Flexible assembly system layout considering workforce strategies: a review and future research directions

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Abstract: Today's market demands always more different products with smaller batch sizes. Consequently, it is important for manufacturing systems to be reactive and flexible in meeting customer requirements. These systems are designed to respond to this changeable demand quickly and economically, considering different layout strategies. Moreover, in assembly systems, there is still a significant and justifiable need for manual labor, as it offers a high level of flexibility and versatility that cannot be reached with machines or robots. In this context, the aim of this work is to investigate the relation between the workforce strategy and the process layout, in order to optimize the flexibility and reactivity of an assembly system. The paper presents a literature review on assembly systems, focused on workforce strategy and layout design. The objective is to investigate the correlation between workforce and layout choices, also considering the product and the assembly systems' characteristics, in order to maximize profit. This research would simplify the designer's work by speeding up the decision-making process and leading to better results. The study was carried out using Scopus database, and 77 results were selected out of 336. The analysis shows that only few studies present a method for selecting the best layout and/or the best workforce strategy, but none of them analyses these aspects together, and no study was found that analyses the correlation with the product characteristics. Future research will focus on finding this correlation through the development of mathematical models or simulation studies.

Keywords Assembly system, Workforce, Layout, Product characteristics.

I. INTRODUCTION

Today's market demands always more different products with minimum batch sizes, and it is important for a manufacturing system to be able to face changes in customer requirements. Assembly systems must be flexible and easily reconfigurable to adapt to changing needs [1]. In many industries, especially in assembly systems, manual labour is still essential and cannot be replaced by robots or machines. This is because people are the most flexible and versatile resource and are essential for certain types of tasks. Since the strong use of the manual labour, flexibility in assembly systems can be reached through a strategic and suitable layout choice and an appropriate workforce strategy [2].

There are many possibilities in the choice of layout and workforce strategy. The most common layouts for a manual assembly system are the straight-line layout, parallel stations layout, U-shaped layout [3], and cellular layout [4]. As workforce strategy, a manufacturing system can present, for example, fixed workers, walking workers, bucket brigades, or temporary workers [5]. With fixed workers, each station in the system is staffed with a worker who performs the same set of tasks on each product that moves along the system. Walking workers, on the other hand, involve workers moving along the system performing all the tasks on the product [6]. Temporary workers may also be employed during periods of increased workload, but their need for training and different level in productivity should be considered.

The configuration of the manufacturing system is generally related on the characteristics of the products to be obtained. For example, the dimensions of the product and the number of components can influence the choice of both the layout and the workforce strategy. While there are many studies on assembly lines in the literature, only a few of them help to choose the best solution for a given system. When making both decisions, it is important to consider a range of factors, such as the product's characteristics, available space, number of workers, and their skill levels. Given all these constraints, the decision-making process can be complex. It is important to note that preferences are changing over the years. In the past decades, with mass production, the preferred layout was linear, and workers were fixed in their station doing the same operations on every product of the line. Nowadays, the needs are different due to the evolution of the market, and it is becoming fundamental to adapt the systems in order to remain competitive in the global scenario.

In [5], the authors present a review of the literature on workforce strategies with a focus on reconfigurability in different types of manufacturing systems. Through their analysis, they point out the lack of research on reconfiguration in flexible manufacturing systems and reconfigurable manufacturing systems, even though reconfigurability plays an important role in these systems. We believe that making the right choices at the beginning of the design process of a system is as important as making it flexible and reconfigurable. For this reason, with this review, we are looking for a correlation between the product characteristics and the choices of workforce strategy and system layout configuration.

The aim is to provide a decision support tool to help determine the best manufacturing system in terms of productivity and cost. In the following sections there is a description of the research methodology, followed by an analysis and discussion of the results obtained, and at the end some conclusions with some final remarks identifying areas for further research.

