FLEXIBILITY NEEDS AND ENABLERS IN ASSEMBLY SYSTEMS

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Abstract
The purpose of the research presented in this paper has been to analyze flexibility needs and enablers in assembly systems. The methodology used for the research has been a literature review and a case study at a Swedish manufacturing company. Flexibility as a competitive factor has been shown to be needed in order to satisfy the changing demands, at low cost and with delivery precision. The level of customization and changes in volume also increases the flexibility needs. The results from the case study indicate that there are four flexibility enablers in assembly systems: capacity and production planning, production development, material supply, and work organization. The needs of flexibility should be considered during the design process of the assembly system to respond to changes in product variants and production volumes in a cost-effective way.

Keywords:
Flexibility, assembly system, case study

1 INTRODUCTION
In today’s competitive environment, the ability to handle changes, in both product variants and production volumes in a cost-effective way, is crucial for the competitiveness of manufacturing companies.

The ability to change and respond to changes has been described at different production levels; one of them is, the segment level where assembly has been included [1].

The assembly system is a core process of the production system and is very much in focus when handling changes securing quality, and maintaining a competitive and cost-efficient production.

The ability of the assembly systems to respond to changes is often defined as “flexibility” within assembly. Flexibility is a term widely used in industry and in theory, and it has been mentioned to be one of the most important competitive factors within industry [2].

In literature it is possible to find various scientific works regarding manufacturing flexibility. Flexibility is described as a broad term and several definitions of flexibility are given e.g. it has been described by Upton (1995) “as the ability to change and react with little penalty in time, effort, cost or performance” [3]. However, it has been mentioned that regarding flexibility there are variation in perspectives specially when broken down into its dimensions, elements, and measures [4].

Therefore, to respond to the increasing demands of flexibility in industry, the ambiguity regarding to how flexibility is defined could be problematic. As there are a wide number of definitions, it is unclear how industry should work with flexibility within assembly systems and what consequential challenges this entails. There is a need for more knowledge about flexibility as a concept, as well as how to respond to changes in assembly systems.

Based on this challenge, the purpose of the research that has been done and is presented in this paper, is to analyze flexibility needs and enablers in assembly systems. The paper presents an overall view of flexibility in a manufacturing company. The central questions in this case study have been:
- What are the needs of increasing flexibility within assembly?
- Which enablers could be identified when managing flexibility in the assembly system?

The paper will first present a theoretical framework regarding assembly systems and flexibility. Following this, the methodology used to collect data will be described. A case study in a heavy duty manufacturing company will be presented. Finally, a discussion of the result will be given as well as suggestions for future work are made.

2 THEORETICAL FRAMEWORK
2.1 Assembly System
The integration of geometrically corresponding parts and components according to specifications of a product in a given quantity and within a given time characterises assembly. This integration can be obtained through a process in which important operations are transformed with the support of material, energy and information [5]. Furthermore, both the product structure and the configuration of assembly work settings affect the sequences of the assembly process [6]. The area where the integration takes place is typically called assembly system [7].

Although the assembly system is a separate unit, it is simultaneously a subsystem of the production system and it depends on its surroundings [2, 8]. When studying the assembly system it is important to have a comprehensive view of all constituents parts of the assembly system needed to assemble the product and the relation between the parts. Expanding on earlier research Rösiö [1] discusses five constituent parts of the assembly system: (1) the technical system, (2) the human system, (3) the material handling system, (4) the computer and information system and (5) the building and premises.

Several studies of manufacturing companies identified the impact of assembly systems in terms of production time [9], production cost [10] and labour share [11]. These studies reveal that there is a constant need to enhance effectiveness and efficiency of assembly. In addition, Lampel and Mintzberg [12] point out that the dominant pattern in manufacturing is that components and the production of components are often standardised, while customisation is achieved through the assembly of a...
customised set of products. The demand for customisation requires that a company’s assembly system can handle frequent changes in market demand and quickly adapt to new products/variants. Therefore, the main strategy of manufacturing companies is assemble-to-order, which means that final assembly is based on specific customer orders. However, this strategy implies that the assembly system has to deal with high uncertainties and complexity in their processes.

