# BALANCING ASSEMBLY LINE IN THE FOOTWEAR INDUSTRY USING SIMULATION: A CASE STUDY

Virginia Fani, Bianca Bindi, Romeo Bandinelli
Department of Industrial Engineering
University of Florence
Florence, Viale Morgagni 40/44, 50134, ITALY
E-mail: virginia.fani@unifi.it

**KEYWORDS**
Simulation, Optimization, Balancing, Footwear.

**ABSTRACT**

Fashion is one of the world's most important industries, driving a significant part of the global economy representing, if it were a country, the seventh-largest GDP in the world in terms of market size. Focusing on the footwear industry, assembly line balancing and sequencing represents one of the more significant challenges fashion companies have to face. This paper presents the results of a simulation-optimization framework implementation in such industry, highlighting the benefits of the use of simulation together with a finite capacity scheduling optimization model. The developed simulation-optimization framework includes the conduction of a scenario analysis that compares production KPIs (in terms of average advance, delay and resource saturation) related to different scenarios that include or not one or more type of stochastic events (i.e. rush orders and/or delays in the expected critical components delivery date).

## INTRODUCTION

Assembly line balancing and sequencing represent one of the most important challenges widely discussed in the literature. Even if several classifications and optimization models can be found, as a matter of fact, in non-traditional industries, such as the fashion one, where quality and craftsmanship are the main Critical Success Factors (CSFs), empirical rules and non optimal solution are still applied (d'Avolio et al., 2015b).

According to this, the work aims to present the result of a case study, where a structured framework able to optimize the production planning and scheduling of the production has been applied, with the use of a solver and a simulator.

The paper is organized as follows. In section 2, we presente a brief literature review on balancing and sequencing models, with a focus on the fashion industry. The proposed model has been detailed in section 3, and its application in a case study has been shown in section 4. Finally, in the last section we discuss the main conclusions of this work.

## PRODUCTION OPTIMIZATION IN THE FOOTWEAR INDUSTRY

### Balancing assembly line review

The problem of the line balancing has been discussed several times in the literature. The first published paper of the Assembly Line Balancing (ALB) problem has been the one of Salveson (1955), who suggested a linear programming solution. After that, two articles by Scholl and Becker (2006) and Becker and Scholl (2006) provide the state-of-the-art about exact and heuristic solution procedures for Single Assembly Line Balancing (SALB) problems and a survey on problems and methods in Generalized Assembly Line Balancing (GALB) respectively. SALB problems refer to the assembly lines configured as single-model, while the GALB refers to the ones configured as multi- or mixed-models.

As reported by Pachghare et al. (2014), SALB problems can be divided into the following categories: SALBP-1 Assigning tasks to stations minimizing the number of stations themselves for a given production rate (i.e. fixed cycle time), SALBP-2 Minimizing the cycle time (i.e. maximizing the production rate) for a given number of stations, SALBP-E: Maximizing the line efficiency minimizing, at the same time, the cycle time and the number of stations, considering their interdependency, SALBP-F: Establishing whether or not a feasible line balancing exists for a given combination of number of stations and cycle time, SALBP-3: Maximising the workload smoothness for a given number of stations, SALBP-4: Maximising workload relatedness and SALBP-5: Taking into account multiple objectives.

Among the GALB problems, the leather footwear assembly line can be described as a Mixed Assembly Line Balancing (MALB) problem. MALB problems can be classified in the same way as the previous one, having: MALBP-1: Assigning tasks to stations minimizing the number of stations themselves for a given production rate (i.e. fixed cycle time), MALBP-2: Minimizing the cycle time (i.e. maximizing the production rate) for a given number of stations, MALBP-E: Maximizing the line efficiency minimizing, at the same time, the cycle time and the number of stations, considering their interdependency, MALBP-F: Establishing whether or not a feasible line balancing exists for a given combination of number of stations and cycle time.

