Journal of Industrial and Systems Engineering
Vol. 13, Special issue: 16th International Industrial Engineering Conference
Winter (January) 2020, pp. 66- 77

(IIEC 2020)
TEHRAN, IRAN
22-23 January 2020

Assembly line balancing problem with skilled and unskilled workers: The advantages of considering multi-manned workstations

Azadeh Esfandyari[1], Abolreza Roshani[2*]

[1]*Department of computer engineering, Faculty of Engineering, Gilan-e-Gharb Branch, Islamic Azad University, Gilan-e-Gharb, Iran*

[2]*Department of industrial Engineering, Faculty of engineering management, Kermanshah University of Technology, Kermanshah, Iran*

azadeh.esfandyari@gmail.com, a.roshani@kut.ac.ir

Abstract

This paper address a special class of generalized assembly line balancing in which it is assumed that there are two groups of workers: skilled and unskilled ones. The skilled workers are hired permanently while the unskilled ones can be hired temporarily in order to meet the seasonal demands. It is also assumed that more than one worker may be assigned to each workstation. To show the advantages of assigning several workers instead of single workers to each workstation in such a class of problem, a mixed integer programming formulation is presented. This model minimizes the number of temporary workers on the line as the first objective and the number of workstations as the secondary one while cycle time and the number of permanent workers are fixed. The proposed formulation is applied to solve some experimental instances found in the literature. The comparison between the optimal solutions of the proposed model and those of traditional assembly lines with a single-manned workstation indicates that our model has been able to reduce the line length on average of 24.40 per cent while the number of unskilled workers remains optimal.

Keywords: Mathematical programming, assembly line balancing problem, skilled and unskilled workers, multi-manned workstations

1- Introduction

In the current challenging and competitive dynamic business world, it is crucial that the production companies try to be more effective and productive than before. To this end, they must be able to not only meet their customers' demands but also to keep the production costs to a minimum level. However, due to the stochastic nature of demands and the limitations in the availability of workforce, achieving these goals is not always without challenge. Assembly line systems are an example of such production systems that are currently being used to produce a variety of products.

*Corresponding author
ISSN: 1735-8272,

One of the strategies applied in these systems to minimize the cost of manpower and to cope with the fluctuating level of demand is to employ two groups of workers, namely, permanent skilled and temporary unskilled ones. In this strategy, the capacity of the current permanent manpower is used to cover the regular demand, and if there is a change in its level which needs more manpower capacity than the current capacity of the labour force, external unskilled temporary labours are hired. Applying this strategy, the production manager must solve the assembly line balancing problem (ALBP) to reallocate the assembly tasks to workers, whenever the level of manpower is changed, in order to optimize a specific objective, such as minimizing the number of unskilled workers on the line for a given production cycle time.

Salveson (1955) introduce simple ALBP (SALBP) and mathematically formulated it for the first time. This problem is among the most studied version of ALBPs. The basic assumptions of SALBP are the mass-production of one homogeneous product, deterministic processing times, given precedence relationships, serial line layout with single-manned workstations, and the same skilled workers. The objective function is to maximize the line efficiency or equivalently to minimize the total idle time at workstations. In recent years, several researchers have put their efforts to address and solve generalized versions of SALBP by considering additional characteristics such as mixed-model production, workers with different skills, multi-manned assembly lines (MAL) among many others (Becker and Scholl, 2006) and (Battaïa, and Dolgui, 2013).

Corominas, Pastor, and Plans (2008) study ALBP with skilled and unskilled workers (ALBP-SUW) for the first time. They propose a mathematical formulation to rebalance an assembly line which has been designed to produce a motorcycle with different levels of demand in each season of the year. Three main characteristics they consider for the problem are 1) hiring temporary unskilled staff who can carry out the assembly tasks slower than permanent skilled workers, 2) at least one skilled employee must work alongside an unskilled one 3) there is incompatibility among tasks. The objective is to minimize the number of temporary workers required, given a cycle time and the team of workers on staff. Moon, Shin, and Kim (2014) addressing ALBP-SUW develop a mixed-integer program to minimize the sum of total annual workstation costs and annual salaries of workers for predetermined cycle time. Since the problem is NP-hard, they also develop a genetic algorithm (GA) to solve large-sized problems. Kim, Moon, Moon, (2018) address a mixed-model ALBP-SUW and propose a heuristic approach based on the GA algorithm to solve it. All of these researchers consider assembly lines with single-manned workstations. However, in the assembly line of large-scaled products such as tractors, trucks, and autobuses, the workstations are multi-manned in which several workers may carry out the assembly tasks of the same product. The installation of multi-manned workstations has several advantages over single-manned ones; for the majority of cases, it not only reduces the assembly line length but also it decreases the amount of throughput time, the cost of tools and fixtures, the material handling, and setup time. These advantages are adequate to justify the use of the MAL for the assembling of large-size products (Fattahi, Roshani, Roshani, 2011).

