Mobile Manufacturing Systems: Market Requirements and Opportunities

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Abstract
Managing the global competition within the manufacturing industry emphasizes the need for more flexible production capacity. One way to achieve improved flexibility is to implement a mobile manufacturing system. The authors participate in the research project "Factory-in-a-Box", which key performance indicators are: mobility, flexibility, and speed. The objective of the Factory-in-a-Box concept is to develop mobile manufacturing capacity on demand, which can either be moved between different productions sites or within a plant. There are several reasons for introducing a mobile manufacturing system, such as:

- Entering new markets where there is a necessity to have local production.
- Being able to share low frequent used production capacity with other companies.
- Covering occasional peaks in production.

Principally, the demands on a mobile manufacturing system are high in terms of reconfiguration ability, generality, and an efficient knowledge and information handling system. By increasing the mobility of the manufacturing system, both small and medium sized enterprises (SMEs) as well as larger companies could increase their competitiveness.

By conducting semi-structured interviews at several companies of different type and size, both market and individual company requirements concerning mobile manufacturing systems have been identified. This paper describes the Factory-in-a-Box concept, and results discovered during a multiple case study. By explaining existing manufacturing theories and relating the Factory-in-a-Box concept to some of these theories, the authors give practical examples of how the concept can be applied.

This paper gives an overview of the requirements set on the mobile manufacturing system, and enlightens practical examples of how, and under which circumstances, the Factory-in-a-Box concept could be applied.

1. Introduction

To stay competitive and manage global competition within the manufacturing industry, the need for a more flexible production capacity has grown. Manufacturing industry customers can choose suppliers from all over the world, and it is not possible for a manufacturing company in for example Western Europe or USA to compete solely on cost. It is necessary to offer additional value to customers by e.g. responsiveness, flexibility, short delivery times, etc. But what are the key factors to surviving in this fierce competition? And, more importantly, how can these be realized?

The paradigm of Mass Customization, introduced by Stan Davis [1] and further developed by Joseph Pine [2], is now well accepted. Its key features are: fragmented demand, heterogeneous niches, high quality, customized goods and services, and short product development and product cycles [3]. One example of continuously decreased product life cycles is from the automotive industry. There, the development of a car from start of design to entering the market has been reduced from 60 to 18 months [4]. As stated in the key features of mass customization, in addition to shorter life cycle times, customers also require more individual products. To obtain mass customization on product level, a product structure that supports standardized modules based on customer needs is required [4].

To conclude the market requirements, the paradigm of mass customization is well established and there are several manufacturing theories that on a generic level describe how to fulfill this paradigm. Agility and quick responsiveness to changes have become mandatory to most companies. *Agile manufacturing* aims at achieving manufacturing flexibility and responsiveness to new market needs. Agility can be defined as a manufacturing system with extraordinary capabilities, such as hard and soft technologies, human resources, educated management and information, to meet the rapidly changing needs of marketplace. It describes how to create a system that shifts quickly among product models or between product lines, ideally in real-time response to customer demand [16]. Agile manufacturing focusing on the manufacturing enterprise and the business practices needed to adapt to a changing global market. It does not provide any operational technique or any engineering solutions [15]. Agile manufacturing is a methodology to mass customization realization [14]. The *Holonic Manufacturing Systems* is another concept where modularity is a key factor. It has its origin in the word hollow, which means a particle or part. The holons need to be autonomous, and they have to be cooperative. The HMS is therefore considered as a whole where autonomous parts cooperate in order to achieve a common goal, which in this case is to produce products. In the *Flotilla* [8] the factory is compare to a flotilla consisting of small ships or modules centered around a stage in the production process or an operation. The flotilla is alert all commanded at the same time as each module has its own control.
The *Fractal Company* can be described as a company with an organization of cooperating and self-regulating fractals [9]. High individual dynamics and the ability to react to changing conditions characterize this concept. The Fractal Company is an open system consisting of independently acting self-similar units. It is a vital organism, due to its dynamic organizational structure. The concept is based on western structures, mentality, and strengths and is a European answer to Lean Production [19].
An additional concept, which is on a more operational domain compared to for example agile manufacturing is the *Reconfigurable Manufacturing System* (RMS). The RMS will allow flexibility not only in producing a variety of parts, but also in changing the system itself [15]. There are several key factors in the RMS. The system must be customized in order to match the applications. The system and their components must be modularly designed, and also designed to be ready to integrate and adapted for future introductions of new technologies. Both the convertibility, to quickly change between products, and the diagnosis ability, to quickly identify the sources of quality and reliability problems that occur in large systems, must be high.

