Design and improvement of big-size products assembly lines: state of the art and characteristics

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Abstract: Manual assembly lines are flow-line production systems where human operators perform the various tasks needed to obtain the final product in different assembly stations which are directly linked to each other. Up to now, different models have been developed, which, for example, define the best line configuration in order to reduce the total costs or to increase the productivity. These approaches usually refer to the assembly of standard products, which are produced in high quantity and large variety. In spite of these, the present paper focuses on the design and on the balancing of assembly lines for big size products, characterized by a lot of different needed parts with some of them that are also very large. Hence, it turns out that there are a lot of peculiarities and constraints which have to be taken into consideration during the choice of the configuration of the line. The objective of this paper is to analyse the state of the art regarding the design and the improvement of this type of assembly lines, with the aim of identifying the main factors which could have an impact in their realization. In particular, the impact of materials feeding design on assembly process performance, the integration of the different subassembly systems necessary to obtain the final product, the distinction between direct and indirect activities, the operators' ergonomic conditions and the layout of the line are taken into consideration.

Keywords: Manual Assembly line; design; worker; big size products

1. Introduction

Manual assembly lines are flow-line production systems divided into many stations on which some tasks are performed by operators in order to obtain the final product (Scholl, 1999).

The main objective of assembly lines designers is to increase the efficiency of the line by maximising the ratio between throughput and required costs (Rekiek et al., 2002). Different approaches can be followed to achieve this goal, as defined by Rekiek et al. (2002), for example the assembly line balancing, the study of the best layout, the choice of the most appropriate feeding policy for all parts necessary to obtain the final product, the reduction of the no added value activities, the definition of the appropriate number of workers.

A lot of models concerning the assembly balancing problem have been developed to obtain a better configuration of the assembly line. The simplest optimization problem is called simple assembly balancing problem (SALBP) and it assigns each task to a station, respecting the precedence relations of the process and the cycle time, which is define as the time between the exit of two consecutive units from the line. Two versions of this problem are proposed by Scholl (1999) which are called SALBP-1 and SALBP-2. In the SALBP-1, the number of stations is minimised for a given production rate while in the SALBP-2, the sum of cycle time is minimised for a given number of stations.

During the years, these two approaches have been modified and a lot of constraints have been introduced. In particular, spatial and ergonomic considerations, various line layouts, mixed-model production and tasks scheduling have been introduced into the formulation of the model as defined by Battaïa and Dolgui (2013). The models proposed are referred especially to standard products which are characterized by: high demand, high production rate, standard assembly operations, high degree of standardization and a mixed-model production.

In some cases, the product, which should be realised, does not reflect the characteristics of the one considered in the models so there is the necessity to develop other models able to take into considerations different features (Neumann et al., 2006).

This is the case of the assembly of big size products such as trucks, aircraft, buses, bulldozers, agricultural machinery, machine tools. These types of products are characterized by the following aspects:

- High degree of customization and the low-volume demand as they are special products if compared with the main products considered in other optimization models (Mas et al, 2006).
- The final product is made by using a small number of large-sized components which are

