Applied Computer Science, vol. 14, no. 1, pp. 42–52
doi:10.23743/acs-2018-04

Submitted: 2018-02-10
Revised: 2018-03-20
Accepted: 2018-03-23

line balancing problem, manufacturing simulation, Tecnomaix Plant Simulation, manufacturing, production system modeling

Wojciech DANILCZUK[*]

THE USE OF SIMULATION ENVIRONMENT FOR SOLVING THE ASSEMBLY LINE BALANCING PROBLEM

Abstract

The paper describes the application of a simulation environment (Tecnomatix Plant Simulation) for solving a real manufacturing problem. The studied case consisted in rebalancing the production line with a specified number of operators on the line. The first stage of the study involved determination of the production cycle and key performance indicators. The production system was then divided into work cells. After that, proposed design assumptions were verified via a simulation model.

1. INTRODUCTION

One of the main challenges for modern manufacturing companies lies in tailoring their products and manufacturing methods to market needs (Esmaeilian, Behdad & Wang, 2016). Due to dynamically changing demands, companies must be able to quickly adapt their manufacturing systems to create new product types. New solutions for manufacturing systems should not only be developed in a short time, they should also be fully refined. The use of simulation tools enables the verification of intended changes and testing them in a given simulation environment (Longo, 2010). This prevents costly errors that could arise during solution implementation.

[*] Lublin University of Technology, Faculty of Mechanical Engineering, Department of Automation, Nadbystrzycka 36, 20-618 Lublin, tel.: +48 81 538 4267, wojciech.danilczuk@pollub.edu.pl

This paper provides an example of the use of simulation software for the development and verification of a new concept for the organization of an existing production line. This example comes from the author's professional experience. Solutions for similar industrial problems can be found in (Kłosowski & Kozłowski, 2017). The literature of the subject also provides theoretical studies devoted to problems of this type, for example Gola & Wiechetek (2017) or Danilczuk, Gola & Cechowicz (2014).

2. DESCRIPTION OF THE ASSEMBLY LINE BALANCING PROBLEM

The objective of this study was to rebalance an existing assembly line with respect to both layout constraints (its architecture could not be changed) and those of precedence (technological route). The manufacturing plant's management wanted to change the number of workers working on this line. Consequently, the allocation of workstations to workers had to be changed. The entire assembly process is described below. A schematic illustration of the above technological constraints is given in Figure 1.

The investigated assembly line is dedicated to the production of wooden windows. Although some work is done using power tools (e.g. drills), most tasks are performed manually. The first stage of the production process is a parallel assembly of two main parts, A and B. Both parts are assembled in two stages. Subpart A is formed into part A, and between this operation there is a buffer place for one part. Subpart B and part B are assembled in a separate zone. The next step of the technological route consists in fixing parts A and B together and thus creating part C. In this segment of the production line, the workers move parts manually. After that, part C is put on the conveyor. The main material flow takes place in a line segment consisting of the conveyor and an additional assembly station where accessories are attached to the main product. The first operation on the conveyor cell is to attach accessories 1 and 2 to part C. From there part C gets to a quality control station (where it is provided with accessories 3). Another segment of the line is a cleaning station. The last stage is a packaging station. Prior to packing, the worker has to prepare a box and product-protecting elements (e.g. styrofoam corner protectors) as well as to print manuals and documentation.

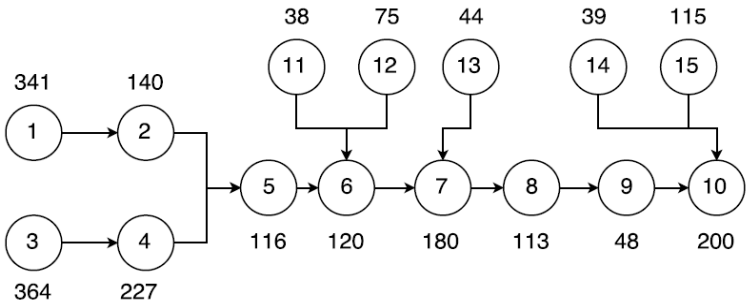

Fig. 1. Technological constraints

The first stage of the study consisted in the revision and validation of the existing technological route. Technological route documentation includes the description of all work tasks that must be performed at every workstation (e.g. drilling holes, gluing corners), the assumed time of every operation and Gantt charts for all operations (Fig. 2). The purpose of validation was to reveal the differences between the operating times specified in the documentation and actual operating times of the line. It was decided that the assembly time of every operation on the line would be measured in order to update the technological documentation. In addition, time measurements were used to calculate new operation cycle times and to assign tasks to individual workers.

