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Consideration of workforce differences in assembly line balancing and worker assignment problem

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Abstract: Workforce differences in terms of skill, age, gender and physical measures have a large impact on production systems performance. Moreover, the role of differences between workers can be particularly seen in assembly lines, where a vast range of tasks are performed manually, and workers are involved widely. In this work, we introduce a new assembly line balancing and worker assignment model with consideration of workers' diversity in terms of both workers' expertise and perceived physical effort to implement an age-inclusive workforce. Here, a new Worker Task Categorization Matrix is introduced to assure the complete involvement of the individual during the balancing process. Following, a bi-objective linear programming model is proposed and solved by using the $\boldsymbol{\varepsilon}-$constraint approach. Finally, we test and validate the model through a real-case application.

Keywords: Workforce difference, Assembly line, balancing, Production system, Ergonomic assessment

1. INTRODUCTION

In manufacturing, a high number of tasks are still human-centred and their performances largely depend more on workers than on machines (Calzavara et al., 2020). This happens especially in big size highly customized product assembly systems (Zennaro et al. 2019). The workforce may vary in terms of many factors, such as skill, age, gender and physical attributes and these differences can affect the overall performances of the production system in terms of time (i.e. Ramezanian and Ezzatpanah, 2015), cost (i.e. Martignago et al., 2017) and throughput (i.e. Buzacott, 2002). Therefore, the consideration of workers' differences in production systems plays an important role, particularly in all human-centred fields like manual assembly systems (Katiraee et al. 2021). The issue of including workers differences in assembly systems design has already been faced by previous research, in different ways (Finco et al., 2020). Some previous contributions, for example, face the workers assignment problem subsequently to the assembly line balancing (Koltai et al., 2014). On the other side, other authors propose to include the workers assignment into assembly line balancing (Sungur et al. 2015), with each worker type considered by his qualifications for performing each task. In this paper, we propose an integrated bi-objective linear programming model, which allows to balance the assembly line and define the workers assignment. While the first objective function considers the minimization of the cycle time, the second one considers the minimization of the workers' physical effort, measured through Borg scale evaluations (Borg, 1990). In this way, we can include workers during a strategic decision like the assembly line balancing. The proposed approach allows to directly involve the workers in the task analysis, reaching an individual measurement of their expertise and a personal evaluation of their perceived physical effort in performing tasks. Indeed, the expertise is measured through their task execution times, while the physical effort is assessed by Borg scale evaluations, made by each worker for each task. This is different from what has been done by previous methods that have focused, for example, on the consideration of energy expenditure or other ergonomic methods (i.e. Battini et al. 2015), which are usually based on measurements made by expert evaluators without involving the worker in the analysis. Moreover, the method presented in this paper is in line with the suggestions provided by Sgarbossa et al. (2020), which highlights the strong need to design individualized, customized solutions in the context of managing increased diversity in workers, including cognitive and physical capabilities. Consequently, the novelty of this paper is to address assembly line balancing and job assignment problems by introducing the Worker Tasks Categorization Matrix (WTCM) including the individual characteristics and perceptions of the workers both for measuring their experience and their physical effort. Finally, to figure out the trade-off between the cycle time and the physical effort, we apply $\varepsilon-$constraint algorithm to solve the model. The remainder of this paper is structured as follows. Section 2 provides a literature review of studies related to assembly line balancing and workers assignment problem considering workers' differences. Section 3 presents the problem description and model formulation. Section 4 describes the model application to a real case study and discusses the obtained results. Finally, Section 5 presents conclusions and future perspectives.

2. LITERATURE REVIEW

Workers can vary between each other in terms of, for example, skill level, age, gender and physical capability. Therefore, not every worker can perform every task at the same processing time, since human characteristics may differ (Battaïa and

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Dolgui, 2013). These differences can be influential widely in sections with a high percentage of workers' involvement, like assembly line in production systems.