Table 1: Aspect analysed in the papers

		Type of assembly line				Number of model			Type of product		Workforce scheduling and tasks balancing							Assembly system layout			Assembly line feeding systems			
PUBLICATIONS	***Year***	***Two-side assembly line***	***Straight line***	***Parallel line***	***Fixed position / Job shop***	***Single model***	***Mixed-model***	***Multi-model***	***General product***	***Big size products***	***Worker scheduling***	***Worker efficiency***	***Worker allocation***	***Workforce planning***	***Worker exposure risk***	***Single-skilled***	***Cross-trained***	***Space constraints***	***Layout***	***Ergonomy***	***Kitting***	***Trolley to work station***	***Pallet to workstation***	***METHODOLOGY***
Kim, Y. K. Et al.	2000	x					x		x															Genetic algorithm approach
Rekiek, B. et al.	2002	x	x	x	x	x	x	x	x									x	x	x				Survey
Techawiboonwong, A. et al.	2005	x							x			x	x	x	x									Mixed integer linear program
Corominas, A. et al.	2006								x			x		x	x		x							Binary Linear Program
Neumann, W. P. et al	2006		x	x			x		x			x			x					x				Case study
Bautista, J. et al.	2007		x						x									x	x					Case study
Noack, D. et al.	2008									x	x	x												Simulation
Niemi, E.	2008				x					x			x	x			x							Mixed integer linear program
Boysen, N. et al.	2008	x	x	x	x	x	x	x	x									x	x	x				Survey
Wänström, C. et al.	2008						x		x			x							x	x	x	x	x	Case study
Battini, D. et al.	2009		x				x		x									x	x		x	x	x	Cost formulation
Rios, J. Et al.	2011				x		x			x		x						x						Simulation
Kovalev, S. et al.	2011		x						x										x					Mixed integer linear program
Mas, F. et al.	2013		x				x			x								x	x					Simulation
Ziarnetzky, T. et al.	2014						x												x					Simulation
De Bruecker, P. et al.	2014										x	x	x	x	x	x	x			x				Survey
Falck, A. C. et al.	2014		x				x		x			x					x		x	x				Case study
Sternatz, J.	2014		x						x		x	x												Enhanced multi-Hoffmann heuristic
Bertolini M,. et al.	2015								x		x								x					Integer linear programming
Battaïa, O. et al.	2015		x						x		x	x	x	x			x		x					Integer linear programming
Yang et al.	2014		x				x		x		x	x												Simulation
Sali, M. et al.	2015		x				x		x									x						Cost formulation approach
Kara et al.	2014		x				x					x			x	x	x							Integer linear programming
Chica et al.	2016		x															x	x					Multi-objective approach
Sternatz, J.	2015		x				x		x			x							x		x	x	x	Case study
Martignago, M. et al.	2017		x				x			x	x	x		x		x	x							Integer linear programming

formed by many assemblies (Niemi, 2009).

- Bills of Material are very complex and there is a high degree of parallelism between the different tasks (Falkenauer 2005). In this way, the different components can be assembled in the same time and after that it is possible to assembly the final product. This final process is called Final Assembly Product as defined by Mas et al. (2008). The process time depends on skills and on the quantity of the worker which performed the different tasks and, in general, there are a small number of stations and long cycle time.
- Workers can operate at the same time on the same part of the final product and workforce assignment should guarantee that all tasks are performed before the deadline expires, in order to deliver the product in time (Falkenauer 2005).
- The space required can have a considerable impact during the design assembly line phase as some components are very large and it could be necessary to use some particular tools to move the object from an area to another one (Biele et al, 2014). The space constraint creates also the problem to define the buffer capacity and the optimal feeding policy.

All these aspects impact on the design of the assembly line and for these reasons it is the necessary to develop new models specially created for the big size product which have different characteristics from standard products. In literature, few models regarding this type of products exist, they are especially referred to the final assembly aircrafts or buses and they consider only some aspects of those define above.

The aim of this paper is to define the state of the art about the constraints defined above and outline the impact they could have in the design and improvement of the manual assembly lines for the large size products.

The paper is organized as follows. In Section 2 previous related literature is reviewed and it is divided into the main characteristics that can impact on the design of assembly lines. In Section 3 considerations on the existing literature are made and the next steps of the research are proposed.

2. State of the art analysis and discussion

As stated in the previous section different constraints should be considered when it is necessary to outline the design and the balancing of a manual assembly line for large size products.

Table 1 considers the twenty-six papers analysed for this literature review. The methodology to classify the articles underline these following aspects:

- Type of the assembly line. The four main types of assembly line define by Boysen et al. (2008) have been considered. They are straight line, parallel line, fix-position or workstation and two-side assembly line. The last one plays an important role in the buses assembly line systems as defined by Kim et al (2000);
- Number of product models with the distinction between single model, multi-model and mixed-model. In a single model line only one type of product is manufactured (Kara et al, 2009). In a mixed-model line several models from a basic product family are assembled simultaneously (Yang et al, 2011). In multi-model lines, several products are manufactured in separate batches and the line can be rebalanced for each batch (Boysen et al. 2008);
- Type of products with the distinction between general products and big size products;
- Workforce scheduling and tasks balancing;
- Assembly systems layout design;
- Assembly line feeding systems.

For last three aspects, special sections have been developed as they play an important role to increase efficiency and performance in both standard and big size products assembly systems (Battaïa et al, 2013).