Dimitriadis (2006) introduce the MAL balancing problem (MALBP) for the first time and propose a two-level heuristic-based approach to solve it. Cevikcan, Durmusoglu, and Unal (2009) present a mathematical formulation for mix-model MALBP. Since the proposed formulation is too complex, they develop a heuristic algorithm to solve some instances of the problem arisen in a final assembly line of different models of a tractor. Becker and Scholl (2009) address MALBP with a variable parallel workstation. They also develop a branch-and-bound algorithm to solve the problem. Fattahi, Roshani, and Roshani (2011) mathematically formulate MALBP for the first time. They apply their model to solve some small-sized instances of the problem optimally. However, Since MALBP is NP-Hard, they also develop an ant colony optimization approach to solve it. Considering the minimizing the number of workstations as the objective function for given cycle time, Kellegoz and Toklu (2012) propose a branch-and-bound algorithm to solve MALBP. Chang and Chang (2010) address mixed-model MALBP (MMALBP) and present a mathematical formulation to solve it. Roshani et al. (2013) state that it is necessary to solve MALBP considering the line efficiency, the number of workstations, and the smoothness index as the performance criteria. Kellegoz and Toklu (2015) present a mathematical formulation and a genetic algorithm for MALBP to minimize the total number of workers on the line. Roshani and Ghazi Nezami (2017) address MMALBP. They also propose a simulated annealing algorithm (SA) to solve this problem. Roshani and Giglio (2017) address the

MALBP with the objective of minimizing the cycle time as the primary objective, for a given number of workstations. Besides the mathematical formulation, two meta-heuristics based on the SA algorithm are developed to solve the problem indirectly and directly. Sahin and Kellegz (2019) propose a mathematical formulation and a particle swarm optimization algorithm hybridized with a special constructive heuristic for MALBP. More recently, Roshani et al. (2020) address Multi-sided ALBP to minimize the cycle time for a given number of workstations. They propose a mathematical formulation and a hybrid adaptive meta-heuristic approach to solve it.

Based on the authors' knowledge, there is not any published study that addresses MALBP with skilled and unskilled workers (MALBP-SUW). For this reason, in this paper, to show the advantages of allowing multi-manned workstations in assembly lines with skilled and unskilled workers, we propose a mixed-integer linear programming (MILP) formulation for MALBP-SUW. In this regard, in section 2, MALBP-SUW is introduced. In Section 3, the MILP formulation is proposed. In Section 4, the computational experiments are presented. Concluding remarks will follow in Section 5.

2- MALBP-SUW

MALBP-SUW is introduced in this section. In this kind of ALBP, there are two sets of workers: skilled and unskilled ones. The skilled workers are permanent while the unskilled operators may be hired temporarily in order to meet the seasonal demands. Temporary and permanent workers are able to perform all the assembly tasks. However, since the temporary workers are unskilled, they cannot perform the tasks with the same speed of skilled workers. Thus, the actual processing time of a task, if it is performed by a temporary worker, can be expressed as the product of the nominal processing time of the given task and a coefficient ($\beta>1$), which is approximately equal for all the tasks that the temporary workers perform (Corominas, Pastor, and Plans, 2008). In this problem, the unskilled workers cannot be assigned alone to a workstation unless alongside the workstation assigned to the unskilled worker there must be at least one workstation assigned to a skilled worker. In contrast to the problem addressed by Corominas, Pastor, and Plans (2008), the workstations are multi-manned. That is, it is possible to assign more than one worker (skilled and unskilled) to each workstation. Thus, in such a kind of assembly line, it is also possible to assign temporary workers to those multi-manned workstations in which at least one skilled worker is assigned. Note that, the total number of workers that can be assigned to each multi-manned workstation is limited to the maximum feasible worker concentration parameter (M_{max}). This parameter is preset according to the product size, workstation design, tools availability, and so on (Fattahi, Roshani, Roshani, 2011). The problem is to assign the assembly tasks to the fixed number of the skilled and variable number of unskilled workers so that the precedence relations constraints among tasks and cycle constraint are satisfied and the number of workstations is minimized as the primary objective and the number of unskilled workers on the line as the secondary one.

