Strategic Framework for Manual Assembly System Design

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Abstract. Manual assembly is necessary for production of many products today, as products are becoming more complex and customer specific. Manual assembly systems are important for competitiveness and are therefore a strategic issue. Previous literature has looked at specific problems, such as line balancing, although a strategic perspective is required to effectively fulfil market requirements. Before designing a manual assembly system, it is important to consider the different impact factors to find the ideal manual assembly system configuration. This study discusses the different impact factors and decisions in strategic manual assembly system design. The purpose of this paper is to develop a framework to assist in strategic design of manual assembly systems. Testing the framework in a case company shows that by designing the manual assembly system according to the identified impact factors, significant reductions of throughput time and non-value adding time in manual assembly can be achieved.

Keywords: Manual assembly, assembly system design

1 Introduction

Manual assembly is a critical value-adding activity for many products. Manual assembly performs better than automated assembly for low-volume high-variety production [1]. As products are becoming more complex and customer specific [2, 3], manual assembly will continue to play a dominant role in assembly operations in the future [4].

An assembly system consists of the workers, materials and equipment that produces either components or end products [5, 6]. Assembly system performance has a major impact on competitiveness, and therefore assembly system design is an important strategic decision for companies. A manual assembly system should effectively utilize the workforce to meet customer requirements, and limit disruptions to production [5, 6]. Assembly systems perform better when they are designed according to the product and market characteristics [7]. Assembly lines, for example, are often designed for low cost and high volume produce, whereas assembly cells have been used for flexibility. Assembly system design includes many different elements, such as number of workstations, number of workers, and ergonomics considerations [8, 9]. Two key strategic issues, though, are the work organization and the layout type which directly affect the flexibility and volume a system is able to achieve [10].

Many authors have addressed problems within assembly, such as the assembly line-balancing problem [11], assembly line design optimization [12], and sequencing [13]. These assess problems in an existing system, such as an assembly line or cell. There is limited research, however, addressing the strategic aspects related to manual assembly system design. The purpose of this paper is therefore to develop a framework to assist in strategic design of manual assembly systems.

The structure of the paper is as follows: a brief overview of assembly system configurations from literature are presented, where after the impact factors in manual assembly systems are listed and discussed. The factors and previous types are then combined into a framework that will assist in the strategic design of manual assembly systems. A Mid-Norwegian industrial company is presented as a case. The case company produces large, complex electronic equipment, almost entirely with manual assembly. The case company initiated an improvement project to reduce the cost of production, where a new manual assembly system was tested with positive results. We conclude the paper by describing the applicability of the framework and further research opportunities.

2 Assembly systems

Work organization and layout type have changed over the last century. Assembly lines have been in focus since Ford's development in the early 1900's [14]. At AB Volvo, however, there was a trend to move away from assembly lines in favor of other types of assembly systems [7]. In Japan, assembly cells have become widespread [15, 16]. A list of different examples are shown in **Table 1**. Examples like these show that certain assembly systems can be more appropriate in certain situations.

Table 1 Examples of assembly system configurations

Configuration	Description	Ref.
Line	*A product flow where a product is connected by transport technology on a line.*	[9, 15]
Serial flow	*A product flow where every product goes through the same sequence of stations.*	[7]
Semi-parallel product flow	*Product flows that have a common start station, which then branch to include serial and parallel workstations. Products end at different stations.*	[7]
Parallel product flow	*Product flow where some stations that are serial, and other stations are parallel. All products start at the same station.*	[7]
Different assembly cells	*A grouping of stations arranged in a form as to facilitate the work of one or several workers*	[7, 15, 16]
Fixed position	*Products remain in place, with workers coming to the product to perform the assembly work*	[5, 7]

Henry Ford's assembly line, and later adaptation by Toyota are well known and have been studied extensively [14]. Ford's assembly line was designed to reduce the costs of production. There was little room for customization in the assembly line, where workers performed the same operations many times per day.

Semi-parallel and parallel product flow were implemented by Volvo in different plants [7]. These systems were designed to be able to rely more heavily on worker engagement and teamwork. The market changes requiring higher degrees of customization was the main trigger to attempt the implementation of such systems.