Initially, the Simple Assembly Line Balancing Problem (SALBP) has been widely discussed in the literature by considering equal workers in terms of experience, age and wage (i.e. Boysen et al., 2007). In 2001, Carnahan et al. proposed the first approach to include workers physical demand during the assembly balancing phase. Then, several studies and models have been proposed by including ergonomics, postures, physical fatigue during the assembly line design phase (Otto & Battaia, 2017).

A first extension of the SALBP in which task execution times are worker-dependent has been introduced in the literature by Miralles et al. (2007) and named the Assembly Line Worker Assignment and Balancing Problem (ALWABP). In this extension, each task has different execution times depending on the selected worker, due to his/her skill level (Polat et al. 2016). Moreover, some studies have concerned ALWABP, in which the operating time for a task and its cost differ depending on operator skills (Ramezanian and Ezzatpanah 2015). Sungur and Yavuz (2015) presented a model for ALBP with hierarchical worker assignment where tasks differ concerning their qualification requirements and the qualification levels of workers. Furthermore, other studies explored ALWABP for U-Shaped assembly lines (e.g. Oksuz et al. 2017). In all these previous studies for ALWABP, tasks execution times vary only due to workers' skill levels and abilities. On the other side, rare studies concerned other aspects of workers' differences such as age, gender, or physical capacity in ALWABP, which can impact time, cost and productivity directly or indirectly. Concerning this issue, Efe et al. (2018) analysed different age categories to assess the impact of age and gender on physical workload capacity. Another influential criterion that can differentiate among workers and can impact task time is the perceived physical strain and effort for performing the tasks. This factor can typically be influenced by both workers' age and gender. To measure workers' physical effort in assembly line balancing, various quantitative and ergonomic methods are proposed by previous studies (e.g. Mutlu and Özgörmüş 2012). Furthermore, other studies have put a large emphasis on ergonomics issues, even if related to average standard workers instead of considering the actual differences among them (e.g. Battini et al., 2016), on the impact of fatigue on tasks duration (Calzavara et al., 2019) or energy expenditure (Finco et al. 2019). To the best of our knowledge, no one of the existing contributions considers the impact of the physical effort in ALWABP. Moreover, no contributions related to assembly line design measure the physical effort of workers with their direct involvement in giving self-assessment (Borg score) evaluations to tasks.

As already stated, the variation of task time according to workers' skill levels has been considered widely in previous studies, while other aspects of workers' differences have not been much addressed (Katiraee et al., 2021). In this study, we aim to cover this research gap, not only by considering different tasks times depending on workers' expertise but also by evaluating workers' perceived job strain and effort individually for each task in assembly lines. Since workload is something that is experienced individually by each person, there are no effective "rulers" that can be used to estimate the workload of different tasks. Therefore, it becomes useful to ask workers to describe the feelings they experienced. This is done in this study through a subjective method, the Borg scale (Borg, 1990), which is a well-known method in the ergonomic literature, that has the potential to directly involve the workers in the evaluation of their perceived fatigue level to design the system following their specific needs.

3. PROPOSED MODEL FOR ALWABP

3.1 Problem description

The present model aims to integrate workers with individual characteristics to be sure that the most appropriate tasks are assigned to the right workers in terms of workers' expertise and physical demand. Both expertise and physical aspects of workers can be influenced by other criteria, such as age and gender, directly or indirectly. For example, age can have a positive impact on workers' experience, while it can decline the functional capacities of workers. Therefore, ageing workers could use their experience to compensate for declines in physical capacities (Boenzi et al., 2015). However, we consider that this compensation can happen only in case the ageing worker is familiar with the tasks he has to execute. Then, we could also have an aged worker with a low level of experience. Another aspect could be related to the gender of the operators: male workers could be more suitable for high physically demanding tasks, performing them faster or with a lower physical effort than female workers. Therefore, to understand the effect that the assignment of a task to a certain worker has in terms of execution time and physical effort, we propose to consider four different tasks categories in terms of the task expertise and physical effort need, shown in Figure 1. The Worker Tasks Categorization Matrix (WTCM) is intended to be different for each worker. The worker will be involved right from the beginning in the filling of this matrix by analysing his/her task execution times and his/her efficiency level integrating the worker's ergonomic self-assessment. Here, the workers' expertise is evaluated according to their task execution time, while the physical effort is assessed based on the well-known Borg scale. However, other self-assessment tools such as NASA-TLX could be a useful alternative in this case (Börner et al. 2012). In Figure 1, for task type 1, the worker feels a slight or moderate exertion during performing tasks (Borg score ≤ 4) and he can perform the task with duration time less than or equal to standard company task time, while for critical tasks the worker requires higher physical effort (Borg score > 4) and expertise in terms of execution time to perform. Task types 2 and 3 need higher expertise (in terms of execution time) and higher physical effort (Borg score > 4), respectively.

