SPS2022
A.H.C. Ng et al. (Eds.)

doi:10.3233/ATDE220129

Supporting Manufacturing Investment Decisions in New Product Introductions Through Line Balancing Techniques

Filip SKÄRIN[a,1], Mohamed Elnourani ABDELMAGEED[a], Gary LINNÉUSSON[a] and Carin RÖSIÖ[a]
[a] *Department of Industrial Product Development, Production and Design, School of Engineering, Jönköping University, Sweden*

Abstract. Nowadays customer needs are changing rapidly, resulting in shorter product life cycles and a need for a higher product introduction rate. This requires manufacturers to introduce new products whilst keeping production efficiency at a satisfactory level and production costs low. Based on these challenges, there is a need to consider both production efficiency and potential assembly line investment costs during the planning of new product introductions. Hence, this paper aims to support decision-making regarding whether to introduce and produce a new product in an already existing assembly line or to invest in a new assembly line. To its support, a tool which illustrates how to support manufacturing investment decisions through line balancing techniques has been developed. The tool was based on theoretical findings from two literature reviews, investigating assembly line balancing techniques and assembly line investment costs, and through data collected in a single case study, including how a company is currently supporting investment decisions and performing line balancing. The case study was conducted with a large Swedish company from the automotive industry. Data was collected through semi-structured interviews, document studies and a focus group. The proposed decision-supporting tool conducts line balancing for both combined and separate assembly lines, and converts the results into costs. These costs are then compared with the potential investment costs of either producing in an already existing assembly line or investing in a new assembly line. The final output is a summarization of the potential costs related to both alternatives which provides the user with the most economically beneficial alternative by taking both production efficiency and investment costs into consideration.

Keywords. Decision-support, Line balancing, Assembly line investments, New product introductions

1. Introduction

Globalization and rapidly shifting demand patterns put companies under pressure to offer new products frequently in order to remain competitive and meet customer requirements. Therefore, many manufacturers pursue a low-cost production strategy by using optimization tools which improve the system's productivity and performance [1]. Line balancing has been used as a mathematical tool to design and calculate the efficiency of sequential operations for a production line. The operations in the production lines are

---

[1] Corresponding Author, e-mail: filip.skarin@ju.se

grouped within stations. The grouping is performed in order to distribute the workload by arranging tasks among production system's resources, which enables the possibility of coping with variation of machine performance to match the overall production rates [2,3]. An early model for line balancing, developed in the 1950-ies by Salveson [4], was created to reduce waste, waiting time, inventory, and absorb alterations within the production system. Several mathematical models have since then been developed to solve line balancing optimization problems [3,5,6]. These models usually include calculating the number of stations and setting the layout based on the throughput time and task time for every operation. Line balancing facilitates an understanding of the dependency between processes and the identification of the bottleneck operation, which is needed to make assembly lines more efficient. Consequently, applying line balancing can lead to relocating resources and merging operations or modification of the layout [3,7].

Since the initial models were proposed, improvements have been proposed to enhance line balancing techniques and to address challenges associated with production layout constrains, products variety and setup times delays. For instance, as a response to the aforementioned growing customer trend, introducing higher levels of product variability and shorter product life cycles, the mixed-model assembly line balancing method has evolved into being capable to operate in a system capable of producing more than one product variant within the same line [8,9]. This type of line balancing is considering the production of several products from the same product family when calculating the line efficiency [10,11].

However, an increased product introduction rate also forces decision-makers to more frequently make rapid and accurate decisions. One of these decisions recurrently taken during the early phase of the new product introductions includes deciding how and where to produce new product variants [12]. These complications in changing demands and increased product introduction rates are creating increased uncertainties within investment decisions. Thus, decision-makers not only need to consider the product producibility but also potential assembly line investments, including capital and operational costs [13]. In previous research the possibility of combining production efficiency and potential assembly line investment cost throughout the decision-supporting process for developing new products has not yet been addressed. In fact, the results from studying the literature, shown in this paper, indicates that there is no coherence in current research on assembly line investment costs. Similarly, in terms of line balancing techniques, a second literature review highlighted that no classification based on the usability of the line balancing techniques in the industrial sector has been established. Consequently, the purpose of this paper is to support decision-makers regarding the identification whether to introduce and produce a new product into an already existing assembly line or to invest in a new assembly line. To accomplish this, a decision-supporting tool is proposed that takes both line balancing and potential investment costs in new assembly lines into consideration.

