

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

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ABSTRACT

Change and uncertainty dominate today's business environment. 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 within industry. This paper will present an ongoing research project in Sweden called Factory-in-a-Box with the objective to develop mobile production capacity on demand. The Factory-in-a-Box concept consists of standardized production modules that are installed in e.g. 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 flexibility, mobility, and speed. In the research project five fully operative demonstrators have been 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 is becoming increasingly difficult to sustain and 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.

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It is well accepted that the mass-production paradigm based on high-volumes has been replaced by a more flexible and responsive approach [1].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 reconfigurability within operations. The question is how to develop and implement such a production system philosophy in a real world setting?

The objective of this paper is to analyze and investigate possible production system philosophies enabling flexibility and reconfigurability. 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 are mobility, flexibility and speed. Five fully operative demonstrators have been developed and implemented in close cooperation between different academic and industrial partners in Sweden. These demonstrators have been realized and tested in a real operative setting where its industrial benefits have been evaluated.

This paper will first discuss some current manufacturing challenges and trends and will relate these to different theoretical production system 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 have been developed in the Factory-in-a-Box project 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]. The National Research Council presents six grand challenges or fundamental goals for manufacturing industries that are specified to be the basis for future research within manufacturing:

- Concurrency in all operations
- Integration of human and technical resources
- Transformation of information into useful knowledge for effective decisions making
- Reduction of waste
- Rapidly reconfiguring manufacturing enterprises
- 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 that are becoming increasingly important. Fragmented markets stress the need for abilities to continuously adapt to new demands and to integrate new technologies.

Several different production system philosophies exist which share similar views about a changing and turbulent business environment and the need for flexibility as well as the idea of autonomy and modularity. Mass Customization, Agile production systems and Holonic Manufacturing Systems are the modern production philosophies which are based on flexibility, 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 can 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 price of a product 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, activities are performed to a specific extend only after customers order is placed
- Split of customer product into a standardization and a 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 reconfigurability 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 included a detailed view of an agile manufacturing enterprise, its components, infrastructure and operating method. This report gained popularity among academic, industry practitioners and US government authorities. Although further research on this concept is identified, this report is still acknowledged as pioneer in this field.

The driving force behind Agility is the rapidly changing business environment of the 21st century, characterized as a 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 an adaptable system and with concurrency in operations [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.

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

- Responding to changes in proper ways and in 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
- Mobilization of core competencies
- Synthesis of diverse technologies
- Intra-enterprise and inter-enterprise integration

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, 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 is 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 the 21st century turbulent market. Agile system was developed in the USA whereas Holonic System was developed in Japan and Europe. Both seem to have the same purpose or goal but different procedure is adopted.

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 in the visionary production system concepts. Cooperation is another word that is frequently used. The production systems philosophies presented 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. The fundamental question, how to set up a modular, flexible and responsive manufacturing system, in a real world setting remains unanswered. The conclusion is that there is a gap between theory and practice regarding the realization of flexible and reconfigurable production systems.

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 the Factory-in-a-Box project is to provide solutions for availability and mobility of flexible production capacity for Swedish industry. There are different ways to increase flexibility, mobility, and speed of a 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. The 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 FACTORY-IN-A-BOX DEMONSTRATORS

Five demonstrators have been developed in order to exemplify and realize the Factory-in-a-Box concept. The demonstrators are 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

A first example of a Factory-in-a-Box module has been developed and demonstrated within ABB Robotics production system – an automatic production module to assemble robot components. The overall goal of this pilot demonstrator was to develop an automatic production module, which assembles robot controller cabinets, meeting the overall Factory-in-a-Box requirements of flexibility, speed, and mobility. The demonstrator has been developed in parallel with an ongoing product development project of a new robot controller at ABB Robotics: “IRC5”.

