A Heuristic and Simulation Hybrid Approach for Mixed and Multi Model Assembly Line Balancing

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Abstract. Industry 4.0 is focused on creating smart products, procedures and processes and calls for the need to create fully dynamic reconfiguration production lines in which products move autonomously through the system from one available resource to another. Planers should be equipped with the methods and IT tools required to develop a complex planning and explanatory models to control and re-configure manufacturing resource networks and production flow based on situation. In this paper a heuristics and simulation based approach for balancing of mixed and multi model assembly line is presented. The proposed IT solution is a computer hybrid implementation of combined data-driven automatic simulation models generation and heuristic for line balancing methods. A computer implementation of the proposed solution using the FlexSim simulation software with a practical example of its application are presented as well.

Keywords: Factory 4.0 · Mixed-model · Assembly line balancing · Data-driven · Simulation · Data mapping · Data transformation · Automatic model generation

1 Introduction

Increasing market competition, globalization, access to modern means of production and information cause that today the success on the market can be achieved by the manufacturers, who have the best and quickest ways to adapt to the new environment. Customer requirements become increasingly higher and still are modified, whereby are less predictable, but at the same time they are more specific and sophisticated. Constantly grows demand for different types and variations of the same product. Manufacturers must continuous improve the quality of products, periodically reduce the price of products (including production costs), and reduce the time of their execution to keep on demanding and often changing and highly competitive market. Meeting their requirements often occurs by changing the traditional approach towards more flexible production systems and up to the one-piece flow production system. In order to meet these requirements, the achievements of the Third Industrial Revolution are no longer enough. A third industrial revolution included Computer Integrated Manufacturing (CIM) and Flexible Manufacturing Systems (FMS) concepts of fully automated and unmanned factories, which were associated with the enormous investments and complexity in planning, operation, and maintenance [1, 2]. On the other hand, Lean manufacturing,

A. Burduk and D. Mazurkiewicz (eds.), *Intelligent Systems in Production Engineering and Maintenance – ISPEM 2017*, Advances in Intelligent Systems and Computing 637,
DOI 10.1007/978-3-319-64465-3_10

Lean Management and Continuous Flow concepts were emerged with simple production principles. In this context, it calls for uses lean technologies, reduces in complexity for decentralized structures and self-organization [1–3]. Today, the answer to the growing word-market demand is to be the fourth industrial revolution (Industry 4.0) which will create the global networks – Cyber-Physical Systems (CPS) – containing manufacturing resources, warehousing and material handling systems and production facilities, capable of autonomously exchanging information to achieve increased flexibility and differentiation of management, planning and control of processes flow. It enables to simply changes to production plans and delivers the ability to respond flexibly to changing customer requirements. Industry 4.0 is focused on creating smart products, procedures and processes and on the aspect, i.e., digital integration of engineering and networked manufacturing systems. Research and development activities, among others, in the area of managing complex systems will need to be carried out if the concept of Industry 4.0 is to be successfully implemented. Engineers should be equipped with the methods and IT tools required to develop a complex planning and explanatory models. In this context, the modelling plays a key role in managing the increasing complexity of production systems [1–4].

Automatically planning and balancing of processing flow to use them in an online controlling of the production systems from available data is one of the big challenges. It will enable to control and re-configure manufacturing resource networks and production flow based on situation and geared towards meeting individual customer requirements. Current methods and tools are still based on "manual" data entry and analysing the results, neither on the full exploiting available data nor on the use of advantages on automated generated simulation models methods. Especially that the assembly line balancing problems traditionally consider the production resources as the only constraints in the system. The motivation regarding assembly line balancing results from the lack of intelligent methods and tools for an automatic creation of simulation model with simultaneous implementation of algorithms supporting the line balancing process. The proposed IT solution, which is a computer hybrid implementation of combined data-driven automatic simulation models generation and heuristic for line balancing methods, is consistent with the applications provided by CPS platform assumptions (support for collaborative manufacturing, service, analysis and forecasting processes [3]). The approach allow to eliminate the disadvantages associated with the traditional – expensive and time-consuming process of creating the simulation models. Methods of data mapping, data transformation and data exchange, between heterogeneous IT systems in the process of the simulation models generation have been used. It also suits the needs related to modularization and reuse strategies in order to enable ad hoc networking and reconfigurability of manufacturing systems [3].

The paper is organized as follows. Section 2 is dedicated to presenting a production organization in flexible continuous flow. Mixed Model assembly line balancing problem is discussed in Sect. 3. In Sect. 4 the methods for automatic generation of simulation models are presented. A computer implementation of the proposed solution and a brief description of the FlexSim simulation system with a case study of its application are presented in Sect. 5. Finally, in Sect. 6 our conclusions are presented.