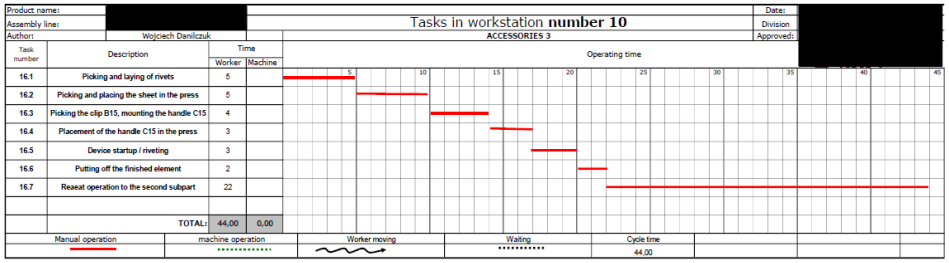

Fig. 2. Example of Gantt chart

3. ASSEMBLY LINE BALANCING

As it was mentioned above, the first step was to update the assembly process documentation, especially with regard to the cycle time of every operation. The measurements were made during normal operation of the line, and the workers were informed about them. They were asked to perform all operations as usual, without rushing or slowing down because of the measuring process. Mean times of all operations (operating time, Top) are listed in Table 1. Once required measurement data was collected, the line balancing procedure was started.

Tab. 1. Operating time

Number	Part / Process	Time (Top)
Operation 1	Subpart A	364
Operation 2	Part A	227
Operation 3	Subpart B	341
Operation 4	Part B	140
Operation 5	Part C	116
Operation 6	Part C + Accessories	120
Operation 7	Accessories 1	75
Operation 8	Quality Control	180
Operation 9	Accessories 2	38
Operation 10	Accessories 3	44
Operation 11	Corner protectors preparation	39
Operation 12	Box preparation	115
Operation 13	Corner protectors assembly	48
Operation 14	Cleaning	113
Operation 15	Packing	200

In single assembly line balancing (SALB), one can distinguish two main types of problem. One is SALB TYPE I, and it occurs when we have a fixed production time and want to find the minimal number of workstations. This problem has been widely described in the literature of the subject (Salveson, 1955; Groover, 2000). There are a few methods for solving SALB TYPE I problems, for example Largest Candidate Rule (Groover, 2000), Kilbridge and Wester Method (Kilbridge & Wester, 1961) or Ranked Positional Weight Method (Helgeson & Birnie, 1961).

The other type of problem occurs when you design a new line for a new product. Nowadays, many lines are modified when a new product is introduced to production. Problems arising from such modifications can be classified as SALB TYPE II – they occur when we have a fixed number of workstations and want to estimate the cycle time (Zemczak, 2013; Grzechca, 2010).

The problem investigated in this study can by classified as single assembly line balancing problem type II. The assembly line in question has a fixed number of workstations, one per every operation. Given the architecture of the line, its layout could not be changed. The technology used in the manufacturing plant enabled the tailoring of the entire line to replicate other line models, depending on the market demand.

The main task was to calculate the cycle time of every operation, assign one worker per every operation (workstation), and thus create a work cell. In addition to this, it was necessary to check whether the line's efficiency met expectations of the manufacturing plant's management; if not, to calculate the value that would fall in line with the expectations. Cycle times were determined with Equation (1) (Zemczak, 2013; Grzechca, 2010)

$$Tc = \frac{\sum Top}{N} = \frac{2160}{6} = 360 \quad (1)$$

where: *Tc* is the estimated cycle time, [s],
Top is the operating time, [s],
N is the number of workers.

One can observe that when the estimated cycle time *Tc* is 360, the operating time of the longest operation (operation 1, assembly of subpart A) is max(*Top*)=364. None of the work tasks can be divided into smaller parts. At this stage of solution design, the author set the cycle time *Tc* equal to 364. This calculation did not take account of transportation time.

