# FACTORY-IN-A-BOX – SOLUTIONS FOR AVAILABILITY AND MOBILITY OF FLEXIBLE PRODUCTION CAPACITY

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Abstract: The objective of this paper is to present examples of how to realize a flexible and reconfigurable production system. An ongoing research project in Sweden called Factory-in-a-Box will be presented which is one research initiative within this area. The purpose of the Factory-in-a-Box project is to develop solutions for mobile production capacity on demand. Three key features have been identified as enablers for these kinds of production capabilities: mobility, flexibility, and speed. The concept consists of standardized modules that can be installed in e.g. containers and easily transported by trucks, rail vehicles, and boats. The modules can easily be combined into complete production systems and reconfigured for new products and/or scaled to handle new volumes. The goal of the Factory-in-a-Box project is to build fully operative production modules that are developed in close cooperation between different academic and industrial partners. This paper will present the reults from these demonstrators giving examples of the usability of the Factory-in-a-Box concept in industry.

Keywords: Flexibility, Reconfigurability, Mobility, Speed, Production System, Demonstrator

## 1. INTRODUCTION

Globalization makes competition within manufacturing more difficult to sustain, and it is recognized that low cost and high quality alone are not enough to guarantee a firm's competitive position in the market place. The uncertainty in markets and rapid introduction of new products has created a growing need for flexible, reconfigurable, and responsive manufacturing systems. Meeting customer demands requires a high degree of internal flexibility, as well as the ability to reconfigure operations to suit new demands.

The national Swedish ambition to increase the number and size of Swedish manufacturing industries is counteracted by lack of production capacity available on demand and at any location. 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.

Thus, to develop the next generation of products and services, there is a need to find and implement new innovative methods and concepts that will support industry in generating new ideas to quickly realize these into successful products and competitive production systems. There is a need for flexible and reconfigurable production systems, enabling quick product realization as well as flexibility and reconfigurability (Jackson, 2000). The question is how to develop and implement such a production system?

The objective of this paper is to present and give an example of how to realize a flexible and reconfigurable production system. An ongoing research project in Sweden called Factory-in-a-Box will be presented which is one initiative within this area (Jackson and Zaman, 2006). The objective of the this project is to build fully operative production modules that are developed in close cooperation between different academic and industrial partners. This paper will present the reults from these demonstrators as examples of the usability of the Factory-in-a-Box concept in industry.

## 2. METHODOLOGY

This paper is based on a literature review, a series of interviews, as well as case studies that have been used to collect data and experiences from the development of the demonstrators in the Factory-in-a-Box project. In collaboration with industrial partners a number of problem areas was selected and case-studies was conducted to explore the different areas and the applicability of the Factory-in-a-Box concept.

In general, case study method is the preferred strategy when 'how' or 'why' questions are being posed, when the investigator has little control over events, or when the focus is on a contemporary phenomenon within some real-life context (Yin, 1997), which is relevant for this work.

Case studies may be criticized for lack of statistical reliability and validity. Furthermore, it is argued that it is not possible to test hypotheses. To overcome this dilemma, it is increasingly important to select a representative case and to validate the result continuously, and not simply at the end of the study. It is also important to describe the actual case carefully and only to draw conclusions that are valid exclusively for similar systems.

## 3. THE FACTORY-IN-A-BOX CONCEPT

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 (Tidd et.al., 2001). 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. For example, Mass Customization, Agile production systems and Holonic Manufacturing Systems are the modern production philosophies, which are based on the concepts of modularity and autonomy, see e.g. Piller (2002), Yusuf et.al. (1999), Jackson (2000), and Molinari et.al. (2004).

Production system philosophies as e.g. Mass customization, Agile, or Holonic systems are not very specific on *how* to reach the desired goals. There is a need for applications and implementations of these production system philosophies; the Factory-in-a-Box concept is one initiative within this area (Ask, 2006).

The Factory-in-a-Box concept consists of standardized production modules that can be installed in a container and transported by e.g. a truck or by train. The modules may then rapidly be combined into production systems that can be reconfigured for new product and/or scaled to handle new volumes. Production capacity may be provided as a mobile and flexible resource that rapidly can be tailored to fit the needs of a company, at a specific point of time. The emphasis on mobility in the Factory-in-a-Box concept is important in Sweden, where geographic limitations are a reality.