In this study, we consider a simple assembly line with different tasks and different workers with the aim of minimization both cycle time and the maximum physical effort of the stations.

The assessment of the workers' physical effort is done through the Borg scale (Borg, 1990), a subjective assessment tool that helps to understand how workers feel while performing tasks. Here, we use the CR10; the scores, ranging from 0 (no exertion at all) to 10 (maximal exertion). All the workers are asked to

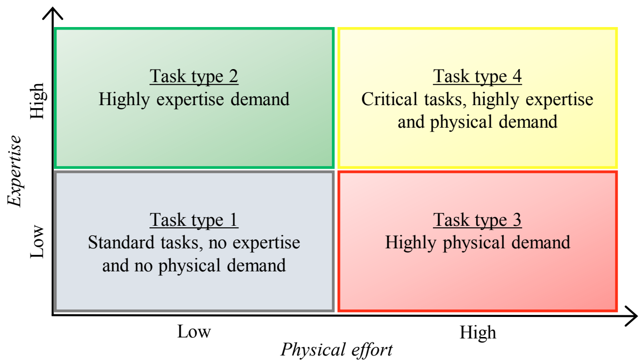

Fig. 1. Worker Tasks Categorization Matrix (WTCM).

give a score for performing each task. Then, depending on the score obtained by the workers from their self-assessment, their physical status and perception can be evaluated for each task.

3.2 Problem formulation

We formulate the ALWABP-2 with consideration of workers' differences in terms of expertise and physical effort in a bi-objective model. Notations are defined below.

Sets, indices, and parameters

i, j	indexes for tasks
h	index for workers
s	index for stations
$N = \{1,..,n\}$	set of tasks
$H = \{1,..,w\}$	set of workers
$S = \{1,..,m\}$	set of stations
A	set of tasks precedence
t_{ih}	Mean completion time of task *i* when worker *h* performs it
pw_{ih}	perceived physical effort for task *i* when worker *h* performs it

Decision Variables

CT	Cycle Time
PES_{max}	Station Maximum Physical Effort

$$x_{ihs} = \begin{cases} 1 & \text{if task i is assigned to worker h at station s} \\ 0 & \text{otherwise} \end{cases}$$

$$y_{hs} = \begin{cases} 1 & \text{if worker h is assigned to station s} \\ 0 & \text{otherwise} \end{cases}$$

Mathematical model

$$\text{Minimize} \quad CT \tag{1}$$

$$\text{Minimize} \quad PES_{max} \tag{2}$$

Subject to:

$$\sum_h \sum_s x_{ihs} = 1 \qquad \forall i \in N \tag{3}$$

$$\sum_s y_{hs} \leq 1 \qquad \forall h \in H \tag{4}$$

$$\sum_{h \in H} \sum_{s \in S} s\, x_{jhs} \leq \sum_{h \in H} \sum_{s \in S} s\, x_{ihs} \quad \forall (j,i) \in A \tag{5}$$

$$\sum_{i \in N} \sum_{h \in H} t_{ih}\, x_{ihs} \leq CT \qquad \forall s \in S \tag{6}$$

$$x_{ihs} \leq y_{hs} \qquad \forall i \in N, \forall h \in H, \forall s \in S \tag{7}$$

$$\sum_{i \in N} \sum_{h \in H} pw_{ih} x_{ihs} \leq PES_{max} \quad \forall s \in S \tag{8}$$