In Table 1 there is also the methodology referred to each paper. Surveys have been useful in order to understand which are the main papers which deal to the workforce management and assembly systems in general. Solution methods can be divided in two main categories: exact or approximate. Exact methods give the optimal solution but they require a lot of computational time for obtain the solution. On the other side, approximate methods do not guarantee optimality, but they are able to achieve good feasible results in an acceptable computation time. The main exact methods used to solve some problems about assembly balancing are: integer linear program, mixed integer program, binary linear program. The case study analysis helps to define the limits within which each method can be used. Instead, approximate methods can be divided in: simple heuristics, metaheuristics and bounded exact methods. Simulation can help to evaluate the dynamic behaviour of a particular assembly system (Mas et al. 2008).

In the next sections three main aspects are considered. For each of them a literature review and a discussion are proposed.

2.1 Workforce scheduling and tasks balancing

Workforce management is an aspect that has an important impact in the efficiency of all types of assembly lines. Outline the number of workers for each station and the tasks that each of them should perform is the first step to define the best configuration of the assembly line. The explanation of how many workers are necessary to perform the tasks into a station mainly depends to: the type of task and the cycle time. Certain problems, required tasks that can be carried out only by worker's workforce who possess a specific skill. For this reason, the total labour cost and the performance of the line could change if some workers do not have the competences to execute some tasks. On the other hand, if some tasks are performed by workers who have more features than those required, this represents an inefficiency of the line as the task can be performed by a lower qualified worker. As defined by De Bruecker (2015) five main elements can be affected by the skills and the level of skills of a person. These are: the labour costs, the speed of work, the quality of work, the tasks that he or she can perform and the flexibility of the tasks.

When a large product assembly line is considered there is the possibility that more workers operate at the same time to the same tasks (Martignago et al, 2017). Furthermore, assembling large products requires some efforts that cannot be performed by only a worker as it is necessary to guarantee a certain level of ergonomic and security of the tasks to avoid injury. On the other hand, as defined by Niemi (2009) adding more workers tends to reduce work efficiency because of the space around the product and the potential for parallel working are limited. Yazgan et al. (2011) proposed a heuristic to assign more workers to the same task and thus to the same station of an automotive assembly line. The assignment of more workers to the same workstation in the automotive industry is addressed also by Becker and Scholl (2006), but with workers working on different tasks on the same product at the same time.

Niemi (2009) proposed a flexible model in order to define the allocation of workers in a workstation in the make-to-order assembly products. The time labour costs are minimized and the timing constraints are met. The model allows the productivities to be set for different jobs. He takes into account the set-up times and the worker absenteeism through a dummy job. The model is flexible and the effects of the workers' skills and experience are taken into account.

For Corominas et al. (2008) an important aspect that has to be taken into account during the assembly line balancing phase is the impact of skilled and unskilled workers. Unskilled workers in many cases are seasonal workers who have not the same skills level to permanent worker, consequently, consequently the time necessary to perform a task for a temporary worker is higher than the one required for permanent worker. For this reason, the cycle time depends on the type of worker performing the task. Through the model proposed the number of temporary workers required in a motorcycle-assembly plant is minimized. The main hypotheses considered to develop the model are the following: the tasks necessary to obtain the final product are divided in two main categories, clean-hand tasks and dirty-hand tasks, a worker can be assigned to at most one of those two sets of tasks, the line is a straight line and at least one unskilled worker and one skilled worker can be assigned to a station. The last hypothesis can be applied if the assembly of a big product is considered as more worker can operate in a station.

The distinction between skilled and unskilled workers is analysed also by Techawiboonwong et al. (2006) who proposed a master scheduling model for the scheduling of temporary workers in mixed model flow lines. Through the mixed integer model proposed it is possible to define the number of workers that are needed during a period, the assignment of the work time of workers to the work stations, and the usage of overtime hours.

This approach could be adapted in the big size assembly product as some tasks could be performed by unskilled workers as does not require particular skills. By contrasts other specific tasks must be performed by skilled workers as particular expertise is required.

Noack and Rose (2008) propose a simulation-based optimisation approach to define the workforce quantity and the slack reduction. To run on a certain work-centre, each activity requires workers with different skills. So, if one small element is being changed in the schedule, like the assignment of one worker to another operation, it affects all related elements. One activity will be delayed, another activity will be accelerated. All following activities on these workstations will be delayed or accelerated as well. At the end this small decision affects the whole assembly line and its performance.

Through the model proposed by Kara et al. (2014) the assignation of workers to station is made together with the tasks assignation to workers. In this case, less skilled workers are considered and for our case the model proposed could be useful to assign these assistant workers to stations where there is a skilled worker and it is necessary some help in executing some tasks.