The Factory-in-a-Box concept presents a future possibility for a production-on-demand market. Mobility, flexibility, and speed are order-winners on that market. Three examples of customer segments for the Factory-in-a-Box are:

- Company A has a new product design, but without production capacity. The options for the company are to invest in new production capacity or to outsource production. If the company chooses to outsource, chances are that production will be placed abroad and that the company may lose control of their product. Company A may lease a Factory-in-a-Box production system for the time needed and then return the system to the lessor providing the production modules.
- Company B has a peak in their production, which exceeds their capacity to produce. The company may need to outsource production

or make large investments. Company B may lease production capacity in the form of a Factory-in-a-Box as an alternative to outsourcing.
- Company C is a large enterprise, which wants to ensure quality and availability of the manufacturing of a sub-system, provided by a supplier. Company C can help a supplier by providing a Factory-in-a-Box module to improve quality or handle volume variation.

It should be possible to place a Factory-in-a-Box close to product development or customers within the distribution chain. A likely scenario is that the Factory-in-a-Box can be rented or leased from production specialists, i.e. a type of functional sales of production capacity. This would improve the preconditions for a larger degree of production, and hence product development, to remain locally.

There are a number of requirements for the Factory-in-a-Box concept in order to realize the key features of Mobility, Flexibility, and Speed. These requirements are:

- Modules that are easy to transport to the production site as well as to move them within site, e.g. external and internal mobility.
- Ability to dynamically adapt the degree of automation and flexibility.
- Reconfigurability in order to meet changing demand and automatic/semi-automatic configuration of modules and system is prerequisites for scalability for changing production volumes and for fast ramp up of the production.

The use of standardized production modules provides autonomy and reusability. A Factory-in-a-Box installed at a company should be integrated with the company's existing technical production capacity and its present workforce. The intention is to balance automation and manual labour in the Factory-in-a-Box modules. Thus, each configuration will include e.g. automation requirements, operator staff requirements, configuration simulation modules, and case-based experience/knowledge databases.

## 4. REALIZING A FACTORY-IN-A-BOX

The Factory-in-a-Box demonstrators have been accomplished by teaming the resources and knowledge of four running ProViking projects: ExAct, DYNAMO, Flexible and Accurate Automation, and Robust Design & Variation Simulation. The Factory-in-a-Box project has thus formed a unique combination of flexible and accurate manufacturing technology, concepts for strategic development of automation, and tools for intelligent reuse of experience, knowledge, and information.

### 4.1 CONTRIBUTION FROM THE ROMUS RESEARCH GROUP AND THE "DYNAMO" PROJECT

The DYNAMO project is part of the ROMUS research group and the research is conducted at Jönköping University and Chalmers University. The contribution of the DYNAMO project has provided the Factory-in-a-Box concept with tools for design, measurement, visualization, and management of dynamic levels of automation (LoA). Automation strategies have been investigated connected to the demonstrator projects, proposing how to achieve the right level of automation for each specific life-cycle situation of the production module by utilizing LoA-variation. The goal has been to increase robustness during multiple stages of the module (such as start-up, ramp-up, and operation) by varying automation level of tasks related to operations, transfer, testing, materials handling, and supervision when necessary.

LoA describes the relationship between human and machine in terms of function/task allocation, and should be set within a pre-defined span between 1 (manual) and 10 (full automation) for each task. For each demonstrator, requirements have been specified for how much the automation level should be possible to vary. It means that requirements on technology, IT-systems, and human skills are necessary. Creating robustness is made during design and reconfiguration where most parameters are set, and LoA could, therefore, be utilized as a design variable.

By implementing the research results from the ongoing Dynamo project in the Factory-in-a-Box demonstrators, it has been possible to illustrate the potential of controlled dynamic automation levels for both product and production practitioners. It has also been a necessary precondition to make mobile production capacity on demand possible.