Different types of assembly cells have been developed, and have gained interest especially in Japan [15, 16]. Assembly cells can be considered to encompass a few stations, where a worker or workers move around within the cell. These have been implemented to increase the flexibility of assembly systems.

Fixed position (craftsmanship) is considered the original way to perform assembly [14]. This type of assembly is still heavily used in shipbuilding and in assembly of large electronic components [5]. This type of assembly system is used both for practical reasons, as moving large products such as ships can be difficult, but also due to the complexity of the work to be done does not allow for standard work stations.

3 Assembly system impact factors and decisions

In order to gain an understanding of why and how certain manual assembly systems perform better than others do, it is necessary to understand the different impact factors on manual assembly systems. The following main factors are considered:

- Variation in work content [17]
- Handover complexity [17]
- Volume/variety of production [18]

Variation in work content

Some types of assembly systems require a higher degree of worker specialization [19]. A workstation can have a small or large amount of work in the process step ranging from adding a single component, such as a screw, to completing an entire assembly [20]. As the total amount of work increases at a station, so does the variance in operation time at that station. The skill level of workers also has an effect on the resulting complexity in the system, because each worker will complete tasks in a different amount of time [21]. These aspects all contribute to the variation in task completion time.

Handover complexity

In assembly systems, workers have to make choices about which components, tools, and procedures to use in the assembly operations [17]. This complexity is inherent in the variation at their own station, but also of the activities that occurred prior to the station. The variation in operations carried out prior directly affect the complexity of choices of the following operation. The authors suggest this type of complexity to be called "handover complexity".

Volume and variety
The product-process matrix uses volume and variety for determining process structure [18]. Similarly, in assembly the volume and variety affect the type of assembly system that is appropriate [21]. As the volume increases and the variety decreases, automation is more appropriate. However, manual assembly is more appropriate when the production volume is low and the number of variants and customer specifications is high. The authors suggest that within the design of manual assembly systems, volume and variety also affect the most appropriate manual assembly system.

The impact factors discussed above especially affect the following two decisions related to manual assembly system design:

- Layout type [10, 18]
- Number of work groups involved in assembly of one product [7, 10, 20]

Layout type
Layout types can range from fixed position to a single line depending on the volume and variety of production [18] A higher volume and variety will favor a line-based production; where as a lower volume and variety will favor a fixed position. Between these two extremes, there are several configurations such as parallel flow, which can be ideal in certain situations.

Number of work groups involved in assembly of one product
If the work content at each station in an assembly system varies, having workers follow a single product throughout the entire assembly system can yield better resource utilization [19, 20]. In this way, one worker or work group "chases" the product through the assembly processes, performing all the assembly tasks, without the involvement of other workers. This gives the workers the ability to work at a different pace than other workers in the system, unlike traditional assembly lines. A major issue for "walking workers" is the need for a cross-trained workforce, though, which needs to be considered.

4 Manual assembly system framework

A framework has been proposed (see **Figure 1**) to show the ideal assembly system based on the related product, process and market characteristics.

The layout type is directly related to the volume and variety of production, as mentioned earlier. Therefore, as a company moves towards a higher volume of production with lower variety, the layout will tend to favor a simplified line flow rather than fixed position. This is in part due to economies of scale that have to be achieved in order to produce in higher volumes [18].

Within manual assembly, the question remains whether a worker should operate a single station or be involved in several or all of the workstations. The type of worker dedication is directly related to the handover complexity and the variation in work content. As variation in lead time of each of the process steps increases, it becomes more beneficial to have a single worker follow the product through each of the process steps. A single worker following the product will also be favored if there is an increase in the complexity in handing a product over to the next process step.

Shipbuilding is placed in the top left corner whereas the Ford assembly line is placed in the lower right. The placement of the case company's product family is shown in the ideal position, and is described in detail in the following section.