2.2 Flexibility

There are different definitions of flexibility in the literature. One of them is from Sethi and Sethi (1990) who defined “flexibility of a system as adaptability to a wide range of possible environments that may encounter. A flexible system must be capable of changing in order to deal with a changing environment” [13]. There are also definitions according to characteristics, like the eight characteristics developed by Browne et al. [14], regarding machine flexibility, process flexibility, product flexibility, routing flexibility, volume flexibility, expansion flexibility, operation flexibility and production flexibility.

Another example of definitions of flexibility is: volume flexibility, product mix flexibility, and flexibility to introduce new products and new technology [15]:

- Volume flexibility is the ability to handle variations in volume.
- Product mix flexibility is the ability to handle different products.
- Flexibility to introduce new technology and products is the ability to introduce this in the existing system.

Flexibility of a production system is determined by its sensitivity to change [16]. High flexibility or low sensitivity to change brings three principle advantages to a production system, and these can be divided into three main categories:

- Product flexibility enables a production system to make a variety of parts with the same equipment. In short-term horizon this means that the system has the capability to produce in small batch sizes and adapt to changing demands, still being profitable. In the long-term horizon the system can be used across multiple product life cycles, increasing the investment efficiency.
- Operation flexibility refers to the ability to produce a set of products using different machines, materials, operations, and sequences of operations. This gives breakdown tolerance and is provided by the processes, machines, the product design, and the structure of the system itself.
- Capacity flexibility allows a production system to vary the production volumes of different products to accommodate changes in demand while remaining profitable. This means that the system must be able to contract or expand easily.

Flexible as well as reconfigurable production systems have been extensively discussed by several researchers in for example the Reconfigurable Manufacturing System framework (RMS). A reconfigurable manufacturing system is a system designed at the outset for rapid change in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality within a part family in response to sudden changes in market or in regulatory requirements [17]. There is a close connection between the terms flexibility and reconfigurability and sometimes flexibility could be achieved through reconfigurability. RMS is a system installed with precisely the production capacity and functionality needed and may be upgraded in the future, exactly when needed [17]. In the RMS field much research effort is devoted to development of techniques and tools enabling reconfigurable hardware and software [17,18], layouts in the form of determination and classification of various configurations [19], and ways of considering future product variants [20,21,22].

3 RESEARCH METHODOLOGY

The results presented in this paper are based on a literature review and a case study performed at a heavy duty manufacturing company. The literature review focused on flexibility and assembly systems. The empirical part of the research study consist of a case study that is related to an on-going project which aims to develop an assembly system that can handle continuous changes in product variants and volumes. The authors have an active role in the project. In addition to this, another project related to flexibility was identified at the company, and investigated as a part of this research study.

Applying a case study made it possible to study flexibility needs, enablers and challenges in the assembly system in depth and in its natural setting [23]. Data were collected by multiple sources of evidence including observations, semi-structured interviews and document studies. A general description of the data collected is provided in Table 1.

The assembly area is composed of two assembly lines and a workshop. For this study, the assembly lines were selected for the study due to the quantity of product variants assembled: 5 product variants are assembled in the first assembly line and 10 product variants are assemble in the second one.

Templates to collect assembly information were developed as observational instruments. Also, observations were conducted at the line and on a workstation level. In order to get an understanding of the assembly system data was collected about the processes, the work organization, the assembly flow, the layout, the assembly sequence, the equipment, and the material handling systems. The observations were complemented with explanations and information provided by the workers in each workstation. Information like the assembly line layout, and production times, were provided from the production engineers, as well as several explanations about the assembly. In addition, information regarding the sizes of the different products was also collected in a specific template for this purpose to understand the dimensions of the different product variants that are handled in the assembly work. This was also taken into account during the observations. Also, documentation from the participation in the project has been studied.