Accordingly, the key performance indicators for those theories are flexibility, modularity, short ramp-up time, self-organization and clean interfaces. Nevertheless, there are very limited examples of practical enablers even if the level of concretization differs between the concepts. They realize the earlier described theories and also add mobility as a vital part of the

practical solution. One way to achieve improved flexibility is to implement a mobile manufacturing system.

The implementation of manufacturing philosophies in an industrial context and implementing theory into actual business is often difficult. This paper gives an example of a concept that offers mobile manufacturing capacity on demand. It is called "Factory-in-a-Box" and its key performance indicators are: mobility, flexibility, and speed. The Factory-in-a-Box concept is developed by a project team that connects industrial and academic interests. The authors have an active role as project managers in the research project.

2. Methodology

The study is based partly on the research project Factory-in-a-Box, which is composed of a multiple case study consisting of five demonstrators (see Figure 1). Semi-structured interviews have also been done in order to verify the outcome of the multiple case study, as well as to receive new opinions regarding the Factory-in-a-Box concept. Three production managers at companies not connected to the demonstrators or the Factory-in-a-Box project have been interviewed. By conducting semi-structured interviews at several companies of different type and size, both market and individual company requirements concerning mobile manufacturing systems have been identified. The objectives of the paper are two-fold: to give an overview of the requirements set on the mobile manufacturing system and to provide practical examples of how, and under which circumstances, the Factory-in-a-Box concept could be applied. The requirements are a result of previous work in the Factory-in-a-Box project, and those are presented to give the readers a more complete picture of the concept's possibilities. Thus, the intention is not to validate the results of the multiple case study. Rather, it is to receive an indication of existing requirements and opportunities in order to lay a basis for the further research of mobile manufacturing system characteristics.

The semi-structured interviews began with a presentation of the Factory-in-a-Box concept. Subsequently, a number of questions were posed and answered to clarify the concept and to ascertain the company's point of view about mobile production (see attached questionnaire in Appendix II).

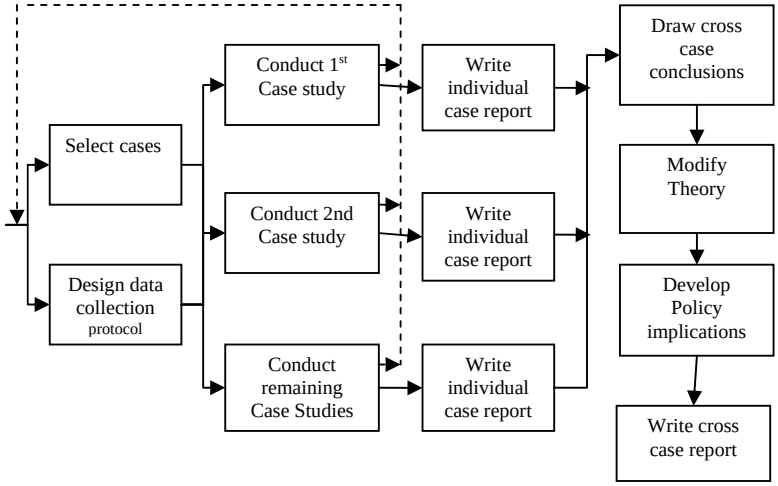


Figure 1. Multiple case study methodology [11].

The three companies are different in terms of size, business area, and type. The selection of companies was done on the basis of:

- ***Size***. One small, one medium sized and one large company are studied to be able to make a comparison of their needs and challenges.
- ***Location***. Since an important factor of the project is to strengthen the Swedish manufacturing industry, all companies have their main production sites in Sweden. However, the concept is valid for countries and regions with similar conditions, such as USA, Japan and Western Europe.
- ***Type***. The companies are positioned on different places in the supply chain
- ***Possibility to employ the Factory-in-a-Box concept.*** Only companies having production equipment feasible to move were chosen.

Three companies were selected from among the companies that met those requirements.

3. Factory-in-a-Box

The aim of the Factory-in-a-Box concept is to provide solutions for mobile and flexible production capacity on demand. Within the project, five fully operative Factory-in-a-Box units are designed and built. Universities and industrial partners closely cooperate in developing the manufacturing units. The Factory-in-a-Box units are realized and tested in an operative setting in the industry, where the benefits of the concept will be evaluated. Adding or increasing the level of mobility and employing a Factory-in-a-Box unit may fulfill different purposes:

- ***Cover occasional volume peaks,*** where there is an unexpected increase in volume and when the duration of the volume peak is difficult to predict.
- ***Reach new markets.*** It is easier to enter geographically new markets with the above changes. It could be an attractive offer when there is a necessity to have local production, which sometimes is an important political objective in large projects.