$$x_{ihs} \in \{0\,,1\} \qquad \forall i \in N, \forall h \in H, \forall s \in S \tag{9}$$

$$y_{hs} \in \{0\,,1\} \qquad \forall h \in H, \forall s \in S \tag{10}$$

$$CT \in \mathbb{R}^+ \tag{11}$$

$$PES_{max} \in \mathbb{R}^+ \tag{12}$$

The objective function (1) minimizes the cycle time CT, while the objective function (2) minimizes the station maximum physical workload PES_{max}, calculated by summing the Borg scores of the worker assigned to the station. Constraint (3) guarantees that each task i is assigned to exactly one station occupied by worker h. Constraints (4) ensures that each worker is assigned to only one station and that each station is assigned to only one worker. The precedence constraints between tasks are guaranteed by constraint (5). Constraint (6) prevents the total task time of each station exceeds the CT considering each workers' tasks processing time. Constraint (7) assures that a task is assigned to a worker h in station s only if the h-th worker is assigned to the s-th station. Constraint (8) defines the maximum physical effort we can find in a station. Finally, constraints (9)-(12) set the domains of the decision variables.

3.3 $\varepsilon -$ Constraint algorithm

To solve the bi-objective model we use the $\varepsilon -$constraint algorithm method. Here, the CT objective has to be minimized by using the PES_{max} as a constraint. By parametrical variations of PES_{max}, solutions of the problem are obtained. We solve two problems. The first one, noted as *ALWABP-*PES_{max}, corresponds to the minimization of PES_{max} subjected to (3)-(12). On the other side, the second problem, noted as *ALWABP-2,* minimizes CT, subjected to (3)-(13).

$$PES_{max} = K \qquad \forall s \in S \tag{13}$$

The following steps are adopted to execute the method.

Step 1: Solve the problem *ALWABP-*PES_{max}.
Step 2: Set PES_{max} (K) in (13) with the solution of step 1.
Step 3: Solve *ALWABP-2* and consider the stopping criterion. The stopping criterion is met when the cycle time is minimized. Therefore, no better solution can be achieved. Otherwise, it has to be set $K \rightarrow K + 1$, and go back to step 3.

4. INDUSTRIAL CASE

4.1 Case setting and input data

The case considered in this section deals with the production of a burner used for industrial applications, with an assembly cycle of 71 tasks performed in 6 workstations. Of course, performing some tasks could be challenging for some workers. Therefore, the tasks can vary between workers depending on their expertise levels and/or physical condition. In this industrial case, we consider the ranges in terms of execution time and physical effort to define the WTCM shown in Table 1. In other companies, different task types and ranges could be defined according to their needs and priorities. t_i in Table 1 is a normalized standard task time which is determined to achieve the desired efficiency without consideration of workers differences

Table 1. The task types range

Task types	Physical effort (Borg score)	Expertise (execution time)
Type 1	$pw_{ih} \leq 4$	$t_{ih} \leq t_i$
Type 2	$pw_{ih} \leq 4$	$t_{ih} > t_i$
Type 3	$pw_{ih} > 4$	$t_{ih} \leq t_i$
Type 4	$pw_{ih} > 4$	$t_{ih} > t_i$

(i.e. the Bedaux efficiency equal to 80). However, here, the execution times of all workers for each task t_{ih} are measured individually, to determine the required expertise of each task for each worker (each worker has performed the whole assembly cycle, 71 tasks, 5 times in 5 days to find the mean value for task completion time). Furthermore, each worker is involved individually to assess his/her physical perception in performing each task pw_{ih}. To evaluate workers' physical status the given Borg scores of the workers are used for each task to understand what the worker physical perception for each task is (which score 4 indicates moderate activities while sever activities usually rate a 5 or higher (Ramalingam et al.,2019)). The precedence constraints are shown in Figure 2. As an example, in the same figure, tasks are coloured according to their type for a specific worker h.