2 Flexible Continuous Flow

Production in a continuous flow is a production organization in the manufacturing cells or production lines, where the parts are processed and conveyed directly from the work station to the next work station, one by one. It is the most efficient method of processing materials to the finished products and therefore should be used wherever it is possible [5, 6].

Continuous flow means that each station processes only one part that the next station expects, shortly before this, before actually needs it, whereas transport batch size is equal to one. Workstations are set close together in arranged sequence of technological operations for the product, the respective details are often transmitted directly from one station to another one. Employees are situated inside the manufacturing cell. The materials are supplied from the outside which does not restrict movement of employees. The result of such a production organization is that products flows continuously through all of the stations, without production downtime and stopping which are characteristic of the batch production.

The benefits from the use of the continuous flow is:

– minimization the flow time of the product through the process, which allows a quicker response to customer requirements,
– reduction of inventories of production (work in progress),
– short time of “turnover of money” (the time that elapses between paying for raw materials and receiving the money from the sale of products made from these raw materials),
– quick identification of the problems such as lacks, by possibility of quick identification of their occurrence,
– activating communication between stations which are connected together on the principle of “customer – supplier”.

An important feature of industrial production is the type of production which results from customer demand for the product. Flow production system is well suited to volume production and mass production. In the case of the production in small or medium series although a flexibility of assortment plays a very important role, often are allocated designate groups of product with similar technological routes. This means the possibility of the production specialization which in practice transfers into the ability to build the manufacturing cells.

Moreover, the continuous flow is suitable for the type of production in which machines satisfy or could satisfy (after achieving the required improvements) two conditions:

– flexibility condition – quick change of the produced assortment in the manufacturing cells—which is possible in the case of short machine set-up times,
– specialization condition – avoiding universal machines but utilizing the machines performing a few operations in the one production cycle.

Assembly line is a specific example of flow production system and it is very typical for production of large quantities of standardized product. Due to the mass production character the assembly lines contain a certain number of stations located around the transmission belt or other conveyor system. Produced semi-finished products comprising on the final product, are they placed on a conveyor belt and transferred from one station to the next. At each stations suitable tasks are performed, necessary to produce the semi-finished products and thereby the finished product.

Industry 4.0 calls for the need to create fully dynamic production lines in which products move autonomously through the system from one available resource to another and allow for dynamic reconfiguration lines (Fig. 1) [3].

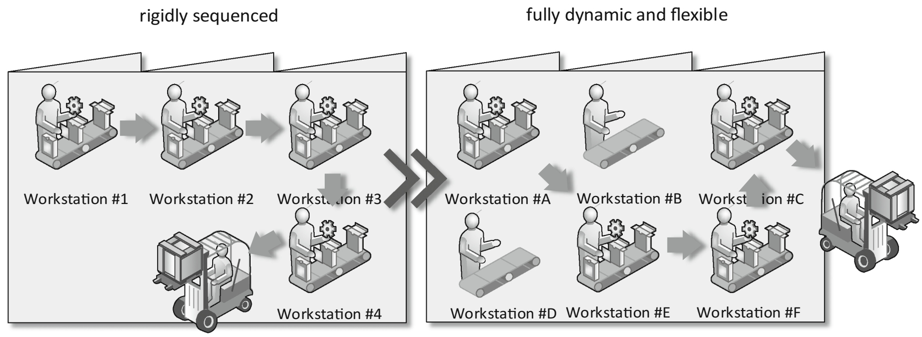

Fig. 1. Flexible dynamic manufacturing mixed/multi model line [3]

3 Mixed Model Assembly Line Balancing Problem

Over several decades the problem of balancing the assembly line is considered and solved by many scientists and engineers involved in scheduling. Description of the assembly line balancing problem requires knowledge of the number of tasks, their execution times and the relation of the order occurring between tasks assigned to the workstations. To achieve satisfactory efficiency of system, the assembly line has to be balanced, which means such and tasks assignment to respective stations, so the load on each of them is as equal and reasonable as possible. The basis of balancing problem is assignment a set of task to ordered set of work-stations so as the succession relationship are sustained while simultaneously and total idle time for all workstations is reduced [7, 8].

The assembly line is considered to be balanced when it performed all the operations according to the assumptions on the production in assembly lines, viz:

– operations are indivisible each task is assigned to exactly one station,
– previous relations (production technology) exacts earlier performed the appropriate tasks,
– time of performing the tasks on all the workstations does not exceed the duration of the time cycle,
– when all of workstations have to perform the same amount of work, then the line is balanced. In fact most of the line is unbalanced, because the actual amount of work at respective positions is different.