- ***Perform maintenance close to customer,*** when the customer is located at different locations and equipment is needed for maintenance purposes.
- ***Educate.*** When for instance training new operators and the ordinary production equipment cannot be occupied, additional equipment can be leased for educational purposes.
- ***Share equipment between companies,*** where the shared production capacity is used at a low frequency level.
- ***Facilitate product/prototype development and manufacturing..*** Instead of disturbing the ordinary production during the development of prototypes during the early phases of a product, a Factory-in-a-Box unit could be installed to cover such needs.
- ***Demonstrate Equipment.*** Equipment can be moved between different locations for marketing and demonstration.
- ***Cover temporary disturbances in a supply chain.*** When unexpected incidents occur that disturb the rest of the value chain, a Factory-in-a-Box unit performing the same work tasks may be installed temporarily.
- ***Lease.*** Offer the manufacturing industry attractive leasing contracts of production capacity.

The Factory-in-a-Box concept consists of production modules that preferably can be installed in a standard freight container and thereby can easily be transported by for example truck or train. Besides the production module, the Factory-in-a-Box concept contains solutions to securing the logistic set-up, the education and training of the personnel, as well as how to form best form an organization to optimize the output of the concept. The modules may rapidly be combined into production systems that can be reconfigured for a new product and/or scaled to handle new volumes. Production capacity may be provided as a mobile and flexible resource that can quickly be tailored to fit the needs of a company at a specific point in time. By implementing the Factory-in-a-Box concept, a company does not have to make large investments, instead equipment can be used temporary.

To offer mobile production capacity could strengthen a company's competitiveness when acting on a geographically large market. Consequently, the emphasis on mobility in the Factory-in-a-Box concept is strong. 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.

3.1. Requirements on the Factory-in-a-Box Concept

As the Factory-in-a-Box project has evolved, several complex interfaces, arising from introducing mobility into a manufacturing system, have become known during previous studies. To implement the Factory-in-a-Box concept in an efficient way, the major parts of the following set of generic requirements need to be covered:

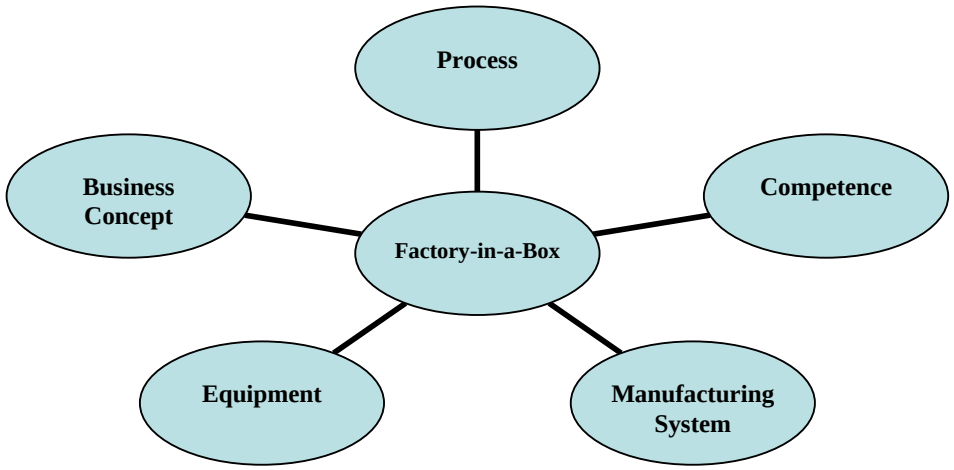


Figure 2. Generic illustration of the requirements set-up for a Factory-in-a-Box unit.

- ***Business concept.*** To fulfill the Factory-in-a-Box concept's key performance indicators *mobility*, *flexibility*, and *speed*, the business concept should be as general as possible within the targeted business segmented.
- ***Process.*** The process must be *quick* and *flexible* through the different phases of configuration, transportation, installation and ramp up.
- ***Competence.*** The concept must include all the competence needed to employ the manufacturing units, from the moment it is delivered until it is sent returned/sold to the customer. This manifest itself either in terms of securing education and training of the available personnel at site or offering manpower as part of the business offer. Accordingly, there must be personnel to operate the equipment, as well as maintenance personnel.
- ***Manufacturing System.*** To optimize the use of mobile manufacturing units, the manufacturing system needs to comply with the following set-up [13]:
    - Detailed documentation of processes and products.
    - A product structure that allows the modularization of sub-systems and is adapted to suit the manufacturing system.
    - Managerial, flexible and adaptive Master Production Scheduling System.
    - Allow a dynamic automation level, in other words define a system flexible enough to handle variations.
- ***Equipment.*** The equipment has to be easy and speedy to adapt to new situations. Thus, it must be both *general* (to fit various application areas) and *flexible* (to handle changes in volume).

