Int. J. Res. Ind. Eng. Vol. 10, No. 1 (2021) 56–66
DOI: 10.22105/riej.2021.269298.1184

International Journal of Research in Industrial Engineering

www.riejournal.com

Research Paper

Presentation and Implementation Multi-Objective Mathematical Models to Balance the Assembly Line

E.Shadkam*, F. Ghavidel

[1] Department of Industrial Engineering, Faculty of Engineering, Khayyam University, Mashhad, Iran.
*e.shadkam@khayyam.ac.ir

A B S T R A C T

The use of assembly lines is one of the important approaches in the mass production of industrial products. Unbalanced assembly lines increase cycle time and idle times, resulting in reduced production rates, line efficiency, and increased system costs, which ultimately lead to low productivity. A hybrid model assembly line is a type of production line on which various models of products are assembled. These assembly lines are increasingly accepted in the industry in order to overcome the diversity of customer demand. The hybrid model assembly line is able to respond quickly to sudden changes in demand for different models of a product without high inventory maintenance. The purpose of this paper is to present a linear integer mathematical model of multi-objective for balancing assembly lines, in order to solve which the global criteria method has been used. The three objective functions considered in this model are: (1) minimizing the cycle time, (2) minimizing the idle time of each station, and (3) increasing the productivity of the assembly line. In order to study the model, Iran-Shargh Neishabour Company has been considered as a case study. The results show an improvement in the values of the objectives after the implementation of the proposed model for this problem.

Keywords: Assembly line balancing, Multi-product assembly line, Multi-objective optimization, Linear programming, Cycle time.

Article history: *Received: 19 November 2020 Reviewed: 28 December 2020 Revised: 22 February 2021 Accepted:25 February 2021*

Shadkam, E., & Ghavidel, F. (2021). Presentation and implementation multi-objective mathematical models to balance the assembly line. *International journal of research in industrial engineering, 10*(1), 56-66.

1. Introduction

An assembly line is a line in which semi-finished products travel through a sequence of stations that are connected to each other by material handling systems, and during each station, an operation is performed to complete the product [1]. An assembly line consists of a series of stations that assemble a particular product or family of products. Component processing is done according to a set of activities [2]. This processing is performed at each station according to a fixed time called cycle time. If the total time of activities performed in each workstation is not balanced with other stations in the line, the unemployment rate will

increase in some stations and bottlenecks will occur in some stations [3]. To eliminate these shortcomings, it is necessary to balance these stations according to the cycle time. The problem of assigning activities to stations as one or more goals are optimized according to a certain number of constraints is called the assembly line balance problem [4]. The main purpose of the assembly line problem is to allocate the activities of an assembly line to workstations, so that the number of workstations and the idle time of each station are at a minimum, provide the prerequisite relationships for assembly line activities, and the assembly line can meet the required output based on the decisions of the organization's senior managers [5]. Problems due to assembly line imbalance include: Increased production costs, unfair allocation of labor, unemployment of operators, low efficiency and production, and bottlenecks in the system [6]. The following are some of the objectives of the assembly line balance: minimize the number of stations, minimize the cost of all tools, minimize cycle time, priority and latency relations should be observed after assigning activities to stations, the total time of activities at each station does not exceed the cycle time, improve productivity, reduce process redesign time, increase production volume, optimize the use of resources to reduce production costs [7].

2. Literature Review

The first scientific paper on the problem of assembly line balance was published in 1956 by Jackson [8]. Since then, due to the growth of industries and also the importance of the problem of balance of assembly lines, various papers and research have been published in this field which each have different objectives, conditions and constraints. There are different categories for the balance of assembly lines. For example, based on the number of different product models, this problem can be divided into single, hybrid and multiple models. In single models, a homogeneous product is generally produced for a long period of time in high circulation. In hybrid models, different models of one type of product are produced simultaneously in a single assembly line [9], in this type of assembly line, the differences between production models are small and are usually based on customers' custom options, and in multiple models, and various products are assembled in batches of different sizes, in addition to assembly lines. They are also divided into one-way and two-way assembly lines. In one-way assembly lines only one side of production (right or left) and in two-way assembly lines, two side of the production line can be used and operations on a product can be performed simultaneously. Design of one-way or two-way assembly lines depends on the technical, structural and operational characteristics required to assemble the product; For example, for large products such as trucks and wagons, two-way assembly lines are more suitable than one-way lines; Because the use of these lines reduces the length of the line, reduces delivery time and also reduces the cost of purchasing equipment, tools and transmission equipment. In two-way assembly lines, two stations facing each other are called pair stations and two operators, each located on one side of the station, are equipped. They perform different operations on a product in parallel, without the operation of one interfering with the operation of the other [10]. Liu and Liu has been considered in situations where one or more of its parameters have uncertainties in the problem of assembly line balance. These uncertainty parameters can be operating time, cycle time, equipment cost, etc. [11]. They also