2. Single-, mixed- & multi-model assembly lines

Typically, assembly lines consist of workstations where labors or machines conduct a specified sequence of operations before the product is moved to the next workstation. The machinery and material handling equipment are normally associated with a high level of investment costs [14]. This emphasizes the need for companies to implement an optimal assembly line configuration in order to minimize modifications necessitated by future consumer demand [3,14,15]. Originally, assembly lines were implemented as a means for companies to accomplish mass production of identical products while staying cost-efficient [14,15]. In line with organizational and technological development the complexity of assembly lines has increased and single product lines has been replaced by assembly lines, targeting several product variants [15]. The configurations of product and assembly lines can be divided into three main categories; single-model assembly lines, mixed-model assembly lines and multi-model assembly lines [10,11,16].

Single-model assembly lines are the least complex assembly line. These are commonly implemented in mass production facilities. Primarily since they traditionally enable the possibility of having operators with little training to manually assemble complex and detailed products [9]. Mixed-model assembly lines (MMAL), are used to manufacture several products within the same product family [10,17]. These are assembled on the same line [18]. In MMAL, each specific product variant has its own task precedence rules, which are combined into a precedence diagram of the entire product family [17]. MMAL are frequently used in car-manufacturing facilities as these tend to produce a limited fixed set of product families. Normally, these do not require any machine- or tool setup between different product variants [10]. However, if the products assembled in the production line are of comprehensive difference, setup time might be required between producing the products in sequence. These are referred to as multi-model assembly lines [10].

3. Line balancing problems

Assembly line balancing originally targeted the enhancement of production efficiency by reducing cycle times and idle times, which usually requires a set of sequenced unidentical operations to create the final product. These operations require different times to be completed. This leads to differences in workload between workers and stations, which causes delays and time waste, a problem labelled as the assembly line balancing problem (ALBP) [19,20]. The first attempt to solve the ALBP was carried out by Salveson back in 1955 [4]. Since then have many researchers continued to address the ALBP with regards to different restrictions and assumptions [2,4,21]. Many literature review articles have been published in order to summarize different approaches and contexts for solving the ALBP, see, e.g. [20,22–24]. The approaches have two factors in common that must be addressed in order to achieve a smooth task allocation through assembly lines. First, the number of workstations should be maintained to a minimum. Second, logical precedence restrictions must be observed [22,25,26].

As the complexity of ALBP grows, additional classifications have been proposed based on assumptions of the assembly line setup. A common classification regards the number of product variants possible to be manufactured concurrently in the assembly line. This classification is two folded and includes single assembly line balancing problems (SALBP), in which only one product can be manufactured in the line, and the mixed-model assembly line balancing problems (MMALBP), which involve multiple products being produced within the same line [18]. Furthermore, according to [27,28], ALBP can be classified through balancing techniques based on its goal, such as reducing the number of stations, classified as Type I line balancing problems, or enhancing line throughput by reducing job cycle time, classified as Type II line balancing problems.

The goal for a Type I problem is to decrease the number of stations or personnel required to meet the output requirement while considering the task time a constant value, whilst Type II strives for the highest production rate and lowest cycle time while keeping a fixed number of workstations. However, both types assume that the cycle time for a single station does not exceed the assembly line cycle time [29,30].

4. Line balancing models

Several authors have developed different software tools to solve the assembly line balancing problem through a simple structure and user friendly interface [31,32]. Although these models differ, they are based on the same foundation, which can be summarized into two basic phases. The first phase begins by determining if the workstations are eligible to be assigned tasks. This logical test is carried out on the basis of two factors. First, all tasks are assigned to available stations. Secondly, the total task duration within any station must be less than or equal to the maximum cycle time [32,33].

The second phase involves allocating the tasks based on the priority rule. Then the model runs several iterations during each task assigned at a time. In previously developed models, see [32,33], the two steps are computed by combining built-in functions in Microsoft Excel.

5. Methodology

In order to identify how to support manufacturing investment decisions through line balancing techniques, two literature reviews and a single case study were carried out. The former included investigating what assembly line balancing techniques and assembly line investment costs exists in the literature. The latter involved data collection at a case company, focusing on how they currently support investment decisions and perform line balancing. The results from the literature reviews and case study were used to create a decision-supporting tool. Microsoft Excel spreadsheets were chosen as the interface for the tool design since it enhances usability through being well-known and frequently used by industrial companies.

5.1. Literature reviews

The literature reviews were carried out through a standardized process inspired by Booth et al. [34], where initial searches were based on carefully selected combinations of keywords, see Table 1. In order to exclude non-relevant papers, search filters were used. The literature review process worked as follows: in the first round relevant papers were selected by reading all abstracts, in the second round these papers were briefly read through to identify the relevant papers. In the third and final round the most relevant papers was selected, and included a detailed review of the articles, taking notes, excerpting quotes, and highlighting relevant findings. The findings from the literature reviews are described and summarized in chapter 6.1 and 6.2.