The above-mentioned requirements illustrate that to succeed in implementing the Factory-in-a-Box concept and fully utilize its possibilities, it is necessary to have control of all related processes. Most likely, parts of the existing system need to be changed during a potential implementation of the Factory-in-a-Box system.

A brief description of the five Factory-in-a-Box units follows below.

3.2. Factory-in-a-Box 1

The first Factory-in-a-Box application provides an example of a highly automated production cell that is mobile and will be used on multiple sites within a factory. The production unit, which will be used for the folding, caulking and assembling of sub-parts for a robotic control box, is developed to demonstrate a quick and easy configuration of new work processes. The workload within the manufacturing cell can change with only small effort. The unit also allows for a short ramp-up time of production. This Factory-in-a-Box unit consists of a number of modules, tools, fixtures and robots, all designed with maximum flexibility to allow for the effortless configuration of future work tasks.

3.3. Factory-in-a-Box 2

The second Factory in a Box application is used for the cutting, bevelling and welding of carbon steel pipes. All machinery will be fitted into a standard container that contains fume hood exhaust, lighting, computer terminal, etc. When tendering for large projects, there is a significant variance in workload on all levels in the company, and it is a challenge to balance resources to fit this purpose. One way to adjust the manufacturing system to this inconsistent workload is to implement flexible and mobile manufacturing cells that can quickly and easily be used on different production sites. Consequently, it allows the company to invest less in manufacturing equipment, while still increasing manufacturing effectiveness, improving the quality of the performed work, and maximizing the overall equipment efficiency.

3.4. Factory-in-a-Box 3

The Factory-in-a-Box 3 is a mobile manufacturing unit, which will be shared between small companies in the same business. The manufacturing unit will grind fins that are remove scrap from the casting. It allows cooperation between iron foundries. Consequently, there are strong incentives on mobility, product flexibility and short ramp-up times. This Factory-in-a-Box application allows small companies to take advantage of automated solutions in a way that significantly reduces the risk of investing in advanced equipment. This option may not have been possible if the company had to make such an investment itself.

3.5. Factory-in-a-Box 4

The fourth Factory-in-a-Box unit is an example of functional sales of manufacturing services. The concept is a reconfigurable small-scale assembly line that can be rebuilt according to the present demand in terms of product and volume. The different sub-parts of the Factory-in-a-Box can be a mix of machines, robots, manual workstations, and conveyors. Each sub-part can be exchanged, improved or made more efficient. The benefit of using the Factory-in-a-Box concept is that the company can increase its manufacturing capacity, without incurring heavy investment in production equipment. Moreover, if a decrease in demand occurs, it is easy to reduce the cost of the assembly line by returning the whole line or parts of it.

3.6. Factory-in-a-Box 5

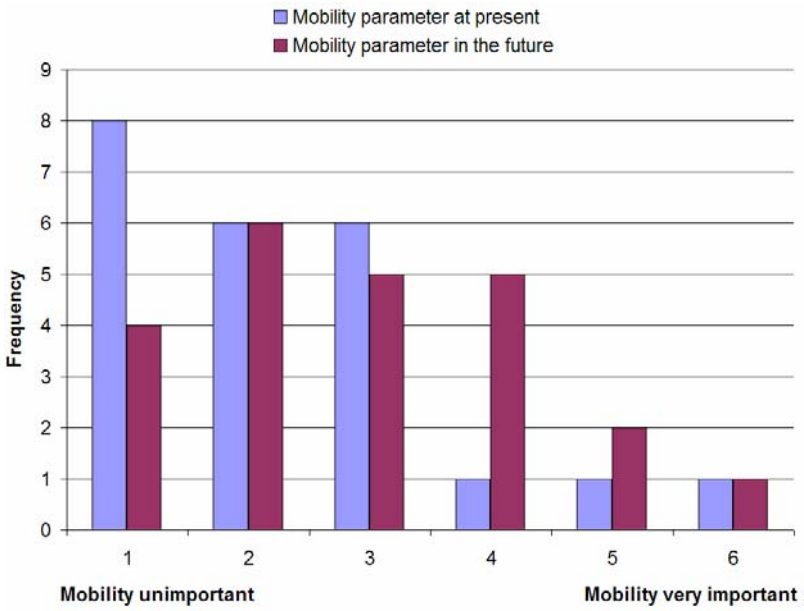
The fifth and last Factory-in-a-Box demonstrator will increase the possibilities of getting into new markets while keeping the main part of the production in-house, to prevent outsourcing and to retain control of the production. It is a concept in which a portion of the work is performed close to final assembly and thereby closer to the end-customer. This concept opens up a lot of new markets that were previously impossible to compete in. That is due to the fact that some of the customers require that a certain amount work must be performed in their home country. The Factory-in-a-Box concept offers the end customer the development of production- and testing know-how among its employees. The concept also offers a controlled transfer of production and technology. This Factory-in-a-Box concept relies on a selection of

technical scope, logistic set-up, educational programs for "customer-appointed" employees, managerial concepts, production and commissioning.