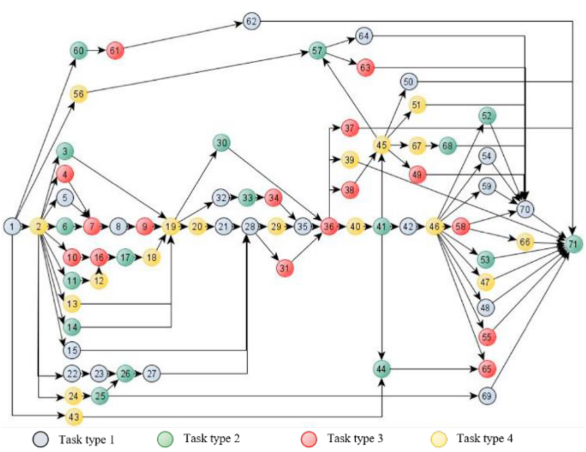

Fig. 2. Precedence constraints and tasks types for worker h

4.2 Results and discussion

The ALWABP-PES_{max} and ALWABP-2 problems were solved with IBM CPLEX v12.8.0, with default parameters. All computational experiments were conducted on a personal computer with Intel(R) Core (TM) i7-6500U 2.50 GHz 12GB RAM. Figure 3 shows the obtained Pareto front. As we can see, by increasing PES_{max}, CT decreases. The complete results for all Pareto front points are reported in Table 2. Moreover, Table 2 reports the time, the sum of the perceived effort, the maximum Borg score according to the tasks assigned and the weighted Borg score, obtained from the Borg scores of the assigned tasks and their durations for each station. Here, it is interesting to see that the extremal points of the Pareto front have a strong difference in term of PES_{max} (i.e. for point 1 it is almost double than for point 13) while CT differs only 2 minutes and 43 seconds. Moreover, by evaluating the PES and the stations time we can see that in point 13 stations time is not well balanced, while the PES is. On the contrary, point 1 presents a balanced station time with the PES differing a lot. Finally, looking at the maximum Borg scores and at the weighted ones per station, in both points 1 and 13, at least one station presents a score higher than 5. However, for point 13 the weighted value is always lower than 5, while for point 1 the worker assigned to station 6 presents a weighted value higher than 5 and, consequently, he could experience some fatigue since he perceives a high physical strain for about 25 minutes.

By evaluating the other points, we can see a significatively reduction of PES_{max} with a low increment of CT. For example, according to the first three rows of Table 2 (points 1, 2, 3), it can be seen that CT has increased only a few seconds with a reduction of PES_{max} from 68 to 48. Although this difference is not significant in terms of time, it can be remarkable from a physical point of view. In fact, as PES_{max} increases, the stations are more balanced in terms of time, while the workers' physical exertion is not much respected.

Aiming to avoid assigning to a worker a task for which he/she gave a Borg score higher than 5, we solved the model also by adding constraint (14). This assures that workers are assigned to the more appropriate tasks in terms of perceived physical effort and strain. By looking at Figure 3, we can see that by adding constraint (14) the Pareto front moves from left to right with a slight increment of the cycle time. Looking at Figure 3 and Table 3, we can see that the extremal point that leads to the minimization of the PES_{max} (point 10) remains the same. However, it can be seen that at this point the time of station 6 is strongly lower than the others.

$$pw_{ih} x_{ihs} \leq 5 \qquad \forall i \in N, \forall h \in H, \forall s \in S \tag{14}$$

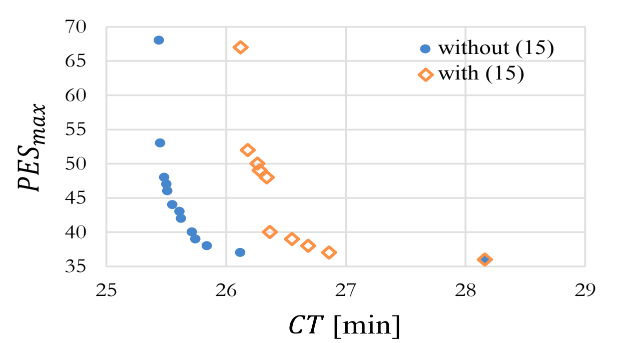

Fig. 3. Pareto feasible solutions without and with (14).

