MIXED-PRODUCT ASSEMBLY LINE: CHARACTERISTICS AND DESIGN CHALLENGES

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Customized demands accompanied by assemble-to-order strategies require that the assembly system needs to handle uncertain market changes based on specific customer orders and adapt to new products or variants. This article will describe the characteristics of a mixed-product assembly line (MPAL) concept and its design challenges, based in an ongoing case study. The study shows that aspects of flexibility in assembly systems can be considered in an early conceptual design phase.

Keywords: mixed-product assembly line, design, flexibility, reconfigurability.

1. INTRODUCTION

From historically high volume production of standarized products, companies are moving to a more specilized, customized, and personalized production. In the report Made in Sweden 2030 – Strategic Agenda for Innovation in Production, flexibility of manufacturing processes it is mentioned to be one of the current challenges of the Manufacturing Industry in Sweden. In that report it is also stated that out of 80,000 trucks built by manufacturers in Sweden less than two of the vehicles are alike. In the U.S. the vehicle models have increased from 44 in 1969 to 165 in 2006 (Hu, S.J. et al 2011).

If assemble-to-order strategies are used, the assembly system needs to handle uncertain market changes based on specific customer orders and adapt to new products or variants. The assembly system design in the automotive industry in Sweden have faced transitions, for example, from non-traditional assembly systems designs during 1970s-1990s to the reintroduction of assembly lines (Blomquist, B. et al. 2013) and currently mixed-model assembly lines. Flexible and mixed-model assembly are frequently considered as an industrial logic in competing in the future, however little is done in decision support during the design work or regarding its impact on the practical implementation. Thus, there is a need to increase knowledge on how to design flexible assembly systems and how to reach solutions increasing the ability to handle variation within assembly. Given this context this article will, through the presentation of an ongoing case study, analyze an example of the design of a mixed-product assembly line (MPAL) concept. The purpose of this paper is to describe two specific aspects: (1) the characteristics of the mixed-product assembly line concept under study and (2) the challenges of its design.
First the paper presents a brief literature study on assembly systems design, forming the frame of reference for the study. In Section 3, the research design is described. Section 4 presents the findings from the case study, constructing the empirical base. In Section 5, the findings are analyzed supported by the literature study showing also the contributions of the paper. In the last section, conclusions are presented.

2. ASSEMBLY SYSTEMS DESIGN

Based on Bellgran (1998) p. 14, the *design of assembly systems* is referred as “to the design activities needed in order to accomplish a description of the assembly system proposal (but not its realization). The *assembly system design process* involves the activities performed when designing”; it concerns the way or the procedure that guides the work that is performed to achieve the selected assembly system proposal. During the assembly system design process, two levels of design options are often described: (1) on a system conceptual level (selecting assembly principles, automation degree, principles for material and product flow, type of work organization, etc.) (2) On a system detailed level (selecting suppliers, equipment, job design, etc.). The selections of these options make differences between the designs. Typical activities carried out when designing the production system are framed in phases of: initiation, background study, pre-study, design of conceptual production system, evaluation of conceptual production system, detailed design of chosen production system. (Bellgran and Säfsten, 2010; Bruch, 2012; Rösiö, 2012)

Furthermore, the assembly system is complex and it is composed of some constituents mentioned in the literature such as: the technical system, human system, material handling, information system, and building and premises (Rösiö, 2012).

There is a historical context related to the design of assembly systems. The introduction of the assembly line and concepts of standardization by Ford in 1913 accompanied by scientific management and division of work principles from Taylor, were some of the characteristics during the mass-production era. The design of this kind of assembly system consists of a serial assembly flow with single products moving continuously, repetitive tasks with short work cycles are assigned to operators, and high levels of control and hierarchy exist.

Later on, the Human Relation School and Socio-technical organizational developments have influenced the work organization (Johansson and Abrahamsson, 2009). In Sweden, examples such as the Kalmar and then the Uddevalla automotive plant showed alternative assembly system designs. Some of the characteristics of Uddevalla´s plant for instance, consisted of a parallel product flow also called dock assembly where complete products were assembled at one station or by one small workgroup with longer work cycle times (Blomquist, *et al*., 2013). These experiences have also been studied from the material supply perspective and product description (Medbo, L., 1999), and analysis of the preconditions for long cycle time assembly and its management (Engström and Medbo, 1992). Ellegård, *et al*., (1992) described them as "reflective production". Blomquist, *et al*., (2013) presented forces driving the reintroduction of the assembly line.

