



**HAL**  
open science

# Straight and U-Shaped Assembly Lines in Industry 4.0 Era: Factors Influencing Their Implementation

Marco Simonetto, Fabio Sgarbossa

► **To cite this version:**

Marco Simonetto, Fabio Sgarbossa. Straight and U-Shaped Assembly Lines in Industry 4.0 Era: Factors Influencing Their Implementation. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2021, Nantes, France. pp.414-422, 10.1007/978-3-030-85914-5\_44. hal-03897880

**HAL Id: hal-03897880**

**<https://inria.hal.science/hal-03897880>**

Submitted on 14 Dec 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License



This document is the original author manuscript of a paper submitted to an IFIP conference proceedings or other IFIP publication by Springer Nature. As such, there may be some differences in the official published version of the paper. Such differences, if any, are usually due to reformatting during preparation for publication or minor corrections made by the author(s) during final proofreading of the publication manuscript.

# Straight and U-shaped assembly lines in Industry 4.0 era: factors influencing their implementation

Marco Simonetto<sup>1</sup> and Fabio Sgarbossa<sup>1</sup>

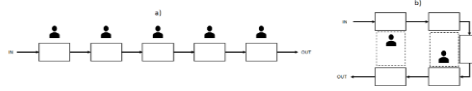
<sup>1</sup> Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, S P Andersens V 3, 7031 Trondheim, Norway  
marco.simonetto@ntnu.com

**Abstract.** The increasing of products variety is moving companies in rethinking the configuration of their Assembly Systems (ASs). An AS is where the products are being configured in their different variants and its configuration needs to be chosen in order to handle such high variety. Two of the most common AS configurations are the straight-line and the U-shaped line. In this paper we want to first determine and define, through a narrative literature research, which are the factors that are relevant in order to compare these two AS configurations. Additionally, with the advent of Industry 4.0 (I4.0) technologies it is possible that these new technologies have an impact on these factors. For this reason, first, we investigated how I4.0 technologies impact these factors and then we saw how the choice of the AS configuration, between straight-t line and U-shaped line, change based on the impact of the technologies. The seven factors here defined open the opportunity for future research challenges.

**Keywords:** Assembly System, Configuration, Straight-line, U-shaped line, Industry 4.0.

## 1 Introduction

An AS configuration is a sequence of several workstations organized in a certain way in order to assemble different parts to final products. The assembly process consists of a sequence of typically ordered tasks which cannot be subdivided and should be completed at its assigned workstation [1]. The two AS configurations more used are the straight-lines and the U-shaped lines [2, 3], Figure 1. A straight-line configuration is represented by a sequence of workstations in a line. Simply rearranging the straight-line into a U-shaped it is possible to obtain the U-shaped line. In both cases, there can be a human worker in each workstation or there can be single workers managing more workstations [4, 5]. However, in U-shaped lines, it is easier for human workers to move from one workstation to another since they can move across both sides of the line, allowing more flexibility and degrees of freedom in the number of workers that can be assigned in these configurations with respect of the straight-line configurations.



**Fig. 1.** Straight-line configuration (a) and U-shaped line configuration (b).

Traditionally, a straight-line is suitable for mass-production of standardized products [6]. Because of the growing demand for customized products, in the last few years, the products' variety is increased [7]. The U-shaped line is an example of layout that can handle this increase of variety [8]. However, recently also straight-lines are gained more importance in low volume production of customized products [9]. This can complicate the decision process of which layout configuration to choose. Moreover, the introduction of I4.0 technologies in these configurations can have an impact in this decision.

Industry 4.0 emerges from the synergy of the availability of innovative technologies and the demand by consumers for high quality and customized products and it aims at connecting resources, services, and humans in real-time throughout the production in order to attain an advanced level of operational effectiveness and productivity, as well as a higher level of automatization [10]. Its economic impact is supposed to be huge [11]. It holds the promise of increased flexibility, better quality, and improved productivity [12]. Industry 4.0 technologies are starting to be an integrated part of the AS creating a new generation of AS, the so-called Assembly System 4.0 (AS4.0) [13]. The technologies that can be adopted from AS4.0 can be grouped into Collaborative Robots, Augmented Reality (AR), Internet of Things (IoTs), and Cloud Computing and Data Analysis [13].