### 4.2 CONTRIBUTION FROM THE DIVISION OF ASSEMBLY TECHNOLOGY/PRODUCTION SYSTEMS, LINKÖPING UNIVERSITY, OF THE "FLEXIBLE AND ACCURATE AUTOMATION" PROJECT

The "Flexible and Accurate Automation" (FlexAA) contribution has been concentrating on the technical realization of the Factory-in-a-Box concept and demonstrators. The main research question for the FlexAA project has been how to make the production module/cell accurate and flexible enough to both fulfil product quality requirements in an assembly- or light-machining cell, and to do this rapidly and effortlessly. The FlexAA project has contributed to both the operation planning level as well as to the hardware level.

On the operation planning level, process-oriented operation planning and 3D-CAD, simulation software, has been investigated to shorten and simplify path planning on a robot-oriented abstraction level, and processes on a task-oriented abstraction level. By using generic robot programming in the execution of the process at hand, in combination with embedded system controller over standard TCP/IP networks, the sequence of operation on the factory floor with robots and operators, can be quickly implemented. This shortens lead-time in ramp-up, and simplifies changes and changeovers throughout the manufacturing processes. On the hardware level, production modules have been integrated into mobile platforms. Equipment that will be easily mounted and reconfigured on standardized rigid base plates with flexible fixation points have been investigated. This constitutes the Factory-in-a-Box containers that can easily be moved by a truck and/or forklift.

Existing experience from partners in the FlexAA project has been used, using 6DOF flexible tooling modules that do not require conventional calibration. These tools have been investigated and tested in the Factory-in-a-Box project. This approach is based on building assembly fixtures that are configured and reconfigured by the robot that also perform the assembly- and lightweight machining operation.

### 4.3 CONTRIBUTION FROM THE MÄLARDALEN UNIVERSITY RESEARCH GROUP OF THE “EXACT” PROJECT

Experience is one of the most valuable assets in the manufacturing industry, both during design and development of products and manufacturing systems. During continuous development and improvement of production methods, technology and techniques to achieve quality and production capacity together with cost reductions experience is important. A key issue for the Factory-in-a-Box project is to achieve flexible, efficient and quick configuration and production ramp up, which is easy to maintain and adjust if requirements change on product or if input parts specification change. Experience is essential, and if all experience related to a box is stored and can be reused for similar production tasks. The value of the box increases by offering greater flexibility, faster and more reliable configuration and production. Valuable experiences to reuse are: designs and configurations, fault reports, diagnoses and solutions, quality improvements, cost reductions, production increase actions, and software components used in producing a specific product.

Also subparts of the production process are seen as experience components. If similar products are produced, the “programming” of the operations may become the task of composing previous successfully sub-parts into a complete program. Experience and knowledge is spatial and only relevant in specific contexts. A designer designing a specific part of the production process will have access to relevant experience and previous solution to the same or similar problems that may be reused after some manual or automatic adaptation. Parts of the software components also have “learning” capability, which will improve their performance. Finally, experience collected in other Factory-in-a-Box’es can be reused by any Factory-in-a-Box (standards and remote facilities will be a part of the Factory-in-a-Box concept).

All properties are parts and subprojects of the ExAct project, developed in more generic form for production industry. This is a complex reality, where many compromises have to be made. Some of the projects have to deal extensively with how to integrate with, and change, a large and often inflexible production process in order to preserve the valuable features of the subprojects. In the Factory-in-a-Box, the context and environment is controllable and limited. The resources will be used to produce a number of fully functional Factory-in-a-Box systems. This will convince industry of the advantage and motivate them to invest in modifications, enabling the vision of the ExAct project (flexible, learning and experience sharing semiautomatic and automatic tools and systems continuously improving production, quality, and cost reductions).

### 4.4 CONTRIBUTION FROM WINGQUIST LABORATORY/FRAUNHOFER CHALMERS CENTRE AND THE “ROBUST DESIGN & VARIATION SIMULATION” PROJECT

Robust design and variation simulation are important quality assurance activities in the product realization process. Geometrical variation, originating from individual manufacturing and assembly processes, often propagates and accumulates during production, resulting in non-nominal products and production equipment. Geometrical quality problems are often discovered during pre-production or when the product is getting ready for market introduction. A change in the product or production concept at this stage often results in huge costs for product and/or production changes, market delays, and bad publicity. Therefore, more and more efforts are made in early concept phases to virtually verify product and production concepts with respect to geometrical variation. These efforts can be used as a natural base for non-nominal path planning to meet future demands on accuracy and throughput.