According to the literature, any of the GALB problems can be classified according to two dimensions: the

Communications of the ECMS, Volume 34, Issue 1,
Proceedings, ©ECMS Mike Steglich, Christian Mueller,
Gaby Neumann, Mathias Walther (Editors)
ISBN: 978-3-937436-68-5/978-3-937436-69-2(CD) ISSN 2522-2414

Objective Function (OF) that has to be optimized and the methodology used in order to solve it.
Looking at the first dimension, it is possible also to optimize more than a single OF simultaneously, moving from a single- to a multi-OFs. The OFs that can be taken into account are: Minimization of the number of stations, once fixed the desired output, specifying the cycle time, Minimization of the cycle time, once determined the number of stations, Maximization of the line efficiency, Minimization of the costs, Maximization of the profit, calculated as the difference between the revenues and the costs, Minimization of the deviation between the production time of every different type of item for every single station (i.e. horizontal balancing), Minimization of the deviation of the production time in every single station (i.e. vertical balancing) and Minimization or maximization of different scores related to line bottle necks, efficiency and quality of components.
The methodologies that can be used in order to solve ALB problems are: Linear optimization, Non-linear optimization, Limit value, Heuristic procedure, Analytic value, Simulation, Iterative procedure and Metaheuristic procedure (Battaia, 2013; Becker, 2006; Faccio, 2008; Pachghare, 2014).
Most of the publications in line balancing deal with SALB problems, in which only one type of product is processed in the assembly line (Sewell and Jacobson, 2012). On the other hand, as reported by Sivasankaran and Shahabudeen (2014), most of the papers dealing with MALB problems are academic, and few deals with a real-world environment. Moreover, in order to solve MALB problems on real assembly lines they are usually translated into SALB problems, assuming a single "equivalent item" to be produced having as processing time the average value of the different processing times of the original items.
Regarding the fashion industry, the footwear market segment is the analysed one where the balancing problems are applied and, according to this, where most of the academic contribution for the fashion industry have been found. For example, in their work Guimarães et al. (2014) talk about workers' macro-ergonomic evaluation, while Zangiacomi et al. (2004) dealing with production planning and scheduling for mass customisation. Concerning the design of assembly lines, Chen et al. (2014) use simulation to configure the layouts of stitching lines, Ulutas and Islier (2015) work on the layout problem and Dang and Pham (2016) design an assembly line using simulation. Other works are the ones of Chen et al. (2012), that propose a heuristic approach for scheduling problems in parallel sewing lines, and Quyen et al. (2017), that study the resource constrained assembly line balancing problem in a single model line.
In conclusion, there is an extensive literature about ALB problems, but few articles include applications in the fashion industry (Sadeghi et al., 2018).
Together with the long-term balancing problem, there is also the Mixed-Model Sequencing Problem (MSP) which goal is to define the better sequence of the items (Baybars, 1986; Boysen, 2006; Scholl and Becker, 2006) in order to maximize the productivity of the assembly line.
MSP regards the optimization of the sequencing of mixed-models according to a specific OF, assuming as already defined the balancing problem and the layout of the conveyors. As assumptions, jobs are considered to be equally divided among the different employees in the stations, the line is considered to move at a fixed speed and the operator is free to start a new job when it has finished the previous one if there are, otherwise he waits for the next job.
Independently from the techniques adopted, objective function of sequencing problems can be classified as: Minimization of processing time, Minimization of processing cost and Minimization of the stocks (e.g. using JIT techniques).
Within the first category (Schneeweiß and Söhner, 1991), some examples include the minimization of the number of additional resources or the minimization of the workers' free time (i.e. the time occurring when an operator is waiting for the next item after he finished to process the previous one).
In the second category, a first objective that can be defined is the total labour cost, defining a regular cost for the operators working inside their station and an extra cost for the operators that work outside their station. Costs can differ depending on the type of jobs (Ziegler, 1990), the station (Thomopoulos, 1967) or the time needed to move outside the stations (Vrat and Virani, 1976).
In the third category, the availability of the material at the station is taken into consideration, in order to quantify and reduce the relative stock per station.
Research on this topic has been increased with the development of new technologies, like the AI techniques, that enabled the possibility to solve complex problems. Nerveless, few papers deal with the fashion industry (Sivasankaran and Shahabudeen, 2014), whilst most of them are referred to traditional industries like automotive, especially when techniques, like JIT, are applied (Inman, 1991).