Semi structured interviews were conducted, based on an interview guide regarding flexibility definitions. The respondents belong to different areas of the company: logistics, production planning, capacity planning, assembly and production in order to get an understanding about flexibility from different perspectives.

The information that was given to the respondents beforehand the interview was a brief introduction of the topic of interest and its relation to the current project and the research project.

The interviews were recorded and transcribed. All the interviews were supported with documents provided by the respondents and in order to ensure the validity of the findings the transcription of the interviews was sent to the respondents.
4.1 Flexibility needs at the case study company

The studied company had more than 10 manufacturing sites, each with unique assembly processes and products. The company had a strategy to start regional manufacturing, i.e. different products should be assembled in the same assembly system. With the aim of assembling different products in the same assembly system, the company needed to increase their volume and product mix flexibility.

At the case company, volume flexibility had been described as being able to adapt quickly to the changes, increases and decreases in the assembly, but also to “catch up” the assembly when there have been delays due to some disturbance. It could be summarized as the ability to assemble different product variants or customized products. Workers played an important role, since the flexibility of the assembly work depended mostly on them, for example, to adapt different product variants or customized requirements, including the assembly of unique products, implied different instructions, operations and in some cases sequence. Since customers could select requirements for their products from several hundred options, the workers were able to follow and learn assembly instructions for those options as well.

Globalization also showed to have a large impact in the assembly process in different ways. One example of that was in relation to some features of the product, those features should guarantee that specific rules were followed to be sold or used in some countries. This also required other kinds of instructions for the workers who also knew the destination of the product.

The workers managed also critical processes due to quality assurance, safety, ergonomics, etc., safety and ergonomics as well as the design of the workstation were important for the development of their work. They were also in some extent in charge of quality control.

The assembly system handled some changes in volume, so the workers were able to handle different assembly times. However, major volume changes could require time to be actually executed.

The workers had the competence to manage different kind of tools and computer systems when performing the different operations.

In assembly, much of the work was related to the process of balancing the line. This means that every time that a change in the demand occurred, the balance in the line was recalculated. These changes affected directly the work of the assembly operators as there was a need to establish a new tact time, reorganize the groups and divide the work content. Specific rules about the changes in the assembly were desired, defining clear boundaries about how the assembly could change, as fast as possible to get the different times, flexible for the customer, but with an stable assembly system, considering also best ways of training and teaching the people in the line.

4.2 The assembly system structure

Human System

The assembly process was semi-automated. The work was carried out in teams who rotated between a number of stations. The teams were organized according to the division of the work content. The division of the work content was done based on the demand from which the assembly times were calculated, but also according to the products and the estimated time required to assemble.

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Technical system

The workers used different kinds of tools and fixtures to carry out the assembly operations. The fixtures were manufactured and customized according to the needs in the assembly process and the products. In assembly, how to produce different products in the same system required a special analysis. Different aspects are to be analyzed like the similarities in the products and processes, but also the technology identifying similarities so for them to be possible to be used for different products. The equipment and tools to be used when moving the parts and assembly were crucial. The workers needed to move parts to be assembled and eventually work around the products to carry out the operations.

Material Handling System

One of the starting points in the assembly process where a high level of coordination was needed was between the manufacturing area and assembly. The volume flexibility in manufacturing should be enough to satisfy the internal demand of assembly components. To handle changes in volume demands, the manufacturing and assembly area need to be adjusted to each other.

The provision of material to assembly was done with different means like forklifts and cranes. Pallets and shelves were also used. With a stop and go system, the products were moved with a chain conveyor. The transporting devices eased the movement of materials to the assembly reducing time and carrying effort. The material availability contributed to the production flow and the flexibility in the system assuring the material supply to the line.