Table 1. Literature searches

Theoretical topic	Keywords	Hits	Incl. filters
Line balancing	"Mixed model assembly line balancing"	144	118
	"Mixed-model assembly lines" AND "Line balancing"	214	192
	"Multi-model assembly line*"	32	29
	"Line balancing" AND Algorithm*	1229	234
	"Line balancing" AND Technique*	373	117
	"Line balancing" AND "Decision making tool"	2	2
Assembly line investment costs	*"Assembly line*" AND Investment* AND* (*"New product introduction*" OR* NPI)	1	1
	"Assembly line*" AND Investment*	214	156
	Investment* AND Costs* AND Calculation* AND (Production OR Manufacturing)	607	212

5.2. Single case study

To study how current assembly line investment decisions and line balancing are carried out in practice, the empirical method of single case study was used [35]. The case company was a large Swedish manufacturer within the automotive industry.

To get an understanding regarding how the case company applied line balancing and investment cost calculations, document studies were conducted. These were carried out through the process of extracting information from existing documents [36], which was used as a foundation for the decision-supporting tool. In total, two document studies were performed, and a total of 6 documents were reviewed (see Table 2).

Table 2. Studied documents

Date received	Document description	Study field	Source
210121	Current staffing and line balancing procedure	Line balancing	Production engineer
210121	Detailed information of two products	Line balancing	Production engineer
210301	LCC analysis template	Investment costs	Production engineer
210301	LCC analysis assembly line update case	Investment costs	Production engineer
210301	Business case calculation model template	Investment costs	Production engineer
210301	Business case calculation model – assembly line update case	Investment costs	Production engineer

Semi-structured interviews [37] were conducted to continuously collect feedback regarding the developed decision-supporting tool and to get a deeper understanding of how the case company works with line balancing and investment cost calculations. The interviews took place in the form of discussions with a production engineer at the case company. Before each occasion, questions and discussion topics were prepared. The interviews occurred bi-weekly from January to May 2021.

A focus group was set up at the case company to collect feedback regarding the developed tool. In total, four employees from departments responsible for both assembly line balancing and investment cost calculations were selected for the focus group. The focus group occasion lasted for two hours and followed a structure consisting of a premade questioning route which covered five major parts; opening questions, introductory questions, transition questions, key questions and ending questions, as according to [38].

6. Results

6.1. Line balancing techniques

The findings of the initial review of the literature are depicted in Figure 1. The literature review resulted in a description of line balancing techniques which emphasizes the usability and accuracy of the techniques. Two main systematic approaches to solve ALBPs were recognized: 1*) Exact methods*, which use numerical analysis to investigate all feasible solutions to find the best one. This approach was discovered to be impractical in the industry due to their complexity, particularly as the scale of the problem grows. 2) *Approximate methods,* which include both *dynamic programming* and *heuristic methods*. The first employs the same principle as *Exact methods*, but with the goal of narrowing the space of solutions [24,39]. *Heuristics methods*, on the other hand, do not generate optimal solutions for a given situation, but rather use a rational series of steps to find approximate solutions. Furthermore, when assigning tasks to assembly stations, multiple priority rules may be used. The most popular methods and techniques identified in the literature review included operation times, following tasks, positioning weight, or a combination of these [20,40].

Despite the reality that numerous models for exact and approximate approaches have been developed, due to the complexity of these models, their practicality in the industry has been called into doubt. *Heuristic methods*, on the other hand, were identified to be more suited for industrial applications since they provide solutions with an acceptable level of accuracy [41,42].

