeed survival, is increasingly difficult to ensure and it requires continuous development and improvement of how the products are produced. This highly competitive environment force companies to identify and develop unique manufacturing capabilities and to be innovative in producing and delivering products.

The national Swedish ambition to increase the number and sizes of Swedish industries is counteracted by lack of production capacity available on demand and at any location. Also companies, without in-house production capacity, have few options if they need resources for pilot production. Instead, manufacturing orders are often placed in low-wage countries, e.g. China or Eastern Europe. The uncertainty in markets and the rapid introduction of new products

has created a growing need for a flexible, reconfigurable and responsive manufacturing system. It is well accepted that the mass-production paradigm based on high-volumes has been replaced by a more flexible and responsive approach [1]. Meeting customer demands requires a high degree of flexibility, as well as abilities to reconfigure operations to suit new demands [2].

Thus, to develop next generation products and services, there is a need to find and implement new innovative methods that will support industry in generating new ideas and quickly realize these into successful products and production concepts. There is a need for new production system philosophies enabling quick product realization as well as flexibility and reconfiguability within operations. The question is how to develop and implement this production system philosophy?

The objective of this paper is to analyze and investigate future production system philosophies. An ongoing research project in Sweden called Factory-in-a-Box will be presented which is one initiative in this area. The idea with the Factory-in-a-Box concept is to develop solutions for mobile production capacity on demand and the key features of Factory-in-a-Box are mobility, flexibility and speed. Five fully operative demonstrators are currently being developed and implemented in close cooperation between different academic and industrial partners in Sweden. These demonstrators are realized and tested in real operative settings where its industrial benefits will be evaluated.

This paper will first discuss some current manufacturing challenges and trends and will relate these to different theoretical philosophies regarding flexible and reconfigurable production systems. The Factory-in-a-Box research project will be presented and the status of the five different demonstrators that are being developed in the Factory-in-a-Box will be presented.

Theoretical Framework

The global distribution of highly competitive production resources, including skilled workforces, will be a critical factor in the organization of manufacturing enterprise [3]. Six grand challenges or fundamental goals for manufacturing industries are specified to be the basis for future research within manufacturing. The challenges are:

- Concurrency in all operations
- Integration of human and technical resources
- Transformation of information into useful knowledge for effective decisions making
- Reduction of waste
- Reconfiguring manufacturing enterprises rapidly
- Developing innovative processes and products

In a competitive environment, where the products have the same performance, quality and functionality, the process of developing products within shorter intervals compared to the competitors becomes increasingly important [4]. The product itself is a smaller part of the complete offering to the customer, with branding, design, financing, services, smart products and other aspects becoming increasingly important. Fragmented markets stress the need for abilities to continuously adapt to new demands and to integrate new technologies. In a business

environment dominated by change and uncertainty it is becoming more and more important to define and sustain the competitive advantage of the corporation.

Several different philosophies regarding future production systems exist which share similar views about changing and turbulent business environment. One similarity in modern production system philosophies is the idea of autonomy and modularity. Mass Customization, Agile production systems and Holonic Manufacturing Systems are the modern production philosophies which are based on modularity and autonomy. These philosophies are presented and analyzed in this section.

Mass Customization

The term mass customization was first anticipated by Alvin Toffler in 1970 in his book "Future Shock". The concept was further refined by Stan Davis in his book "Future Perfect". After its initiation this concept has undergone extensive research work comprising both conceptual notes and propositions for its implementation at various levels. The conceptual visionary definition of mass customization is the ability to provide your customer with anything they want, profitably any time they want it, anywhere they want it and any way they want it. This visionary definition however is of conceptual nature and can not be shaped to deliverable form. The practical definition should be the use of flexible process and organizational structures to reduce varied and often individually customized products and services at low cost at a standard mass production system [5].

The benefits of Mass customization can be expressed as [6]:

- Improved fit with customer's unique needs.
- More efficiency due to lower inventory levels throughout the distribution channel.
- Ability to raise the praise of a good or service.
- Improved ability to analyze opportunities due to continuing dialogue with customers.

Certain principles to achieve mass customization are [7]:

- Modularization of product architectures and use of product platforms (reusability, commonality) following the concept of reusability and a product family design approach.
- Made-to-order approach (values creating activities are performed to a specific extend only after customers order is places)
- Split of fulfillment system into standardization and customer specific part (decoupling or postponement point)
- Use of dedicated information system for configuration, manufacturing planning, order tracking and relationships management.