TABLE 1: GROUPS OF KEYWORDS USED FOR THE RESEARCH

Group A Production System	**Group B** Workforce Strategy	**Group C** Method	**Group D** Aim
Flexible assembly line	*Multi-manned*	*Design*	*Performance*
Flexible assembly system	*Fixed-worker*	*Configuration*	*Effectiveness*
Flexible manufacturing system	*Walking-worker*	*Layout*	*Efficiency*
Dedicated manufacturing system	*Utility worker*	*Strateg**	*Skill*
Cellular manufacturing system	*Temporary worker*		
Reconfigurable manufacturing system	*Bucket brigade*		
Mixed model assembly line	*Workforce*		
Multi model assembly line	*Worker*		
Assembly line	*Operator*		
Manufacturing system			

II. RESEARCH METHODOLOGY

The search was conducted on the Scopus database using four groups of keywords that describe the production system, the workforce strategy, the method, and the aim respectively (Table 1). Each query was performed by combining one word from each group using the logical operator "and". Filters were applied to the search results, including limiting the publication year to after 2000, the subject area to engineering and decision sciences, and the document type to article, review, or conference paper. In addition, only articles in English were considered. The research focuses on manual assembly lines since humans are the most flexible resource to perform many different tasks as needed in a just-in-time line. To refine the results, articles with the following keywords in the title or abstract were excluded: robot, cobot, digital twin, collaborative, and 4.0.
The research led to 336 results.
From these, all articles concerning automatic systems and off-topic articles were excluded, leaving 164 results.

These were then classified into four categories: human factors/ergonomics, layout, workforce strategy, and balancing/scheduling/sequencing. For this research, only the articles in 'layout' and 'workforce strategy' categories were considered, resulting in a total of 77 articles, 18 of which belong to both categories. The layout category contained 55 articles that referenced or compared specific system layouts, while articles assigned to the workforce strategy category (40) are all those that contain a reference to a specific strategy or present a comparison of several possibilities.

III. LITERATURE ANALYSIS

In this section, the articles obtained from the selection are analysed to identify the main research areas already investigated in the literature and possible areas for further research. Production and assembly systems have been a topic of study since the introduction of mass production at the beginning of the 20th century. Figure 1 illustrates the publication trend over the years of the articles selected for this review. The research indicates a more concentrated distribution of publications in recent years, although the trend is not entirely clear. As the market moves towards mass customization, flexibility and resource optimization have become increasingly important issues. Therefore, it is hoped that the publication trend in this area will increase in the coming years.

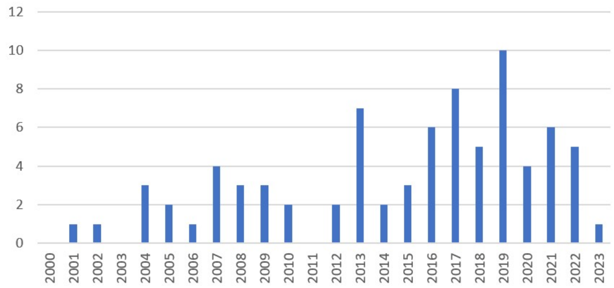

Figure 1: Publication years distribution

From the selected documents, the most recurring journals have been reported in Table 2, in order to show which journals are most interested in this topic, considering that the 26% of the selected articles are from conference proceedings. 'Other journals' includes all journals that have only one paper involved in the search.

TABLE 2: JOURNALS WITH THE HIGHEST NUMBER OF PUBLICATIONS

Journals	#	%
International Journal of Production Research	*9*	*12%*
International Journal of Production Economics	*3*	*4%*
Assembly Automation Study	*3*	*4%*
International Journal of Industrial and Systems Engineering	*3*	*4%*
Manufacturing and Service Operations Management	*3*	*4%*
European Journal of Industrial Engineering	*2*	*3%*
Computers and Industrial Engineering	*2*	*3%*
European Journal of Operational Research	*2*	*3%*
International Journal of Computer Integrated Manufacturing	*2*	*3%*
IIE Transactions	*2*	*3%*
Other journals	*27*	*35%*
Conference papers	*20*	*26%*

The selected documents in the layout category can be classified according to their topics, as shown in Table 3. The layouts considered are mainly cellular layout, linear layout, and U-shaped layout. Some papers compare two possible layouts or study the best configuration for the system to increase productivity or reduce costs ('Study'). Speaking of flexibility, it is important to note that most of the selected articles are about cellular layout.