Battaïa et al. (2015) propose the industrial application of a model with the aim to minimise the workforce required for a mixed-model assembly line. For their study an automotive assembly line is considered. Since a mixed-model is considered, different type of products with different attributes can be assembled and for this reason the distribution of workload among workstation could vary over time and could create inequalities of task processing times for different variants. As a consequence, inefficiency of the use of workforce resources can come up. Through the model proposed the assignment of workers to workstations can be dynamic and can adapt to the type of products which is assembled. An important hypothesis of this model is the high level of flexibility of some workers with respect to different models of the same products. This type of workers is defined as cross-trained workers by De Bruecker et al. (2015) and they can perform a lot of different tasks. They can help other workers if there is an increase of work in a station and they can also float between two or more stations. For Yang et al. (2014) the use of cross-trained workers is a possible solution if it is necessary to increase the efficiency and flexibility of the assembly line.

Multi-skills workers have an important role in the big size product assembly lines as they can perform different tasks in the different stations and total work can be re-planned if it is necessary. In fact, in these type of assembly lines the assembly of different components requires long cycle time and it could be possible that some components are not completed in time. As a consequence, to avoid delay in delivery for final product cross-trained workers play an important role as they can float in the station that requires an increase of workforce. This type of problem is analysed by Martignago et al. (2017) who propose an integer linear program model through which it is possible to determine the optimal requirement in single-skilled and cross-trained workers involved in the assembly process.

Another important aspect that has to be investigated when it is necessary to define the design of a big size product assembly lines is the relationship between the complexity of some tasks, workers' ergonomics conditions and the final assembly quality. Since the completition of a final product may take a lot of time the tasks must be execute in the correct way to avoid to the re-assembly the product due to errors committed by workers. Falck et al. (2012) analyse this aspect in a car manufacturing system. The purpose of their study is to investigate the relationship between degrees of manual assembly complexity and assembly quality and compare these results with the quality results related to ergonomics load levels. To evaluate the products quality the failure output and the cost for correction of manual assembly errors were used. Through the case study analysed they demonstrate that assembly at high ergonomics load level and high complexity level should not be accepted.

2.2. Assembly system layout design

The space necessary to perform the tasks plays an important role in the assembly of big size products as the workers must be able to work in adequate conditions and a lot of tools and components are necessary to perform the different tasks (Chica et al, 2016). As a consequence, it is necessary to define the best configuration for each station.

In order to solve this type of problem Bautista and Pereira (2007) propose an ant algorithm which takes into consideration the space required to perform the tasks into a station. This type of problem is called TSALBP: Time and Space Constrained Assembly Line Balancing Problems, and it may be stated in the following way: given a set of n tasks with their temporal tj and spatial aj attributes and a precedence graph, each task must be assigned to a single station such that: all the precedence constraints are satisfied, no station workload time is greater than the cycle time and no area required by the station is greater than the available area per station. The model proposed is specific for automobile sector but it could be adapted to the problem under observation with the appropriate constraints.

In the model proposed by Bautista and Pereira changes in demand are not considered. This does not represent the real conditions as the environment changes are very frequently in all the principal sectors. The products' demand is almost never fixed and certain. For this reason, the operation time changes and the line configuration may need a re-balancing with the effect that some stations can vary the total requirement space. In order to solve this problem Chica et al. (2016) propose a multi-objective model for assembly line balancing to search the most robust line when demand changes. This model is called r-TSALBP and its aim is to provide practitioners with the most efficient assembly line configuration when demand changes with a low impact on the management of the plant.

Ziarnetzky et al. (2014) propose a simulation model for a low-volume model assembly line. The aircrafts’ assembly is taken into consideration and the problem of the spaces into a workstation is underline. The type of assembly line analysed in this model is a flow line and the buffer capacity between stations is defined by the dimension of some of the components of the airplane as they are huge. In this way only a small quantity of these components can be stored there and it is necessary to decide which they are. This type of workstation is equipped by some auxiliary resources like jigs or cranes because some tasks cannot be performed without these auxiliary resources. The number of workers employed to perform specific tasks into a single station influence the total required area as they must be able to execute their tasks in safety and ergonomic conditions.