Lean production, which has its origins in the automotive industry in Japan and related to Toyota Production Systems, has been presented as an assembly line with continuous flow for mass production of variants or models. It consists of different principles and methods such as *muda* in Japanese referring to waste in effort, material, and time or *kanban* systems which is a build-to-order system where the starting point is the customer (Womak, 1990). There is documentation of early experiences in Sweden of the Japanese manufacturing philosophy and kanban systems (Yamashina, H. *et al*., 1982).

Experiences of assembly system designs of many cases in Sweden have been further studied and described by Berggren, C., 1992. In those analyses the way in which equipment and work station are grouped and how the physical flow is organized was one central dimension. It is also described 5 kinds of assemblies: orthodox line, flexible line, parallel series system, complete and integrated assembly. A model for analysing the assembly design and work organization was also developed.

Netland, (2012) studied the phenomenon of XPS which are company-specific production system created from TPS-Toyota Production Systems. He studied commonalities and differences between numbers of companies in relation to their lean production models, raising the question of companies' one-best-way or own-best-way.
In addition, production systems have also been described in relation to flexibility and reconfiguration (ElMaraghy, 2006), agility, evolvability (Onori and Barata, 2009), etc.

Assembly systems could be designed with mixes of configurations. These includes different arragements of the layout, machines, and organization. Some examples mentioned in the literature are: asynchronious, flexible-general, serials in paralell, serial with cross over, agile (Hu, S.J. et al., 2011). Some non-serial line configurations beside paralell stations or paralell lines are also U-Lines, or work centers (Rekiek, B. et al. 2002).

There are also descriptions of different assembly lines: singel model lines, where the workpieces are identical, mixed-model line, producing different models in arbitrary sequence and multi-model line producing a sequence of batches with intermediate setup operations (Tolio, T. and Urgo, M. 2013). There are also flow lines of multiple products simultaneously (Konz, S. and Johnson, S. 2008). Mixed-product assembly lines have been described by Rekiek, (2000, p. 268) as "*a production line capable of producing a variety of different product models (called variants) simultaneously and continuously. Stations are sufficiently flexible to perform their respective tasks on different variants. All these variants are represented by a generic product model which* *contains the necessary information to characterize variations in model styles, options, etc.*" He also mentions that the most important technical problems of MPAL´s are: generic product modeling, line balancing, resource planning, and model launching (ordering variants) that deals with scheduling the sequence of the different models.

Aspects of complexity within assembly have also been studied, a method for measuring perceived production complexity called complexity index have been tested in the automotive industry (Mattsson, S. *et al*, 2012) and there are studies that recognized the increasing complexity in mixed-model workstations and highlight the importance of appropiate definitions and measures. (Zeltzer, L. *et al*, 2013).

Some different alternatives and options for organizing workstations have been mentioned by (Konz, S. and Johnson, S. 2008) in regard to:

- General-purpose equipment or special-purpose equipment (the last one perform a unique task which is considered not flexible when more jobs need to be done).
- Group technology has been mentioned as an answer to flow lines with low volume. Product families fall into two categories: (1) Product design (reducing the number of items, standardization, and variety reduction.) An existing part can be used in place of a proposed new part, modify an existing part to replace a new one and design information of existing parts are used to assist in the design of new parts. (2) Common manufacturing (Use of existing tooling, die or fixtures, small modification for new parts, close-in-time benefits setup cost reduction).
- Progressive assembly (the work is split, job simplification, flow line). Non-progressive assembly (workers do a complete job, a complete workstation, job enlargement, multi-skilling). Team work has been mentioned to have advantages, beside others for example due to its flexibility covering different skills and managing new demands (Broms, 2009). Proactive assembly systems, combines skilled human operators, dynamically semi-automated assembly systems and the aspect of emerging and self-configuring systems (Dencker, 2011). Requirements of the work organization design have been developed by Mårtensson (1995): A versatile work content, responsibility and participation, information processing, influence on physical work performance, contact and cooperation with colleagues, competence development.
- Assembly lines need to deal with balancing techniques. Three aspects of the balance problems are: (1) a tasks/elements list with times, (2) the precedence relationship of the task/element and (3) the required unit/minute from the line. Afterwards it is determined: (1) the number of stations, (2) number of workers at each station and (3) the elements/tasks to be done at each station.
- Alternatives of material handling can be used to reduce distance by adequate layouts and arrangements. Material flows have been described for example according to its shape A, V, X, T (Bellgran and Säfsten, 2010 p. 196)
- Flow lines can be operation-only line (the component goes through the operations without extra components added) order-picking lines (e.g. warehouses), and assembly lines (operations performed and items added/transported to the stations). Different processes such as single item, intermittent or continuous flow have been related to a layout choice such as fixed position layout, functional layout, batch flow or line based layout. (Bellgran and Säfsten, 2010 p. 203)
- Decisions are made in regards to what to assemble in sub-assemblies and on the main line, minimizing the components added to the final assembly.
- Conveyors movements, location of work and posture of the operators:
  - Continuous movement, the work is removed from conveyor, and the operator stands or sits in one spot.
  - Continuous movement, the work stays on conveyor, and the operator stands or sits on moving system or walks.
  - Starts/stop on timer, the work stays on conveyor, and the operator stands or sits in one spot.
  - Starts/stops at operator discretion, the work stays on conveyor or removed from conveyor, and the operator stands or sits in one spot.