The vision of this demonstrator has been a production system that can be assembled and configured according to specific needs and that can be delivered to any location. Factory-in-a-Box module #1 has explored this vision and tried to make this a reality. The focus of this demonstrator has been to investigate the following requirements that were specified in the original project plan:

- Modules that are easy to transport to the production site as well as to move them at the site, e.g. external and internal mobility. In order to attain internal mobility i.e. air cushions can be used for fast and smooth transports of modules or for the entire Factory-in-a-Box.
- Reconfigurability in order to meet changing demands and automatic/semi-automatic configuration of modules and system are prerequisites for scalability for changing production volumes and for fast ramp up of production.

- Reusability of system components and modules together with simple and fast simulation and programming makes conditions for faster and cheaper system solutions and system robustness towards disturbances, especially during ramp-up of production. The reusability also makes it possible to achieve a profitable reduction of production capacity. This is as important as the ability to increase the capacity. The reusability makes it possible to reuse the equipment in other applications in the same or in other companies. Many companies hesitate to invest in new production capacity/equipment because of the financial risk involved in the case of future declining production volumes.
- Standardized hard- and software interfaces and integrated highly flexible production equipment, integrated metrology, and sensor-based calibration, combined with sensor-integrated robot/equipment control are prerequisites for flexibility/agility.

The Factory-in-a-Box module at ABB Robotics consists of two robots, a number of fixtures, a gluing station, a folding station, and robot handled tools. Material and components are presented to the robots via conveyors and carriers placed in a lock-system. The cell is designed for mobility using mobile base plates that either are heavy enough to be placed directly on the floor or, as in the case of the robot, a base plate which can be secured to the floor by vacuum or air cushions for fast and smooth transports. Figure 1 shows an illustration made to show that each piece of equipment is thought of as being placed on a piece of a puzzle; the different parts are mobile, with well defined interfaces between them. Figure 2 shows mobile fixtures and robots on base-plates.



Figure 1: Illustration of the concept of Demonstrator 1

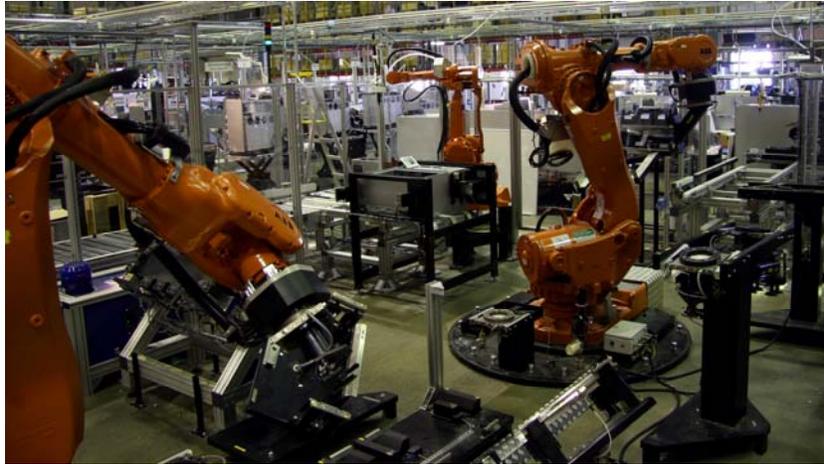


Figure 2: Mobile fixtures and robots on base-plates in demonstrator 1 at ABB Robotics

The cell is flexible, using flexible equipment, and designed for reconfigurability. Four different types of controllers are today assembled in the cell. Through technical solutions, supporting mobility and flexibility, the requirements of speed are achieved by e.g. quickly reconfiguring the cell at another location and /or introducing a new product. The I/O communication in the cell is established through wireless communication pads to enable easy reconfiguration. The two robots are equipped with swivels and tool-changers so that they may handle all product variants, and also to make it easy to introduce future product variants that require other tools for handling. Factory-in-a-Box module at ABB Robotics has been commercially developed and put into operation during December 2006.