presented an interactive fuzzy planning method for the equilibrium problem of direct and multi-objective horseshoe production line [12]. Types of simple assembly balance problems based on the function, the purpose of the assembly line balance problem is to assign activities to workstations, taking into account existing constraints and assumptions, and to strive to achieve one or more optimization criteria. According to the optimization criterion, simple assembly line balance problems are divided into four types:

- According to the given cycle time, the object is to minimize the number of workstations available. The problem with this objective function is called the type one Assembly Line Balance Problem "SALBP-1".
- Given the number of fixed stations, the object is to minimize the production cycle time. The problem with this objective function is called the second type Assembly Line Problem "SALBP-2".
- If it is possible to change both the cycle time and the number of stations at the same time, then the performance of the benchmark is the quality of the balance.
- If both the cycle time and the number of stations are constant, the object is to find a possible solution to the problem. The problem with this criterion is called the Possible Balance Problem "SALBP-F" [13].

The following is a review of related papers and the background of previous research in this field in ***Table 1.***

Table 1. Categorize articles and how to solve them.

Author (year)	Ref No.	Description	Approach	Method
Baybars (1986)	[14]	Detailed inspection of assembly line balance problems.	Exact	Mathematical programming
Xiaofeng et al. (2010)	[15]	Reduce the length of the two-way assembly line.	Exact	Branch and bound
Özbakir & Tapkan (2011)	[16]	Investigation of two-way assembly line problems.	Meta-heuristic	Artificial bee colony algorithm
Chen et al. (2002)	[17]	Investigate multi-objective assembly line problems.	Meta-heuristic	Genetic algorithm
Mansouri (2005)	[18]	Multi-objective combination hybrid assembly line.	Meta-heuristic	Genetic algorithm
Nourmohammadi & Zandieh (2011)	[19]	Multi-objective assembly line balance.	Innovative	TOPSIS
Delice (2018)	[20]	Two-way assembly line balance.	Meta-heuristic	Ant colony
Alavidoost et al. (2016)	[12]	Straight line assembly and u-shaped.	Stochastic	Fuzzy mathematical programming
Ogan & Azizoglu (2015)	[21]	U-shaped assembly line balance considering equipment.	Exact	Branch and bound
Graves & Whitney (1979)	[22]	Balancing the assembly line and selecting equipment.	Exact	Mathematical planning
Graves & Lamar (1983)	[23]	Investigation of design line problems and assembly line balance.	Exact	Integer planning
Ahmed et al. (2020)	[24]	Application of Line Balancing Heuristics for Achieving an Effective Layout.	Exact	Mathematical programming

Author (year)	Ref No.	Description	Approach	Method
Zhang et al. (2020)	[25]	Multi-manned assembly line balancing.	Meta-heuristic	MILP model and memetic ant colony
Zhang et al. (2021)	[26]	Balancing and sequencing problem of mixed-model U-shaped robotic assembly line.	Meta-heuristic	Mathematical model and dragonfly algorithm
Li et al. (2021)	[27]	Type II assembly line balancing problem.	Exact	Enhanced branch-bound-remember and iterative beam search algorithms
Meng et al. (2021)	[28]	Multi-objective model of assembly line balancing considering preventive maintenance scenarios	Meta-heuristic	Heuristic and grey wolf optimizer algorithm

According to the reviewed papers in the field of assembly line modeling, so far the simultaneous efficiency of the mathematical model has not been studied. While product line efficiency is a very important issue. In the proposed model of this paper, the third objective function is the efficiency objective. In fact, in addition to balancing and reducing line idle time, the efficiency of assembly line will be maximized simultaneously, which can make the mathematical model of the paper very practical.