The next step was to arrange work cells and to assign workers to work-stations. To do so, the author had to cooperate with the plant's management, as this required taking into account factors such as employee qualifications, the ease of training new employees on particular operations, and staff rotation. Given those limitations, heuristic algorithms could not be applied. The author, in cooperation with the manufacturing plant's management, decided to divide operations into work cells manually, based on an "expert method" and the experience of the managerial and technology staff. Together with the plant's management, the author prepared a worker cell matrix (Table 2). The workload of workers is shown in Figure 3. The work cell diagram (Figure 4) illustrates the allocation of workers to operations.

Tab. 1. Worker cell matrix

	Time (T_{op})	Worker 1	Worker 2	Worker 3	Worker 4	Worker 5	Worker 6
Operation 1	**364**	364					
Operation 2	**227**			227			
Operation 3	**341**		341				
Operation 4	**140**			140			
Operation 5	**116**				116		
Operation 6	**120**				120		
Operation 7	**75**				75		
Operation 8	**180**					180	
Operation 9	**38**				38		
Operation 10	**44**					44	
Operation 11	**39**					39	
Operation 12	**115**						115
Operation 13	**48**						48
Operation 14	**113**					113	
Operation 15	**200**						200
Σ T_{op}	**2160**	**364**	**341**	**367**	**349**	**376**	**363**

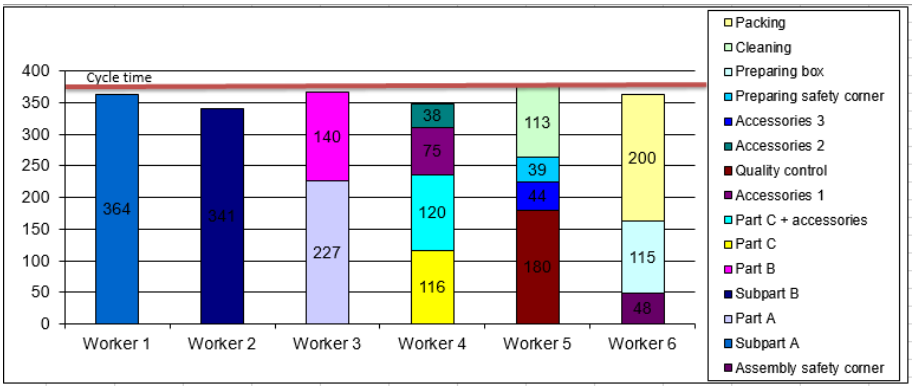

Fig. 3. Workload of workers

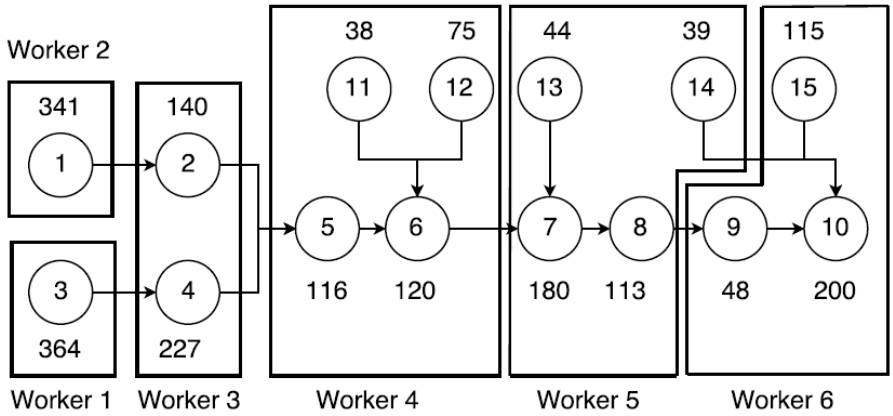

Fig. 4. Work cell diagram

After dividing the operations into work cells, their cycle time and theoretical efficiency were estimated. Based on the work cell matrix, the optimal max(*Tc*) = 376. Because the operations could not be divided into smaller parts, it was not possible to calculate the cycle times of *Tc*=360 nor the time resulting from max(*Top*)=364. The cycle time of the line was assumed to be *Tc* = 376. Based on the assumed cycle time, efficiency indexes (2) were calculated (Scholl, 1999; Grzechca, 2010). An additional variable used in the calculations was a coefficient describing the number of parts manufactured by one employee per shift, KPI (3).