4. Results from the Field Investigation

A previous study, done on 23 companies in Sweden with the purpose of investigating the importance of mobility within the manufacturing industry, shows that there are interesting market benefits from increasing the level of mobility on manufacturing capacity (see Table 1).

Table 1. Mobile Manufacturing Systems at present vs. future industrial need [12].



Consequently, it is interesting to analyze which specific needs and requirements companies place on mobile manufacturing capacity. In order to obtain this general opinion about those specific needs and requirements, the concept has been discussed with three companies unconnected to the research project.

The three companies are briefly described in this chapter. Subsequently, their view of the Factory-in-a-Box concept is presented, as well as their view of application areas within their business. (Detailed company information is presented in Appendix I.)

4.1. Company A-C

Company A is a small company working as a second tier supplier. Company B is a middle-sized company working as a first tier supplier. Finally, company C is a large company producing finished products (see Figure 3).

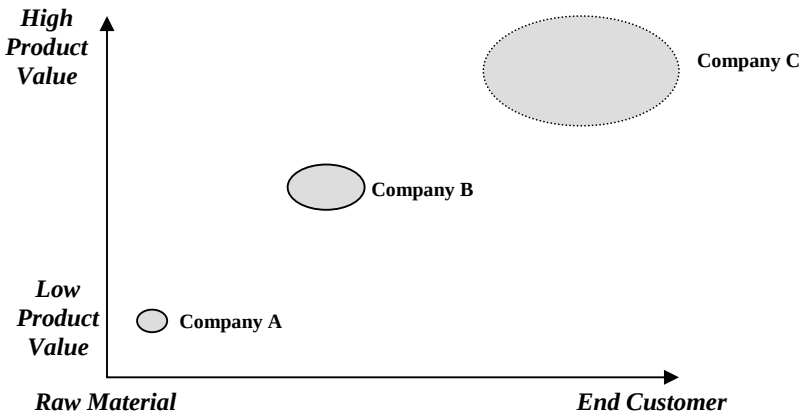


Figure 3. Company A, B and C's position in the value chain. The size of the ellipses indicates the size of the companies.

Global competition that is continuously increasing, greatly affects all the companies. As a consequence, during the last five years they have been forced to amplify the production output in proportion to the number of employees. These changes were made possible by investing in an enlarged level of automation. Additionally, all the companies are continually trying to improve their functional prognosis- and planning system, since the product life cycle tends to be shorter and shorter at the same time as the volumes increases.

In analyzing their need for mobile production capacity, the following aspects have been considered (see also Appendix II):

- Market Segment
- Location
- Position in the value chain
- The location of, and relation to, customers and subcontractors
- Use of alternative business concepts (Outsourcing, Joint Ventures, Alliances, etc)
- Responsiveness, for example how to handle changes in capacity/products
- Owning, leasing or sharing production capacity

4.2. Company A

Company A is a small sized industry with 25 employees. It consists of three plants located on three different sites, all in the same region in southern Sweden. All the plants are focused on the same type of business and products. They work as a second tier supplier, delivering components to a wide range of industries, and they have a large variety of products. The product life cycle varies widely, depending on the product and customer. The machine park consists of a large number of automate lathes of high generality that are placed in a functional layout, subsequently all articles are produced in single machines.

The connection to regional companies is considered very important. Most of the customers, as well as the subcontractors, are situated in Sweden, and the company has no thoughts of moving parts of their production to low wage countries. In the increasing turbulent market, with short product cycles and lead times, changes in capacity are common. Normally, the delivery time varies between two and eight weeks. If there is a lack of capacity, the delivery

time is extended. This means that during times of capacity shortage, the customers with high demands on the delivery times are prioritized. Hence, if the company does not have enough capacity and the delivery time is too long, they let another company in the region do the job.

Presently, the company does not lease equipment. Instead, they own all their equipment. They purchase in installments, with an installment time of between three and five years.

4.3. Company B

Company B is a traditional, middle-sized Swedish engineering industry with 90 employees. It works and acts in Sweden as a subcontractor to the automotive and engineering industry. The production operations include tube bending, robot welding, and complete assembly. Thus, the process is rather complex, and the level of automation in the production line is high.