Based on both Tables 2 and 3 it can be derived that, since constraint (14) limits the maximum Borg score to 5, it provides more acceptable solutions from a physical point of view. Besides, the maximum value of the weighted Borg score for all the points belonging to the Pareto front is 4.8, with 8 points out of 10 having the maximum weighted Borg score equal to 4.2. To select the most appropriate solutions, we propose to ignore all the points with a weighted Borg score ≥ 5. Furthermore, also the solutions with a maximum Borg score ≥ 7 should be neglected since this corresponds to a 'very severe' exertion for the worker. Hence, among the remained solutions, we suggest selecting the points which can balance the CT and the physical exertion in a better way, without increasing too much the cycle time and then, penalizing too much the system throughput. These could be points 10 and 11 of Table 2 or points 6, 7 and 8 of Table 3. Finally, for this specific case, we can say that the results of the model without constraint (14) are even better than the ones obtained with constraint (14). Points

Table 2. Pareto front points (values of the objective functions in bold)

Point	CT PES_{max}	Station time [min] PES						Station maximum Borg score Station weighted Borg score					
		1	2	3	4	5	6	1	2	3	4	5	6
1	**25.44**	25.26	**25.44**	**25.44**	25.40	25.42	25.43	5	3	4	7	3	6
	68	66	45	29	21	20	**68**	4.0	2.7	3.8	2.1	2.8	5.1
2	**25.45**	25.39	25.45	25.44	25.38	**25.45**	**25.45**	5	3	4	4	3	6
	53	**53**	52	29	12	43	38	4.0	2.7	3.8	2.0	3.0	4.8
3	**25.48**	25.36	25.37	25.46	**25.48**	25.33	25.42	6	3	4	7	3	5
	48	**48**	42	38	25	43	35	4.9	2.8	3.7	1.9	3.0	4.0
4	**25.50**	25.16	**25.50**	25.42	25.48	25.46	25.42	6	3	4	7	3	5
	47	44	36	**47**	25	45	35	4.9	2.8	3.7	1.9	3.0	4.0
5	**25.51**	25.26	**25.51**	25.47	25.48	25.48	25.46	5	3	4	7	3	6
	46	**46**	39	**46**	25	32	**46**	4.2	2.8	3.8	1.9	2.7	5.2
6	**25.55**	25.16	**25.55**	25.51	25.48	25.49	25.54	6	3	3	7	3	5
	44	**44**	42	38	25	42	39	4.9	2.8	3.7	1.9	2.9	4.0
7	**25.61**	**25.61**	25.59	25.49	25.52	**25.61**	25.58	5	3	4	4	3	6
	43	**43**	**43**	**43**	25	35	40	4.3	2.7	3.8	2.2	2.7	5.0
8	**25.62**	25.60	25.61	**25.62**	**25.62**	25.58	25.61	5	3	4	7	3	6
	42	**42**	41	**42**	34	35	40	4.3	2.7	3.7	2.4	2.7	5.0
9	**25.72**	**25.72**	25.65	25.71	25.57	25.68	25.57	6	3	3	5	7	4
	40	38	38	36	**40**	39	39	4.8	2.7	2.7	4.0	2.5	3.8
10	**25.74**	25.72	25.69	25.67	**25.74**	**25.74**	25.70	6	3	3	5	4	4
	39	38	**39**	35	38	**39**	**39**	4.8	2.8	2.7	3.9	2.5	3.8
11	**25.84**	25.72	**25.84**	**25.84**	25.70	25.69	25.72	6	3	3	5	4	4
	38	**38**	**38**	**38**	36	**38**	**38**	4.8	2.7	2.7	4.0	3.7	2.7
12	**26.12**	25.98	25.98	25.82	**26.12**	25.91	25.72	4	3	6	5	4	3
	37	**37**	**37**	36	36	**37**	**37**	2.9	2.8	5.6	3.7	3.9	2.3
13	**28.16**	**28.16**	27.39	28.10	23.96	23.88	24.04	3	4	3	6	4	5
	36	**36**	35	**36**	**36**	**36**	**36**	2.6	3.0	2.8	4.5	3.7	4.1