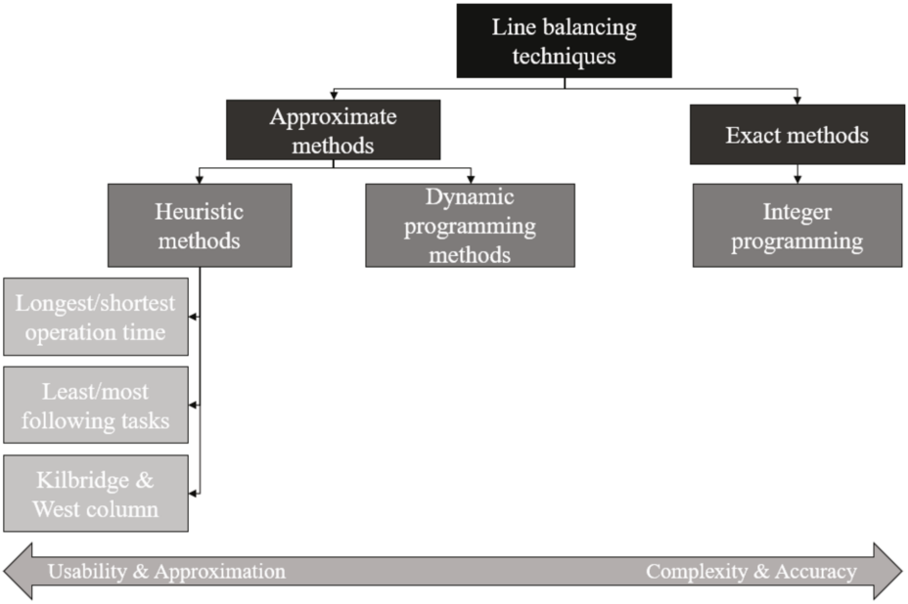


Figure 1. Line balancing techniques classification

6.2. Assembly line investment costs

The results from the literature review concerning assembly line investment costs indicated that there is no well-established classification of assembly line investment costs. Instead, many researchers propose different approaches to predict investments, such as life-cycle costing. Similarly, the level of detail in the investment costs also differ amongst researchers. For instance, Tosatti [43] divide costs into three categories; investment costs, fixed costs, and variable costs. The investment costs are covering installations and the production system configuration. The fixed costs can relate to overhead and space rent costs, while variable costs may cover maintenance and energy, i.e., costs dependent on the demand [43]. Bond & Jenkinson [44], on the other hand, argue that investments are two-folded and comprise of intangible capital, which e.g. includes skills and education, but also fixed capital, which e.g. include machinery. Michalos et al. [45] developed a sophisticated method for developing and evaluating assembly line alternatives, which incorporates the decisions needed to be taken when designing an assembly line. In their research, the investment costs are calculated as the total cost for acquiring and installing resources, e.g., machines and tools needed in the production. Similarly, Padrón et al. [46], presented a methodology for cost-oriented assembly line balancing problems. Based on their previous research and consulting experience, Padrón et al. [46], divided investment costs, specifically for highly manual assembly lines, into two main categories; short-term operating costs and capital investment costs. Short-term operating costs cover employee wages and floor space costs, e.g., rent and complementary utilities. The capital investment costs are divided into two categories: task-related investment costs and workstation capital investment costs.

As an attempt to create a uniform classification of the above-presented literature, covering the investment costs which can be considered vital in new product introductions, Figure 2 was created. The classification of investment costs has been divided into two major parts: intangible costs and fixed costs. The former is further divided into labour costs, including education and salaries, and floor space costs, including construction, engineering, rent, heating and energy. Fixed costs, on the other hand, is divided into task-related investment costs and workstation investment costs. The task-related investment costs include machines, fixtures and tools, i.e., costs related to the completion of a task or operation. Workstation investment costs are related to upgrading and enhancing the workstations. These include purchasing chairs, workbenches, and mats.

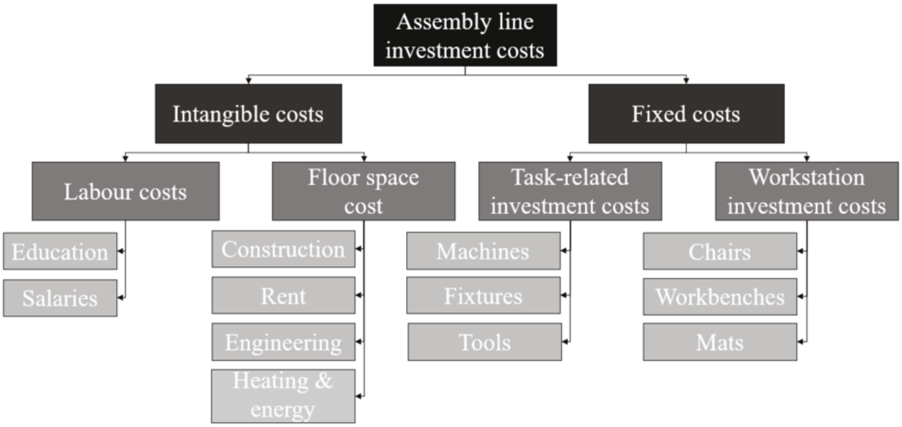


Figure 2. Assembly line investment costs categorization

6.3. Decision-support during new product introductions

The results from the literature studies and case study provided valuable inspiration for developing the proposed decision-supporting tool. The general layout and single-model line balancing function were both based on the model created by Weiss [33]. The model by Weiss [33] was expanded to handle MMALBP Type II, whilst also including the heuristic methods described in the previous chapter. The applied investment cost terminology was based on literature findings complemented by the case study findings. Furthermore, the input data assumptions were carefully considered in close collaboration with the case company. As a result, it was possible to include a suitable level of complexity while still achieving industrial usability. The decision-supporting tool is based on the assumption that two (or more) products are theoretically possible to produce in the same line, without any noteworthy setup times or other restrictions. However, the decision maker might not know before using the tool if the products are compatible from a line balancing perspective since the cycle times may vary for each task depending on the product. The developed decision-supporting tool, as illustrated in Figure 3, aids decision-makers in deciding whether it is more economically beneficial to produce the products in an already existing line, or to invest in a new assembly line and produce the products separately.