3. METHODS AND TECHNIQUES

The research method used in the study presented in this paper was based on a literature review and a longitudinal case study. According to Yin (2014), case study methods could be used in investigations of contemporary phenomenon in industrial contexts and the longitudinal rationale of the case study allowed covering trends over an extended period of time, following in depth the developmental course, in this case concerning the design of the assembly system. Limitations about case studies have been mentioned in the literature since it cannot be used to generalize the results, but they are useful in the “collective process of knowledge accumulation in a given field or in a society”(Flyvbjerg, 2006). An ongoing industrial project about the design of an assembly concept in a heavy vehicle manufacturing company has been actively studied from the time it started in September 2012 until the proposed solution in March 2014. Planning activities for a concept verification have been under development. The scope of the project focused on coping with product flexibility. An interactive research approach was used in this study ensuring independency of the researcher in the analysis of the academic results supported by frame of references for the analysis. Additionally, one of the authors was involved as project manager contributing to validate the data gathered from the project. In interactive research the aim is to conduct theoretically-related analysis that can contribute to long-term theoretical development, but practically relevant for the participants (Svensson, L., et. al, 2007). A knowledge creation model through interactive research has been created by Ellström, (2007), where the research system and the practice system have a joint point in the conceptualization and interpretation of the research object. Interactive research approaches have been used in studies of information management in the design process of production systems (Bruch, 2012) and development of strategy tools (Winroth and Säfsten 2013).

The researcher kept a holistic system perspective in the analysis, which means that all the constituent parts of the assembly system mentioned in the literature has been taken into account. Data were collected by multiple sources of evidence including participation in the project meetings and workshops where data was collected about the project and its corresponding development areas, design process, design of the assembly and material handling concept, etc. Participant observations were also performed in different assembly systems setting in Sweden and Internationally supported by the development of templates as observational instruments to collect data such as: Production flow and its connection to assembly and subassemblies, layout, assembly sequence, product variants, tools and equipment, methods, times, work content, processes, material handling, working instructions, etc. There were also a wide range of informal conversations about explanations of the assembly system, logistics, etc., as well as company and project document studies.

4. EMPIRICAL FINDINGS

The case study company is a global manufacturer with multiple manufacturing sites. The case study has been focusing on the design of a large-scale mixed-product assembly concept. An on-going assembly system design has been attempting to find solutions to mix assembly of very different products from different manufacuring sites in the same flow. This goal includes overcoming challenges to handle different product design, length and weight in the same assembly flow.

The projet is global with representative factories from different sites around the world, such as Korea, USA, Germany, Poland, and Sweden with competence about their products, assembly processes and methods. The project was divided into four development areas (1) the development of a main assembly line concept, (2) the development of a material handling/logistics solution connected to assembly and the proposed assembly concept, (3) investigations of a possible application and implementation of the concept in a specific factory, and (4) the specification of flexible requirements on product development.

4.1 A Mixed-Product Assembly Line Concept Design and its Characteristics

A first analysis of current products within the corporation resulted in a first proposal for grouping of products. For this, aspects such as: size – weight and product design, assembly process, sequence and tooling, volumes and assembly times were considered. This grouping exercise was used in selecting a first group of products to start the detailed assembly system design.

The detailed design of the main line concept continued towards a layout/process proposal with the main principles of;

- having a generic assembly sequence,
- using generic assembly zones – a clear zone/station for defined major product modules,
- using standardized and common interfaces towards sub-assemblies/product modules,
- common tooling/equipment in each zone.

Based on this, a first generated line concept and layout were generated. More data was collected regarding detailed work content for each product in each zone. Specific analysis was also done regarding necessary tooling and equipment. The project tried to move as much work content as possible to sub-assemblies, in line with the overall vision in the line concept.