Mas and Rios (2008) analyse the final assembly balancing problem for aircraft. In a first phase a preliminary design is created based on requirements related to: delivery plan, budget, technologies, space availability, logistic. After that a specific simulation model is developed taking into account the constraints of the workstation in term of space required, use of particular jigs and tool necessary to carry the assembly component from a workstation to another. In this model space is defined on the basis of the tasks that should be executed into a specific workstation and it depends also to the subassembly component that has to be realised. The bill of material play an important role in this phase as it is possible to define the total auxiliary tools required and the items required to assembly the subassembly component.

For Neumann et al. (2006), design decision made early in the development process affect both ergonomics and productivity conditions. To explain this, a case study regarding an automotive system is analysed and two different types of assembly lines are considered. Through this analysis, the changes of the layout in term of space needed to perform different tasks can influence directly the workers’ ergonomics conditions in term of distance travelled and risk reduction.

2.3. Assembly line feeding systems

When a big size product is assembled a lot of components are needed. Some of them are usually heavy and very big but other ones can be rather small. For this reason, in order to define the space required in each workstation, there is the necessity to define how to supply the line or the workstation with all the necessary items to obtain the subassembly component or the final product. There are two primary supply policies as defined by Sternatz (2015):

- Direct supply where parts are supplied in a homogenous container to the assembly line;
- Indirect supply where parts are supplied in a mixed container to the assembly line. In this case, a supermarket is created near the assembly area. This type of supply saves space at the line but at the same time there is an extra-cost due to the installation of the supermarket and the picking operations.

The right choice of direct and indirect supply allows the minimization of the global holding costs and the flexibility and efficiency of the assembly systems (Battini et al. 2009).

During the design process of an assembly systems the location of parts and components plays an important role as they have an impact on time, costs and performances (Neumann et al, 2006).

For every assembly line, the production scheduling defines how many components are required in every work stations during a specific period of time. The choice of the method to carry the necessary components from a central warehouse to a specific station is defined as feeding policy. Different type of feeding policies exists and they require different amount of space and different aisles in assembly system for materials movements and storage (Battini et al. 2009).

Material feeding policy can be divided into three main groups: line stocking, kitting and sequencing. In line stocking mode, all components are stored in the preparation area and in the border of the line; the replenishment of the stock on the border of the line is performed by a consummation renewal or a Kanban call signal at regular time interval. In kitting, only components needed to realise the assembly of final products are prepared and delivered to the line according to the assembly schedule. In this way, there is no storage of parts at border line. Sequencing feeding policy considers a particular form of stationary kit containing only some of the components that are needed to the station, and, in this case, some particular devices are used at border line to receive the pieces. These three-different types of feeding policy are compared by Sali et al. (2015), who proposed a cost model with the aim of identifying how a type of feeding system can be used. Through this model these aspects are taken into account: preparation process, transportation process and assembly process. For each scenario described above, the costs associated are calculated and it is demonstrated that there are a set of variable parameters that can influence the choice of a feeding policy. The main parameters are: number of components, number of variants per components, bill of material coefficient, component class, usage profile. Benefit and drawbacks of different line feeding modes appear to depend on the characteristics of the production.

The material feeding design has an impact on assembly process performance in terms of manufacturing flexibility, process support, material planning and work task efficiency as defined by Wänström et al. (2008) who proposed a structured model of material feeding design. The method proposed can be used to define how the component racks and the packaging impact on assembly process performance. The model does not consider the material handling and storage aspect which is considered by Sternatz

(2015) through a model that integrates the material handling with the line balancing. Generally, material feeding and line balancing problems are considered separately even though there is a direct link between them. The objective function of this model minimized the total production time per order which contains both the required production time in manufacturing and the additional logistic time per order through applying indirect supply.

In the big size assembly process the correct feeding strategy should be analysed in order to reduce the no added value activities that usually represent the major cost factor of these kind of systems (Neumann et al., 2006) In this type of assembly, feeding policies can influence also the total area required in the border of the line or workstations as some components are very huge and it is not always possible to put them near the stations as there are some space restrictions.

3. Conclusions

Worker scheduling, workers' conditions, assembly systems layout design and feeding policies can influence the efficiency of big-size products assembly line. As discussed above, a lot of model exists for these types of constraints in manual assembly line refer to standard products, which are characterized by small parts, high volume demand, short cycle time, high degree of variability.