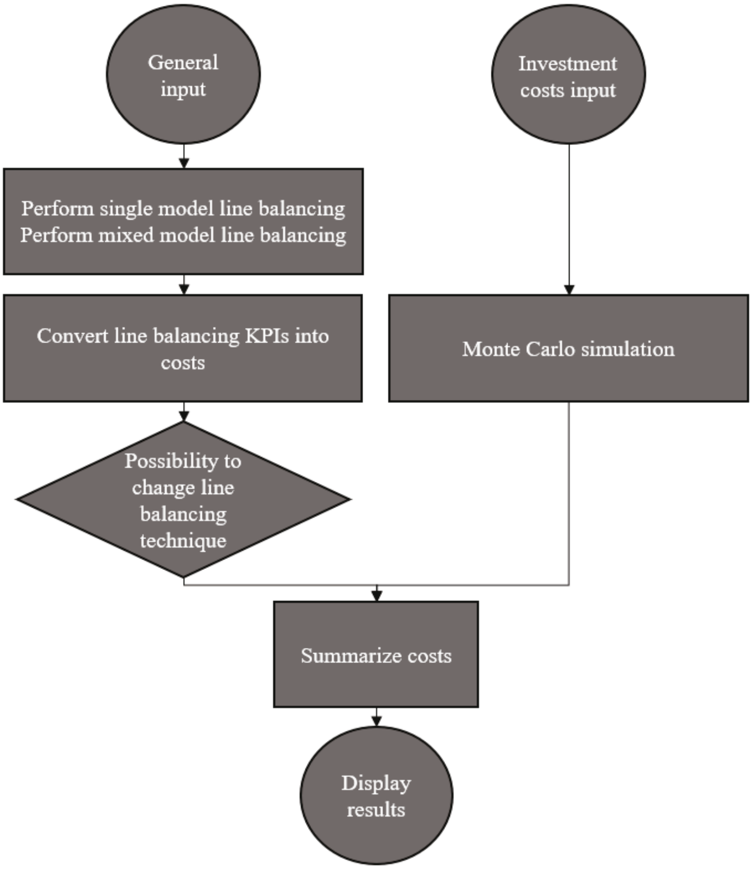


Figure 3. Decision-supporting tool structure and outline

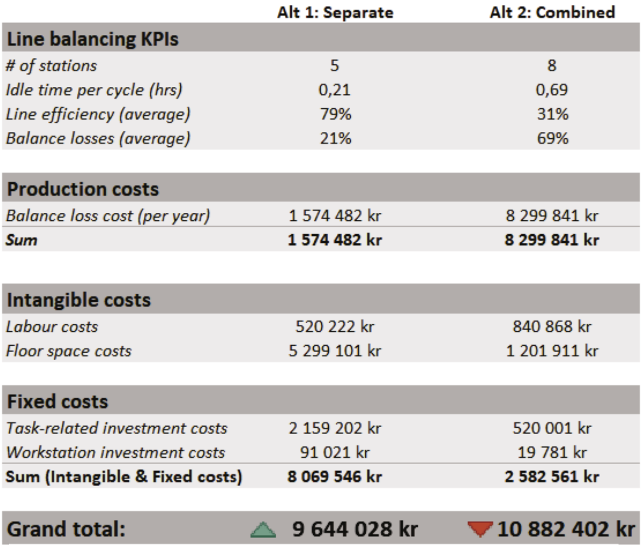
The decision-supporting tool consists of several steps which are required for the user to follow in order for the tool to function. In the first step in the decision-supporting tool the user inserts the required inputs, including task information, general input and estimated assembly line investment costs. The task information includes task names, task times, predecessor tasks and number of following tasks. The general input includes demand per year, total production time available per operator, Overall Equipment Effectiveness (OEE) target and total number of working shifts. The assembly line investment costs include both estimated investment costs and standard deviations. The investment costs are, for instance, associated with equipment, tools, and installation, but also intangible costs related to area, energy consumption and employee salaries. Once the user has inserted the necessary inputs, the decision-supporting tool automatically conducts both mixed-model assembly line balancing and single-model assembly line balancing for all products. The latter is achieved by using four different heuristic methods: *Longest Operation Time, Most Following Tasks, Shortest Operation Time* and *Least Following Tasks*. The user is then able to select either the most line-efficient option as suggested by the decision-supporting tool, or another method if recognized as being a better fit for the company. The tool is using the heuristic method *Longest Operation Time* in the mixed-model line balancing, however, the cycle time can be calculated in different ways. This decision-supporting tool is conducting line balancing based on two approaches: *Max task time* and *Weighted average task time*.