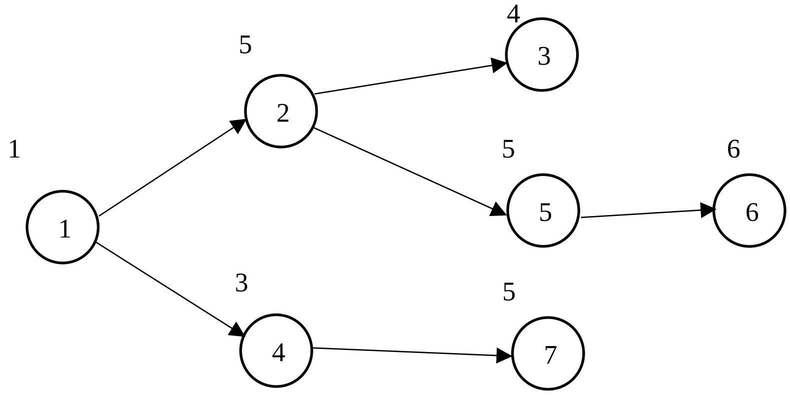

Fig 1. the precedence graph

Consider for example the precedence graph illustrated in figure 1. It is assuming that the available number of skilled workers is five, β equals 2 and due to the seasonal change of demand, the cycle time must be reduced to six-time units. The optimal solution to this problem using the MIP formulation presented by Corominas, Pastor, and Plans (2008) considering single-manned workstations is illustrated in figure 2. In this solution, the optimal number of workstations is six, the number of skilled workers on the line is five and the optimal number of unskilled workers is one. Besides, the throughput time is 36 time units and the work in progress is six. Note that, in this solution, the unskilled worker is assigned to workstation IV, thus, the task time of task 4 assigned to this worker is multiplied by β which is equal to 2.

Workstation no.	I	II	III	IV	V	VI
Finishing times of Tasks	1 6	5	6	6	5	4
Tasks	1 2	5	6	4	7	3
Type of Worker	Skilled	Skilled	Skilled	Unskilled	Skilled	Skilled
Throughput time	6	12	18	24	30	36

Fig 2. the optimal solution of ALBP-SUW

The optimal solution of the above-mentioned problem is also found by allowing multi-manned workstations. M_{max} is three. The optimal solution found by the proposed mathematical formulation in section 3 is illustrated in figure 3. As can be seen from this figure, similar to the solution represented in figure 2, the numbers of skilled and unskilled workers are five and one, respectively.

Workstation no.	I	II	III
Finishing times of tasks			5
Worker III			7
Type of Worker III			Skilled
Finishing times of tasks		5	4
Worker II		5	3
Type of Worker II		Skilled	Skilled
Finishing times of tasks	1 6	6	6
Worker I	1 2	4	6
Type of Worker I	Skilled	Unskilled	Skilled
Throughput time	6	12	18

Fig 3. the optimal solution of MALBP-SUW

The comparison between the number of workstations in figure 2 and the solution represented in figure 3 shows that, in the case of allowing multi-manned workstations, the number of workstations reduces to three and thus, the line length, the work in process and throughput time reduces of 50%.

3- The mathematical formulation

In this section, first, the problem assumptions are given; afterward, the mathematical formulation is presented.

3-1- Assumptions

- The system is configured for the mass-production of one homogeneous product;
- the processing times of the assembly tasks are deterministic and known in advance;
- for each task, the set of immediate predecessors are given;
- each task must be assigned to a single worker;
- the time each worker spent to walk around the work piece is ignored;
- parallel tasks are not allowable;
- the workstations are multi-manned;
- there two sets of workers, namely, skilled and unskilled one;
- unskilled workers cannot be assigned alone to a workstation unless alongside the workstation assigned to the temporary worker there must be at least one workstation assigned to a permanent

(and skilled) worker;

- skilled workers are permanents;
- the number of skilled workers are given;
- unskilled workers are hired temporarily;
- the number of unskilled workers are determined by solving the model;
- the maximum number of workers (M_{max}) that can be assigned to each workstation is given;
- workstations are serially aligned;
- cycle time is given and fixed;
- no assignment restrictions besides the cycle time and precedence constraint;
- for all workstations, transportation facility is identical;
- for all workers, tools, and equipment are similar;
- MALBP-SUW consists of assigning the assembly tasks to the skilled and unskilled workers working in the multi-manned workstations on the line to minimize the number of unskilled workers as the first objective and the number of workstations as the second one.