Mass customization concept is used successfully for "made-to-order" product types and in situations where product family approach is applicable. Modularization approach is proved to be successful in certain industries. But still, true economies of scale are not fully achieved and its reason is mainly technical barriers which include slow responsiveness and expensive reconfiguability of production systems.

Agile Production System

The concept of Agile Manufacturing was proposed by a group of researchers at Iacocca Institute, Lehigh University in 1991 [8]. This research group published a report which includes a detailed view of Agile manufacturing enterprise, its components, infrastructure and operating method. This report gained popularity among academic, industry practitioners and US government authorities. Further research on this concept identified various flaws in this research, but this report is still acknowledged as pioneer in this field.

The driving force behind Agility is the rapidly changing business environment of 21st century, characterized as century of uncertainty and change. Various researchers have expressed the concept of agility in different ways. It has been defined as total integration as well as flexibility of manufacturing system, people and organizations [9]. Other researches have defined it as adaptable system, concurrency and complex whole of IT system [10]. This work is however of academic nature and still there is no such practical example where any firm has successfully gathered all these specifications practically. In practical, every firm has crafted its own definition depending upon ground situation as well as available resources.

The consensus is found on at least following two factors while addressing agility [11]:

- Responding to changes in proper ways and due time.
- Exploiting changes and taking advantages of changes as opportunities.

The salient features of agility as defined by various researchers can be presented as [12].

- High quality and highly customized products. Goldman et al 1993, Kidd 1994, Booth 1995, Hilton 1994.
- Mobilization of core competencies. Goldman et al 1993, Kidd 1994.
- Synthesis of diverse technologies. Goldman et al 1993, Kidd 1994.
- Intra-enterprise and inter-enterprise integration. Vastag et al, Kidd 1994, Youssef 1992, Yusuf, 1996.

Agile manufacturing system was developed in the USA to help American companies to face the current market challenges where traditional US mass production strategy is not successful. Agility is a business philosophy and it focuses on manufacturing enterprise and business practices needed to adapt in a fragile global market. This philosophy do not provide any "specific" operational tool or engineering solution like those provided in mass production and lean production systems [13].

Holonic Manufacturing

The central concept of Holonic Manufacturing is the term "holon". A holon is defined as simultaneously a whole and a part of the whole [14]. A holon is an autonomous and cooperative building block of a manufacturing system that can be a part of another holon. Holons are self-contained units, capable of functioning independently but also dependent of other units.

The architecture of Holonic manufacturing systems is [15]

- Holon as 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 processing part and often a physical processing part and a holon can be part of another holon.
- Autonomy with the meaning that a holon can create and control the execution of its own plans and/or strategies.
- Cooperation between different holons and development of mutually acceptable plans and execution of these plans.
- Holarchy as a system of holons that can cooperate to achieve a goal or objective. The holarchy defines the basic rules for cooperation of the holons and thereby limits their autonomy.

Holonic manufacturing system is more of a control system. The cooperative control proposed instead of traditional command-response control system is useful in highly vulnerable situation. It ensures rapid response and hence used in distributed production systems. Both Agile and Holonic manufacturing system are developed with ambition to face the challenge of 21st century turbulent market. Agile system was developed in USA whereas Holonic System is developed at Japan and Europe. Both seem to have same purpose or goal but procedure adopted is different.

The conclusions from this section are that flexible and reconfigurable production systems should be designed according to modularity ideas. Autonomy and independence with central organization are stressed. Cooperation is another word that is frequently used. The modern production systems- namely Agile, Fractal Factory, Bionic System and Holonic systems- are not very specific on how to reach the desired goals but provide valuable input to develop a method for evaluation, analysis, and development of flexible and reconfigurable production systems. There is a need for applications and implementations of existing future production system philosophies.

The Research Project: Factory-In-A-Box

The visionary definition of Factory-in-a-Box concept is “mobile production capacity on demand”. The aim of the concept and Factory-in-a-Box project is to provide solutions for availability and mobility of flexible production capacity for Swedish industry. Modern production philosophies namely, holonic manufacturing system, fractal company and mass customization, which emerged during last thirty years has limited industrial impact. The main reason is that these concepts were not tested in real industrial settings. The Factory-in-a-Box project is believed to be a practical solution to these theories. There are different ways to increase flexibility, mobility, and speed of product delivery process, for instance:

- Increase the level of automation in manufacturing process
- Work with product structuring and increase the modularity in the product
- Move pre-fabrication of sub-systems closer to final assembly
- Closer collaboration with sub-contractors/sub-suppliers
- Develop and improve the logistics and IT-support

Companies that succeed in transforming their product delivery process to a more flexible, mobile and rapid process will create a major competitive advantage to its competitors. One way of doing

such a transformation is to implement the Factory-in-a-Box concept for one or more functions in their product delivery process, i.e. a flexible unit that is mobile and can be moved around the factory, construction site etc. By implementing such a system it is possible to increase the production capacity during high strains.