$$EI = \frac{\sum Top}{N * Tc} = \frac{2600}{6 * 376} = 95{,}7\% \qquad (2)$$

where: *EI* is the efficiency index,
Top is the operating time, [s],
Tc is the cycle time, [s],
N is the number of work cells.

$$PpS = \frac{St}{Tc} = \frac{7{,}5 * 3600}{376} \approx 71 \tag{3}$$

$$KPI = \frac{PpS}{N} = \frac{71}{6} = 11{,}83 \tag{4}$$

where: *PpS* is the number of parts manufactured per shift,
St is the shift time, [s],
Tc is the cycle time, [s],
KPI is the number of products manufactured by one employee per shift,
N is the number of work cells.

4. SIMULATION ENVIRONMENT

Following the design phase but prior to the implementation of a new assembly line organization, a simulation was performed in the Plant Simulation software. Since the line worked in accordance with old procedures during the rebalancing process, it was reasonable to carry out the simulation before implementing desired changes. This approach enables the verification of proposed solutions without disturbing the line's operation (Banks, Carson, Nelson & Nicol, 2010). In the event of an error, it is possible to make amendments without interrupting operation of the line and decreasing its performance. What is more, theoretical calculations take no account of manual transportation of parts between the work-stations nor the movement of the workers on the line. In contrast, a simulation model allows for taking these phenomena into account.

The environment used to prepare a model and perform simulation was Tecnomatix Plant Simulation 11. This environment is part of the Siemens software for PLM and digital manufacturing. Plant Simulation enables the simulation, visualization and analysis of manufacturing processes (Bangsow, 2010). The advantage of the software is that it can be integrated with other SIEMENS tools including Teamcenter, Process Simulate and Solid Edge ("Plant Simulation", 2018).

The program enables the introduction of random variables to the simulation, e.g. the supply of raw materials according to preset statistical distributions and the parameterization of individual objects, e.g. the definition of MTTF machines. Thanks to the integration with CAD tools, it is possible to import ready-made machine models and to prepare a simulation model while maintaining

the geometry of objects on the production line. The functionality of standard components can be extended with the tool for writing scripts in the embedded programing language SimTalk (Bangsow, 2010). An example of such a script is given in Figure 5. This enables the preparation of algorithms that control both line operation and events occurring during the process. The program also generates reports on line performance and production line statistics.

A simulation model of the analyzed line is shown in Fig. 6.

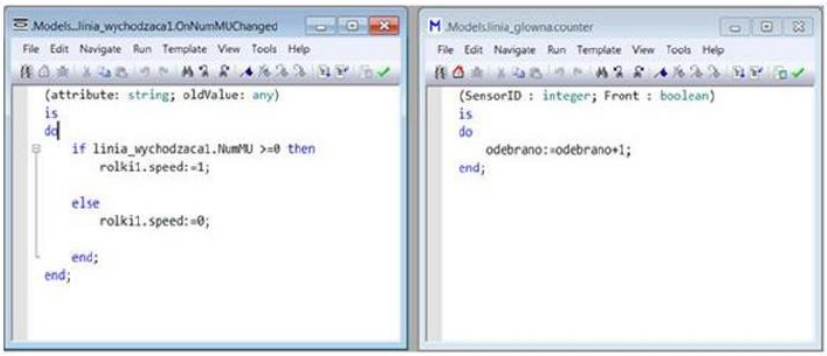

Fig. 5. Example of a script in SimTalk (Danilczuk, Gola & Cechowicz, 2014)