The first described line was serial line, but in relation to today's production systems it was the line without any restrictions. Today, the issue of balance line refers to a much wider group of production lines (lines with parallel stations, lines in the U-shaped, mixed- and multi-line, with positional constraints, with tools constraints, with surface around the workstation constraints, etc.). However, the solution in each case, taking into account constraints, comes to minimize. Minimization criteria may be different, depending on what is desired, for example, to minimize the time or to minimize the cost. Mixed assembly line has better benefits compared with the traditional one in respect of system flexibility, lead time, cost and product quality. The versatility of the system with the application of flexible operators and machines, means that the set-up times between models could be reduced enough to be ignored. Multi lines are the assembly lines for the production of two or more models belonging to different product groups. They are used in a range of industries and it improves the flexibility to cope with the changes in global demand. Multi-model lines, produce one set of products before proceeding with different set of products on the same production line.

3.1 Heuristic Algorithms in Assembly Line Balancing Problem

Assembly line balancing problem belongs to the NP-hard class problems. Therefore heuristic methods are used for finding the solution. Heuristic methods are very useful for finding acceptable solutions. Some measures of solution quality allow for assessment and acceptance of the resulting solution. The heuristic methods to be implemented with proposed simulation IT toll are [7, 9, 10]: Largest – candidate rule (LCR) method, Kilbridge and Wester column (KWC) method and Ranked positional weight (RPW) method. LCR method determines the minimum number of stations necessary to obtain the desired cycle time. Cycle time is defined as the ratio of the total available time and demand rate. The aim is divide tasks among the workstation. KWC column method is a heuristic procedure that assigns work elements to stations in accordance to their positions in the precedence diagram. In the KWC method the work elements are arranged into the columns. The biggest difference between this method and LCR is that the tasks which are at the end of precedence graph may first be assigned to the station with the reasons for the large value of task time. RWP combines the strategies of the LCR and KWC method. In this method tasks are ranked according to their importance in the precedence graph. Ranked positional weights take into account the positions in the precedence graph task and time value [9, 10]. These are only selected heuristics that we implemented in the proposed software solution, nothing stands in the way to add more methods to the software.

4 Data-Driven Automatic Simulation Models Generation

The proposed IT solution is a computer hybrid implementation of combined data-driven automatic simulation models generation and heuristic for line balancing methods. Automatic model generation approaches can be classified into three main categories: parametric approaches, structural approaches and hybrid-knowledge-based approaches. Our software is based on hybrid parametric-approach, data mapping and transformation methods. The distinguishing feature of the proposed solution is that the simulation model is created automatically based on specific data instances, obtained from the existing in the enterprises MRP/ERP systems, simultaneously with its parameterization according to data about the planned assembly process. The models could therefore be created by planner without knowledge of how to build the simulation model. In this approach to build a simulation model does not require the use of specific modules of simulation systems which are used in traditional approach (the model is created automatically using data analysis methods and algorithms processing) [11–13].

The results of the simulation model generator is script code in internal script language (FlexScript) of FlexSim simulation software, creating specific parts of the simulation model for the specific structure of the production system based on data obtained from the MRP/ERP systems [14]. This code is responsible for creating simulation objects that make up the manufacturing system, i.e.: manufacturing resources, inter-operational buffers, warehouses, input and output buffers, and information resources, i.e.: tables containing data about the number of models to be produced, the set of tasks and task times for each model, the quantity to be produced for each model and data on processes routes as a function of carrying out the connection between appropriate objects in the model to perform calculations and simulation experiments. The model is supplemented by scripts containing the algorithm for the sequencing heuristic where the work elements are assigning to different workstations in generated balancing feasible solution (Fig. 2). Apart from supporting the balancing process the generated model can be used by the planner for the analysis of the production flow, which include, among others, resource utilization, storage capacity optimization, completion date of production orders