The key features of the concept are flexibility, mobility, and speed. The concept consists of standardized modules that can be installed in containers and easily transported by, e.g. trucks, rail vehicles, boats etc. The modules shall be easy to combine into complete production systems and easy to reconfigure for new products and/or scaled to handle new volumes. In Sweden, with its great geographical limitations considering the low number of inhabitants (~9 million), mobility of production systems is one of the key features in winning orders. Goal of this project is to build five fully operative demonstrators – Factory-in-a-Box production cells– that are developed in close cooperation between different academia's and industrial partners. The production cells will be realized and tested on operative setting in the industry where the benefits of the concept will be evaluated.

FinaBox Industrial Demonstrators

Five demonstrators are developed in order to exemplify and realize the Factory-in-a-Box concept. The demonstrators will be practical examples of the usability of the concept in industry. All demonstrators are practical solution for a particular function(s) and provide a real business case for the concept.

Factory-in-a-Box 1 – Automatic assembly with focus on flexibility

The first example of a Factory-in-a-Box module will be demonstrated within ABB Robotics production system – an automatic production module to build robot components. The overall goal of this pilot demonstrator is to develop an automatic production module, which assembles robot controller cabinets, meeting the overall Factory-in-a-Box requirements of flexibility, mobility, and speed, with specific focus on flexibility within the plant.

Factory-in-a-Box 1 will approach the key concepts flexibility, mobility, and speed as follows:

- Flexibility - In order to assemble different variants of cabinets with short set-up time, it is necessary to have flexible equipment and fixtures. There will be a need of reconfiguring the module and resources, e.g. configuring the robot online to a customer specific product while still having a robust and efficient manufacturing. The optimal level of automation will be investigated in the project.
- Mobility - Factory-in-a-Box 1 will have to be designed as a "Mobile Platform" to be moved anywhere within ABB Robotics production system. Possibly also moved to a supplier or another production site. The equipment should easily be mounted and reconfigured on i.e. a standardized rigid base plate with flexible fixation points.
- Speed - Short set-up time is vital for the success of this module. The "programming" of the operations should be fast, which will demand reuse of experience. Factory-in-a-Box 1 will enable a structured production requirement process and a support for design of future cabinet variants. A "standard" Factory-in-a-Box module will also enable virtual system configuration and module modeling and simulation.

Factory-in-a-Box 2 – Welding with focus on mobility

Factory-in-a-Box 2 is developed in collaboration with Pharmadule Emtunga. Pharmadule Emtunga is a supplier of modular facilities to the off-shore, telecom, and pharmaceutical industries. At present the company is striving to implement the same concept in their manufacturing system as they have in their products, i.e. modularization.
Factory-in-a-box 2 will be a semi-automated manufacturing cell, which is used for cutting, beveling, and welding of carbon steel pipes. All machinery will be fitted into a standard container, which also will contain, fume hood exhaust, lighting, computer terminal etc.
Factory-in-a-Box 2 will approach the key concepts flexibility, mobility, and speed as follows:

- Flexibility - In order to weld different variants of pipes as well as conducting different joint preparations with short set-up time it is necessary to have flexible equipment and fixtures. There will be a need of reconfiguring the module and resources, e.g. configuring the robot online still having a robust and efficient manufacturing. The optimal level of automation will be investigated in the project. Different machining operations in the module are drilling, joint preparation, and cutting.
- Mobility - The Factory-in-a-Box module will have to be designed on a "Mobile Platform" to be moved anywhere within the production system, to a supplier, or to site. The equipment should easily be mounted and reconfigured on standardized rigid base plates with flexible fixation points. The Factory-in-a-Box module should be moveable by a truck – specifying the need of a standardized container.
- Speed - There is a need to quickly reconfigure the module without long set-up time. Operations should be started as soon as possible after movement within the manufacturing system or transport to site. The Factory-in-a-Box module will reduce the welding time compared to today's manual process.