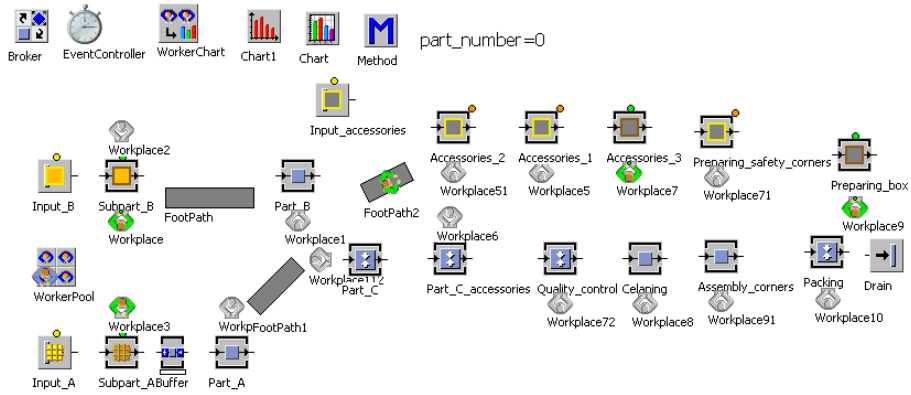

Fig. 6. Simulation model of the analyzed line

5. RESULTS

The use of simulations allowed for testing the proposed solution before implementing it into the production process. In the first stage of the design process, the transportation time between individual operations was not taken into account. In the simulation model, however, this variable was considered.

Additionally, the simulation allowed for examining the line start-up effect. The efficiency of the workers operating the line and the utilization of individual workstations are plotted in Figure 7.

The worker efficiency on all work cells is similar and exceeds 90% of their working time. This indicates a proper balance of the production line. None of the workers is overloaded with assigned tasks.

The use of the buffer between operations 1 and 2 (assembly of subpart A and part A) amounts to 72%, therefore it is justified to maintain it.

The number of parts manufactured per one shift is 68 (assuming that there are no intermediates on the line after start of work). The difference between the number of parts manufactured per shift, *PpS*, obtained in the theoretical calculation (71 items) and that obtained from the simulation (68 items) results from the simplifications made in the calculations. Also, the number of parts manufactured by one employee per shift, *KPI* (3) is different for the theoretical calculation value and that obtained from the simulation – it is 11.83 and 11.33, respectively.