In literature is it possible to find some qualitative guidelines about when to choose an AS configuration respect to another [14] and a work that gives an idea of factors that can be considered is the one of [8]. The factors that [8] used are the number of tasks, network density, and the cycle time. However, these are not the only factors that need to be taken into consideration to compare straight-line and U-shaped line. Therefore, we are going to look through a narrative literature review, at which are other factors that need to be taken into consideration when one wants to compare the two configurations.

This research is done in order to answer the following research questions:

1. Which are the factors that have to be considered in order to compare the two AS configurations straight-line and U-shaped line?
2. How Industry 4.0 technologies impact on these factors?

The research wants to help companies that are facing the problem of the increase in product variety, or that are simply thinking in changing their AS configuration, in understanding which are the factors that they need to know in order to be able to compare the two AS configurations. This to facilitate their decision process. The implementation of the right Industry 4.0 technologies can give further help to companies to reach their production performance but can also influence the factors. Therefore, it is important to know if and how the technologies are going to impact on the factors. The remainder of this paper is structured as follows. In Section 2 we explained the

methodology applied in the paper. In Section 3, we answered at the first research question. In Section 4, we answered at the second research question and finally, Section 5 concludes the work.

## 2 Methodology

In this paper, to answer at our two research questions, we conducted a narrative literature review. The keywords that we used for the research of the papers are presented in Table 1. We used the Scopus database, searching only result in English as language without limits in the document type and in the year of publications of the papers.

**Table 1.** The two groups of keywords used in the research

<b>First group of keywords</b>	Assembly*, Assembly system, Line*, Straight line, U shape, U shape*
<b>Second group of keywords</b>	Augmented reality, Cloud computing, Collaborative robo*, Data analysi*, Internet of thing, Assembly*, Assembly time, Quality, * time, Products quality, Products variety

These keywords were used as a single keyword or, most of the time, as a combination of two, or more, words thanks to the operator “AND”. For example, one combined research can be: “Assembly\*” AND “Collaborative robo\*”.

## 3 Factor influencing the configuration selection

In this section with an inductive approach, we derived the relevant factors that a company has to know when it has to decide which is the best configuration for their AS between straight-line and U-shaped line. Here below there is the list of identified factors followed by an analysis of the selected papers which helped us to derived them.

**Cycle time:** indicates the time elapsed between completions of two consequent units.

**Number of tasks:** it is the number of different activities that each operator must do in each workstation and is a measure used to indicate the problem size for combinatorial problems such as the SALB (Simple assembly line balancing) and UALB (U-shaped assembly line balancing) problems.

**Network density:** calculating network density entails dividing the number of actual precedence relationships by the theoretical maximum number of relationships that could exist for a problem of that size. Extreme network density values of 0.0 and 1.0 correspond to flexible and rigid assembly sequences, respectively [8].

**Products variety:** is the number of different products that are assembled in an assembly line.

**Volumes variety:** is the difference between the quantity to produce of a product one day and the quantity to produce of the same product the following day.

**Quality:** is the quality of the final assemble products that come out from the assembly line.

**Complexity of tasks:** is the complexity of each task of the assembly process.

Following the definitions here above introduced, the papers found by the literature are here presented in order to better explain the different factors.

In straight-line it is not easy as in U-shaped line to adapt to changes in cycle time. This because of the high potential of rebalancing the U-shaped line with a new cycle time and the reallocation of workers [6]. The productivity in straight-line is lower than the one of U-shaped line when network density is high. Indeed, when the network density is low is better to use straight-lines [8]. Straight-lines can guarantee less flexibility in manufacturing volumes respect to U-shaped lines since in U-shaped lines you can increase or decrease the number of operators on the line [15] and the quality of final assembled products is usually better in U-shape lines [2]. The quality in U-shaped is higher thanks to the improved visibility and communication between operators on the line, which facilitates problem-solving and quality improvement [16]. In U-shaped lines usually, a human worker does more tasks than one in a straight-line. As operator responsibilities expand to include more assembly tasks, operators are used more efficiently when using a straight-line configuration [8]. This because more are the different assembly tasks that one human worker must remember and higher will be his mental workload. When a human worker has to walk from a workstation to another one to do his work, the things to keep in mind are not only the time lost by the worker to walk and his physical strain but there is also the possible congestion that can be generate in the line by all the workers that have to move [4, 8]. This congestion can be more problematic in the U-shaped line due to the limited space within the line generating a lost in performance. The walking time of human workers not only influence the physical demand of workers and the congestion of the lines but adding it at the processing time significantly increases the number of workers that are requested in order to execute the assembly tasks [17]. U-shaped lines are a good choice when the workers have to do repetitive actions and avoid keeping wrong postures during the execution of their activities [18]. Moreover, the U-shape lines are more flexible than the straight-lines, balancing by reducing the precedence relations thanks also to the multiskilled workers that perform various tasks in different workstations along the assembly line [19]. U-shaped workers are required to possess more skills than on straight-lines [20].