**The footwear Industry**

This footwear industry is one of the most critical of the fashion ones, due to complexity of the product and of the Supply Chain (SC). Most of the production phases are commonly outsourced, especially cutting and stitching but, sometimes, also the final assembly. In fact, subcontracting in footwear is a common practice, due to the high specialization required for the production of each component of shoes. This is one of the reasons why the footwear SC is really fragmented, with a lot of SMEs working along it, each one of them highly specialized on one of the steps described above.
These evidences can be translated in a high complexity to be managed in terms of information and production flows exchanged between different companies.
In this way, as highlighted in the work of Bord and Dulio (2007), investments on ICT solutions in terms of software integration between different SC partners but

also higher performance of the ones used at the single-company level represent a key to gain competitive advantages within the industry, with the main purpose of being able to monitor real-time each production process step in order to guarantee the flexibility needed to quickly respond to the unpredictable changes in demand.
Due to the fact that most of the companies along the footwear SC, and in the fashion SC in general, are SMEs, using an open-source software, as the optimization one integrated into the proposed framework, positively impacts their effectiveness and efficiency in working on the market, as demonstrated by Chituc et al. (2008) in their work.

## MODEL DESCRIPTION

### Problem description

Suppliers working in the footwear market segment have to develop their production plan according to their strategic objectives, guaranteeing the compliance to the requested delivery date, that is the main KPIs that brand owners use for evaluating their supply base performances.
The main objectives these companies take into account are related to maximize their performances, like more or less every supplier working in the fashion SC, but also the production mix balancing and sequencing, that represent a peculiarity of this market segment that has to be managed.
Footwear manufacturing encompasses major processes such as cutting, stitching and assembly.
Looking at the production process, the labour-intensive production steps followed to realise shoes can be summed up as suggested by Carpanzano and Ballarino (2008).
The pilot regards the assembly line process. Because of the fixed cycle time, the availability of raw materials, first of all leather, is an important variable in managing production plans. It represents one of the main constraints that has to take into account in the production of leather goods.
According to this, as in the leather goods pilot, it is needed to take into account another stochastic events during the simulation runs, that is the analysis of the impact that delays in the expected critical components delivery date have on KPIs value and the combined impact considering rush orders too.
Moreover, if compare with other pilots, modeling companies working in the footwear SC requires to include balancing and sequencing problems in the optimization and simulation models respectively.
This way, the MSP approach, taking into account that some items need major labour time in comparison with other ones, determines the right alternation of different type of products on the line, in order to guarantee the minimization of free time in every station of the assembly line. Then, the distributed simulation is used as empirical technique to validate the result.

### Model overview

The simulation-optimization framework utilized within this work has been previously published by the authors in (Fani et al., 2017; Fani et al., 2018).
The model is composed by an optimization tool, developed using an open source solver named OpenSolver (www.opensolver.org) and a commercial simulator named AnyLogic® (www.anylogic.com).
The optimization model has been developed in order to fit the different companies' peculiarities including an OF defined as a combination of weighted parameters chosen by the single company and reflecting its CSFs. In fact, the weighted sum OF reflects the commercial agreement between these companies and the brands: different weights for different sub-objectives. Moreover, a solution implementable with an open source solver and a commercial spreadsheet has been chosen according to their low IT investment capability. Anylogic has been chosen for the possibility to implements different type of simulation approaches and for the easy interface with commercial databases (i.e. Microsoft SQL Server).

## CASE STUDY

### Optimization model in the footwear industry

Starting from the literature review previously described, the proposed framework, as reported in Section 3.2, has been used in order to resolve MALB problem of type F (i.e. MALBP-F), using the parameters rpbw (the resources balancing-related weight considering the whole resources pool considering the whole production plan ) and rbw (the resources balancing-related weight considering the single resource r Є RR considering the whole production plan) in the linear model optimization and including the objective function to minimize the horizontal balancing.
The elementary objectives included in the OF (i.e. the ones having positive weight) have been chosen because they better fit the CSFs of companies working in the footwear industry, and the results of the optimization model implementation have been validated comparing themselves to both the historical data and the production manager's experience.
The pilot has been carried out in a footwear company producing leather shoes for a big Italian Luxury brand, and the working phase analysed has been the conveyor.
Using the MALB problem approach, shoes have been classified into three types: "easy", "medium" and "difficult". In this company the number of products assembled is 8, with a total number of tasks equals to 42, comprising 91 elementary jobs. Every station can do one or more tasks. Taking the data from the balancing schema, the association between tasks and station has been done. The names of the tasks have not been reported because the company has not permitted to publish them, together with the names of both the stations and the items codes. Starting from the production cycle of the 8 different products, every code of the single item has been associated to one of the three categories ("easy", "medium" and "difficult").