A long-term vision within the field of production technology is the virtual factory, with high level of accuracy regarding realism and functionality. Early programming, simulation, verification, and visualization of virtual production equipment make it possible to reduce the ramp up time in the real factory. Despite that modern industries use virtual prototypes to replace physical prototypes, visualize assembly processes and program industrial robots off-line, the full potential of the virtual factory is still not reached. A major limitation is programming time. Most programming of motions and paths for robots and equipment is still generated manually, since the existing support for automatic path planning and load balancing is very limited. Another limitation is the geometrical accuracy between the virtual model and the physical reality. Today, all virtual models used for robot and assembly simulation and verification are nominal. However, in the real world, all equipment, parts and subassemblies are inflicted by geometrical variation, often resulting in conflicts and on-line adjustments of off-line generated paths.

Increased demands on ramp-up time, flexibility and plant throughput require robot paths to be generated and verified with respect to both robot precision and assembly tolerances. Therefore, the goal is to create knowledge, simulation tools and working procedures that will enable non-nominal path planning for rigid bodies and industrial robots. The project integrates two basic disciplines that have never been combined before, variation simulation and automatic path planning. Non-nominal path simulation and verification in concept phases reduces cycle time as well as need for physical verification meets demand on flexibility and speed by avoiding unnecessary tight tolerance, design changes and on-line adjustment of robot programs. Automatic non-nominal path-planning supports the Factory-in-a-Box vision of mobility and reconfigurability by allowing for fast robot program updates on site.

## 5. FACTORY-IN-A-BOX DEMONSTRATORS

The key features to realize a Factory-in-a-Box 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 easily combined into complete production systems and reconfigured 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 goal with the demonstrators is to exemplify and realize the Factory-in-a-Box concept; they will be practical examples of the usability of the concept in industry. All demonstrators are a practical solution for a particular function(s) and provide a real business case for the concept. The five different demonstrators are described in the paper.

### 5.1 DEMONSTRATOR 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".

- 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 for reconfiguring the module and its components while still having robust and efficient manufacturing.
- Speed: Short set-up time is vital for the success of this module. The Factory-in-a-Box module 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 modelling and simulation.
- Mobility: The Factory-in-a-Box module 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 in Bryne, Norway.

The vision of this demonstrator has been a production system that can be assembled and configured according to the company needs and that can be delivered to any location. Demonstrator 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 transportation of modules or for the entire Demonstrator.

- 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.
- 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 platform which can be secured to the floor by vacuum or air cushions for fast and smooth transportation. 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 one of the robots and one fixture mounted on platforms.

Fig. 1. Illustration of the concept of Demontstrator 1; mobile prodution equipment with well defined interfaces

Fig. 2. Picture of one of the mobile fixtures and one robot on a platform

During the Demonstrator 1 project, software for cell programming and control was developed (Hedelind and Hellström, 2007). This software was developed in order to enable the hardware reconfiguration that was needed in the resulting robotic working cell.

The cell uses flexible equipment, and is 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 since December 2006.

## 5.2 FACTORY-IN-A-BOX 2 – WELDING WITH FOCUS ON MOBILITY

Demonstrator 2 is developed in collaboration with Pharmadule Emtunga (PHEM). PHEM is a supplier of modular facilities to the offshore, 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. modularisation.

Demonstrator 2 is a semi-automated manufacturing cell, which is used for cutting, bevelling, 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 has approached 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 for reconfiguring the module and resources, e.g. configuring the demonstrator online and 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. Pipes will have different dimensions in terms of diameter and thickness.
- 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 for a standardized container.
- Speed - There is a need to quickly reconfigure the module without a 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 with today's manual process. With increased automation, quality will be improved and more consistent, and the disturbance time will decrease.

Demonstrator 2 can perform the following operations;

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

One of the major challenges with Demonstrator 2 is the usage of known technologies in a new application and context. Orbital welding of carbon steel pipes with straight-angle chamfers has never been done before within the company.