The size of the products were also important regarding the material handling system and flexibility, for example, with a length that can vary from 7.4 to 10.9 meters and maximum weights handled of 17 ton in the first line and 32 ton in the second one, special pallets were used for the parts and components.

Computer and information system

Informatics systems were also supporting the assembly, for example regarding the material supply. In regard of flexibility, every time that the product passed from one station to another, the workers used the informatics systems to order new parts, assuring the availability of materials on time to continue the assembly. Work instructions were situated in every workstation and information boards were placed along the line in specific points.

The building and premises

This is related to the layout. The assembly system consists of assembly lines and workstations. The material in assembly was placed near and surrounding the assembly line. The flexibility of the assembly line was dependent on the workplace design, in for example to the size of the products and how the operations could be done within the workplaces.

5 FLEXIBILITY ENABLERS IN ASSEMBLY SYSTEMS

Based on the flexibility needs, the empirical findings indicate four flexibility enablers in assembly systems. Flexibility enablers in this respect can be described as what could make flexibility possible. The enablers were capacity and production planning, material supply, production development and work organization. The four enablers are discussed below with further detail.

Capacity and Production Planning

The order handling process has an important influence in assembly. One main problem constitutes the relation between the demand and the organization of the assembly to respond to it. Over capacity constitute excessive resources, limited capacity could constitute sale losses. Seasonality and fluctuation of the market influence the assembly system, adapting it according to this which requires that the created capacity should be actually utilized. The results are in line to Petersson [24] who argued that an assembly system is likely to experience decreased productivity during periods of weak demand if it is not flexible enough.

In order to enable flexibility by means of capacity and production planning some of the challenges are:

- Production leveling. Due to increases and decreases in volume and product variants.
- Reducing the frequency of changes in the production rate. Flexibility is not desired if the production pace is changed too often.
- Achieving a right mix of products. Depending on the workload, if more product variants are assembled, the mix of products could be more complicated.
- Changing volumes. For example if different product models are assembled in only one line and there is a disturbance in the line, one consequence could be a reduction of the production volume for all the models.
- Assurance of resources availability. If more products are to be produced, more quantities and maybe kinds of material should be assured.

Material Supply

To enable flexibility the provision of material is important both internally as well as externally. The relation with the suppliers to provide the material to the factory is an important issue, but also how the material is provided to the line is relevant to support the work. When it comes to volume flexibility, the handling of the differences in quantity is important. Regarding mix flexibility, when there are different product variants assembled in the system, the number of articles could vary significantly if there is a lack of commonality.

The internal logistics is an important factor for the work and the flow in the assembly system. The space where to put the material in the workstations and how to provide them to the line, raise the question of an appropriate workplace design as well as the kind of methodologies to manage the material. The layout is important in this sense. Enough space and the size of the parts should be considered in the design of the material handling system with appropriate transport devices.

According to Sethi and Sethi (1990) the material handling has been discussed in relation to flexibility through the ability to move different part types efficiently for proper positioning and processing through the manufacturing facility that it serves, increasing availability of machines and their utilization and reducing throughput times. These could be achieved having appropriate transporting devices and layout design [13].

In order to enable flexibility by means of material supply some of the challenges are:

- Building buffers or warehouses. It is a cost even though it could be a solution to use long distance suppliers.
- Number of items. In the case that different models are produced in the same system and there are an increased number of items, the implementation of
Agreements with suppliers. A certain level of flexibility could be agreed with the suppliers when the suppliers provide a certain safety stock. Thus, flexibility could imply investments for them, if a higher level of flexibility is set, the result could be more expensive items.

Investments. To achieve flexibility some investments could be necessary, for example in reconfigurable technology and layout.

Flexibility could be costly. This could happen if a higher amount of flexibility than actually required is build up. It is necessary to find a right level of flexibility that could be defined for example through the analysis from the customers’ demands.