In the following, first, the proposed mathematical models of the paper will be introduced. After describing the model, using the global criteria method, the proposed multi-objective mathematical model is implemented on the Iran-Shargh Neishabour Company problem, and finally, in the conclusion section, the data obtained from the model and the final results are analyzed and reviewed.

3. The Proposed Three-Objective Mathematical Model of Assembly Line Balancing

In this section, a proposed mathematical model is presented to balance the assembly line in a multi-objective mode. In this model, the integrated balance of the assembly line for all production models in order to achieve 1) minimum cycle times, 2) minimize unemployment time, and 3) increase the efficiency of the assembly line. Due to the existence of such conflicting goals, the multi-objective optimization method has been used to achieve the highest level of satisfaction between the above goals [29]-[32]. The basic assumptions in the model are as follows: mass production, activity time is fixed and static, unlimited market demand is assumed, equipment, and tools are available continuously and there are no restrictions on access to the required raw materials and parts. The proposed mathematical model of the paper is presented through relationships 1 to 8. ***Table 2*** shows the parameters and symbols used in the proposed model.

Table 2. Parameters and symbols used in the proposed model.

Description	Symbol
Number of activities	m
Number of stations	n
Standard time of activity i	t_i
Time of station i	S_j
Production work cycle	c

$$\min Z_1 = C\,. \tag{1}$$

$$\min Z_2 = \sum_{j=1}^{n}\left(C - S_j\right). \tag{2}$$

$$\min Z_3 = \frac{\sum_{j=1}^{n} S_j}{n.\,C}. \tag{3}$$

s.t.

$$\sum_{j=1}^{n} X_{ij} = 1\,; \qquad \forall i \in I. \tag{4}$$

$$\sum_{k=1}^{n}\left(KX_{hk} - KX_{ik}\right) \geq 0\ ; \qquad \forall i \in I, h \in P_i. \tag{5}$$

$$\sum_{j=1}^{n} t_i\, X_{ij} \leq C\ ; \qquad \forall i \in I. \tag{6}$$

$$\sum_{i=1}^{m} t_i\, X_{ij} = S_j\ ; \qquad \forall j \in J. \tag{7}$$

$$X_{ij} \in \{0,1\};\ \ \forall i \in I, \forall j \in J \quad ; \quad C \geq 0 \quad ; \quad S_j \leq C. \tag{8}$$

Eq. (1) indicates the optimality of the cycle time and the object is to minimize cycle time. ***Eq. (2)*** guarantees the second objective, which is to minimize the idle time of each station. ***Eq. (3)*** determines the third objective, which is to increase the efficiency of the assembly line. According to ***Eq. (4)***, each work element can only be assigned to one workstation and it is not possible to division of labor between two stations or more. ***Eq. (5)*** is the order of precedence in the allocation of elements, i.e. an element can be assigned to a station when the prerequisite elements are assigned to one of the previous stations or to the current station. ***Eq. (6)*** does not allow the workload in a station (total time of elements assigned to a station) to exceed the cycle time. ***Eq. (7)*** added to other constraints in order to determine the time of each station by having a set of activity times assigned to each workstation that is used to calculate the productivity objective.

4. Implementing the Proposed Mathematical Model in Iran-Shargh Neishabour Company

Iran-Shargh Neishabour Company, located 2 km from Mashhad Road, which was established in 1977. The factory has been established on a land with an area of 30130 square meters with 7500 square meters of infrastructure. The company produces heaters, oil and gas water heaters. The heater assembly line of this company has 18 working elements and 3 workstations. The assembly line employs 25 workers, who spend about 420 seconds assembling a heater. The division of labor in some stations has caused bottlenecks. According

to the diagram in ***Figure 1*** in the first line at station 6 (control and testing of other connections), second line at station number 1 (cleaning and placing the boiler windshield), in the third line in station number 9 (packing) we are facing an increase in time. Also, according to the obtained statistics, the capacity of one shift is about 500 heaters.