Once defined this association, the binary diagram of the tasks done for every type of product in every station has been defined.
Whilst in the leather pilot the processing time of the product mix has been assumed by the experience of the company's production manager, in this case a production time data collection has been done together with the company, in order to find the processing time of every task and, consequently, the cycle time of each product.
The technique utilized to collect the data has been the one named Bedaux (Weatherburn, 2014). Every processing time has been recorded 10 times and then the standard time has been evaluated.
In the end, the standard time has been defined as the registered time plus an extra-time considering: Increases for physiologic factors, Increases for fatigue and Increases for unexpected events.
Once the cycle time of every category of the products has been defined, the optimize plan has been evaluated according to the following input data: Item code, Stock Keeping Unit (SKU) type, Requested quantity, Requested date.
Consider a production launch of 4,890 shoes of the different 8 skus, the optimized assembly line has been evaluated starting from a balancing plan declared by the company's management and, according to this, not included in the optimization model. In fact, the requested quantities for the items xxxxx1-8 included in the production plan received from the brand owner have been previously balanced according to the number of the stations and the binary diagram of the tasks.
Moreover, the constraint of the raw material availability has been previously taken into account. In fact, all the raw materials were available before the first day of production. This way, the constraint has not been included into the OF.
As a result, the balanced production plan has been optimized through the proposed model including only the daily mix of products in terms of “easy”, “medium” and “difficult” items and taking into account the delivery date of each order.
On the other hand, the resolution of the sequencing problem has been demanded to the simulation model implementation, in order to evaluate the feasibility of the production plan changing the sequencing rules.

## Simulation model in the footwear industry

In order to run the proposed simulation model, it has been set in a really different way if compared to the pilots on metal accessories and leather goods companies. In fact, the model moves from a job shop to an assembly line configuration, requiring a different set of input data such as the length of the assembly line and the constant speed it moves at. The company’s assembly line moves 87 boxes, each of them with a maximum capacity of 4 pairs of shoes to be assembled, and 18 stations and relative machineries are located in the perimeter.
Moving solidly to the assembly line, the items have to pass in front of all the 18 stations but, according to the items’ classification between “easy”, “medium” and “difficult” shoes, each of them can be or not processed on a single station and the workers will do only the tasks of the station that are included in the item’s production cycle. If no tasks have to be done for processing an item on a specific station, the related worker has to skip the item and look for the next one in the assembly line that has to be processed in that station. According to this, in the modeled system workers can move from the station they have been associated to the assembly line, in order to take the first item that needs to be processed on the station and put again the item itself on the box where it was once it has been processed.

## RESULTS

The first runs of the simulation model have been done in order to validate the processing time measured and assigned to each SKU type (i.e. “easy”, “medium” and “difficult”) considering a single worker per station. In particular, runs of simulation have been done using as input only the “easy” shoes, only the “medium” shoes and only the “difficult” ones respectively. According to the expected results, 700 pairs of “easy” shoes, 360 pairs of “medium” shoes and 280 pairs of “difficult” shoes can be processed per day.
Due to the fact that the scheduled production usually refers to few SKUs per day, the feasibility has been checked through second runs of the simulation model considering different sequencing empirical rules, represented by the different combination of “easy”, “medium” and “difficult” shoes according to the products mix defined by the daily scheduled production plan.
Because of the fact that the simulation model starts with an empty conveyor, a warm-up period of 2 hours has been taken into account in order to achieve the steady-state situation.
In order to check the feasibility of the simulation model, the KPI that has been evaluated is the average daily assembly line productivity, especially the average percentage of the assembled products and the daily scheduled production detailed in Table 1. Moreover, the saturation of all the active stations (i.e. “Station 6” and “Station 16” are the excluded ones) for the SKUs to be produced has been taken into account, in order to compare the feasible solutions.