For the investment calculation, the tool is simultaneously running 500 simulations of the inserted assembly line investment costs and standard deviation, and calculates the average of these runs. The simulations were structured according to the Monte Carlo method, which has found to be a usable method when desiring to identify key insights regarding the relationship between inputs and outcomes and thus enable better decision making when uncertainty is present [47,48]. In the developed decision-supporting tool, the Monte Carlo method is used to minimize the uncertainty of estimating investment costs at an early stage of the product development. Once the line balancing and investment costs simulations have been completed, the tool converts the balancing loss to a cost by using the following equation:

$$Balancing\ loss\ cost\ = No.of\ stations\ \times Idle\ time \times Available\ production\ time\ per\ operator\ \times No.of\ shifts\ \times Operator\ cost \tag{1}$$

Thereafter, the tool calculates the total cost by summarizing the balancing loss cost and the sum of intangible and fixed investment costs. The tool then suggests the user to choose the alternative with the lowest total cost. Figure 4 shows the tool's display of final result. However, due to confidentiality, the numbers in the figure are fictional.

Additionally, the decision-supporting tool proposed in this paper considers the monetary value in two parts to guide investments associated with the introduction of new products into production lines. The first part involves the strategic aspects related to the investment in assets like machinery, tools, buildings, and area utilization. These are fixed investments and expected to satisfy the production needs for a long time [49]. The second part involves the operational aspects concerning the organizing the work such as number of shifts, idle time, throughput and work layout. However, in different scenarios, one of the aspects may overweight the other based on assumptions such as product variety, production required capacity and available workforce. Consequently, the suggested decision-supporting tool can manage these aspects simultaneously to simulate different scenarios and examine the production and operational setup changes.



	Alt 1: Separate	Alt 2: Combined
Line balancing KPIs		
# of stations	5	8
Idle time per cycle (hrs)	0,21	0,69
Line efficiency (average)	79%	31%
Balance losses (average)	21%	69%
Production costs		
Balance loss cost (per year)	1 574 482 kr	8 299 841 kr
Sum	**1 574 482 kr**	**8 299 841 kr**
Intangible costs		
Labour costs	520 222 kr	840 868 kr
Floor space costs	5 299 101 kr	1 201 911 kr
Fixed costs		
Task-related investment costs	2 159 202 kr	520 001 kr
Workstation investment costs	91 021 kr	19 781 kr
Sum (Intangible & Fixed costs)	**8 069 546 kr**	**2 582 561 kr**
Grand total:	▲ **9 644 028 kr**	▼ **10 882 402 kr**

Figure 4. The decision-supporting tool’s display of final results

7. Conclusions

This paper introduces a decision-supporting tool that focuses on investment decisions and mixed-model line balancing to address whether to produce a new product variant in an already existing assembly line or invest in a new assembly line. It has been developed in an industrial case study setting and based on the findings from reviewing the literature on assembly line investment costs and line balancing techniques. By using the proposed decision-supporting tool, companies can be able to define where and how to introduce new products and support the selection of appropriate line balancing technique for both mixed-model assembly lines and single-model assembly lines. As a result of the theoretical findings and case study findings this paper presents the decision-supporting tool’s structure and outline.

The theoretical findings reveled a gap concerning defining which investments costs can be considered vital when it comes to introducing new products, resulting in a classification presented herein. Furthermore, the theoretical landscape of line balancing techniques has been investigated, resulting in a classification that considers the usability and complexity levels of line balancing techniques in industrial contexts. This classification was identified as existing within the current literature, concealed inside larger categories that consider wider ranges of solving teachniques and grouping constraints, in need of being clarified to be realized in the decision-supporting tool developed in this research. The case study enabled developing a tool to support companies in achieving better investment decisions during the early stages of new product development, which most likley will become an even more frequent activity in industrial companies. Moreover, the industrial setting has enabled testing and developing the tool in close relation to the real world problem. The final decision-supporting tool was tested through a focus group wherein real data was inserted into the model and a discussion regarding the output was held. The feedback gained during the focus group involved confirming a suitable level of complexity and relevant input parameters. Thus the focus group was found to enhance the decision supporting tool's industrial usability.