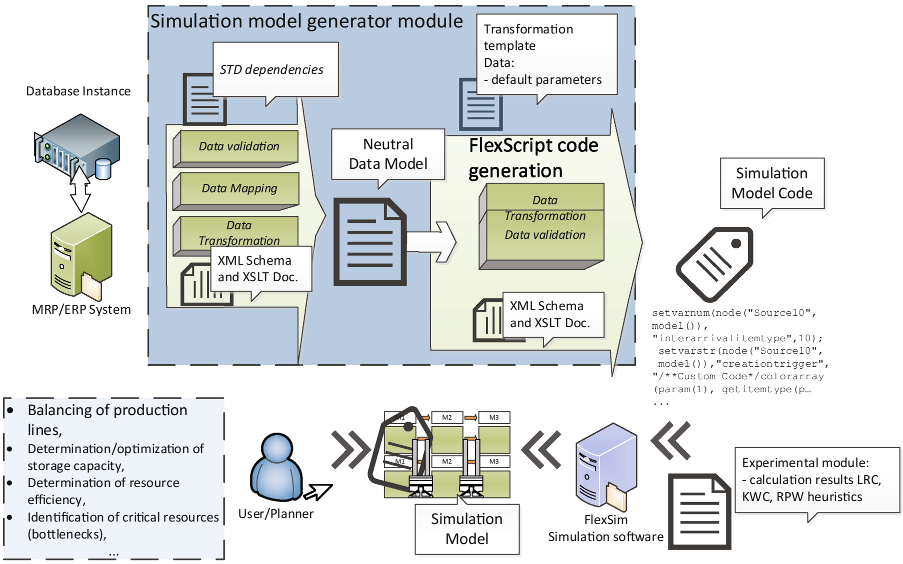

Fig. 2. Data-driven automatic simulation models generation

verification and to manage the quality of the production system (working without deadlocks and starvations).

5 Practical Implementation Example

Practical implementation of the presented method was carried out using a commercial FlexSim simulation software [14]. The process of data transformation (model generation) was carried out using RapidSim software, which is computerized implementation of the previously described methods. FlexSim provides extensive support for building, analysis and verification simulation models developed by the FlexSim Software Products, Inc. FlexSim is fully customizable, graphically-oriented simulation software that integrates modelling, simulation and 3D visualization and animation in 3D object oriented drag-drop-connect environment. In FlexSim, discrete or fluid pre-defined modelling object are the most basic building element of a simulation and allows users to change the behavior of objects, which can be parameterized at the stage of creating the model. The discrete objects (objects that create, send, store items awaiting processing, move items through the model, group and perform operations on products, etc.) are used to develop discrete-event simulation models where model behavior results from events that occur at discrete points in time [15]. Objects are available in the libraries of objects the extent corresponding to the possible uses of the various versions. Further provides mechanisms that import and export data and facilitate the analysis of data. Most of the tasks related to the construction and parameterization of the model and writing custom logic can be realized using the internal programming scripting language FlexScript. Also, FlexScript is nearly identical to C++ in its syntax and application.

The data mapping and transformation is realized in the RapidSim author software [14], for which the data transformation documents (XSLT) can be developed independently. Input files to the RapidSim are XSLT documents constitute the definition of transformation functions for data where the process of data exchange and data transformation between the data source (from MRP/ERP system) and the target (FlexScript) is executed. Finally, the code of the simulation model is generated (Fig. 3).

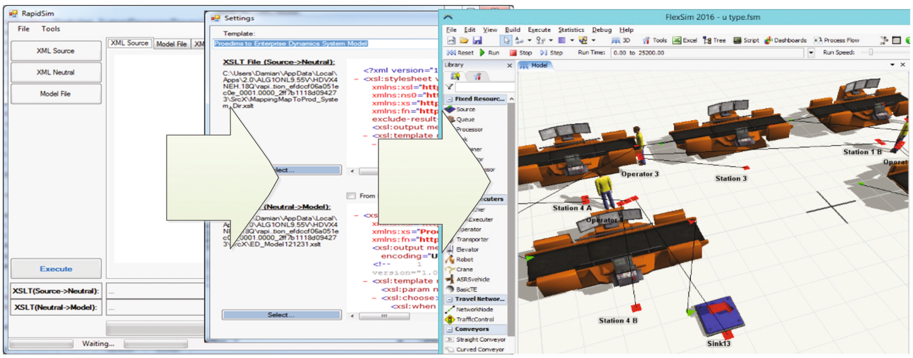

Fig. 3. RapidSim—data mapping and transformation

To analyze the solution of assembly line balancing problem, using 3 heuristic methods described above, an example of gear motor production (two models) was considered.

Figure 4 shows a precedence graph, which is constructed to help visualize the preceding tasks. Numbering of the nodes in the graph, corresponds to the number of a task and values in the upper right corner of each node correspond to duration of this task. Table 1 includes the processing times for 12 tasks.