To stay competitive, they may be forced to start up production in low wage countries. Additionally, the high requirements the automotive industry put on their subcontractors and suppliers highly affect the business. The company has approximately 140 subcontractors, of which 15 % are foreign. Their subcontractors, often very small companies, do not always share the same focus on quality and delivery time as the automotive industry does. Developing the subcontractors' way of working and their thoughts to follow the trends and strategies of the automotive industry is an ongoing project.

The company owns most of its equipment, and the pay off time is normally four years. Usually, any bottleneck in the production capacity results from the number of operators, not the equipment. There are two ways of handling changes in capacity: increase the number of employees or increase the number of working hours. The company tries to stabilize the variations in capacity changes by having a satisfying planning function and good control of the bottlenecks. If it is necessary to implement an additional working shift, the ramp up time is about three weeks. An important factor is the ramp up time for each product, which has to be as short as possible. Sometimes the time between a placed order/finished design of a product and delivery is as short as three days.

4.4. Company C

Company C is a large company, and has plants located in 20 different countries. The studied factory is situated in Sweden. The company principally manufactures products for heating, ventilation and air conditioning.

Company C's manufacturing process includes everything from fully automatic processing to manual assembly. Since the products are very bulky and the ratio of product price/transportation cost is relatively high, most of their customers are closely located. If the product will be used in another part of the world, the product is most likely purchased from a competitor located close to the final site of the air-handling unit.

There are plans to have remotely controlled production with plants located wherever in the world. The company has a joint venture in Egypt where the production is conducted in this way. Furthermore, the company has a "satellite production" located in Russia. Finished components are shipped to the plant, where the final assembly is done, closer to the customer site. In this way, the import duties are kept low, as compared to delivering finished products.

A strategic choice has not been made as to whether the equipment should be owned by the company or leased. It varies between the types of equipment. For example, trucks are leased

and production machines are bought. Depending on the type of equipment, the pay-off time varies between one and three years.

The required production capacity follows the seasonal changes of the construction industry. This results in a tripled working force during the summer. It is not the equipment that is needed in capacity changes, as in the case of Company B. Rather, there is a lack of manpower. To control the variations in capacity, a flexible working hour system has been implemented. Sometimes the company buys parts from other suppliers as a way to handle capacity changes.

4.5. Respondents View of the Factory-in-a-Box Concept

Possible applications and requirements on the concept were discussed during the interviews. The companies´ view of the Factory-in-a-Box, new areas of interest to the concept, and criticism regarding the concept were identified.

Overall, company A is critical of the Factory-in-a-Box concept, and they find it difficult to implement in their business. They noted that:
"It is difficult to get a high generality that is attractive for several industries."

They also say that:
"It would be difficult to find skilled machine operators, since it already is challenging to find trained personnel in the region."

According to company B, the Factory-in-a-Box concept is an interesting idea with numerous usage areas. Nevertheless, the need for mobile production capacity in their business is low. And the reason is that they find their processes too complex to fit the mobile production concept. In addition, they do not have a number of similar factories to share equipment between. Also, their bottlenecks primarily are related to lack of manpower. However, it might be useful with mobile equipment that could be moved between different departments within a plant to increase the utilization rate within the factory. There is a production philosophic dilemma:
"Production is our core business, which makes it impossible to lease mobile production equipment from another company."
According to company B, the production equipment is their way of making money.

Finally, company C considered the Factory-in-a-Box concept very interesting. They find great advantages with increased possibilities to rapidly move production equipment and produce wherever it is desired. Actually, they are discussing sharing machine capacity between companies in the region and offering external subcontractors to manufacture components inside their plant. There are no examples of this yet. Company C does not find much use of having mobile equipment within their existing factories. However, the company may use the concept to reach new markets. By implementing satellite production plants, consisting of one or more Factory-in-a-Box units, the company sees a possibility to extend their market by getting closer to more customers. At present, the company is losing orders due to its location. Further, there is a great problem with high import duties in certain markets. Accordingly, the reason for adding mobility to their production equipment would not be enhanced efficiency. Instead, it would involve possibilities to enter new markets, avoiding import duties, access to local labor and reduced transportation costs. An additional advantage of being close to customer sites is the enhanced possibilities to make late product changes without extending delivery times. It would be possible to use their present production equipment and machines

in a mobile unit. Moreover, they find it more appropriate to use simpler equipment with a lower level of automation, i.e. a kind of machinery that would be more general and easier to adapt to every single situation.

5. Discussion

For a manufacturing supply chain to respond successfully to a volatile demand, it requires better coordination and collaboration, both horizontally between divisions within a company, and vertically between partners along the supply chain [22]. As discussed earlier, the mass customization paradigm is a strong driving force in terms of fulfilling customer requirements while still being efficient. One of its key factors is the idea of splitting products into modules. By implementing the modular concept on the product level, companies can offer their customers a wide variety of products by mixing different modules. The Factory-in-a-Box concept tries to stretch the generic ideas of mass customization on the product level and implement it on a manufacturing system level. Consequently, by implementing mobility in a modular manufacturing system, improved flexibility as well as increased responsiveness is obtained. The latter parameters are fundamental driving forces in the mass customization theory [2], [3].