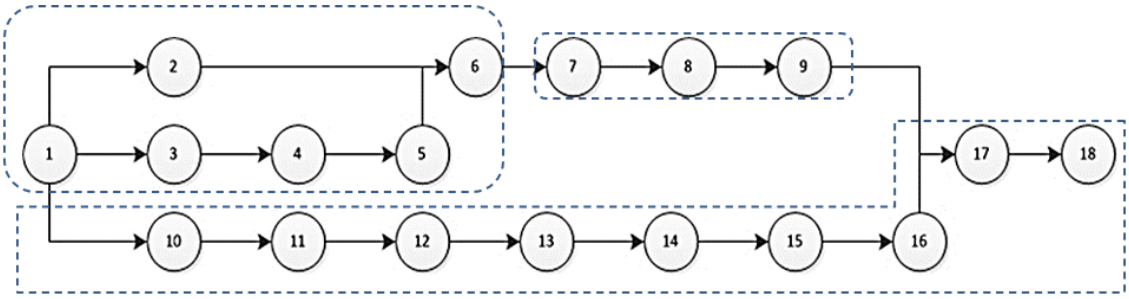

Figure 1. Workstation diagram of the current state of the factory.

In order to implement the proposed model of the paper and determine the exact time of each element, stopwatch timing has been used. The times obtained are shown in ***Table 3.*** Also ***Table 4*** shows information on activities assigned to workstations in the factory and before the implementation of the model.

Table 3. Information on each element in the heater assembly line.

NO.	Task	Prerequisites	time
1	Cleaning and placing the glass in front of the boiler.	-	3
2	Insert and install bronze.	1	18
3	Insertion and installation of thermocouples.	1	21
4	Insert 6 and 8 mm tubes.	3	27
5	Tight work and installation of pipes.	4	17
6	Quality control to ensure the correct installation of connections.	5 & 2	32
7	Clean and place the windshield of the boiler.	6	30
8	Install the connection bar above and below the boiler windshield.	7	20
9	Installation of side connection strips on the windshield of the boiler.	8	16
10	Placing the boiler in the side walls.	1	11
11	Install the side frame.	10	13
12	Insert the front frame.	11	22
13	Place the heater series on the frame.	12	10
14	Install the heater series to the front frame.	13	12
15	Insert and install the back cover of the heater.	14	22
16	Put the board under the heater and install the windshield.	15	25
17	Final control.	16 & 9	17
18	Packing.	17	103

Due to the fact that the proposed model is a multi-objective model, there is a need for multi-objective problem solving approaches. In this paper, the global criteria method has been used due to its ease and applicability. In this method, considering the degree of optimism for the decision maker, all objective functions of the problem are integrated and the problem becomes a single objective. Then the appropriate approach can be used to solve this one-objective problem [33]. ***Eq. (9)*** represents the objective function of the problem. In this relation, α represents the optimist rate of the decision-maker, the p represents the type of distance (which can include the values of 1, 2 and ∞). f_i^- and f_i^* also represent the worst and best values of the

problem function. The desired parameters for implementing the global criteria method are shown in ***Table 5***. In solving the model with the method of global criteria, we have considered the distance as Euclidean and the optimism rate is 50%.

Table 4. Workstations current status.

Station number	Assigned activity code	Time of station
1	1,2,3,4,5,6	118
2	7,8,9	66
3	10,11,12,13,14,15,16,17,18	236
Total	-	420

$$\min z = \alpha\left[\left(\frac{f_1^* - f_1}{f_1^*} + \frac{f_2^* - f_2}{f_2^*} - \frac{f_3^* - f_3}{f_3^*}\right)^p\right]^{\frac{1}{p}} - (1-\alpha)\left[\left(\frac{f_1 - f_1^-}{f_1^* - f_1^-} + \frac{f_2 - f_2^-}{f_2^* - f_2^-} - \frac{f_3 - f_3^-}{f_3^* - f_3^-}\right)^p\right]^{\frac{1}{p}}. \quad \textbf{(9)}$$

Table 5. Three-objective model information for global criteria method.

	Best value of objective function (f^*)	Worst value of objective function (f^-)
The first objective function	142	1000,000,000
The second objective function	6	1000,000,000
The third objective function	-0. 98	-0.3
(Assuming 50% optimism)	α=0.5	P=2

After implementing the proposed model, the results are shown in ***Table 6***. Therefore, according to these results, new workstations are created according to ***Figure 2***.

Table 6. Suggested workstations according to the proposed model of the article.