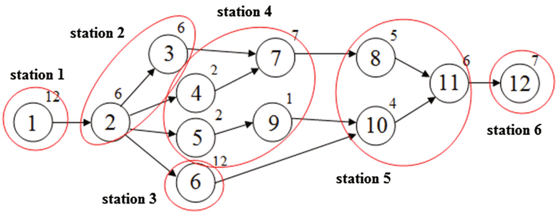

Fig. 4. Precedence graph and task assignment

Table 1. Tasks and operations times

Model #1				Model #2			
Task No	Task times	Task No	Task times	Task No	Task times	Task No	Task times
1	12	7	7	1	10	7	1
2	6	8	5	2	6	8	5
3	6	9	1	3	7	9	1
4	2	10	4	4	6	10	5
5	2	11	6	5	5	11	2
6	12	12	7	6	13	12	6

With the help of RapidSim software, the script code of the model has been generated. Loading the resulting output document (MOD) in FlexSim software allows for automatic creation of a complete simulation model (Fig. 5), which is ready to carry out calculation and simulation experiments, including, i.e. analysis of available quantity and capacity of means of transport, timetables and potential hazards collisions.

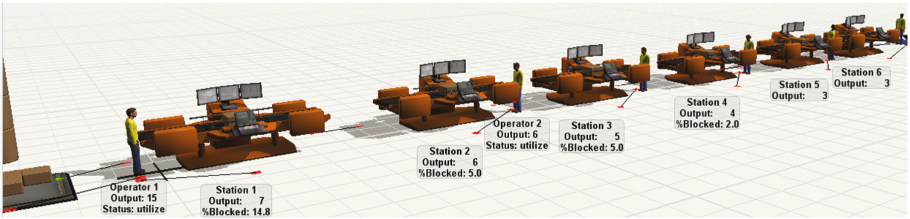

Fig. 5. Simulation model

Both models have been balanced using RPW method. Lines consist of six assembly stations, which carry out individual assembly operations. The generated feasible solutions for fixed number of stations (task assignment) are shown on Fig. 4. After conducting analysis of two manufactured models, following results were obtained. The work on the assembly line is evenly distributed. Data analysis was done for the steady state period of simulation – without taking into account the start-up and cease phases of production in the system. Processing at stations 1–5 is between 77%~95%, except last station, which is utilized in 46%. Similar values were obtained for the utilizer of individual operators in the system. Last station has idle time which is effect of completing its tasks faster. Total processing time of station 6 is shorter than previous station. The results in Table 2 show that workload is evenly distributed amount operators. Efficiency of the all workstations is 81%.

Table 2. Simulation results

Object	Processing/utilize	Idle	Blocked	Waiting for operator	Waiting for transport	Travel empty	Travel loaded
Station 1	77,53%	0,42%	21,99%	0,00%	0,06%	0,00%	0,00%
Station 2	86,85%	0,19%	12,87%	0,03%	0,06%	0,00%	0,00%
Station 3	86,85%	0,15%	12,91%	0,03%	0,06%	0,00%	0,00%
Station 4	94,10%	0,16%	5,65%	0,04%	0,06%	0,00%	0,00%
Station 5	94,51%	5,43%	0,00%	0,00%	0,06%	0,00%	0,00%
Station 6	46,08%	53,78%	0,00%	0,08%	0,06%	0,00%	0,00%
Operator 1	77,53%	21,99%	0,00%	0,00%	0,00%	0,23%	0,17%
Operator 2	86,85%	12,98%	0,00%	0,00%	0,00%	0,03%	0,08%
Operator 3	86,85%	12,96%	0,00%	0,00%	0,00%	0,03%	0,09%
Operator 4	94,10%	5,71%	0,00%	0,00%	0,00%	0,04%	0,09%
Operator 5	94,51%	5,36%	0,00%	0,00%	0,00%	0,00%	0,06%
Operator 6	46,08%	53,64%	0,00%	0,00%	0,00%	0,08%	0,14%

6 Conclusions

The proposed combined method of data-driven automatic simulation models generation and heuristic for mixed and multi model assembly line balancing can become an efficient and effective IT tool to support the engineers in planning, control and re-configure manufacturing resource networks and production flow. The proposed RapidSim software solution enables, among others, to perform rapid analysis in many aspects and to achieve increased flexibility of management, planning and control of processes flow. It allow to eliminate the disadvantages associated with the traditional – expensive and time-consuming process of creating the simulation models and enables to simply verification of changes in production plans and deliver the ability to respond flexibly to changing customer requirements. Thanks to its openness it may be commercialized with practically any ERP or simulation software. The subject of further work in this area will involve analysis of operator assignment to the station and interoperation buffers (place and time) consideration.

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