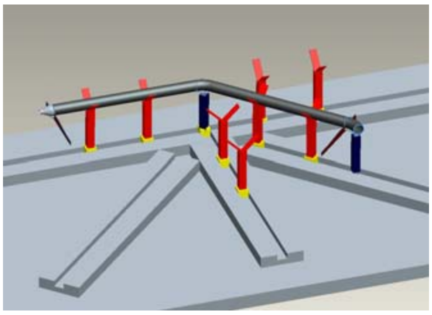

Fig. 3. Illustration of the flexible fixtures developed in demonstrator 2

PHEM has had a business concept in mind when developing the Demonstrator 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 module can be leased out to PHEM by suppliers or be owned by PHEM themselves. The Demonstrator 2 will be implemented within PHEM operations during the fall of 2007.

## 5.3 FACTORY-IN-A-BOX 3 – FOUNDRY WITH FOCUS ON MOBILITY

To further demonstrate the applicability of the Factory-in-a-Box project to industry, a third example of a Factory-in-a-Box module will be demonstrated within the 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.

Varnäsföretagen AB is a Swedish foundry that produces sand-casted aluminium 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 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 unsuitable and generally inefficient, thus motivating Varnäsföretagen 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.

Demonstrator 3 has approached 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 for reconfiguring the module and resources, e.g.

configuring the robot online and still having a robust and efficient manufacturing.
- Mobility - Demonstrator 3 will have to be designed on a “Mobile Platform” to be moved anywhere within the production system, or to another foundry company. The equipment could be encapsulated into a container to enable easy transport, and containment during production. Demonstrator 3 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 with today’s manual process. With the right level of automation, quality will be improved and the disturbance time will decrease.

During 2006 and 2007 a feasibility-study has been performed at the company, 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 one 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 operations. 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 steal-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 simulated fully in a virtual environment, and whether it will be converted into an operational cell is dependent on the company and circumstances outside the research projects control.

## 5.4 FACTORY-IN-A-BOX 4 – FUNCTIONAL SALES WITH FOCUS ON FLEXIBILITY

Demonstrator 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.

Demonstrator 4 has approached 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 for 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 reconfigurable “Mobile Platform” to be moved anywhere and reused for a new customer in a case of leasing.
- Speed - Short set-up time is vital for the success. The “programming” should be fast, which may demand reuse of experience or knowledge sharing.

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 where 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 type of functional sales are already being used in other types of industries, but is still not a common solution within manufacturing industries. No “real” example has been generated so far, which was the initial objective.

## 5.5 FACTORY-IN-A-BOX 5 – MANUAL ASSEMBLY WITH FOCUS ON MOBILITY

This part of the project is conducted in cooperation with Bombardier Transportation. Bombardier Transportation in Västerås is facing a market where the customers are becoming more and more powerful due to the strong global competition. Many 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 can lead to winning orders on markets otherwise closed, which will create job opportunities not only for foreign countries, but also for Bombardier in Sweden since the main part of the order is produced here.

Factory-in-a-Box 5 has approached 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

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 labour, 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 feasibility-study has resulted in two technical solutions for moving and housing production capacity abroad: a special container and a modular building solution. An illustration of a special expandable container solution is shown in figure 4. The choice of final solution will be decided upon including a prognosis on usage frequency, production capacity needed, and the strategically value this solution gives Bombardier.

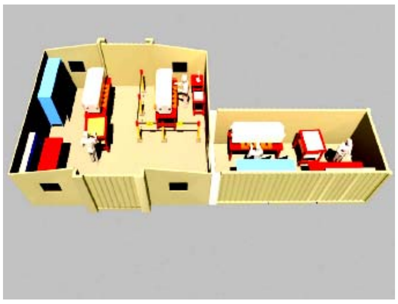

Fig. 4. Illustration of the mobile workstation concept of Demonstrator 5.

In order to exemplify a valid solution with a cost-analysis, the project has focused on a technical solution for the assembly of High-Voltage boxes demanding a capacity of 1-2 boxes a week. Even using this delimitation, the feasibility-study indicates that the Factory-in-a-Box easily can be modified to handle a much higher production volume. It also indicates that the same kind of solution can be useful for other Bombardier products. The feasibility-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. The feasibility study ended in a demonstration of a container solution that was temporarily installed at Bombardier in Västerås, and the concept is used in different offered solutions to customers.