Table 1 - KPIs dashboard per sequencing empirical rules: overall values

| KPI code | KPI | S_1 | S_2 | S_3 |
|---|---|---|---|---|
| Prd_W_Avg | Average daily productivity | 100% | 100% | 100% |
| Sat_W_Avg | Average daily saturation | 29,48 % | 30,08 % | 29,62 % |

| | | | | |
|---|---|---|---|---|
| Mks_W_Sum | Makespan [hh:mm:ss] | 11:43:54 | 11:29:44 | 11:40:32 |

The column "KPI code" in Table 1 links the analysed KPIs. In particular, the KPI analysed in the footwear pilot all refer to the efficiency dimension and have been calculated at the end of the process (i.e. "Sink" block). First of all, the average value per day has been calculated for both the productivity (i.e. "Prd_W_Avg") and the saturation (i.e. "Sat_W_Avg") to obtain an overview of the flexibility and reactivity that the system can guarantee to perform extra-orders requested by the customers. In addition, the time between first item entering and last item exiting from the model (i.e. "Mks_W_Sum") has been calculated in order to identify the sequence that enables to process the whole production plan in the shortest time. More in detail, looking at Table 2, all the sequencing rules confirm the feasibility of the daily scheduling plan (i.e. "Average daily productivity" equals to 100%), enabling the company to process all the scheduled SKUs. Considering the other KPIs, the average daily saturation has been calculated including only the active stations and refers to the makespan (i.e. the difference between the last exit date from a processing block and the first enter date on a processing block). For these two KPIs, the values differ considering the implementation of one or another sequencing rule, highlighting how the "Sequence_2" results in a higher average daily saturation and a shorter makespan.

Table 2 - KPIs dashboard per sequencing empirical rules: overall values (including reworking)

| KPI code | KPI | S_1 | S_2 | S_3 |
|---|---|---|---|---|
| Prd_W_Avg | Average daily productivity | 99,34% | 98,40% | 99,24% |
| Sat_W_Avg | Average daily saturation | 29,15% | 29,55% | 29,21% |
| Mks_W_Sum | Makespan [hh:mm:ss] | 11:43:54 | 11:29:44 | 11:40:32 |

Moving from Table 1 to Table 2, the implementation of the sequencing rules allows the company to process all the daily scheduled SKUs, and this is related to the fact that a percentage of reworking (i.e. 2%) has been introduced according to the management requirements.
On the other hand, the implementation of the simulation model including this type of stochasticity shows how the "Sequence_3" is the worst sequencing rule in terms of KPIs. In fact, its implementation results neither in the higher values for average daily productivity and the average daily saturation or the shorter makespan. On the other hand, the best sequencing rule between the "Sequence_1" and "Sequence_2" depends of the company's CSF: implementing "Sequence_2" results in the higher average saturation and shorter makespan, while "Sequence_1" guarantee the higher average daily productivity. Table 3 shows the detailed saturation per station, highlighting what is the bottleneck station for the analysed assembly line and production plan. The related KPI code is "Sat_S_Avg", that measures the average saturation per resource.

Table 3 - KPIs dashboard per best sequencing empirical rules: average saturation per station

| | Sequence_1 | Sequence_2 | Sequence_3 |
|---|---|---|---|
| St_01 | 57,88% | 58,9% | 57,97% |
| St_02 | 46,18% | 46,9% | 46,25% |
| St_03 | 42,02% | 42,7% | 42,09% |
| St_04 | 25,40% | 25,7% | 25,46% |
| St_05 | 10,95% | 10,9% | 11,00% |
| St_06 | 0,00% | 0,0% | 0,00% |
| St_07 | 5,20% | 5,1% | 5,23% |
| St_08 | 5,19% | 5,1% | 5,22% |
| St_09 | 84,24% | 85,7% | 84,37% |
| St_10 | 1,73% | 1,7% | 1,73% |
| St_11 | 57,88% | 58,9% | 57,97% |
| St_12 | 46,18% | 46,9% | 46,25% |
| St_13 | 42,02% | 42,7% | 42,09% |
| St_14 | 25,40% | 25,7% | 25,46% |
| St_15 | 10,95% | 10,9% | 11,00% |
| St_16 | 0,00% | 0,0% | 0,00% |
| St_17 | 5,20% | 5,1% | 5,23% |
| St_18 | 5,19% | 5,1% | 5,22% |