TABLE 3: ARTICLES IN LAYOUT CATEGORY

Layout	#	%
Cellular	*28*	*51%*
Study	*11*	*20%*
Linear	*10*	*18%*
U-shaped	*6*	*11%*

The workforce strategy category includes articles with specific reference to a particular strategy, as well as articles concerning workforce allocation, training methods, or comparison between different solutions. The groups are visible in Table 4. The group with the highest number of hits is the walking worker strategy because it was introduced earlier than the other strategies analysed in the literature and in the industrial environment.

TABLE 4: ARTICLES IN WORKFORCE STRATEGY CATEGORY

Workforce strategy	#	%
Walking workers	*20*	*50*
Temporary workers	*7*	*18*
Training/Allocation	*7*	*18*
Multi-manned	*3*	*8*
Comparison	*3*	*8*

IV. DISCUSSION

In this section, some of the articles selected with the procedure described in previous sections have been analysed.

The analysis of the articles in the layout category (55) reveals that there are mainly three layouts used in assembly systems: linear, cellular, and U-shaped. The selected studies refer to a specific layout or report an optimisation study or a comparison between different layouts.

As presented in Table 1, half of the articles selected for the review deal with cellular layouts. The cell system is widely discussed in the literature as it offers more flexibility than traditional layouts. In [7] the cellular layout is presented as an easily reconfigurable system since it can be planned in a multi-period way minimising the costs and the cell load variation. Venkata Deepthi et al. in [4] propose a model to convert a traditional linear system into a cellular system to reduce the costs of training the workers and the total production time. Other articles focus on the cell workforce such as [8] that analyses the differences between rotational and divisional Seru in order to define which one offers the most convenient solution changing conditions in terms of: number of tasks, gap in task times, skill level of workers and differences among them.

In particular, the most analysed aspects of this layout are cell formation and workers allocation. In many articles, these aspects are discussed together as bounded choices to be made at the outset of the design phase in order to get the best results from the system in terms of productivity. For example, [9] present a mathematical model for cell formation and workers' allocation with the objective of maximizing the productivity also in situations with stochastic execution times and demand uncertainties. In [10], the different skill levels of workers are also considered during workers allocation; the same did also [11] whose goal is not only the system productivity optimisation, but also the minimisation of the defects rate. For this reason, the authors present a method for allocating workers based on the worker-machine pair that produces the lowest defect rates.

Not all the selected articles agree with the choice of considering the cell formation problem together with the operators' allocation problem. In fact, Behnia et al. in [12] propose a two-step model in which the cell is formed first and then the operators are assigned. Although these problems are solved separately, the authors also take into account the impact the two choices have on each other.

About U-shaped layout, the articles are mostly about the optimisation of the system. Gnanavel et al. in [13] aim to optimise the U-shaped cellular system in terms of ergonomics by subdividing the cell in sub cells and making the workers rotate only in the sub-cells. This change makes workers feel less stressed and bored. In [14], Chutima and Sirovetnukul present a mathematical model to choose between a symmetrical and rectangular U-shaped layout that minimises the number of workers and the walking time. The same authors in [15], state that usually the U-shaped assembly line is used to process the one-piece flow manufacturing of customised products making a correlation between the product and the assembly system.

Only few articles present a comparison of different layout systems to determine the optimal layout configuration or study the best condition to improve productivity or minimise costs. Chand and Zeng in [16] compare the performances of U-shaped and linear layouts under stochastic task times. As a result, the authors said that the two layouts are equivalent in terms of productivity when the task times considered are deterministic and the two systems are well balanced, but in the case of deterministic balancing of the U-shaped system, the straight-line layout has better performance when the task times become stochastic. In [17] the comparison is based on the feeding system characteristics that can be mono-product or multi-product, supplied in stock or in synchronous way. The synchronous feeding system results to be superior to those based on stock. Ergonomic aspects may also be included in the evaluation of the system, like it happened in [18] in which the authors compare different layout possibilities based on the flowtime and on the level of worker fatigue.