Station number	Assigned activity code	Time of station
1	1,2,3,4,5,10,11,12,13	142
2	6,7,8,14,15,16	141
3	9,17,18	137
Total	-	420

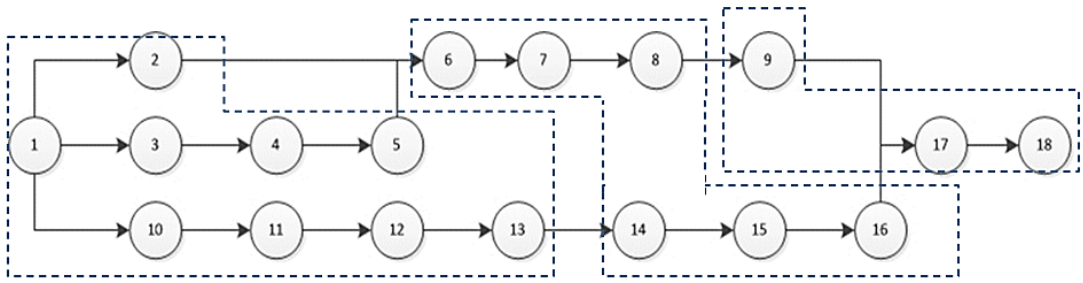

Figure 2. Workstation diagram of the proposed condition of the factory.

In order to validate the proposed model of the paper, workstations before and after the implementation of the multi-objective model are compared and the results are shown in ***Table 7.***

Table 7. Assembly line utility indicators before and after the implementation of the proposed article model.

Assembly line state	working time of station 1	working time of station 2	working time of station 3	Cycle time (f_1)	Stations idle (f_2) time	Line efficiency (f_3)
Proposed state	142	141	137	142	6	0.9
Current state	118	66	236	236	288	0.59

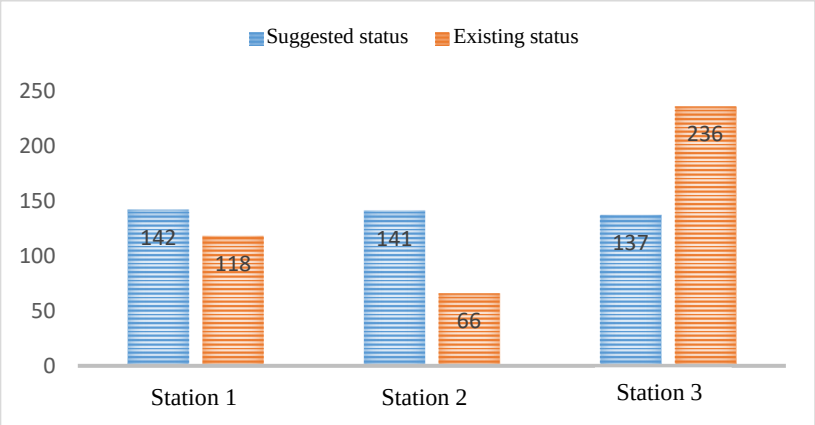

Figure 3. The degree of uniformity and smoothness of the line in the position before and after the implementation of the proposed model.

As shown in ***Figure 3***, in the proposed state, uniformity is observed at the times of each workstation while in the current situation there is a lot of non-uniformity. Also, productivity in the suggested mode has increased dramatically compared to the current situation, and unemployment times have been significantly reduced.

The degree of uniformity is a very important issue in the balance of the assembly line. If the assembly line is not smooth, some stations will be unemployed and others will be bottleneck, which is a problem in the current state of the assembly line and has led to low line efficiency. While in the proposed state, the assembly line has been completely smoothed and the time of each station is close to the cycle time. Line productivity has also increased significantly due to reduced line unemployment. And as can be seen, line unemployment has fallen sharply, which could lead to reduced line costs and increased line output.

5. Conclusion

In this paper, the problem of assembly line balance was analyzed by multi-objective method. A three-objective mathematical model was proposed to solve this problem, which includes the objectives of line unemployment, cycle time, and productivity. In order to validate the proposed mathematical model, a case study was used in Iran-Shargh factory. The proposed model was implemented to balance the heater production line of this factory. The results of the model implementation indicate the improvement of the allocation of activities in the study

line and the achievement of the minimum amount of cycle times for the heater assembly line. Line productivity also increased significantly.

For future research, the mathematical model can be considered for several products and out of the single model mode. The other objectives mentioned in the review of the problem literature can also be considered in the mathematical model.

Conflict of Interest

The author has no conflicts of interest to declare that are relevant to the content of this article.

Funding Source Declaration

The author did not receive support from any organization for the submitted work.

Author Agreement

All authors have seen and approved the final version of the manuscript being submitted.