3-2- Notation

3-2-1- Indexes

i and h : tasks;

j : Workstations;

k and l : workers.

3-2-2- Parameters

n_t: number of tasks;

n_s: number of skilled workers;

I: set of tasks; $I = \{1,2, \dots, n_t\}$;

J: set of workstations; $J = \{1, 2, \dots, n_s\}$, where n_s is a valid upper bound for the number of workstations;

K: set of vacant positions to assigned workers at each workstation; $K = \{1,\dots, k, \dots, M_{\max}\}$;

W: set of workers type; $W = \{1,2\}$, where a skilled worker and a unskilled worker are denoted by1 and 2, respectively;

$P(i)$: set of immediate predecessors of task i;

$Pa(i)$: set of all predecessors of task i;

$S(i)$: set of immediate successors of task i;

$S_a(i)$: set of all successors of task i;

ψ : A large positive number;

Pt_i : nominal processing time of task i;

β: a coefficient.

3-2-3- Decision variables

$$x_{ijkw} = \begin{cases} 1, & \text{if task } i \text{ is assigned to the worker type } w \text{ in } k\text{th position of workstation } j \\ 0, & \text{O.w.} \end{cases}$$

t_i: actual processing time of task i

st_i : The start time of processing of task i

$$wo_{jkw} = \begin{cases} 1, & \text{if } kth \text{ position in workstation } j \text{ is used by worker type } w \\ 0, & \text{o.w.} \end{cases}$$

$$ws_j = \begin{cases} 1, & \text{if workstation } j \text{ is used} \\ 0, & \text{O.w.} \end{cases}$$

$$y_{ih} = \begin{cases} 1, & \text{if task } i \text{ is executed earlier than task } h \text{ in the sequence of tasks assigning to the same worker} \\ 0, & \text{o.w.} \end{cases}$$

3-3- Mathematical formulation

The proposed mathematical formulation is as follows:

3-3-1- Objective function

$$Minimize \quad \sum_{j \in J}\sum_{k \in K}\sum_{w \in W} wo_{jk2} + \frac{1}{M_{\max} \times n + 1} \cdot \sum_{j \in J} ws_j \tag{1}$$

3-3-2- The Constraints

$$\sum_{j \in J}\sum_{k \in K}\sum_{w \in W} x_{ijkw} = 1, \quad \forall i \in I \tag{2}$$

$$\sum_{i \in I} x_{ijkw} \le I \cdot wo_{jkw}, \quad \forall j \in J, k \in K, w \in W \tag{3}$$

$$\sum_{w \in W} wo_{jkw} \le 1, \quad \forall j \in J, k \in K \tag{4}$$

$$\sum_{k \in K}\sum_{w \in W} wo_{jkw} - M_{\max} \cdot ws_j \le 0, \quad \forall j \in J \tag{5}$$

$$\sum_{j \in J}\sum_{k \in K} wo_{jk1} = n_s \tag{6}$$

$$wo_{jk2} \le \sum_{k \in K} wo_{(j-1)k1} + \sum_{k \in K} wo_{jk1} + \sum_{k \in K} wo_{(j+1)k1}, \quad j = 2,...,m-1, k = 1,...,M_{\max} \tag{7}$$

$$wo_{1k2} \le \sum_{k \in K} wo_{1k1} + \sum_{k \in K} wo_{2k1}, \quad k = 1,...,M_{\max} \tag{8}$$

$$wo_{mk2} \le \sum_{k \in K} wo_{(m-1)k1} + \sum_{k \in K} wo_{mk1}, \quad k = 1,...,M_{\max} \tag{9}$$

$$t_i = \sum_{j \in J}\sum_{k \in K} (Pt_i \cdot x_{ijk1} + \beta \cdot Pt_i \cdot x_{ijk2}), \quad \forall j \in J, k \in K \tag{10}$$

$$\sum_{j \in J}\sum_{k \in K}\sum_{w \in W} j.x_{hjkw} \le \sum_{j \in J}\sum_{k \in K}\sum_{w \in W} j.x_{ijkw}, \quad \forall i \in I, h \in P(i) \tag{11}$$

$$st_i + t_i \le Ct, \quad \forall i \in I \tag{12}$$

$$st_i - st_h + \psi.\left(1 - \sum_{k \in K}\sum_{w \in W} x_{hjkw}\right) + \psi.\left(1 - \sum_{k \in K}\sum_{w \in W} x_{ijkw}\right) \ge t_h, \quad \forall i \in I, h \in P(i), j \in J \tag{13}$$