Besides being used as an enabler to win orders, the feasibility-study has shown that the Factory-in-a-Box concept provides a substantial potential for cost-cut in the ongoing production at Bombardier. Thus, the feasibility-study recommends that the development of a prototype should be started at the company.

## 6. SUMMARY AND CONCLUSION

This paper has presented the Factory-in-a-Box project, the four different underlying research projects that contribute to the project, and the five demonstrators that have been developed in order to demonstrate the Factory-in-a-Box concept. The four underlying research projects, as presented in section 4, do all contribute with their own specific research in order to realise the Factory-in-a-Box concept. The five demonstrators that have been developed together with the industrial partners are all examples of how this concept may create “mobile production capacity in demand” – as the project set out to do.

Demonstrator 1 was developed during two years and is now integrated into production within a real manufacturing system. Demonstrator 2 has been developed in a virtual setting and evaluated, and the industrial partner will develop the physical demonstrator during the fall of 2007. Demonstrator 3 was fully developed in a virtual environment, and partly developed in a laboratory setting. The future of Demonstrator 3 lies in the hands of the industrial partner, which may decide to develop and use the concept at a later time. Demonstrator 4 was an attempt at leasing or selling production capacity. The concept has been offered to several customers, and time will tell if a real investment will be made. Demonstrator 5 was realised in a temporarily setup, and a lot of theory around how to realise mobile production facilities was developed within that demonstrator project. The concept of Demonstrator 5 has been offered to customers of the industrial partner and whether any real implementation will be made is left to see.

The scientific contribution of the Factory-in-a-Box concept is primarily the attempt to exemplify and implement a flexible and reconfigurable production system in reality. In the Factory-in-a-Box project we have indicated that it is possible to develop conceptual as well as operational manufacturing cells that meet the requirements mobility, flexibility, and fast set-up and ramp-up of production. Implementing a Factory-in-a-Box is proposed as an innovative solution and a means to exploit new competitive factors enabling future competitiveness within manufacturing industry.

The concept of mobile production capacity has been evaluated together with the concept of functional sales. The fourth demonstrator project had functional sales as the main priority, and an extensive feasibility study and a large number of offerings to customers have been conducted. However, the results from the study are inconclusive, and to fully evaluate the concept more cases will be needed.

Among the different competitive factors that are of importance in the Factory-in-a-Box project, mobility is perhaps the key-enabler. Mobility can be used as a competitive advantage in several different ways: reconfiguration of a manufacturing system, to provide production capacity where needed – when needed, and enabling companies to make an investment in one piece of equipment and reuse it at several production sites or within several projects.

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## REFERENCES

Ask, A. (2006) Factory-in-a-Box – An enabler for Flexibility in Manufacturing Systems. Mälardalens högskola, Licentiate thesis, Mälardalen University Press

Hedelind, M., Hellström, E. (2007). Programming of reconfigurable robotic working cells. To be published in the proceedings of The 4th International Federation of Automatic Control Conference on Management and Control of Production and Logistics, Sibiu, Romania, 27-30 September

Jackson, M. (2000). 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

Jackson M, Zaman A (2006) Factory-in-a-Box – Mobile Production Capacity on Demand. Proceedings of the 2006 IJME – INTERTECH Conference October 12-21 New York City USA

Molinari, T. L., F. Pierpaoli, A. Urbani, and F. Jovane, (2004). New Frontiers for Manufacturing in Mass Customization. *CIRP Journal of Manufacturing Systems*, Vol. 33, No. 3

Piller, F.T. (2002). Mass customization: four approaches to deliver customized products and services with mass production efficiency. Engineering Management Conference, IEEE International, Vol.2

Tidd, J., J. Bessant, K. Pavitt (2001). *Managing Innovation*. Second Edition, John Wiley & Sons, Ltd, England

Yin, R.K. (1997). *Case Study Research*, SAGE Publications Inc., London

Yusuf, Y.Y., M. Sarhadi, A. Gunasekaran (1999). Agile manufacturing: The drivers, concepts and attributes. *International Journal of Production Economies* Vol. 62