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

Factory-in-a-box 2 is developed in collaboration with Pharmadule Emtunga (PHEM). PHEM 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 is 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 can perform the following operations:

- Cutting and seam preparation of pipes
- Manual welding when fitting the pipes together
- Orbital welding, as shown in figure 3
- Flexible fixture to handle the different pipes, as shown in figure 4.

The greatest news value of Factory-in-a-Box 2 is the usage of known technologies in all new applications and context. Orbital welding of carbon steel pipes with straight-angle chamfers has never been done before within the company.

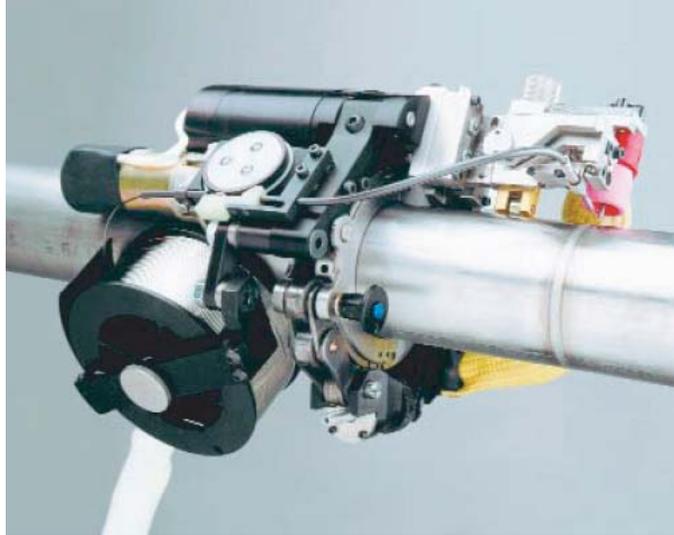


Figure 3: An orbital welding equipment

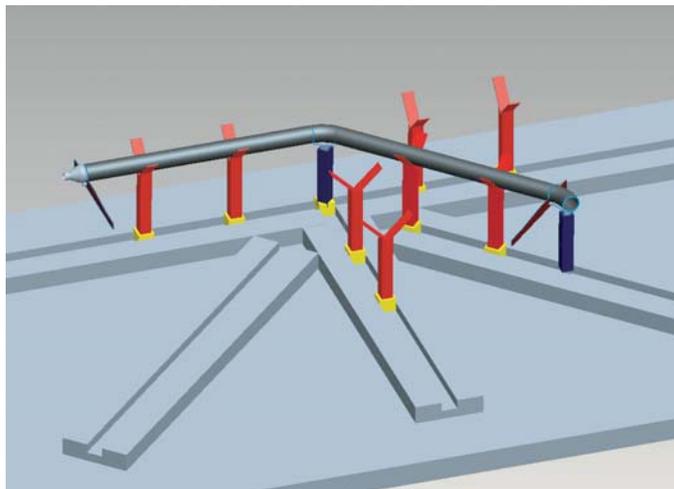


Figure 4: Illustration of the flexible fixtures developed in demonstrator 2

PHEM has had a business concept in mind when developing the Factory-in-a-Box 2. This kind of mobile orbital welding equipment could make a great asset for a lot of different construction and installation sites where carbon steel pipes are being welded. The Factory-in-a-Box can be leased out to PHEM by suppliers or be owned by PHEM themselves; the final commercial solution will be decided at a later time when the concept has been fully developed. The Factory-in-a-Box 2 will be implemented within PHEM operations during the fall of 2007.

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

To ensure applicability of the Factory-in-a-Box project, a third example of a Factory-in-a-Box module will be demonstrated within Swedish foundry industry in cooperation with

the Swedish Foundry Association. To maintain its competitiveness a foundry must meet increasing demands for efficient production and a good working environment.