The common key performance indicators of the visionary manufacturing theories are: flexibility, cooperation between manufacturing cells, short ramp-up time, modularity, distinctive interfaces and self-organization [8], [9], [14], [19]. The indicators are important factors in terms of fulfilling the so-called grand challenge 5 [10]. Established by the US national research council for visionary manufacturing challenges, it calls on industry to "Reconfigure manufacturing enterprises rapidly in response to changing needs and opportunities". Principally, the demands on a mobile manufacturing system are high in terms of reconfiguration ability, generality, and an efficient knowledge and information handling system. The agile paradigm emphasizes competition of supply chains rather than firms [20], and similarly the focus of lean thinking has evolved outside the firm to the entire supply chain [21]. By increasing the mobility of the manufacturing system, both small and medium sized enterprises (SMEs) as well as larger companies could increase their competitiveness.

There are several factors to consider when implementing a mobile manufacturing system into an existing manufacturing system or when increasing the level of mobility in a manufacturing system. The main hardware, software, and methodological enablers have to be identified and configured in order to fit the new requirements. For the purpose of maintaining and increasing performance, the mobility factors imply new challenges on technology, company strategy, organization, information flow, and knowledge reuse.

5.1. Comparison with Factory-in-a-Box Unit 1-5 and Company A, B, and C

When comparing the objectives of why and how to use mobile production capacity between the three companies and the Factory-in-a-Box units developed in the project, there are similarities in terms of business possibilities as well as potential practical solutions. Both company C and Factory-in-a-Box unit 5 can see the possibility to use a mobile production capacity to reach new markets, which also would increase production volumes at their main plants.

Regarding company B, the reason for using a Factory-in-a-Box unit would be to move expensive equipment within the factory, just like in Factory-in-a-Box unit 1. One can also

find similar business incentives for Factory-in-a-Box 2, where the unit is being moved between their production sites in Sweden.

Small companies, such as company C, may need the mobile production capacity to share between companies with a similar production in the region. Small companies usually do not have the possibility to make large investments in new equipment to adapt to a turbulent market. According to a research project conducted by the European commission [17], many SMEs consider access to finance as a consistent problem. In many cases, it is not possible to get the funds needed to invest in expensive manufacturing equipment. Also, it can also be a high risk for a small company to do investment in new technology when acting on a volatile market, where the customers' purchasing power constantly changes [23]. The company could increase their business by leasing or by sharing equipment to cover occasional peaks in volume. Factory-in-a-Box unit 3 is an example of such a solution.

5.2. Challenges

It will most likely be difficult to meet the requirements previously described in chapter 3. The concept must be general and easy to adapt to new situations while at the same time fitting into complex, specific processes.

Another critical necessity to satisfy is the requirements in terms of flexibility, generality, and accomplishing a short delivery time of the Factory-in-a-Box unit. This is particularly true when the offer is to lease production equipment. Moreover, it is a challenging task to quickly set up systems for logistics and information flow, particularly if the Factory-in-a-Box unit is used to get into new markets. Also, the occupations of these units have to be secured. The demand for the Factory-in-a-Box will be high in times of prosperity, and it will not be possible to offer mobile capacity to all companies that desire to hire it. In contrast, the unit might work below capacity or even be unused during times of recession.

Small companies, such as company A, run the type of businesses that to a great extent are being moved to low wage countries. On the other hand, the company's products and machinery could easily be adapted to the Factory-in-a-Box concept. During the field investigation, Company A was most skeptical to the concept. Small and middle sized enterprises, SMEs, have been much more skeptical to the concept than large companies, both during the interviews and in the case study. The reason for that is most likely multifaceted, and covers everything from owner structure/influence to financial strength, investment strategies, product portfolio, market volatility, risk strategy. In the European commissioning report [23] similar reasons are identified, e.g. SMEs find it difficult to implement new technology. Nevertheless, this is a very important market barrier to consider when launching the Factory-in-a-Box concept.

5.3. Opportunities

There are great differences between the companies and their ability to comprehend the concept and picture future applications. As stated earlier, the aim of the Factory-in-a-Box concept is to offer the engineering industry *mobile production capacity on demand*. During the interviews, comments like *"production is our core business and we cannot lose control of it"* and *"we have a far too complex product for such a concept"* were used to criticize the Factory-in-a-Box concept. Nevertheless, the authors of this paper stress that arguments like those need not be correct. The Factory-in-a-Box concept is a way of maintaining control over the manufacturing process, with improved competitiveness.