Additionally, further development of the decision-supporting tool might include testing the possibility to add certain production order sequencing restraints, in order to provide a more accurate result. However, as this is highly dependent on more accurate input data, it was not possible to include within the time limitations of this study. Likewise could future research focus on including a continuum of problems and solutions, whereas not solely two alternatives are taken into consideration. Enhancing the decision-supporting tool's accuracy by adding further line balancing techniques might also be beneficial. Lastly, further development of the tool might be to include more sophisticated line balancing KPIs such as flexibility of staff, process planning, market requirements and planned order execution time to achieve higher levels of usability.

References

[1] Ulrich KT, Eppinger SD. Product Development and Design. 6th ed. McGraw-Hill; 2016. 432 p.
[2] Baybars I. Survey of exact algorithms for the simple assembly line balancing problem. Management Science. 1986 Aug;32(8):909–32.
[3] Hoffmann TR. Assembly line balancing with a precedence matrix. Management Science. 1963;9(4):551–62.
[4] Salveson ME. The assembly line balancing problem. Journal of Industrial Engineering. 1955;6(3):18–25.
[5] Helgeson W, Birnie D. Assembly line balancing using the ranked positional weight technique. Journal of Industrial Engineering. 1961;12(6):384–98.
[6] Kim YK, Kim YJ, Kim Y. Genetic algorithms for assembly line balancing with various objectives. Computers and Industrial Engineering. 1996;30(3):397–409.
[7] Nallusamy S. Productivity enhancement in a small scale manufacturing unit through proposed line balancing and cellular layout. International Journal of Performability Engineering. 2016;12:523–34.
[8] Bukchin J, Dar-El EM, Rubinovitz J. Mixed model assembly line design in a make-to-order environment. Computers and Industrial Engineering. 2002;41(4):405–21.
[9] Cevikcan E, Durmusoglu MB, Unal ME. A team-oriented design methodology for mixed model assembly systems. Computers and Industrial Engineering. 2009;56(2):576–99.
[10] Olhager J. Produktionsekonomi. 2nd ed. Lund: Studentlitteratur AB; 2013. 495 p.
[11] Şeker Ş, Özgürler M, Tanyaş M. A weighted multiobjective optimization method for mixed-model assembly line problem. Journal of Applied Mathematics. 2013;2013:1–10.
[12] Wouters M, Anderson JC, Narus JA, Wynstra F. Improving sourcing decisions in NPD projects: Monetary quantification of points of difference. Journal of Operations Management. 2009;27:64–77.
[13] Karsak EE, Tolga E. Fuzzy multi-criteria decision-making procedure for evaluating advanced manufacturing system investments. International Journal of Production Economics. 2001;69:49–64.
[14] Alghazi A, Kurz ME. Mixed model line balancing with parallel stations, zoning constraints, and ergonomics. Constraints. 2018;23(1):123–53.
[15] Fortuny-Santos J, Ruiz-de-Arbulo-López P, Cuatrecasas-Arbós L, Fortuny-Profitós J. Balancing workload and workforce capacity in lean management: application to multi-model assembly lines. Applied Sciences. 2020;10(24):1–21.
[16] Güden H, Meral S. An adaptive simulated annealing algorithm-based approach for assembly line balancing and a real-life case study. International Journal of Advanced Manufacturing Technology. 2016;84(5–8):1539–59.
[17] Akpinar S, Elmi A, Bektaş T. Combinatorial benders cuts for assembly line balancing problems with setups. European Journal of Operational Research. 2017;259(2):527–37.
[18] Mirzapour Al-E-Hashem SMJ, Aryanezhad MB, Malekly H, Sadjadi SJ. Mixed model assembly line balancing problem under uncertainty. 2009 International Conference on Computers and Industrial Engineering, CIE 2009. 2009;(July):233–8.
[19] Ghosh S, Gagnon RJ. A comprehensive literature review and analysis of the design, balancing and scheduling of assembly systems. International Journal of Production Research. 1989;27(4):637–70.
[20] Erel E, Sarin SC. A survey of the assembly line balancing procedures. Production Planning and Control. 1998;9(5):414–34.

[21] Kilbridge M, Wester L. The balance delay problem. Management Science. 1961;8(1):69–84.

[22] Battaïa O, Dolgui A. A taxonomy of line balancing problems and their solutionapproaches. International Journal of Production Economics. 2013;142(2):259–77.

[23] Hamzas MFMA, Bareduan SA, Zakaria MZ. A review on multi-objective optimization using evolutionary algorithms for two-sided assembly line balancing problems. ARPN Journal of Engineering and Applied Sciences. 2016;11(18):10882–7.