Material handling was identified as one of the most important areas to develop in order to realize mixed-product assembly. Material handling was analyzed from a general level to a more specific level such as material presentation, line feeding and procurement methods. The project considered that improving methods and techniques in logistics will contribute to the flexibility needs of assembly and its availability which in turn will secure the desired productivity. Support from the information systems were identified to facilitate material handling of the different products.

The impact of the product design on realizing the flexible assembly concept was also considered. In general two ways of achieving an efficient mixed-product flow were found: (1) improved flexible capabilities within operations enabling handling different products on the same line or (2) product design changes/solutions using common design solutions between products which decreases the need for flexibility within operations. Examples of product related enablers identified for flexible assembly are:

- Common assembly sequence,
- Similar interfaces,
- Commonality of parts,
- Commonality of product specific processes and tooling.

The work with specifying requirements from assembly on product development has also included specifying a governance structure on how to work with the requirements as well as further developing templates for analyzing assembly requirements in product development projects.

A main proposal for the main line has been developed based on selected products which includes a first balancing of work content per defined zone, as well as identified equipment and tools.

The concept is characterized by two sinchronized but independent serial paralell flows merging in a docking area where a main flow line begins. The concept utilizes limited space and common resources for a variety of products. The material handling consists of generic solutions for the different products. The project has also tried to identify specific technical enablers within assembly to handle the variations on the line when mixing different products in the same flow. These enablers are seen as crucial to make the line efficient enough, compared to a single line alternative. Several enablers for flexibility within the assembly system has been identified;

- a flat assembly base that enables easy and fast configuration and the handling of products with different size and weight. This enabler is important to get a generic approach for all products
- flexible AGV to move products - Enables easy installation without pit works and easy implementation in existing factory layouts. Enables both stop & go/continuous moving
- continuous moving products and assembly zones that enables efficient utilization of assembly length with no fixed station lengths. Enables flexible assembly sequence and flexible manning,
- sequenced logistics with sequenced material to final assembly zones
- moving assemblers and similar methods for balancing that enables shared equipment for products that normally are produced in dedicated bays, rotation between main and sub-assembly, and rotation between kitting/material handling and main assembly
- standardized and reconfigurable equipment
- moving logistics with traveling kits following the products on the line
- methods to reduce complexity,e.g. digital and customized assembly instructions – adaptable to specific products and assembly situation, multiple screens to display BOM, assembly guide, and other guidance, poka yoke solutions – securing right tools for specific assembly, as well as material handling solutions to handle different parts.

4.2. Design Challenges

During the development of the mixed-product assembly concept several challenges were identified specifying the need for flexible capabilities within assembly. Nine challenges and wanted solutions for flexibility and ablity to handle changes with assembly were identified in the project, and are summarized in Table 1. These challenges were divided into specific wanted solutions, specifying requirements on the project and the solutions to be developed/implemented.

Table 1. Identified flexibility challenges in assembly system design project.

	Identified challenges for the mixed-product assembly concept	**Wanted solution**
1	Product mix changes within the assembly line	Solutions to easily make change overs within existing layout/process (adaptation)

2	Large volume changes and/or introduction of new products	Solutions for change of layout/line (quickly, without big investments) - adjusting it to a new product mix (reconfiguration)
3	Need for space for parts within final assembly because of increased number of product families	Solution to handle more parts within assembly line/zones without the need for space at the line
4	Need for different tools/equipment due to a mix of increased number of product families	Flexible tooling/equipment that can be used for different products
5	Variation in work content for different products in specific zones	Solutions to handle workload variation within the assembly system
6	Different and varying assembly tasks in specific zones due to assembly of different products in the same zone	Solutions to reduce perceived complexity in assembly
7	A need to handle different products with different size/weight and design in the same assembly line	Solutions to move/lift/handle different products
8	Increased need to be able to supply/kit material to the different zones in the right sequence	Solutions supporting the supply of parts/material to specific zones in right sequence and in the right time
9	Main assembly line as generic solution that has to work globally	Assembly layout and processes/solutions that are not site/product specific

The project considered that the identified enablers for flexibility within the assembly system have a close connection to one or more of the specified challenges in Table 1. For example a flat assembly base and a flexible AGV solution to move products is an enabler to handle product mix and volume changes within the assembly system. A continous moving line with assembly zones with no fixed station length helps handling different work content for different products. Sequencing of material to the line, in order to handle an increased number of parts within assembly. Finally, the project identified also complexity as an aspect to consider in assembly. According to the project, this is influenced by the design solutions of the products, but could also be handled within assembly, for example by having in place improved assembly instructions or system solutions within the assembly system. The wanted solutions should also respond to a ergonomic and safety issues. The project is currently trying to specify and test detailed solutions enabling assembly to handle more variation, trying to realize a mixed-product assembly concept efficient enough compared to dedicated lines.