Once the feasibility has been checked and the KPIs for the balanced assembly line have been evaluated, the optimization of the number of workers per station has been the object of another scenario analysis conducted through simulation, assessing how the KPIs changes varying the number of workers associated to one or more stations. According to this, starting from the results in Table 5, one more worker has been associated to the station with the higher saturation independently from the implemented sequencing rule (i.e. "Station 9").
Moreover, the sequencing rule chosen to conduct this scenario analysis has been the one that results in better performances in (i.e. "Sequence_2"). The compared scenarios have been listed in Table 4.

Table 4 - Scenarios for simulation model in the footwear case study

| | Description |
|---|---|
| S_1 | No reworking; 1 resource for each station (see "Sequence_2" in Table 1) |

| | |
|---|---|
| S_2 | Reworking; 1 resource for each station (see "Sequence_2" in Table 2) |
| S_3 | No reworking; 2 resources per "Station 9" |
| S_4 | Reworking; 2 resources per "Station 9" |

For each one of the scenarios described in Table 4, the KPIs values used to the comparison have been listed in Table 5.

Table 5 - KPIs dashboard per sequencing empirical rules: overall values

| KPI code | KPI | S_1 | S_2 | S_3 | S_4 |
|---|---|---|---|---|---|
| Prd_W_Avg | Average daily productivity | 100% | 98,40 % | 100% | 99,67 % |
| Sat_W_Avg | Average daily | 30,08 % | 29,55 % | 30,20 % | 29,91 % |
| Mks_W_Sum | Makespan [hh:mm:ss] | 11:29:44 | 11:29:44 | 10:24:56 | 10:24:56 |

Looking at the results in Table 5, comparing the scenarios with no stochasticity (i.e. "Scenario_1" and "Scenario_3"), their implementation results in a shorter makespan (-9.4%) and a slightly higher average saturation (+0.4%) considering 2 workers on the "Station 9". Comparing the other two scenarios that include reworking (i.e. "Scenario_2" and "Scenario_4"), moving from 1 to 2 workers on the "Station_9" the makespan has been reduced in the same way of the previous comparison (-9.4%) while the average saturation increases (+1.2%) in the "Scenario_4". In addition, also the average daily productivity increases (+1.3%).

Table 6 shows the detailed saturation per station (i.e. KPI equals to "Sat_S_Avg", as listed in Table 5) for each one of the three scenarios described in Table 5.

Table 6 - Scenario analysis for the best sequencing rule: average saturation per station

| | Seq_2 Sce_1 | Seq_2 Sce_2 | Seq_2 Sce_3 | Seq_2 Scen_4 |
|---|---|---|---|---|
| St_01 | 59,81% | 58,9% | 66,01% | 65,29% |
| St_02 | 47,72% | 46,9% | 52,67% | 52,09% |
| St_03 | 43,40% | 42,7% | 47,90% | 47,40% |
| St_04 | 26,19% | 25,7% | 28,91% | 28,65% |
| St_05 | 11,17% | 10,9% | 12,33% | 12,33% |
| St_06 | 0,00% | 0,0% | 0,00% | 0,00% |
| St_07 | 5,31% | 5,1% | 5,86% | 5,86% |
| St_08 | 5,30% | 5,1% | 5,85% | 5,85% |
| St_09 | 87,07% | 85,7% | 48,05% | 47,52% |
| St_10 | 1,78% | 1,7% | 1,97% | 1,95% |
| St_11 | 59,81% | 58,9% | 66,01% | 65,29% |
| St_12 | 47,72% | 46,9% | 52,67% | 52,09% |
| St_13 | 43,40% | 42,7% | 47,90% | 47,40% |
| St_14 | 26,19% | 25,7% | 28,91% | 28,65% |
| St_15 | 11,17% | 10,9% | 12,33% | 12,33% |
| St_16 | 0,00% | 0,0% | 0,00% | 0,00% |
| St_17 | 5,31% | 5,1% | 5,86% | 5,86% |
| St_18 | 5,30% | 5,1% | 5,85% | 5,85% |