In mainly manual production or assembly systems, the role of workers is crucial, as humans are highly flexible and multifunctional, especially when compared to a machine. For this reason, there are many studies in the literature about workforce. The downside of having humans in the system is that it is necessary to consider the stochasticity of execution times and the possible unevenness of skills among workers. The advantage of human operators can be emphasised if they are wisely allocated along the system and properly trained. An example can be found in [19]. The article presents a mathematical model to optimise the allocation of workers in a cellular system and in a traditional assembly line considering stochastic times and workers' skill levels. In [20], the authors compare a paced system with an unpaced system from the perspective of allocating workers when they have different skill levels. The study shows that the efficiency of the system can improve when workers are allocated properly. Ayough et al. in [21] used a meta-heuristic approach to show that taking human factors into account when balancing, sequencing, and scheduling the system leads to better results in terms of system performance than not considering them. In [22], a model is reported to study the best skill distribution strategy in order to maximise the fulfil rate in a Seru production system (SPS). It emerged that the production rate of long chain two-skilled SPS is better than the other possibilities analysed by the authors. Many papers present the allocation problem, especially in SPS or when there are workers with different skill levels working on the same assembly system as it happens when some workers are temporary. In these situations, the abilities and the skill levels must be considered during the allocation of tasks and workers to stations in order to obtain an evenly balanced workload among the stations knowing that temporary workers require more execution time to complete the assigned task compared to permanent workers. A mathematical model is presented in [23] to balance a system with unskilled temporary workers. In [24], the gap in execution time is quantified by a deterministic coefficient. That paper ([24]) also proposes a multi-period worker assignment model that results in less total production time and higher production rates.

Since the market is transitioning from mass production to mass customisation, it is becoming essential for a production system to be flexible and reconfigurable. This feature has become increasingly important in recent years. This is evidenced by the fact that, among the selected articles, the most frequently studied workforce strategy is the walking workers (50%) one, due to its possibility to adapt the number of workers to market demand. Wang et al. in [25] used the simulation to study the optimal number of stations and workers for a walking worker assembly system saying that this kind of system can face a higher flexibility level compared to the conventional fixed worker system. The term "walking worker" encompasses more than one strategy, such as rabbit chase (the most common), chasing-overtaking, or bucket-brigade, as compared in [26]. Although all these strategies involve walking workers, the system's productivity could vary greatly if the strategy used changes, especially if the workers' abilities are not smooth. In this situation, it is important to consider that a low-efficiency worker could block the high-efficiency workers if a traditional travelling production line strategy is used. The simulation study in [26] showed that the chasing-overtaking strategy is better than the others in terms of production capacity, labour utilization, and equipment usage when the workers are not all at the same efficiency level. Also Hashemi-Petroodi et al. in [27] consider the walking worker assembly line to be superior to the fixed worker system, especially when task allocation is model-dependent because it leads to a reduction in equipment costs and in the number of workers. Many articles study the walking time to understand whether it penalises or not the productivity, as it happens in [28]. In this article, the authors propose a simulation analysis to investigate the influence of walking time on the system performance in different situations. As a result, they propose a design approach to determine which strategy is better to adopt, between fixed worker and walking worker, as input variables change. In [29], on the other hand, moving time is viewed positively as an activity that masks the waiting time that occurs in traditional assembly lines with fixed workers.