Varnäs företagen is a Swedish foundry that produces sand-casted aluminum goods. The company has modern and highly operational facilities for both casting and subsequent machining. However, the process step between the two, deburring and grinding has been neglected, as it is in so many other foundries. This middle step between the casting and machining is important, but often performed manually using handheld tools. This type of work has a tradition of being ergonomically unsound and generally inefficient. This is the motivation for Varnäs företagen to take part in the Factory-in-a-Box project. The aim of the third demonstrator is to create an automatic solution for deburring of casted products.

During 2006 a pre-study at the company has been performed which included a mapping of the production process at the company and a study of the products that are being produced. After that, the results of the study were analyzed it was concluded that not all the operations could be performed within an automatic solution. The ideal solution would be to use several small and cheap standardized automation cells that could perform a couple of operations each. This project will focus on developing one cell that can perform a set of operations that can be used for some of the deburring work. This first cell could for example be used to saw off larger pieces from the casting followed by some milling and grinding. These operations are today a burden for the persons doing the manual work.

The final concept that has been developed includes a robot, mounted inside a container. The robot is placed on a flexible beam-system that can be moved in and out of the container. A flexible fixture has been proposed that should be able to handle all the products that are supposed to be machined in the cell. The concept has been partly realized in a lab environment, and whether it will be converted into an operational cell is dependent on the company and circumstances outside the control of the research projects.

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

Factory-in-a-Box 4 has been 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.

During 2005 and 2006, a pre-study at the company has been performed which has included an investigation of "functional sales" and a mapping of interested companies for this commercial solution. A number of companies have been contacted (over 40 different companies) and possible candidates for a FlexLink and Factory-in-a-Box commercial application were identified. After identifying one company that was interested, the project has participated in a quoting phase. No order has been placed so far.

The demonstrator 4 project has investigated the concept of functional sales of manufacturing capacity. The project has shown that industry is interested in this concept,

but the circumstances and details in the offering may have to be changed. This demonstrator has shown the importance of further investigating how the sales operations should be designed in a Factory-in-a-Box business context.

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

This part of the project was conducted in cooperation with Bombardier Transportation. Many of Bombardier's customers have strong wishes that part of the production should be carried out locally in order to create new jobs. Instead of building factories, which will be abandoned as soon as the order is processed, Bombardier and the Factory-in-a-Box project aim to develop mobile production facilities, which can be re-located as soon as the production of an order is finished. This opens up markets otherwise closed, which will create job opportunities not only for the customers, but also for Bombardier in Sweden since the main part of the order is produced there.

An analysis has shown that a Factory-in-a-Box, mobile production capacity can be used to reallocate working opportunities in a cost-effective way when the customers demand this as a part of the business deal. The concept contains four parts: a technical solution, a logistics solution, a training solution for the local labor, and a methodology for how to move, install, and put the Factory-in-a-Box into production.

A fully developed Factory-in-a-Box enables a substantial reduction of the resources needed for sharing experience and knowledge compared with a conventional outsourcing strategy. The demonstrator project has resulted in a technical solution for moving and housing production capacity abroad, a special container solution available on the market, see figure 5.

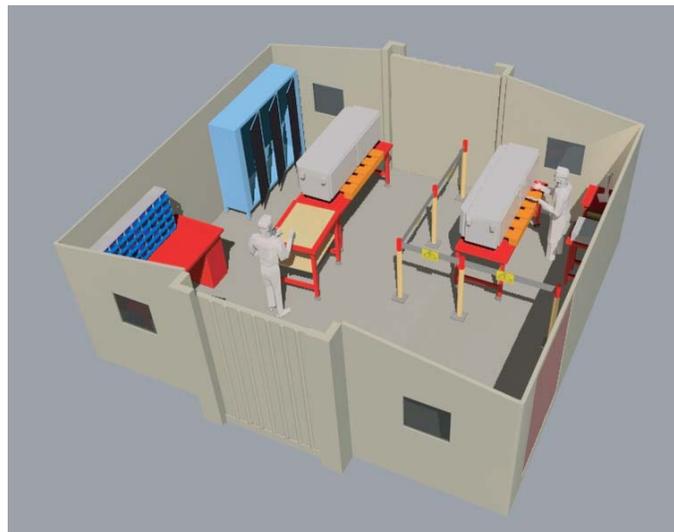


Figure 5: Illustration of the mobile workstation concept of demonstrator 5

In order to exemplify a valid solution with a cost-analysis, the project has focused on a technical solution for the assembly of a high-voltage box and a capacity of 1-2 boxes per