## CONCLUSION

The present work describes the results of the application of a framework that combines simulation and optimization into a model for supporting production planning and scheduling in a fashion footwear company. In detail, once the optimized plan has been chosen, several sequencing rules have been simulated firstly in a deterministic and considering four different stochastic environments. Analyzing the deterministic scenario, one sequencing rule has been chosen and then it has compared with the four different stochastics scenarios.
The results show how the presented simulation-optimization framework can be applied in not-traditional sectors (i.e. the fashion one), where quality and craftsmanship are the main Critical Success Factors (CSFs), and empirical rules and not optimal solution are still applied.

## REFERENCES


Amen, M. (2000). Heuristic methods for cost-oriented assembly line balancing: A survey. *International Journal of Production Economics* 68, 1–14.

Amen, M. (2001). Heuristic methods for cost-oriented assembly line balancing: A comparison on solution quality and computing time. *International Journal of Production Economics* 69, 255–264.

Amen, M. (2006). Cost-oriented assembly line balancing: Model formulations, solution difficulty, upper and lower bounds. European Journal of Operational Research 168, 747-770.

Bard, J. F., Dar-Elj, E. Z. E. Y., and Shtub, A. (1992). An analytic framework for sequencing mixed model assembly lines. The International Journal of Production Research, 30(1), 35-48.

Bautista, J., Pereira, J., (2002). Ant algorithms for assembly line balancing. Lecture Notes in Computer Science 2463, 65–75.

Bautista, J., Suarez, R., Mateo, M., and Companys, R., (2000). Local search heuristics for the assembly line balancing problem with incompatibilities between tasks. In: Proceedings of the 2000 IEEE International Conference on Robotics and Automation, San Francisco, CA, 2404–2409.

Baykasoglu, A., and Özbakir, L., (2006). Stochastic U-line balancing using genetic algorithms. International Journal of Advanced Manufacturing Technology.

Becker, C., and Scholl, A. (2006). A survey on problems and methods in generalized assembly line balancing. European journal of operational research, 168(3), 694–715.

Carpanzano E, and Ballarino A. (2008). Collaborative networked enterprises: a pilot case in the footwear value chain. Innovation in Manufacturing Networks, 57-66.

Chituc, C., Toscano, C., and Azevedo, A. (2008). Interoperability in Collaborative Networks: Independent and industry-specific initiatives-The case of the footwear industry. Computers in Industry, 59(7), 741–757.

Cortez, P. M. C., and Costa, A. M. (2015) Sequencing mixed-model assembly lines operating with a heterogeneous workforce. International Journal of Production Research, 53(11), 3419–3432.

d'Avolio, E., Bandinelli, R., and Rinaldi, R. (2015a). Improving new product development in the fashion industry through product lifecycle management: A descriptive analysis. International Journal of Fashion Design, Technology and Education, 8(2), 108–121.

d'Avolio, E., Bandinelli, R., Pero, M., and Rinaldi, R. (2015b). Exploring replenishment in the luxury fashion Italian firms: evidence from case studies. International Journal of Retail and Distribution Management, 43(10-11), 967-987.

Dörmer, J., Günther, H. O., & Gujjula, R. (2015). Master production scheduling and sequencing at mixed-model assembly lines in the automotive industry. Flexible Services and Manufacturing Journal, 27(1), 1-29.

Drex A., Kimms A., (2001. Sequencing JIT mixed model assembly lines under station load and part usage constrains. Management Science, Vol. 47, No. 3, 480-491.

Fani, V., Bandinelli, R., and Rinaldi, R. (2017). A simulation optimization tool for the metal accessory suppliers in the fashion industry: A case study. Proceedings - 31st European Conference on Modeling and Simulation, ECMS 2017, 23-26 May 2017; pp. 240-246.

Fani, V., Bandinelli, R., and Rinaldi, R. (2018). Optimizing production allocation with simulation in the fashion industry: a multi-company case study. Proceedings - Winter Simulation Conference, Part F134102, pp. 3917-3927.