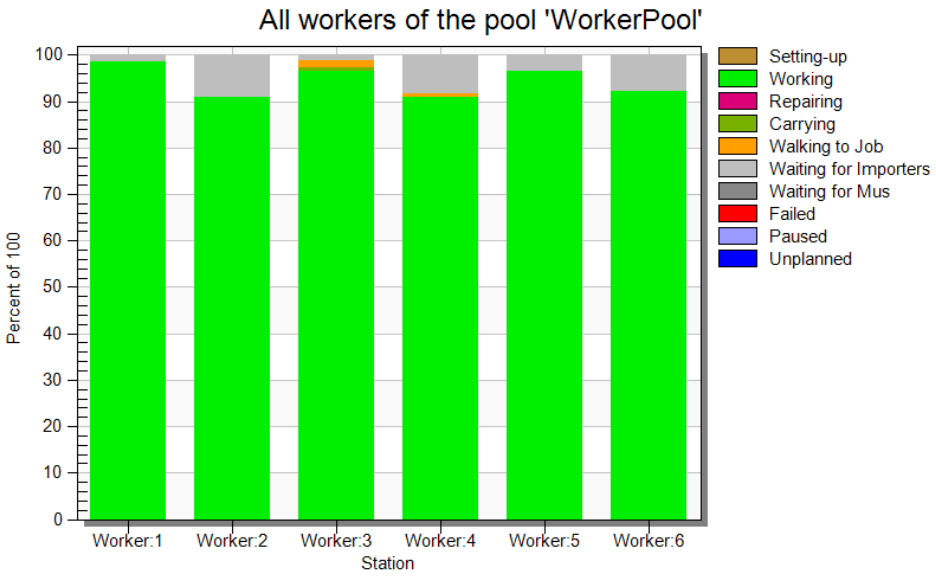

Fig. 7. Worker efficiency

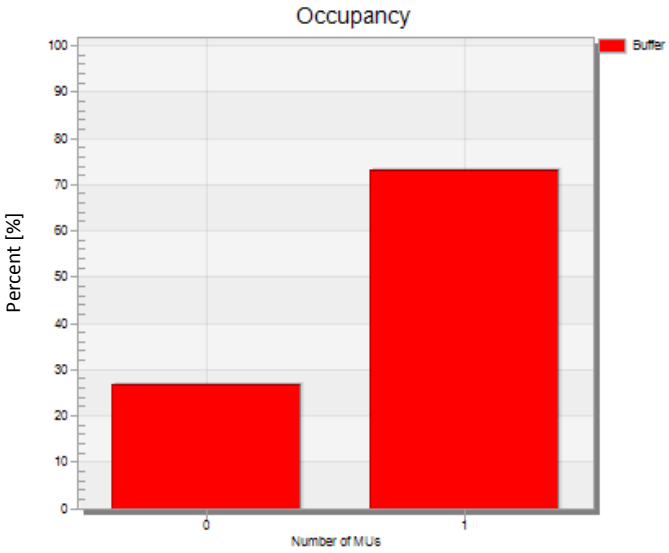

Fig. 8. Buffer occupancy

6. CONCLUSIONS

Although the problem of assembly line balancing is widely described in the academic and industry literature, it still poses a great challenge. This is due to the fact that, under real industrial conditions, even such a basic task as the determination of a production cycle time may occur to be complex.

Simplifications made in the determination of line performance and other indicators may lead to incorrect assessment of the situation and cause disagreements between process engineers, plant managers and production staff. Thanks to the use of simulation tools, the analyzed phenomena could be simulated and visualized, and the target efficiency of the production line was estimated.

Another important aspect of the use of simulation environment is that it enables the verification of design assumptions and the division of the line into work cells before implementing proposed solutions. The possibility of analyzing the proposed solutions in a virtual environment allowed for the verification of their correctness without interrupting operation of the line, which would lead to incurring losses. In addition to this, the use of the simulation software turned out to be an important managerial tool for convincing the management and production staff of new solutions.

REFERENCES

Banks, J., Carson, J. S., Nelson, B. L., & Nicol, D. M. (2010). *Discrete-Event System Simulation*. USA: Prentice Hall.

Bangsow, S. (2010). *Manufacturing Simulation with Plant Simulation and SimTalk*. Berlin: Springer.

Danilczuk, W., Gola, A., & Cechowicz, R. (2014). Analiza konfiguracji linii produkcyjnych na postawie modeli symulacyjnych. In K. Bzdyra (Ed.), *Informatyczne Systemy Zarządzania* (tom 5, pp.25–42). Koszalin: Wyd. Politechniki Koszalińskiej.

Esmaeilian, B., Behdad, S., & Wang, B. (2016). The evolution and future of manufacturing: A review. *Journal of Manufacturing Systems*, *39*, 79–100. doi:10.13140/RG.2.1.2720.0402

Gola, A., & Wiechetek, Ł. (2017). Modelling and simulation of production flow in job-shop production system with enterprise dynamics software. *Applied Computer Science*, *13*(4), 87–97. doi: 10.23743/acs-2017-32

Groover, M. (2000). *Automation, Production Systems, and Computer-Integrated Manufacturing (2nd Edition)*. New York: Prentice hall.

Grzechca, W. (2010). Dualność problem balansowania linii montażowej. In R. Knosala (Ed.), *Komputerowo Zintegrowane Zarządzanie* (pp. 532–539). Opole: Oficyna Wydaw. Polskiego Towarzystwa Zarządzania Produkcją.

Helgeson, W. B, & Birnie, D. P. (1961). Assembly line balancing problem using ranked positional weights technique. *Journal of Industrial Engineering*, *12*(6), 394–398.

Kilbridge, M., & Wester, L. (1961). A Heuristic Method of Assembly Line Balancing. *Journal of Industrial Engineering*, 19(6), 292–298.

Kłosowski, G., & Kozłowski, E. (2017). Optymalizacja wielokryterialna w procesie produkcji mebli. *Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska*, *4*, 101–106.

Longo, F. (2010). Emergency simulation: state of the art and future research guidelines. *SCS M&S Magazine*, *1*(4), 2010-04.

Salveson, M. E. (1955). The Assembly Line Balancing Problem. *The Journal of Industrial Engineering*, *6*(3), 18–25.

Scholl, A. (1999). *Balancing and Sequencing of Assembly Lines*. Physica-Verlag Heidelberg.

Zemczak, M. (2013). Zagadnienie balansowania linii montażowej i szeregowania zadań w systemach produkcji mixed-model. In K. Bzdyra (Ed.), *Informatyczne Systemy Zarządzania* (tom 4, pp. 115–128). Koszalin: Wyd. Politechniki Koszalińskiej.

Plant Simulation. (n.d.). Retrieved 2018, from Siemens PLM Software website https://www.plm.automation.siemens.com/en/products/tecnomatix/manufacturing-simulation/material-flow/plant-simulation.shtml