Despite this, the literature referring to big size products is very poor and only few models exist. Furthermore, these models principally refer to aircraft assembly process and they should be adapted to different products as tractors, buses, machine tools. Some of the existing models that refer to standard products should be considered as a starting point for future researches with the aim to extend the model for this particular type of assembly process. In particular, the SALBP model proposed by Bautista (2007) could be considered as a starting model in order to consider the space and the volume of each components necessary to obtain the subassembly or the final product. In this way, the minimum total area required to obtain the product is defined as well as the final number of workstations. The model proposed by Corominas (2008) could be used to evaluate the impact in the cycle time or the productivity and it could be modified considering the time required to perform the value adding activities and the non value adding activities. Another model is the Multi-Manned assembly line approach (Yilmaz, 2016) and it concerns the workers and their productivity. This type of model is specifically referred to large size product as for each station there are more than a worker. It could be extended by adding the space constraints and the energy expenditure for each worker in order to evaluate in which cases there are a minimum space requirements and better ergonomic conditions. Refered to the feeding policy the model proposed by Battini et al. (2009) could be an initial starting point to define the better choice of feeding in relation to the volume of each items required in each station.

In Table 1, for each article analysed, the main features have been individuated about the type of assembly line, the number of product models, the type of product, the workforce planning, the design of the line and the feeding policies. It is possible to note that papers which define a method for big size products are focused on the workforce planning in a straight line and in a simple workstation, while both the layout design and the feeding policies are not considered. The simulation models proposed by Noack et al. (2008) and Mas et al. (2013) are referred to an aircraft assembly system and both have been developed considering a real case study in an aircraft assembly line. Other articles are referred to general products assembly systems. In this case, different type of models have been developed, some of them proposing a methodology or a case study which could be useful as a basis to develop a model addressed to the big size products.

For future research, a first step will be to consider the workload of workers who perform specific assembly tasks and that of workers who supply the different final workstations. The aim should be to maximize the workload, by reducing at the same time the ergonomic risk and the total cost associated. After that, the space constraints will be investigated, with the design of the optimal feeding policy. The dimensions of some parts could represent a constraint both in terms of space and in terms of quantity that has to be guaranteed near the assembly line, as it is necessary to define the best configuration considering the minimization of the total cost as the sum of the space cost and the worker cost. On the other side, for other smaller parts the space does not represent a problem, so it will be necessary to define the quantity and the correct feeding system with the aim to minimize only the labour cost related to the no value added activities.

References

Battaïa, O., & Dolgui, A. (2013). A taxonomy of line balancing problems and their solution approaches. *International Journal of Production Economics*, 142(2), 259-277.

Battaïa, O., Delorme, X., Dolgui, A., Hagemann, J., Horlemann, A., Kovalev, S., & Malyutin, S. (2015). Workforce minimization for a mixed-model assembly line in the automotive industry. *International Journal of Production Economics*, 170, 489-500.

Battini, D., Faccio, M., Persona, A., & Sgarbossa, F. (2009). Design of the optimal feeding policy in an assembly system. *International Journal of Production Economics*, 121(1), 233-254.

Bautista, J., & Pereira, J. (2007). Ant algorithms for a time and space constrained assembly line balancing problem. *European journal of operational research*, 177(3), 2016-2032.

Boysen, N., Fliedner, M., & Scholl, A. (2008). Assembly line balancing: Which model to use when?. *International Journal of Production Economics*, 111(2), 509-528.

Chica, M., Bautista, J., Cordón, Ó., & Damas, S. (2016). A multiobjective model and evolutionary algorithms for robust time and space assembly line balancing under uncertain demand. *Omega*, 58, 55-68.

Corominas, A., Pastor, R., & Plans, J. (2008). Balancing assembly line with skilled and unskilled workers. *Omega*, 36(6), 1126-1132.

De Bruecker, P., Van den Bergh, J., Beliën, J., & Demeulemeester, E. (2015). Workforce planning incorporating skills: State of the art. *European Journal of Operational Research*, 243(1), 1-16.

Falck, A. C., Örtengren, R., & Rosenqvist, M. (2012). Relationship between complexity in manual assembly work, ergonomics and assembly quality. In *Ergonomics for Sustainability and Growth*, NES 2012 (Nordiska Ergonomisällskapet) konferens, Saltsjöbaden, Stockholm, 19-22 augusti, 2012 (No. Book of abstracts, Abstract B4: 2).

Kara, Y., Atasagun, Y., Gökçen, H., Hezer, S., & Demirel, N. (2014). An integrated model to incorporate ergonomics and resource restrictions into assembly line balancing. *International Journal of Computer Integrated Manufacturing*, 27(11), 997-1007.