References

[1] Fisel, J., Exner, Y., Stricker, N., & Lanza, G. (2019). Changeability and flexibility of assembly line balancing as a multi-objective optimization problem. *Journal of manufacturing systems, 53*, 150-158. https://doi.org/10.1016/j.jmsy.2019.09.012

[2] Zhong, Y., Deng, Z., & Xu, K. (2019). An effective artificial fish swarm optimization algorithm for two-sided assembly line balancing problems. *Computers and industrial engineering, 138*, 106121. https://doi.org/10.1016/j.cie.2019.106121

[3] Sun, B. Q., Wang, L., & Peng, Z. P. (2020). Bound-guided hybrid estimation of distribution algorithm for energy-efficient robotic assembly line balancing. *Computers and Industrial engineering, 146*, 106604. https://doi.org/10.1016/j.cie.2020.106604

[4] Liu, R., Liu, M., Chu, F., Zheng, F., & Chu, C. (2021). Eco-friendly multi-skilled worker assignment and assembly line balancing problem. *Computers and industrial engineering, 151*, 106944. https://doi.org/10.1016/j.cie.2020.106944

[5] Çil, Z. A., Li, Z., Mete, S., & Özceylan, E. (2020). Mathematical model and bee algorithms for mixed-model assembly line balancing problem with physical human–robot collaboration. *Applied soft computing, 93*, 106394. https://doi.org/10.1016/j.asoc.2020.106394

[6] Çil, Z. A., & Kizilay, D. (2020). Constraint programming model for multi-manned assembly line balancing problem. *Computers and operations research, 124*, 105069. https://doi.org/10.1016/j.cor.2020.105069

[7] Eghtesadifard, M., Khalifeh, M., & Khorram, M. (2020). A systematic review of research themes and hot topics in assembly line balancing through the web of science within 1990–2017. *Computers and industrial engineering, 139*, 106182. https://doi.org/10.1016/j.cie.2019.106182

[8] Jackson, J. R. (1956). A computing procedure for a line balancing problem. *Management science, 2*(3), 261-271. https://doi.org/10.1287/mnsc.2.3.261

[9] Ramezanian, R., & Ezzatpanah, A. (2015). Modeling and solving multi-objective mixed-model assembly line balancing and worker assignment problem. *Computers and industrial engineering, 87*, 74-80. https://doi.org/10.1016/j.cie.2015.04.017

[10] Chutima, P., & Chimklai, P. (2012). Multi-objective two-sided mixed-model assembly line balancing using particle swarm optimisation with negative knowledge. *Computers and industrial engineering, 62*(1), 39-55. https://doi.org/10.1016/j.cie.2011.08.015

[11] Liu, B., & Liu, B. (2009). *Theory and practice of uncertain programming* (Vol. 239). Berlin: Springer.

[12] Alavidoost, M. H., Babazadeh, H., & Sayyari, S. T. (2016). An interactive fuzzy programming approach for bi-objective straight and U-shaped assembly line balancing problem. *Applied soft computing, 40*, 221-235. https://doi.org/10.1016/j.asoc.2015.11.025

[13] Ponnambalam, S. G., Aravindan, P., & Naidu, G. M. (2000). A multi-objective genetic algorithm for solving assembly line balancing problem. *The international journal of advanced manufacturing technology, 16*(5), 341-352. https://doi.org/10.1007/s001700050166

[14] Baybars, I. (1986). A survey of exact algorithms for the simple assembly line balancing problem. *Management science, 32*(8), 909-932. https://doi.org/10.1287/mnsc.32.8.909

[15] Xiaofeng, H., Erfei, W., Jinsong, B., & Ye, J. (2010). A branch-and-bound algorithm to minimize the line length of a two-sided assembly line. *European journal of operational research, 206*(3), 703-707. https://doi.org/10.1016/j.ejor.2010.02.034

[16] Özbakır, L., & Tapkan, P. (2011). Bee colony intelligence in zone constrained two-sided assembly line balancing problem. *Expert systems with applications, 38*(9), 11947-11957. https://doi.org/10.1016/j.eswa.2011.03.089

[17] Chen, R. S., Lu, K. Y., & Yu, S. C. (2002). A hybrid genetic algorithm approach on multi-objective of assembly planning problem. *Engineering applications of artificial intelligence, 15*(5), 447-457. https://doi.org/10.1016/S0952-1976(02)00073-8