$$st_h - st_i + \psi.\left(1 - x_{hjkw}\right) + \psi.\left(1 - x_{ijkw}\right) + \psi.(1 - y_{ih}) \geq t_i \quad \forall\ i \in I,$$
$$h \in \left\{ r \mid r \in I - (P_a(i) \cup S_a(i)) \ and \ i < r \right\}, j \in J, k \in K, w \in W$$
$$st_i - st_h + \psi.\left(1 - x_{hjkw}\right) + \psi.\left(1 - x_{ijkw}\right) + \psi.y_{ih} \geq t_h \quad \forall\ i \in I,$$
$$h \in \left\{ r \mid r \in I - (P_a(i) \cup S_a(i)) \ and \ i < r \right\}, j \in J, k \in K, w \in W \tag{14}$$

$$st_i \geq 0, \quad \forall i \in I \tag{15}$$

$$x_{ijkw} \in \left\{0,1\right\} \quad \forall i \in I,\ j \in J, k \in K, w \in W \tag{16}$$

$$y_{ih} \in \left\{0,1\right\} \quad \forall i \in I,\ h \in \{ r \mid r \in I - (P_a(i) \cup S_a(i)) \ and \ i < r \} \tag{17}$$

$$wo_{jkw} \in \left\{0,1\right\} \quad \forall j \in J,\ k \in K, w \in W \tag{18}$$

$$ws_j \in \left\{0,1\right\} \quad \forall j \in J \tag{19}$$

The objective function (1) minimizes the number of unskilled workers as the primary objective and then tries to minimize the number of opened multi-manned workstations. The first term in the objective function (1) corresponds to the total number of unskilled workers on the line. The second term represents the total number of opened Multi-manned workstations. Constraints (2), the assignment constraints, ensure that each task is assigned to exactly one skilled or unskilled worker at one workstation. Constraints (3), the worker constraints, ensure that if at least one task is assigned to worker type *w*, in position *k* of workstation *j*, then wo_{jkw} equals 1 and 0 otherwise. Constraints (4) ensure that only a one type of worker *w* can be assigned to each available position *k* in workstation *j*. Constraints (5) verify that if at least one worker is used in workstation *j*, the ws_j is equal 1. Constraints (6) indicate that the total number of skilled workers is n_s. Constraints (7), (8) and (9) make it necessary for each temporary worker to be located alongside at least one permanent worker. Constraints (10) calculate the actual task time *i* depending on its assignment to skilled or unskilled workers. Constraint (11), the precedence constraint, ensures that all precedence relations among tasks are satisfied. Constraint (12), cycle time constraint, ensures that each task should be finished before the end of the cycle time. Constraints (14) control the sequencing constraints. For every pair of task *i* and *h*, if task *h* is an immediate predecessor of task *i*, in order to verify precedence constraints, the task i must be started after finishing of task h. Constraints (14) ensures that if task i has earlier sequence than task h ($y_{ih} = 1$) and they are assigned to same worker then task h can be started after finishing task i. Nevertheless, if two tasks assigned to different workstations, are not considered in this constraint by introducing a sufficiently larger number ψ for example $\psi = Ct$. Constraints (15-18) show the integer variables.

4- Computational study

In this section, to evaluate the efficiency of the MIP model presented in section 3, this model and the MIP formulation presented by Corominas, Pastor, and Plans (2008) are coded by CPLEX 12.6 optimizer. These two models are applied to solve some small-sized instances in the literature. These sets are obtained from the papers presented by Merten (1967), Bowmen (1960), Jaeschke (1964), Jackson (1956), and Mansoor (1964). Comparisons are made in terms of the number of workstations, the number of workers, and computational times. All the experiments were performed on a Laptop with Intel(R) Core(TM) i7-6700HQ @ 2.60 GHz with 8 GB RAM.

Table 1. The optimal solutions generated by applying the proposed model and the model presented by Corominas, Pastor, and Plans (2008)

Problem	n_t	*CT*	M_{max}	SW	Corominas model			Proposed model			
					UW	Ws	cpu	UW	Ws	cpu	Imp(%)
Merten	7	6	3	5	1	6	0.12	1	3	0.65	50
		8	3	4	1	5	0.11	1	3	0.66	40
		10	3	2	2	4	0.14	2	3	0.65	25
Bowman	8	21	3	3	3	6	0.15	3	5	0.63	16.67
		24	3	3	1	4	0.17	1	4	0.59	0
		28	3	2	2	4	0.15	2	3	0.79	25
Jaeschke	9	6	3	7	1	8	0.17	1	6	0.50	0.25
		8	3	5	1	6	0.15	1	5	0.42	16.67
		10	3	3	2	5	0.17	2	4	0.81	20
Jackson	11	7	3	7	1	8	0.20	1	7	212.29	12.5
		9	3	6	0	6	0.13	0	4	1.23	33.33
		13	3	3	2	5	0.16	2	3	3600	40
Mansoor	11	45	3	3	3	6	0.14	3	4	539.34	33.33
		54	3	3	1	4	0.17	1	3	2.98	20
		63	3	3	0	3	0.18	0	2	0.84	33.33
Average					1.4	5.33	0.15	1.4	3.93	290.82	24.40