Depending on company size, the needs and requirements of companies are different. Smaller companies might lease equipment to cover unforeseen volume peaks. There are several advantages especially for SME:s of leasing compared to buying equipment backed by a loan such as no tie-up of capital and no need for additional collateral since the leasing-company is the owner [17]. By implementing a Factory-in-a-Box in the production process, SMEs could benefit by improving their ability to handle turbulence in capacity. They would also be able to produce most of their orders in their own plant instead of sub-contracting the job and still not have to invest in equipment. The concept can be used to get closer to customers, sub-contractors, and suppliers. Depending on where in the supply chain a company is positioned and what type of market they act in, the relations to and dependence on suppliers, customers and sub-contractors differ significantly.

According to the field investigation, as well as the case study, larger companies are more encouraged by the concept. Some of those companies have already configured parts of their manufacturing system in "unconventional ways", such as satellite production and joint venture alliances. The Factory-in-a-Box concept could be an interesting alternative to a more conventional manufacturing line used for satellite production. For example, one or more Factory-in-a-Box units could be used during production start-up to reduce financial risks in terms of physical fixed assets. When the need for a permanent production facility emerges, the units can be moved to another production start-up.

The production layout is of high importance in terms of the utilization of the concept. In a functional layout, a Factory-in-a-Box unit is proper to use. The machines are not connected to each other, and each product often is processed in one single machine. In a line layout, there are more complex requirements on the concept. However, as long as it complies with the framework for setting up a manufacturing system described in chapter 5, it can still be used.

Depending on the set-up of the individual Factory-in-a-Box unit, the level of automation varies significantly. Flexibility in terms of automation level is one of the concept's advantages. The level of automation on each individual unit is finalized during its design phase, varying from manual assembly to a completely automated unit. For example, when capacity shortage depends on lack of equipment, highly automated Factory-in-a-Box applications might be leased. In another scenario, large companies with a production unit for semi-automated assembly that would like to add mobility to the manufacturing cell (to be able to it move between departments) could benefit from implementing the concept.

6. Conclusion

The Factory-in-a-Box concept is an example of how to add mobility to a manufacturing system. The generic framework of the concept is in line with present product requirements presented in the Mass Customization paradigm, as well as future trends and challenges within the manufacturing industry.

The requirements placed on the mobile manufacturing system in terms of general, flexible and modular equipment that can quickly be implemented in a production system have been described earlier in the paper. Factors like business concept, equipment, competence, and manufacturing process all have a large impact on the conceptual configuration. The multiple case study, as well as the field investigation, give numerous examples of applications for mobile manufacturing units. They range from satellite production to marketing activities. To succeed in realizing the concept, it is important to have a good understanding of the mobility

impact and work in a structured way and be able to identify what type of applications to focus on.

To get a comprehensive picture of the market requirements and opportunities for mobile manufacturing systems, an exhaustive study among more companies should be executed. However, this particular field study indicates that the Factory-in-a-Box concept could be appealing to many companies within the manufacturing industry. The authors stress that it is important to continue the research within the area of mobile manufacturing systems. There is still a lot of work to be done in terms of discussing the need of this type of systems with the industry and developing the Factory-in-a-Box concept into a competitive market offer.

Finally, mobile manufacturing systems in general and the Factory-in-a-Box concept in particular offer new possibilities to the manufacturing industry.

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8. Biography

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Appendix I

Questionnaire used during interviews

1. Would it be interesting to implement a Factory-in-a-Box in your present manufacturing system?

2. Would it be interesting to implement a Factory-in-a-Box in a future manufacturing system, e.g. in need of capacity increase or during the launch of a new product type?

3. What is the present strategy for your production equipment? (owning, leasing or sharing with other companies)

4. What is the normal duration of the product life cycles?

5. Is the present organization suited for using a Factory-in-a-Box?

6. Do you have internal/external requirements of increasing the flexibility within your manufacturing system?

7. How do you solve a possibly need for increase of production capacity (shifts, prolongation of the delivery time, new machine investments)?

8. What is the most critical part when making changes in your production (cost, ramp up time, flexibility)?

9. Is it beneficial to have mobile production equipment?

10. Would it be interesting if there were a company, Factory-in-a-Box, Inc., that could offer you a functional sale by delivering production equipment to your production plant e.g. in order to increase the capacity or offering prototype production capacity? Under what circumstances would you employ such a company?

11. If investing in mobile production equipment, what is the expected pay-off time?

12. Have you ever had thoughts of moving the production to low wage countries?

13. What is your spontaneous thought regarding the Factory-in-a-Box project?