week. Even using this delimitation, the pre-study indicated that the Factory-in-a-Box easily can be scaled to handle a much higher production volume. It also indicated that the same kind of mobile solution can be useful for other Bombardier products. The pre-study has also resulted in a checklist that the person responsible for the installation of the Factory-in-a-Box can use in order to shorten the start-up time at the customer.

CONCLUSION

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 futuristic production philosophies concludes that flexible and reconfigurable production systems should be designed according to modularity ideas. Autonomy and independence with central organization is a vital component of these systems. Cooperation is another word that is frequently used. The presented production system philosophies 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 customer values generated within production. The Factory-in-a-Box concept aims to use production knowledge in unique innovative way – mobile production capacity on demand. Each of the five demonstrators that have been developed emphasize on at least one of three components of mobility, flexibility and speed.

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REFERENCES

- [1] Molinari, T. L., Pierpaoli, F., Urbani, A., and Jovane, F., New Frontiers for Manufacturing in Mass Customization, CIRP Journal of Manufacturing Systems, Vol. 33, No. 3, 2004.
- [2] Jackson, M., An Analysis of Flexible and Reconfigurable Production Systems – An Approach to a Holistic Method for the Development of Flexibility and Reconfigurability, Linköping, Studies in Science and Technology, Dissertation No. 640, Linköping, Sweden, 2000.
- [3] National Research Council, Visionary Manufacturing Challenges for 2020, National Academy Press, Washington, D.C., 1998.

- [4] Tidd, J., Bessant J., Pavitt K., *Managing Innovation*, Second Edition, John Wiley & Sons, Ltd, England, 2001.
- [5] Jiao, J., Ma, Q., Tseng M. M., *Towards high value-added products and services: mass customization and beyond*, *Technovation* Vol. 23, 2003.
- [6] Berman B., *Should your firm adopt a mass customization strategy?* *Business Horizons*, Vol. 45, No.4, 2002.
- [7] Piller, F.T., *Mass customization: four approaches to deliver customized products and services with mass production efficiency*, *Engineering Management Conference, IEEE International*, Vol.2, 2002.
- [8] Iaccoca Institute, *21st Century Manufacturing Enterprise Strategy, An Industry-led view*, Volume 1, Lehigh University, Bethlehem PA, 1991.
- [9] Montgomery, J.C., Levine L.O., *The Transition to Agile Manufacturing - Staying Flexible for Competitive Advantage*, ASQC, Milwaukee, WI, 1996.
- [10] Booth, R., *Agile Manufacturing*, *Engineering Management Journal*, Vol. 6 No. 2, 1996.
- [11] Sharifi, H., Zhang, Z., *Agile manufacturing in Practice: Application of a methodology*, *International Journal of Production Management*, Vol. 21, 2001.
- [12] Yusuf, Y.Y., Sarhadi, M., Gunasekaran, A., *Agile manufacturing: The drivers, concepts and attributes*, *International Journal of Production Economics* Vol. 62, 1999.
- [13] Mehrabi, M. G., Ulsoy, A. G., Koren, Y., *Reconfigurable manufacturing systems: Key to future manufacturing*, *Journal of Intelligent Manufacturing*, Vol. 11, No. 4, 2000.
- [14] Koestler, A., *The Ghost in the Machine*, Arkana Books, London, 1989.
- [15] Browne, J., Rathmill, K., Sethi, S.P., Stecke, K.E., *Classification of flexible manufacturing systems*, *The FMS Magazine*, April, 1984.

BIOGRAPHIES

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