[24] Sivasankaran P, Shahabudeen P. Literature review of assembly line balancing problems. International Journal of Advanced Manufacturing Technology. 2014;73(9–12):1665–94.

[25] Groover M. Automation, production systems, and computer-integrated manufacturing. 4th ed. Harlow: Pearson Education Limited; 2016. 816 p.

[26] Watanabe T, Hashimoto Y, Nishikawa I, Tokumaru H. Line balancing using a genetic evolution model. Control Engineering Practice. 1995;3(1):69–76.

[27] Erel E, Gökçen H. Shortest-route formulation of mixed-model assembly line balancing problem. European Journal of Operational Research. 1999;116(1):194–204.

[28] Asghar E, Zaman UK, Baqai AA, Homri L. Optimum machine capabilities for reconfigurable manufacturing systems. International Journal of Advanced Manufacturing Technology. 2018;95(9–12):4397–417.

[29] Becker C, Scholl A. A survey on problems and methods in generalized assembly line balancing. European Journal of Operational Research. 2006;168(3):694–715.

[30] Rabbani M, Montazeri M, Farrokhi-Asl H, Rafiei H. A multi-objective genetic algorithm for a mixed-model assembly U-line balancing type-I problem considering human-related issues, training, and learning. Journal of Industrial Engineering International. 2016;12(4):485–97.

[31] Ragsdale CT, Brown EC. On modeling line balancing problems in spreadsheets. INFORMS Transactions on Education. 2004;4(2):45–8.

[32] Wellington J, Lewis SA. Interactive excel-based procedure for line balancing. INFORMS Transactions on Education. 2018;19(1):23–35.

[33] Weiss HJ. Teaching note - implementing line balancing heuristics in spreadsheets. INFORMS Transactions on Education. 2013;13(2):114–25.

[34] Booth A, Sutton A, Papaioannou D. Systematic approaches to a successful literature review. 2nd ed. Los Angeles: Sage Publishing Ltd; 2016. 336 p.

[35] Yin R. Case study research and applications. 6th ed. Los Angeles: SAGE Publications; 2018. 352 p.

[36] Coffey A. Analysing documents. In: SAGE handbook of qualitative data analysis. p. 367–380.

[37] Barriball KL, While A. Collecting data using a semi-structured interview: a discussion paper. Journal of Advanced Nursing-Institutional Subscription. 19(2):328–335.

[38] Krueger RA, Casey MA. Focus groups: a practical guide for applied research. 4th ed. Thousand Oaks: SAGE Publications Inc.; 2009. 280 p.

[39] Dissanayake CK, Farris JA. Assembly lines of the future: a literature review of research articles from 2000-2014. In: Long S, Ng E-H, Downing C, editors. Proceedings of the American Society for Engineering Management 2014 International Annual Conference. 2014. p. 1–10.

[40] Cortés P, Onieva L, Guadix J. Optimising and simulating the assembly line balancing problem in a motorcycle manufacturing company: a case study. International Journal of Production Research. 2010;48(12):3637–56.

[41] Bhattacharjee TK, Sahu S. A critique of some current assembly line balancing techniques. International Journal of Operations & Production Management. 1987;7(6):32–43.

[42] Rekiek B. State of art of optimization methods for assembly line design. Annual Reviews in control. 2002;26(2):163–174.

[43] Tosatti LM. Life cycle cost calculation for investment decision in manufacturing. Proceedings of the 13th CIRP International Conference on Life Cycle Engineering. 2006;(June):723–8.

[44] Bond S, Jenkinson T. The assessment: investment performance and policy. Oxford Review of Economic Policy. 1996;12(2):1–29.

[45] Michalos G, Makris S, Mourtzis D. An intelligent search algorithm-based method to derive assembly line design alternatives. International Journal of Computer Integrated Manufacturing. 2012;25(3):211–29.

[46] Padrón M, de los A. Irizarry M, Resto P, Mejía H. A methodology for cost-oriented assembly line balancing problems. Journal of Manufacturing Technology Management. 2009;20(8):1147–65.

[47] Kelliher C, Mahoney L. Using Monte Carlo simulation to improve long-term investment decisions. The Appraisal Journal. 2000;68(1):44–56.

[48] Khalfi L, Ourbih-Tari M. Stochastic risk analysis in Monte Carlo simulation: a case study. Communications in Statistics: Simulation and Computation. 2020;49(11):3041–53.

[49] Bellgran M, Säfsten K. Production development: design and operation of production systems. 1st ed. London: Springer-Verlag; 2010. 340 p.