**Production Development**

This area corresponds to the design and development of the assembly system as well as tools, technology and equipment. When there are changes in the demand, new conditions should be established in the assembly system. The assembly line needs to be recalculated, including the tact time and the number of operators.

This proposal of changes will be analyzed by the production development function, and then new instructions should be elaborated.

Another area of development is the design and investment in appropriate tools and equipment giving necessary flexibility within the assembly. The tools and equipment is very closely related to the design of the products.

In order to enable flexibility by means of production development some of the challenges are:

- Design of the assembly system. Finding appropriate assembly system design solutions and configurations.
- Influencing product design. Some of the results from the analysis of flexibility could result in needs for changes in the product design.
- Tools and equipment. For example, if new products are to be produced in the same assembly system, new techniques and technology could be needed.
- Setting limits to the changes. Establishing rules about how to change, satisfying the demand but keeping stable production.

**Work Organization**

According to Johansson and Abrahamsson (2009), the work organization “refers to the way in which the technology and labour are organized in order to produce goods and services” [25]. This is important to take into account because the way how the work is organized could bring flexibility and mark a difference between industries. If the work is organized in groups this could, besides other benefits, help avoiding repetitive movements and tasks, so that workers can rotate between workstations doing different operations. The members of the groups could also support each other in teaching new assembly processes, techniques and tasks. The level of competence, the education and training system is thus important to achieve flexibility.

According to Nilsson (2009) flexibility has been described under new principles of work organization, meaning that operators and others linked to production, work closely together, alternating between different tasks, and working as a team. Hereby, boarders between different areas including white-collar workers close to production are broken down. Regarding the production processes, this makes the work teams less vulnerable, for example, to absenteeism, disturbances to production and changes in customers’ orders, thus increasing flexibility [26].

Divisions of work content, reorganization of the groups and redistribution of them in the stations have also been done. These changes could also impact the working hours and resources needed. It is important to consider that when it comes to adjusting the capacity in a manual assembly, the people is an important factor [24].

In relation to the work organization, production will also analyze if for example tools or equipment are needed.

In order to enable flexibility by means of work organization some of the challenges are:

- Work organization. Finding appropriate ways on how the technology and labour are organized in assembly in relation to flexibility.
- Labour stability. The working days and contract agreements have a big impact on the work organization. In addition, frequent changes in the assembly could not be maintained for longer periods of time, safety problems could emerge that could end up in ergonomic problems for the workers which could also create costs, affects the quality, and at the end production losses. Labour stability is related to for example the possibilities of handling turn down periods in production and overcapacity.
- Training and education. Finding appropriate ways of training and education. This is important because flexibility could imply that new assembly methods and techniques are necessary. It is important also when defining the workers roles to respond to flexibility.

**6 CONCLUSIONS AND FUTURE RESEARCH**

The purpose of this paper has been to analyze the flexibility needs and enablers in assembly systems. With regard to flexibility needs four different flexibility enablers in assembly systems have been identified (see Figure 1). According to the results of this study, capacity and production planning, material supply, production development and work organization are believed to have a direct impact on the assembly system flexibility.

In the previous sections these areas have been described as well as identified challenges to enable flexibility.

![Figure 1: Four flexibility enablers in the assembly system.](image)
could respond to continuous changes on product variants and volume requires different studies such as the design of the products and its relation with the assembly sequence, the technological and organizational design solutions of the assembly system and sub-assemblies, and the corresponding logistic provision. The limitation of the presented study is that the findings correspond to only one case study, thus further research is needed to verify the results.

With regard to future research, the paper suggests that research should focus on including flexibility demands in the assembly system design process. Earlier research [27, 28] provides valuable insights about the importance of analyzing the needs of flexibility and involving it in the design process of assembly systems. Still, Terkaj, Tollo and Valente [29] highlight that previous research contributes to knowledge about assembly flexibility; however, research about the integration of flexibility needs in the assembly system design process is limited. Thus, the need for integrating flexibility needs requires further attention.

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8 REFERENCES