In order to decide if a configuration is better than another one companies need Key Performance Indicators (KPIs) or objective functions to measure (e.g. costs, flexibility, ergonomics, productivity). Therefore, companies need first to understand how these functions are going to be influenced by the factors and then how to do multi objectives analysis. It will be important to define one or more objective functions and see how these factors impact the decision of the AS configuration. Future works can be indeed related to the definition of these objective functions. Moreover, sensitivity analyses can help to see how the variations of the different factors can change the final decision of which configuration to choose.

## 4 The impact of Industry 4.0 technologies

In this section we are going to investigate the literature to understand how the I4.0 technologies impact the factors defined in the previous section. Collaborative robots do not only improve the performance of the assembly lines [21], but they can also help the human workers in reducing potential occupational risks like awkward postures, mental workload and repetitive actions [22]. This means better ergonomic conditions in the assembly lines. Moreover, collaborative robots can reduce the surface used and so decrease the distances traveled by the human workers [23]. The main improvements that AR can give to assembly operations are the errors reduction and time efficiency. However, researchers have different opinions about these two improvements [24, 25]. There are different opinions also in terms of usability of AR technology. [26] showed how for the participants of their experiments were easier to use paper instructions instead of the AR instructions displayed through Head-mounted display. In [24], experiment's participants instead, in terms of cognitive load, usability and performance, preferred the AR-based instruction than the paper ones. IoT technologies can help companies with the management of the different variants and of the different volumes of products to produce since the consumers can change their orders until the last second and different consumers have different requests [27]. The data collected from the IoT technologies can be analyzed thanks to Data analysis techniques, like machine learning algorithms, and together with the Cloud Computing, that can store data, manage data, and share data and information, the quality of the final products can be guaranteed reducing also the time to do the inspection of the products [28]. These technologies cannot only increase the quality of the final products but can also decrease the amount of scrap parts in a real industrial scenario, consequently saving valuable resources such as energy and raw materials [29] increasing the efficiency of the systems [30].

In Table 2 we can see which are the I4.0 technologies applied in the AS and we summarized the effect of each technology in each factor.

**Table 2.** Impact of the I4.0 technologies on the factors.

<b>Factor</b>	<b>Industry 4.0 technology</b>			
	<i>Collaborative robot</i>	<i>Augmented Reality</i>	<i>IoT technologies</i>	<i>Cloud computing and Data analysis</i>
<i>Cycle time</i>	Decreases	Decreases/ Increases	Decreases	Decreases
<i>Number of tasks</i>	/	/	/	/
<i>Network density</i>	/	/	/	/
<i>Products variety</i>	Increases	Increases	Increases	Increases
<i>Volumes variety</i>	Increases	/	Increases	Increases
<i>Quality</i>	Increases	Increases	Increases	Increases
<i>Complexity of tasks</i>	Decreases	Decreases	Decreases	Decreases

From Table 2 one interesting result that we can see is that there is a technology, AR, that have “Decreases/Increases” as result. This result means that is not well known yet the real impact of this technology with respect to the cycle time. In fact, at the moment the research with this technology regarding this factor are showing different results. This can be related for example to the experience of the human workers in using the technology or on how the AR instructions are designed and presented to the human workers.

Based on the results of Table 2 we created Table 3. Table 3 gives the idea of how the choice of the configuration can change based on the decrease or increase of the factors. In Table 3 we also did the column, based on the review of the literature in the previous section, of the case in which there is no I4.0 technology in the AS.0. This column helps to see that an I4.0 technology can open the opportunity to move to another configuration with respect to the case without technology.

**Table 3.** How the choice of the AS configuration change based on the impact of a I4.0 technology on a factor (U = U-shaped; S = Straight-line; / = not found in literature).