In case of big products, multi-manned assembly systems are typically used, but the articles are few on this topic (only 8% of the selected articles). Şahin et al. in [30] and Pilati et al. in [31] propose a mathematical model to optimise the balance of such systems, minimising the number of workstations and workers. The difficulty with this type of systems is the coordination of workers and the allocation of tasks along the line, taking into account their compatibility in terms of assembly position, worker cooperation and tool sharing. Another study on multi-manned systems is [32], which focuses on the system reconfigurability aspect. The authors propose to assign equipment to stations at the design stage, while tasks can be dynamically assigned to stations at each takt, and workers can also move between stations at the end of each takt. This method results in a better distribution of the workload for each product, since tasks and workers are redistributed every time that the processed model changes.

Very few articles have been found that compare different layouts or workforce strategies. Some of them have already been presented and generally report a comparison between not more than two possibilities, except for article [26] which compares three different workforce strategies in the category of walking workers. Dolgui et al. in [2] do a literature review of mixed model assembly systems with the aim to investigate how the chosen workforce strategy influences the reconfigurability of the system. The study identifies three types of layouts for MMAL (straight lines, U-shaped layouts, and parallel lines) and examines how the literature suggests improving the efficiency of the systems. At the same time, the authors also consider different workforce strategies: cross-trained workers, walking workers, temporary workers, and utility workers. In [5], the same authors extend the research to all production systems, not just mixed models, losing the reference to layout. Both articles do not propose how it is possible to choose one method over the other, but simply list the options to be considered.

V. Conclusion and future research

This paper presents a literature review on assembly systems, with a particular focus on the design choices. The aspects analysed include the choice of layout and workforce strategy, with the aim of investigating whether there is a correlation between product characteristics and the characteristics of the manufacturing system. The research does not include fully or partially automated assembly systems because, as the recent introduction of the Industry 5.0 concept suggests [33], worker flexibility is now more essential than ever in industry, given the wide variety of products to be processed.

Since any change in the industry involves a loss of money and time, it is important to choose the right system to start with. This study lays the groundwork for building support tools to speed up the choice of the best assembly system to maximise at the same time the productivity and the resilience of the system against market variability. Many articles among the analysed ones describe situations in which the system needs to be changed to adapt production to new market demands or to increase the variety of products. Lots of them present the comparison between fixed and walking workers in order to underline the flexibility obtainable with this workforce strategy, also studying the possible drawbacks.

However, since the layout choice is often made as first independently, the applicable workforce strategy is consequently limited. Therefore, it is important to make both choices synergistically and in relation to the product to be processed keeping in mind that, given the ever-changing market demands, it is crucial to design the system to be as flexible and reconfigurable as possible to accommodate varying production mixes and batch sizes.

The articles included in this review were selected using four groups of keywords, resulting in 336 hits, from which 77 papers were chosen for the analysis. The correlation between product characteristics and layout configuration is presented only in [15] which links custom products to U-shaped assembly system, and in [2] which links big-sized products to parallel line layout, while the other articles focus on optimising productivity, ergonomics, or costs within a fixed layout or workforce strategy. The article closest to the purpose of this research is [2], which provides a literature review on mixed-model assembly systems that analyses the possible workforce strategies with the aim of studying how the worker assignment strategy can be considered as a reconfigurability factor.

The most recent review on workforce strategies is [5], in which the authors outline the characteristics of each strategy and focus on the reconfigurability of the assembly system. Some other comparisons are presented in the selected papers but are often limited to only two strategies.

The study reveals several gaps in the literature that could be addressed through future research. Some potential directions are briefly outlined below.

- The study showed that there is a lack of tools and methods that simultaneously consider layout and workforce strategy with the aim of finding the right solution based on product characteristics and production volumes.
- The research revealed a lack of models and simulations that compare the production efficiency of different assembly systems in terms of layout and workforce strategy.
- No articles were found concerning methods for evaluating the resilience and the flexibility of assembly systems or defining the differences between flexibility and reconfigurability.
- Research on multi-manned assembly systems is not extensively explored in the literature. More in-depth studies on assembly systems for large products could be useful, taking into account layout and workforce strategy, including the different skills required of the workers.
- A curious result of the research is that none of the articles involved in the review takes into account the phenomenon of absenteeism of workers and its effects on production, except superficially and without delving into the subject ([4], [26], [5]).

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