[18] Mansouri, S. A. (2005). A multi-objective genetic algorithm for mixed-model sequencing on JIT assembly lines. *European journal of operational research, 167*(3), 696-716. https://doi.org/10.1016/j.ejor.2004.07.016

[19] Nourmohammadi, A., & Zandieh, M. (2011). Assembly line balancing by a new multi-objective differential evolution algorithm based on TOPSIS. *International journal of production research, 49*(10), 2833-2855. https://doi.org/10.1080/00207540903473367

[20] Delice, Y., Aydoğan, E. K., Söylemez, İ., & Özcan, U. (2018). An ant colony optimisation algorithm for balancing two-sided U-type assembly lines with sequence-dependent set-up times. *Sādhanā, 43*(12), 1-15. https://doi.org/10.1007/s12046-018-0969-9

[21] Ogan, D., & Azizoglu, M. (2015). A branch and bound method for the line balancing problem in U-shaped assembly lines with equipment requirements. *Journal of manufacturing systems, 36*, 46-54. https://doi.org/10.1016/j.jmsy.2015.02.007

[22] Graves, S. C., & Whitney, D. E. (1979, December). A mathematical programming procedure for equipment selection and system evaluation in programmable assembly. *1979 18th IEEE conference on decision and control including the symposium on adaptive processes* (pp. 531-536). IEEE. DOI: 10.1109/CDC.1979.270236

[23] Graves, S. C., & Lamar, B. W. (1983). An integer programming procedure for assembly system design problems. *Operations research, 31*(3), 522-545. https://doi.org/10.1287/opre.31.3.522

[24] Ahmed, T., Sakib, N., Hridoy, R. M., & Shams, A. T. (2020). Application of line balancing heuristics for achieving an effective layout: a case study. *International journal of research in industrial engineering, 9*(2), 114-129.

[25] Zhang, Z., Tang, Q., & Chica, M. (2020). Multi-manned assembly line balancing with time and space constraints: A MILP model and memetic ant colony system. *Computers and industrial engineering, 150*, 106862. https://doi.org/10.1016/j.cie.2020.106862

[26] Zhang, B., Xu, L., & Zhang, J. (2021). Balancing and sequencing problem of mixed-model U-shaped robotic assembly line: Mathematical model and dragonfly algorithm based approach. *Applied soft computing, 98*, 106739. https://doi.org/10.1016/j.asoc.2020.106739

[27] Li, Z., Kucukkoc, I., & Tang, Q. (2021). Enhanced branch-bound-remember and iterative beam search algorithms for type II assembly line balancing problem. *Computers and operations research, 131*, 105235. https://doi.org/10.1016/j.cor.2021.105235

[28] Meng, K., Tang, Q., Zhang, Z., & Yu, C. (2021). Solving multi-objective model of assembly line balancing considering preventive maintenance scenarios using heuristic and grey wolf optimizer algorithm. *Engineering applications of artificial intelligence, 100*, 104183. https://doi.org/10.1016/j.engappai.2021.104183

[29] Shafi Salimi, P., & Edalatpanah, S. A. (2020). Supplier selection using fuzzy AHP method and D-Numbers. *Journal of fuzzy extension and applications, 1*(1), 1-14.

[30] Khalili, N., Shahnazari Shahrezaei, P., & Abri, A. G. (2020). A multi-objective optimization approach for a nurse scheduling problem considering the fatigue factor (case study: Labbafinejad Hospital). *Journal of applied research on industrial engineering, 7*(4), 396-423.

[31] Mohammad, P., & Kazemipoor, H. (2020). An integrated multi-objective mathematical model to select suppliers in green supply chains. *International journal of research in industrial engineering, 9*(3), 216-234.

[32] El-Shorbagy, M. A., Mousa, A. A. A., ALoraby, H., & Abo-Kila, T. (2020). Evolutionary algorithm for multi-objective multi-index transportation problem under fuzziness. *Journal of applied research on industrial engineering, 7*(1), 36-56.

[33] Lascelles, B. G., Taylor, P. R., Miller, M. G. R., Dias, M. P., Oppel, S., Torres, L., ... & Small, C. (2016). Applying global criteria to tracking data to define important areas for marine conservation. *Diversity and distributions, 22*(4), 422-431. https://doi.org/10.1111/ddi.12411