5. ANALYSIS

The purpose of this paper is to describe the characteristics of the mixed-product assembly line concept under study and the challenges of its design. To achieve this, a literature review and a case study have been presented. The results indicate that as a mean to be competitive, the company pursues standardized assembly systems setups that could be implemented in different locations. At the same time, different products are combined in the same assembly line to satisfy different demands. In this way, it is also desired to handle fluctuating demands. Aspects that characterize the MPAL concept design are: Layout/process principles of commonality and standardization, product design and product related enablers of flexibility, generic material feeding and supply methods, technical (including information systems) and organizational enablers for flexibility, reconfiguration, and methods to reduce complexity.

Nine design challenges related to the flexibility of the line and its corresponding wanted solutions have been described. Those are also connected in some extend to the enablers that characterize the concept. The concept, the design challenges and the wanted solutions concern elements of the assembly system constituents (technical system, material handling, layout, human system and information system) and also the products.
According to the project, an increased complexity is anticipated in the system. However, this should be evaluated. Aspects such as the work organization and ergonomics also play a role in this regard. Furthermore, cooperation within sites around the world when designing assembly systems might also require support for knowledge transfer between sites.

The study shows that aspects of flexibility in assembly systems can be considered already in an early conceptual design phase. Even though assembly system design has been extensively researched there are many areas that could be further developed and could support industry in becoming more competitive. Alternatives and options for assembly system design exist; those should be further considered in relation to the assembly of different products, variants and models. Earlier research provides valuable insights about the importance of analyzing flexibility, reconfiguration, and the design process of assembly systems (Jackson, 2000; Bellgran 1998; Bellgran, and Säfsten 2010, Christmansson and Rönnäng 2003, Rösiö, 2012). Terkay, *et al.* (2009) highlight that there is extensive work in regard of flexibility but it is limited when linked to the design of production systems.

Flexible and mixed-model assembly are frequently considered as an industrial logic in competing in the future, however little is done in decision support during the design work or regarding its impact on the practical implementation. Thus, there is a need to increase knowledge on how to design flexible assembly systems and how to reach solutions increasing the ability to handle variation within assembly.

Even when significant research has been done in regard of assembly systems for a variety of products, there are opportunities for research that could support the characterization of flexible systems in a comprehensive way identifying all the components of the assembly system. This could also contribute to distinguish systems such as: mixed-model, multi-product, mixed-product, etc., that are usually differentiated based on the production sequence or scheduling or balance, but that have also other implications for the analysis of assembly system constituents and flexibility. Some of the characteristics of mixed-product assembly lines and design challenges presented in this article are not specifically studied in the literature from a design and flexibility perspective considering also global companies. The identified design challenges also represent areas for further study. In order to achieve flexible assembly systems designs for different products, aspects of flexibility should be considered in structured assembly systems design methodologies and processes. A comprehensive picture of the assembly system that considers all its constituents from the design is necessary. Altogether, by systematizing this experience, the article provide discussion elements concerning the assembly system design for different products that could contribute to future assembly systems designs.

6. CONCLUSIONS

The characteristics and design challenges of a mixed-product assembly line concept have been described in this paper. A systematization of experiences can contribute to the development of assembly systems design for a variety of products. This is a challenge for global companies with operations in different locations where assembly systems designs are needed to satisfy regional customized demands. The development of design methods in this context can facilitate collaborative design. The design process is iterative; with different steps that involves many different competencies within the company. Due to the complexity of the assembly system design, there is a need for concept verifications. The study shows that aspects of flexibility in assembly systems can be considered already in an early conceptual design phase. Characterizing flexible assembly systems and analysing its design challenges can contribute to the analysis of how and where flexibility should be considered in the design process. In order to achieve flexible assembly systems designs for different products, aspects of flexibility should be considered in structured assembly systems design methodologies and processes. The design of flexible assembly systems faces also the challenges of handling variation. Further research with a holistic perspective could bring more elements and tools to support the design processes and the practical implementation when trying to achieve an assembly system that is flexible enough to handle changes and different products while maintaining a stable production.

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