Germanes, J. S., Puga, M. F., Sabio, R. B., Sanchez, E. M., & Hugo, J. C. (2017). Improving Efficiency of Shoe Manufacturer through the Use of Time and Motion Study and Line Balancing. Journal of Industrial and Intelligent Information Vol, 5(1).

Jahangirian, M., Eldabi, T., Naseer, A., Stergioulas, L., K., Young, T. (2010). Simulation in manufacturing and business: a review. European Journal of Operation Research. 203(2010), 1–13.

Jayaprakash, J., Reddy, K. M., K., and Ambedkar, P. (2015). Simulation of mixed model assembly line sequencing using PRO-Model software. International Journal of Applied Engineering Researc. 10(68), 854–856.

Jeon, S. M., and Kim, G. (2016). A survey of simulation modeling techniques in production planning and control (PPC). Production Planning & Control, 27(5), 360–377.

Kim, Y.K., Kim, J.Y., Kim, Y., (2000b). A coevolutionary algorithm for balancing and sequencing in mixed model assembly lines. Applied Intelligence 13, 247–258.

Kim, Y.K., Kim, J.Y., Kim, Y., (2006). An endosymbiotic evolutionary algorithm for the integration of balancing and sequencing in mixed-model U-lines. European Journal of Operational Research 168, 838-852.

Kim, Y.K., Kim, S.J., Kim, J.Y., (2000c). Balancing and sequencing mixed-model U-lines with a co-evolutionary algorithm. Production Planning & Control 11, 754–764.

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

Kucukkoc, I., & Zhang, D. Z. (2014). Mathematical model and agent based solution approach for the simultaneous balancing and sequencing of mixed-model parallel two-sided assembly lines. International Journal of Production Economics, 158, 314-333.

Levitin, G., Rubinovitz, J., Shnits, B., (2006). A genetic algorithm for robotic assembly line balancing. European Journal of Operational Research. 168, 811–825.

Nazar, K. A., and Pillai, V. M. (2018). Mixed-model sequencing problem under capacity and machine idle time constraints in JIT production systems. Computers & Industrial Engineering, 118, 226–236.

Sadeghi, P., Rebelo, R.D., Ferreira, J.S. (2018), Balancing mixed-model assembly systems in the footwear industry with a variable neighbourhood descent method, Computers and Industrial Engineering, 121, pp. 161-176.

Sadeghi, P., Rebelo, R.D., Soeiro Ferreira, J. (2017), Balancing a Mixed-Model Assembly System in the Footwear Industry, IFIP Advances in Information and Communication Technology, 513, pp. 527-535.

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

Scholl, A., Becker, C., (2005). A note on an exact method for cost-oriented assembly line balancing. International Journal of Production Economics 97, 343-352.

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

Vrittika Pachghare, R. S. Dalu (2014), Assembly Line Balancing – A Review, International Journal of Science and Research (IJSR), 3(3) 2014

Zamami Amlashi, Z., & Zandieh, M. (2011). Sequencing Mixed Model Assembly Line Problem to Minimize Line Stoppages Cost by a Modified Simulated Annealing Algorithm Based on Cloud Theory. Journal of optimization in Industrial Engineering, (8), 9-18.

## AUTHOR BIOGRAPHIES

**VIRGINIA FANI** is a PhD student at the Industrial Engineering Department of the University of Florence. The issues she is dealing with are related to production processes optimization along the supply chain, with particular focus on the peculiarities that the fashion companies have to face. Her e-mail address is virginia.fani@unifi.it

**BIANCA BINDI** is a PhD student at the Industrial Engineering Department of the University of Florence. During her PhD, she carried out both research and consulting activities in the field of Supply Chain optimization and radio-frequency technologies (e.g. RFId, NFC). Her e-mail address is bianca.bindi@unifi.it

**ROMEO BANDINELLI** is a researcher at the University of Florence, Department of Industrial Engineering. He is member of the Observatory GE.CO. of Politecnico di Milano, program chair of the IT4Fashion conference and member of the IFIP 5.1 "Global Product development for the whole lifecycle". His e-mail address is romeo.bandinelli@unifi.it