SW: number of skilled workers; *UW*: number of unskilled workers; *Ws*: number of workstations;

Table 1 summarizes the results of the comparison results. Each instance is solved by fixing the value of cycle time to three different values. The maximum number of workers and the number of skilled workers are also given. Figure 4 shows a comparison between the results of the proposed MIP and MIP presented by Corominas, Pastor, and Plans (2008). According to this figure, both of the models reach the same number of unskilled workers on the line for all the experiments.

The performance comparison of the proposed MIP and the MIP presented by Corominas, Pastor, and Plans (2008) in minimizing the number of workstations is shown in figure 5. According to this figure, it can be found out that the proposed model is more effective than the methodology of Corominas, Pastor, and Plans (2008) in minimizing the number of workstations. The proposed model has been able to decrease the line length in 14 out of 15 instances with the average improvement rate of the number of workstations equaling to 24.40%.

Finally, the computational times of MIP formulation by Corominas, Pastor, and Plans (2008) are between 0.12 and 0.20 s; instead, the CPU times of proposed MIP were less than 3600 s, for every problem. According to these results, it can be affirmed that the proposed model consumes much more computational times than the Corominas, Pastor, and Plans (2008)'s model. One of the main reasons for complexity of solving the MALBP-SUW in comparison to ALBP-SUW is while balancing a multi-manned assembly line, idle time is sometimes unavoidable even between tasks assigned to the same workstation. Suppose that task h and task p are assigned to worker l1 of workstation j, task i and task r are assigned to the worker l2 of this workstation, and a task i is an immediate predecessor of task h. Task h cannot be started unless task i is completed.