Kim, Y. K., Kim, Y., & Kim, Y. J. (2000). Two-sided assembly line balancing: a genetic algorithm approach. *Production Planning & Control*, 11(1), 44-53.

Kovalev, S., Delorme, X., & Dolgui, A. (2012). Line configuration to minimize setup costs. *Mathematical and Computer Modelling*, 55(9), 2087-2095.

Martignago M., Battaïa O., Battini D., (2017). Workforce management in manual assembly lines of large products: a case study. Accepted for: 7th IFAC 2017, Toulouse, 9-14 July 2017.

Mas, F., Rios, J., Menendez, J. L., & Gomez, A. (2013). A process-oriented approach to modeling the conceptual design of aircraft assembly lines. *The International Journal of Advanced Manufacturing Technology*, 1-14.

Mas, F., Ríos, J., Menéndez, J. L., Hernández, J. C., & Vizán, A. (2008, June). Concurrent conceptual design of aero-structure assembly lines. In *Technology Management Conference* (ICE), 2008 IEEE International (pp. 1-8). IEEE.

Neumann, W. P., Winkel, J., Medbo, L., Magneberg, R., & Mathiassen, S. E. (2006). Production system design elements influencing productivity and ergonomics: A case study of parallel and serial flow strategies. *International journal of operations & production management*, 26(8), 904-923.

Niemi, E. (2009). Worker allocation in make-to-order assembly cells. *Robotics and Computer-Integrated Manufacturing*, 25(6), 932-936.

Noack, D., & Rose, O. (2008, December). A simulation based optimization algorithm for slack reduction and workforce scheduling. In *Simulation Conference*, 2008. WSC 2008. Winter (pp. 1989-1994). IEEE.

Rekiek, B., Dolgui, A., Delchambre, A., & Bratcu, A. (2002). State of art of optimization methods for assembly line design. *Annual Reviews in control*, 26(2), 163-174.

Rios, J., Mas, F., & Menéndez, J. L. (2012, April). A review of the A400m final assembly line balancing methodology. In M. Marcos, & J. Salguero (Eds.), AIP Conference Proceedings (Vol. 1431, No. 1, pp. 601-608). AIP.

Sali, M., Sahin, E., & Patchong, A. (2015). An empirical assessment of the performances of three line feeding modes used in the automotive sector: line stocking vs. kitting vs. sequencing. *International Journal of Production Research*, 53(5), 1439-1459.

Scholl, A., & Scholl, A. (1999). Balancing and sequencing of assembly lines. Physica-Verlag (Springer)

Scholl, A., & Becker, C. (2006). State-of-the-art exact and heuristic solution procedures for simple assembly line balancing. *European Journal of Operational Research*, 168(3), 666-693.

Sternatz, J. (2014). Enhanced multi-Hoffmann heuristic for efficiently solving real-world assembly line balancing problems in automotive industry. *European Journal of Operational Research*, 235(3), 740-754.

Sternatz, J. (2015). The joint line balancing and material supply problem. *International Journal of Production Economics*, 159, 304-318.

Techawiboonwong, A., Yenradee, P., & Das, S. K. (2006). A master scheduling model with skilled and unskilled temporary workers. *International Journal of Production Economics*, 103(2), 798-809.

Wänström, C., & Medbo, L. (2008). The impact of materials feeding design on assembly process performance. *Journal of Manufacturing Technology Management*, 20(1), 30-51.

Yang, C., Gao, J., & Li, J. (2014). Balancing mixed-model assembly lines with adjacent task duplication. *International Journal of Production Research*, 52(24), 7454-7471.

Yazgan, H. R., Beypinar, I., Boran, S., & Ocak, C. (2011). A new algorithm and multi-response Taguchi method to solve line balancing problem in an automotive industry. *The International Journal of Advanced Manufacturing Technology*, 57(1-4), 379.

Yilmaz, H., & Yilmaz, M. (2015). Multi-manned assembly line balancing problem with balanced load density. Assembly Automation, 35(1), 137-142.

Ziarnetzky, T., Mönch, L., & Biele, A. (2014, December). Simulation of low-volume mixed model assembly lines: modeling aspects and case study. In Proceedings of the 2014 Winter Simulation Conference (pp. 2101-2112). IEEE Press.