Factor		Industry 4.0 technology				
		Without I4.0 technology	Collaborative robot	Augmented Reality	IoT technologies	Cloud computing and Data Analysis
Cycle time	Low	S	S	/	S	S
	Medium	U/S	U		U	U
	High	U				
Number of tasks	Low	U	/	/	/	/
	Medium	U/S				
	High	S				
Network density	Low	S	/	/	/	/
	Medium	U/S				
	High	U				
Products variety	Low	S	S	S	S	S
	Medium	U/S				
	High	U				
Volumes variety	Low	S	/	S	S	S
	Medium	U				
	High	U		U	U	U
Quality	Low	S	S	S	S	S
	Medium	U/S				
	High	U				
Complexity of tasks	Low	S	S	S	S	S
	Medium	U				
	High	U				

From Table 3 we can see that, for example, when the quality of the final products increases thanks to the collaborative robots from low to medium, the choice of the configuration of the AS can go to the straight-line configuration instead of the U-



shaped line configuration. Indeed, the increase in quality thanks to the collaborative robot gives the opportunity to use the straight-line configuration that usually, without the technology, guarantees a lower quality with respect to the U-shaped line configuration. Of course, it is not only the focus on one factor that defines the choice of the configuration of the AS4.0. Therefore, the combined behavior of these factors with regard to the choice of the configuration can be a matter of interesting future research. Moreover, it will be interesting to do a deeper investigation of the literature to see what it is possible to find about the cases that in Table 3 are now presenting the “/”. Especially for all the technologies in the case of the factor “Number of tasks”, for the technology “Cloud computing and Data Analysis” for the factor “Network density” and for the technology “Collaborative robot” for the factor “Volumes variety”.

## 5 Conclusion

In this paper, we first determined, based on the literature, the factors that a company has to know when it is time to decide which is the best AS configuration to adopt between the straight-line and the U-shaped line and second we saw how the Industry 4.0 technologies, that can be adopted in these AS configurations, impact in these factors. Being this an exploratory research, our conclusions need to be support by some quantitative results. This is the reason why this work will be used as a starting point for the creation of a mathematical model that will help us validate the assumptions made here.

## Reference

1. Battini, D., Faccio, M., Persona, A., Sgarbossa, F.: Balancing–sequencing procedure for a mixed model assembly system in case of finite buffer capacity. *The International Journal of Advanced Manufacturing Technology*, 44(3-4), pp.345-359 (2009)
2. Rabbani, M., Moghaddam, M., Manavizadeh, N.: Balancing of mixed-model two-sided assembly lines with multiple U-shaped layout. *The International Journal of Advanced Manufacturing Technology*, 59(9-12), pp.1191-1210 (2012)
3. Mukund Nilakantan, J., Ponnambalam, S.G.: Robotic U-shaped assembly line balancing using particle swarm optimization. *Engineering Optimization*, 48(2), pp.231-252 (2016)
4. Calzavara, M., Faccio, M., Persona, A., Zennaro, I.: Walking worker vs fixed worker assembly considering the impact of components exposure on assembly time and en-ergy expenditure. *The International Journal of Advanced Manufacturing Technology*, 112(9), pp.2971-2988 (2021)
5. Chen, Q., Liao, S., Wu, Z. and Yi, S.: Comparative analysis of the performance of a novel U-shaped ‘chasing-overtaking’ production line. *International Journal of Production Research*, 54(12), pp.3677-3690 (2016)
6. Erel, E., Sabuncuoglu, I., Aksu, B.A.: Balancing of U-type assembly systems using simulated annealing. *International Journal of Production Research*, 39(13), pp.3003-3015 (2001)