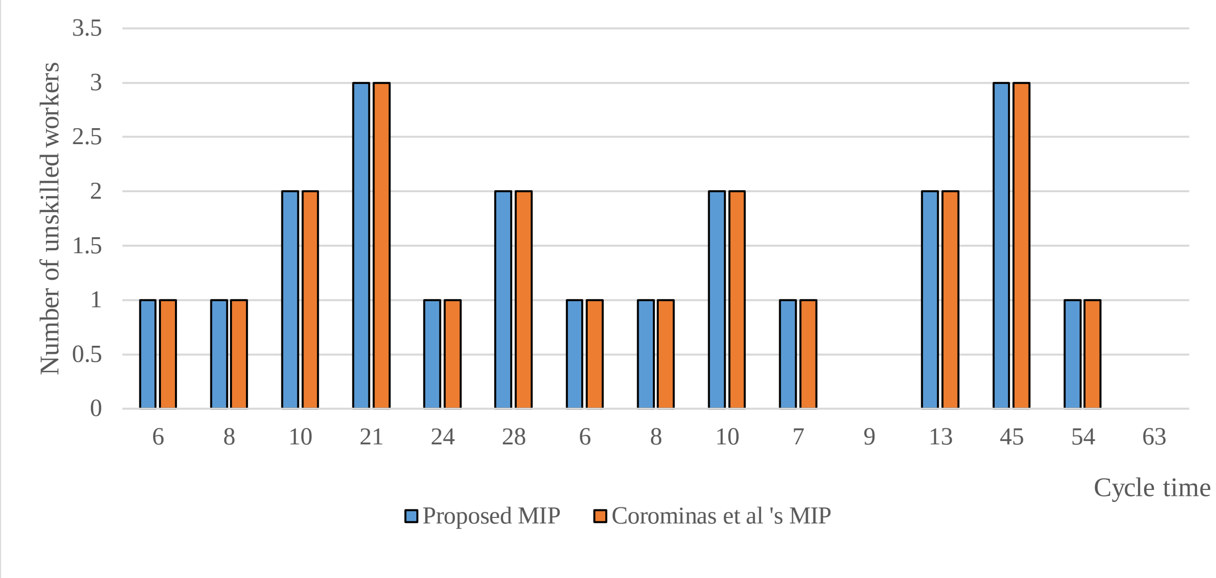

Fig 4. The comparison between the numbers of unskilled workers

5- Conclusion

In this paper, we have studied the advantages of installing multi-manned workstations in ALBP-SUW. An illustrative example indicates if the fixed number of the skilled and optimal number of unskilled workers are allowed to be assigned to multi-manned workstations, the number of workstations, the work-in-progress, and the throughput time are decreased. Thus, a mathematical programming formulation has been also presented to solve the ALBP-SUW with multi-manned workstations. The proposed model minimizes the number of unskilled workers as the primary objective function and number of the workstation as the secondary one. To evaluate the performance of the model, it has been coded with IBM ILOG CPLEX 12.6 and has been used to solve some experimental instances from the literature. The results have been compared with those obtained through the solving of single-manned ALBP-SUW presented by Corominas, Pastor, and Plans (2008). The comparison of results shows that the new model has been able to generate the optimal number of unskilled workers while the average improvement rate of the number of workstations equalling to 24.40%.

The MALBP-SUW is NP-hard, therefore, the mathematical model presented in this paper is able to solve small-sized instances of the problem in a reasonable amount of time. Thus, it is necessary to develop heuristic, meta-heuristics solution approaches, or some efficient optimal seeking algorithms such and branch and band methods to solve MALBP-SUW also in the case of medium- and large-sized problems.

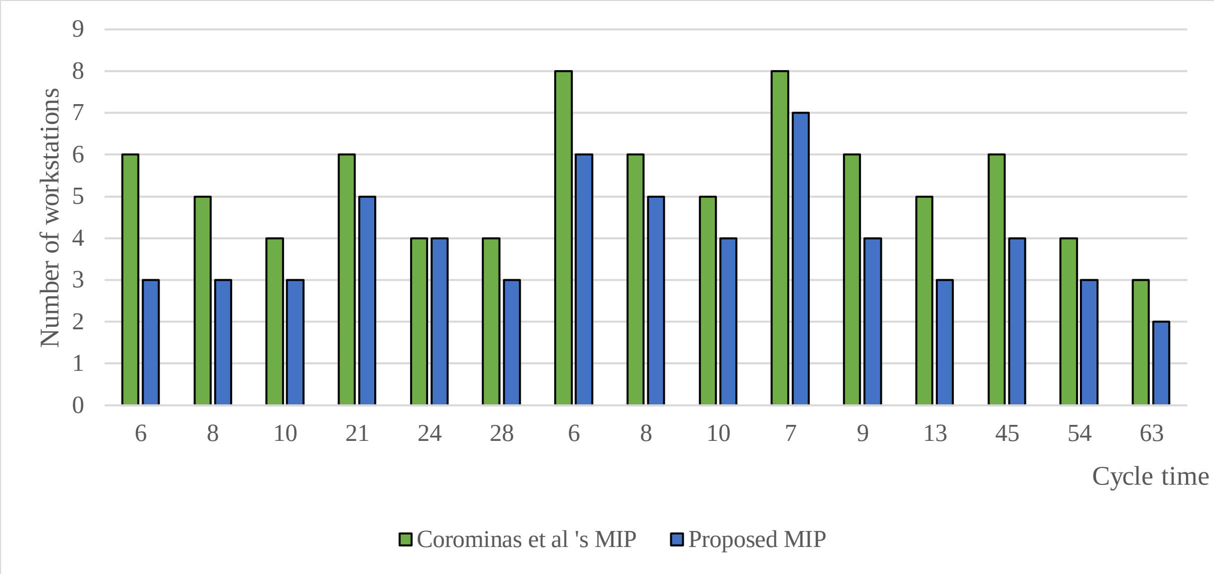

Fig 5. The comparison between the numbers of workstations

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Battaïa, O., and Dolgui, A. (2013). A taxonomy of line balancing problems and their solution approaches. *International Journal of Production Economics*, 142(2), 259-277.

Baybars, I., 1986. A survey of exact algorithms for the simple assembly line balancing problem. *Management science*, 32(8), 909-932.

Becker, C. and Scholl, A. (2006). A survey on problems and methods in generalized assembly line balancing. *European Journal of Operational Research*, 168(3), 694-715.

Becker, C. and Scholl, A. (2009). Balancing assembly lines with variable parallel workplaces: Problem definition and effective solution procedure. *European Journal of Operational Research*, 199(2), 359-374.

Bowman EH (1960) Assembly line balancing by linear programming. *Operations Research*, 8, 385–389.