Factory-in-a-Box 3 – Foundry with focus on mobility

Factory-in-a-Box 3 is an automatic material handling and material removal/surface improvement module. The overall goal of this module is to combine automatically handling with deburring/grinding of casting components still meeting the overall Factory-in-a-Box requirements of flexibility, mobility, and speed.
Factory-in-a-Box 3 will approach the key concepts flexibility, mobility, and speed as follows:

- Flexibility - In order to handle different components with short set-up time it is necessary to have flexible equipment and fixtures. There will be a need of reconfiguring the module and resources, e.g. configuring the robot online still having a robust and efficient manufacturing. The optimal level of automation will be investigated in the project. Different machining operations in the module are deburring, grinding, and cutting.
- Mobility - The Factory-in-a-Box module will have to be designed on a "Mobile Platform" to be moved anywhere within the production system, or to another foundry company. The equipment should easily be mounted and reconfigured on standardized rigid base plates with flexible fixation points. The Factory-in-a-Box module should be moveable by a truck.
- Speed - There is a need to quickly reconfigure the module without long set-up time. The Factory-in-a-Box module will reduce the handling and material removal time compared

to today's manual process. With the right level of automation, quality will be improved and the disturbance time will decrease.

Factory-in-a-Box 4 – Functional sales with focus on flexibility

Factory-in-a-Box 4 will be developed in association with FlexLink Systems. FlexLink's focus is automation of production flow within the following processes: Assembly - Filling - Machining - Packaging. FlexLink will, in this project, use their Dynamic Assembly System (DAS) concept in order to demonstrate the principles in the Factory-in-Box-project - flexibility, mobility and speed- in a real customer case.
Factory-in-a-Box 4 will approach the key concepts flexibility, mobility, and speed as follows:

- Flexibility - Different variants of products with short set-up time require flexible equipment and fixtures. There will be a need of reconfiguring the module and resources online to a customer specific product while still having a robust and efficient manufacturing. The optimal level of automation will be investigated in the project.
- Mobility - The Factory-in-a-Box module will have to be designed as a "Mobile Platform" to be moved anywhere and reused for a new customer in case of leasing.
- Speed - Short set-up time is vital for the success. The "programming" should be fast, which will demand reuse of experience.

Factory-in-a-Box 5 – Manual assembly with focus on mobility

Factory-in-a-Box 5 is developed in collaboration with Bombardier Transportation. Bombardier Transportation is a supplier of rail vehicles. Bombardier Transportation in Västerås, Sweden, is developing a mobile production unit where assembly, test and control of a drive system for rail vehicles will be done manually. This concept will assist in transportation of production equipment to all over the world.
Factory-in-a-Box 5 will approach the key concepts flexibility, mobility, and speed as follows:

- Flexibility - Different variants of products with short set-up time require flexible equipment and fixtures. There will be a need of reconfiguring the module and resources to a customer specific product while still having a robust and efficient manufacturing.
- Mobility - The Factory-in-a-Box module will have to be designed as a "Mobile Platform" to be moved anywhere and reused for a new customer and a new project.
- Speed - Short set-up time is vital for the success as well as readiness for transportation.

Current Status of FinaBox Demonstrators

Until May, 2006, three Factory-in-a-Box demonstrators have been developed. Physical prototypes of Factory-in-a-Box 1, 2 and 5 have been developed in order to inspire and exemplify the concept. In Figure below, Demonstrator 1 at ABB Robotics is shown and this robot application will be implemented in the production system at ABB Robotics in September. The FinaBox Demonstrators at Pharmadule Emtunga and Bombardier Transportation are also displayed and if realized in reality is now awaiting for a management decision. The Factory-in-a-Box project will continue with a focus on Factory-in a-Box 3 which will be developed and implemented during 2006/2007.

Conclusions

The objective of this paper was to present an ongoing research project in Sweden called Factory-in-a-Box aiming to develop unique manufacturing capabilities for industry. The idea with the Factory-in-a-Box concept is to develop solutions for mobile production capacity on demand. The discussion on modern production philosophies concludes that flexible and reconfigurable production systems should be designed according to modularity ideas. Autonomy and independence with central organization is vital component of these systems. Cooperation is another word that is frequently used. The modern production systems- namely Mass Customization, Agile, and Holonic systems- are not very specific on how to reach the desired goals but provide valuable input to develop a method for evaluation, analysis, and development of flexible and reconfigurable production systems.
This paper has shown that it is possible to compete with manufacturing in a high-cost country, but it is important to identify and develop more customer values generated from the manufacturing. FinaBox concept aims to use the production knowledge in unique innovative way. Each of the five demonstrates developed emphasize on at least one of three component of FinaBox concept namely Mobility, Flexibility and Speed.

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