7. Battaia, O., Otto, A., Sgarbossa, F., Pesch, E.: Future trends in management and operation of assembly systems: from customized assembly systems to cyber-physical systems. *Omega*, 78, pp.1-4 (2018)
8. Aase, G. R., Olson, J. R., Schniederjans, M. J.: 'U-shaped assembly line layouts and their impact on labor productivity: An experimental study', *European Journal of Operational Research*, 156(3), pp. 698–711. doi: 10.1016/S0377-2217(03)00148-6 (2004)
9. Boysen, N., Flidner, M., Scholl, A.: A classification of assembly line balancing problems. *European journal of operational research*, 183(2), pp.674-693 (2007)
10. Thames, L., Schaefer, D.: Software-defined cloud manufacturing for industry 4.0. *Procedia cirp*, 52, pp.12-17 (2016)
11. Kagermann, H., Helbig, J., Hellinger, A., Wahlster, W.: Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry; final report of the Industrie 4.0 Working Group. Forschungsunion (2013)
12. Zhong, R.Y., Xu, X., Klotz, E., Newman, S.T.: Intelligent manufacturing in the context of industry 4.0: a review. *Engineering*, 3(5), pp.616-630 (2017)
13. Cohen, Y., Naseraldin, H., Chaudhuri, A., Pilati, F.: Assembly systems in Industry 4.0 era: a road map to understand Assembly 4.0. *The International Journal of Advanced Manufacturing Technology*, 105(9), pp.4037-4054 (2019)
14. Battini, D., Faccio, M., Persona, A., Sgarbossa, F.: New methodological framework to improve productivity and ergonomics in assembly system design. *International Journal of industrial ergonomics*, 41(1), pp.30-42 (2011)
15. Şahin, M., Kellegöz, T.: Increasing production rate in U-type assembly lines with sequence-dependent set-up times. *Engineering Optimization*, 49(8), pp.1401-1419 (2017)
16. Guerriero, F., Miltenburg, J.: The stochastic U-line balancing problem. *Naval Research Logistics (NRL)*, 50(1), pp.31-57 (2003)
17. Sirovetnukul, R., Chutima, P.: The impact of walking time on U-shaped assembly line worker allocation problems. *Engineering Journal*, 14(2), pp.53-78 (2010)
18. Zhang, Z., Tang, Q., Ruiz, R., Zhang, L.: Ergonomic risk and cycle time minimization for the U-shaped worker assignment assembly line balancing problem: A multi-objective approach. *Computers & Operations Research*, 118, p.104905 (2020)
19. Tiacci, L.: The Assembly Line Simulator Project: modeling U-shaped, un-paced, mixed model assembly lines. XIX Summer School Impianti Industriali, The role of industrial engineering in a global sustainable economy, Senigallia (AN-ITA) (2014)
20. Hwang, R., Katayama, H.: A multi-decision genetic approach for workload balancing of mixed-model U-shaped assembly line systems. *International Journal of Production Research*, 47(14), pp.3797-3822 (2009)
21. Bloss, R.: Collaborative robots are rapidly providing major improvements in productivity, safety, programming ease, portability and cost while addressing many new applications. *Industrial Robot: An International Journal* (2016)
22. Mateus, J.C., Claeys, D., Limère, V., Cottyn, J., Aghezzaf, E.H.: A structured methodology for the design of a human-robot collaborative assembly workplace. *The International Journal of Advanced Manufacturing Technology*, 102(5-8), pp.2663-2681 (2019)
23. Gil-Vilda, F., Sune, A., Yagüe-Fabra, J.A., Crespo, C., Serrano, H.: Integration of a collaborative robot in a U-shaped production line: a real case study. *Procedia Manufacturing*, 13, pp.109-115 (2017)
24. Lampen, E., Teuber, J., Gaisbauer, F., Bär, T., Pfeiffe, T., Wachsmuth, S.: Combining Simulation and Augmented Reality Methods for Enhanced Worker Assistance in Manual Assembly. *Procedia CIRP*, 81, p.588 (2019)

25. Longo, F., Nicoletti, L., Padovano, A.: Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. *Computers & industrial engineering*, 113, pp.144-159 (2017)
26. Büttner, S., Funk, M., Sand, O., Röcker, C.: Using head-mounted displays and in-situ projection for assistive systems: A comparison. In *Proceedings of the 9th ACM international conference on pervasive technologies related to assistive environments*, pp. 1-8 (2016)
27. Thramboulidis, K., Kontou, I., Vachtsevanou, D.C.: Towards an iot-based framework for evolvable assembly systems. *IFAC-PapersOnLine*, 51(11), pp.182-187 (2018)
28. Schmitt, J., Bönig, J., Borggräfe, T., Beiting, G., Deuse, J.: Predictive model-based quality inspection using Machine Learning and Edge Cloud Computing. *Advanced Engineering Informatics*, 45, p.101101 (2020)
29. Coupek, D., Lechler, A., Verl, A.: Cloud-based control strategy: Downstream defect reduction in the production of electric motors. *IEEE Transactions on Industry Applications*, 53(6), pp.5348-5353 (2017)
30. Carvajal Soto, J.A., Tavakolizadeh, F., Gyulai, D.: An online machine learning framework for early detection of product failures in an Industry 4.0 context. *International Journal of Computer Integrated Manufacturing*, 32(4-5), pp.452-465 (2019)