Chang, H.-J., and Chang, T.-M. (2010). Simultaneous Perspective-based Mixed-model Assembly Line Balancing Problem. *Tamkang Journal of Science and Engineering*, 13, 327-336.

Cevikcan, E., Durmusoglu, M.B., and Unal, M.E. (2009). A team-oriented design methodology for mixed model assembly systems. *Computers & Industrial Engineering*, 56(2), 576-599.

Corominas, A., Pastor, R., & Plans, J. (2008). Balancing assembly line with skilled and unskilled workers. *Omega*, 36(6), 1126-1132.

Dimitriadis, S.G. (2006). Assembly line balancing and group working: A heuristic procedure for workers' groups operating on the same product and workstation. *Computers & Operations Research* 33(9), 2757-2774.

Fattahi, P., and Roshani, A. and Roshani, A. (2011). A mathematical model and ant colony algorithm for multi-manned assembly line balancing problem. *The International Journal of Advanced Manufacturing Technology*, 53 (1-4), 363-378.

Jackson JR (1956) A computing procedure for a line balancing problem. *Management Science*, 2, 261–272.

Jaeschke G (1964) Eine allgemaine Methode Zur Losung Kombinatoriiicher Probleme. *Ablauf-Plan Forsch*, 5,133–153.

Kellegöz, T. (2017). Assembly line balancing problems with multi-manned stations: a new mathematical formulation and Gantt based heuristic method. *Annals of Operations Research*, 253(1), 377-404.

Kellegoz, T. and Toklu, B. (2012). An efficient branch and bound algorithm for assembly line balancing problems with parallel multi-manned workstations. *Computers & Operations Research*, 39(12), 3344-3360.

Kellegoz, T. and Toklu, B. (2015). A priority rule-based constructive heuristic and an improvement method for balancing assembly lines with parallel multi-manned workstations. *International Journal of Production Research*, 53(3), 736-756.

Kim, D., Moon, D.H., Moon, I., (2018). Balancing a mixed-model assembly line with unskilled temporary workers: algorithm and case study, *Assembly Automation*, https://doi.org/10.1108/AA-06-2017-070.

Mansoor EM (1964) Assembly line balancing-An Improvement on the Ranked Positional Weight Technique. *Journal of Industrial Engineering*, 15, 73–77.

Merten P (1967) Assembly line balancing by partial enumeration. *Ablauf- und planungsforschung*, 429-433.

Moon, I., Shin, S. and Kim, D., (2014), Integrated assembly line balancing with skilled and unskilled workers. *IFIP International Conference on Advances in Production Management Systems*, 459-466. Springer, Berlin, Heidelberg.

Roshani, A. and Giglio, D., (2015). A Mathematical Programming Formulation for Cost-oriented Multi-manned Assembly Line Balancing Problem. *IFACPapersOnLine*, 48(3), 2293-2298.

Roshani, A. and Giglio, D., (2015). A simulated annealing approach for multi-manned assembly line balancing problem type II. *IFAC-PapersOnLine* 48(3), 2299-2304.

Roshani, A., & Giglio, D. (2017). Simulated annealing algorithms for the multi-manned assembly line balancing problem: minimising cycle time. *International Journal of Production Research*, 55(10), 2731-2751.

Roshani, A., Paolucci, M., Giglio, D, and Tonelli, F., (2020) A hybrid adaptive variable neighbourhood search approach for multi-sided assembly line balancing problem to minimise the cycle time, International Journal of Production Research, DOI: 10.1080/00207543.2020.1749958

Roshani, A., Roshani, A., Roshani, A., Salehi, M., and Esfandyari, A. (2013). A simulated annealing algorithm for multi-manned assembly line balancing problem. *Journal of Manufacturing Systems*, 32(1), 238-247.

Salveson, M.E. (1955). The assembly line balancing problem. *Journal of industrial engineering*, 6(3), 18-25.

Sahin, M., Kellegz, T., (2019). A new mixed-integer linear programming formulation and particle swarm optimization based hybrid heuristic for the problem of resource investment and balancing of the assembly line with multi-manned workstations. *Computers & Industrial Engineering,* 133, 107 - 120.

Tonelli, F., Paolucci, M., Anghinolfi, D. and Taticchi, P. (2013). *Production planning of mixed-model assembly lines: a heuristic mixed integer programming based approach*. *Production Planning & Control*, 24(1), 110-127.

Yilmaz H. and Yilmaz M. 2015. Multi-manned assembly line balancing problem with balanced load density. *Assembly Automation*, 35(1), 137-142.