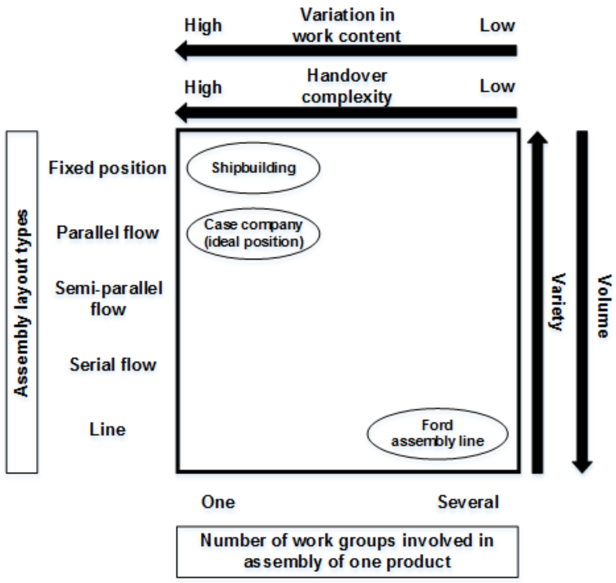

Figure 1 Proposed Manual Assembly System Framework

5 Case study – Mid-Norwegian Industrial Company

The case company produces high-tech electronic equipment for large industries, such as maritime and the oil industry. There are five main product families. Due to high costs and low resource utilization, the case company initiated an improvement project of one of the main product families.

5.1 AS-IS situation for the assembly system

The product family has between 10-20 main variants, although they have some specific requirements from the customer. The BOM for the product family consists of approximately one to two thousand electrical and mechanical components.

Generally, the assembly process is manual and consists of workers using simple tools to fit the components together based on the engineering design. The facility had an open floor area for the assembly of the main products, with some tables used for sub-assemblies as needed. Certain areas in the facility are completely dedicated to machines, or to making some sub-assemblies and components.

The layout was originally fixed position with a group of workers that assembled the different components, and did the final assembly as they saw fit. The assembly system was not optimal, as there was potential to increase performance.

5.2 Redesign of the assembly system and TO-BE situation

After a quantitative and qualitative analysis of the product family, the characteristics were found to have a higher volume and lower variety than the assembly system that they were using indicated. This suggested that the layout should be changed from fixed position to a more flow based configuration. The variation in work content and the handover complexity however was found to be high, which suggested that the workers should be dedicated to a product rather than to a workstation.

The redesign encompassed creating several workstations for the different process steps of the assembly. It was decided that a small group of workers should move the product through each of these workstations, maintaining responsibility for the assembly of the entire product. Each assembly step had similar components to be produced, but the complexity in handing over the product favored having a dedicated group of workers. Therefore, through the redesign process, the assembly system was designed based on the ideal position as illustrated by the framework (see **Figure 1**).

Figure 2 Assembly system pilot with unfinished product shown

A new layout was partially implemented and a product was assembled (see **Figure 2**). A time study was carried out to log the results. The initial results confirmed the improper assembly system. The throughput time for the product was reduced by 38%, due to both reduced material-handling activities and to a simpler material flow through the system. This increased the workers time actually assembling products. Due to the partial implementation, the case company expects up to 50% throughput time reduction in the near future (see Error! Reference source not found.).

Table 2 Expected results of improvement project at case company

	Before	After
Total throughput time	80 hours	40 hours
Value added time (%)	50%	80%
Non-Value added time (%)	50%	20%

6 Discussion

Manual assembly system design encompasses many different aspects such as specific number of workstations and workers, but it is clear that understanding the strategic implications of a manual assembly system can help lead to improved performance.

Analyzing the strategic choice of which type of system is critical in improving performance and remaining competitive in today's market. The framework, as proposed in **Figure 2**, combines different impact factors on manual assembly systems and different decisions that must be taken during the design of a manual assembly system.

The assembly system in use at the case company was a result of years of working in a similar manner, and was ingrained in the workers and management. Upon analysis, it was clear that the fit between the market requirements and the assembly system was not optimal which favored moving towards a more flow based manual assembly system.

7 Conclusion

The assembly of large, complex products often requires a large degree of manual work. The assembly system design has a direct impact on the performance and the ability to utilize the workforce in an effective way. The proposed framework is a step towards theoretical foundation for manual assembly system design, seen from a strategic standpoint. The framework can applied to any company with a high degree of manual assembly.

Further research should aim at testing and refining the framework, as many other elements can affect assembly system design, as well. A quantitative analysis on the impact on performance of different systems for the same products could provide useful insight on how and why performance differs for the different assembly systems.

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