Table 3. Pareto front points with consideration of (14) (values of the objective functions in bold)

Point	CT PES_{max}	Station time [min] PES						Station maximum Borg score Station weighted Borg score					
		1	2	3	4	5	6	1	2	3	4	5	6
1	**26.12**	26.11	**26.12**	**26.12**	23.22	25.99	26.06	5	3	4	4	3	4
	67	**67**	34	33	20	45	29	4.0	2.8	3.8	4.0	2.9	2.7
2	**26.18**	26.10	**26.18**	26.13	23.22	25.98	25.96	5	3	3	4	4	4
	52	**52**	29	38	20	50	37	4.1	2.9	2.7	4.0	4.0	2.6
3	**26.26**	26.03	**26.26**	26.23	23.22	26.24	**26.26**	5	3	3	4	4	4
	50	**50**	31	37	20	49	41	4.2	2.9	2.7	4.0	3.9	2.8
4	**26.28**	26.26	**26.28**	**26.28**	24.23	25.93	26.27	4	3	3	4	4	5
	49	40	38	23	28	48	**49**	2.9	2.8	2.8	4.0	3.9	4.1
5	**26.34**	**26.34**	26.33	**26.34**	23.22	26.16	26.33	5	3	3	4	4	4
	48	46	35	35	20	**48**	39	4.2	2.8	2.7	4.0	3.8	2.7
6	**26.36**	26.26	26.28	**26.36**	24.23	26.05	25.94	4	3	4	4	3	5
	40	**40**	38	32	28	**40**	**40**	2.9	2.8	3.8	4.0	2.8	4.1
7	**26.55**	26.49	**26.55**	26.49	26.49	21.81	26.47	4	3	4	5	4	3
	39	34	**39**	35	37	36	**39**	2.7	2.7	3.8	4.2	4.0	2.8
8	**26.69**	26.60	26.63	26.30	26.66	21.97	**26.69**	4	3	4	3	4	5
	38	37	36	36	**38**	36	**38**	2.8	2.7	3.8	2.6	4.0	4.7
9	**26.86**	**26.86**	26.83	26.79	26.77	22.00	26.51	3	4	4	3	4	5
	37	**37**	35	36	**37**	36	**37**	2.6	3.0	3.8	2.6	4.3	4.8
10	**28.16**	**28.16**	27.39	28.10	26.41	26.00	16.85	3	4	3	5	4	4
	36	**36**	35	**36**	**36**	**36**	**36**	2.6	3.0	2.8	3.6	4.0	4.0

10 and 11 of the first Pareto front have comparable values of PES_{max} concerning points 6, 7 and 8 of the second one, but with lower values of CT.

5. CONCLUSION

This paper presented a bi-objective model that includes workers' differences in ALWABP-2. These differences are considered both in terms of experience and of physical effort, with a double evaluation, in line with what has been suggested by Calzavara et al. (2020). The major findings of this work are: 1) tasks can be categorized into different types based on workers' perception and not just according to the measurements of external evaluators. 2) The application of the new WTCM coupled with the new model allows getting a proper assignment of the workers to the stations by avoiding excessive physical efforts but also not worsening too much the cycle time. 3) It has been seen that solving the same case with a traditional SALBP approach would decrease the cycle time around 5% but with the risk of assigning workers to inappropriate stations in terms of physical workload, with severe long-term effects. The proposed approach could be useful to conduct a new job design to meet workers' needs and capabilities to support an individuality, as also requested by Sgarbossa et al. (2020). The model could be easily extended by including a task postural analysis and by introducing for each task a measure of the OCRA index (Occhipinti, 1998). In the "Force Multiplier" of the OCRA index is in fact considered the Borg Score self-evaluated by the workers. Examples of the inclusion of OCRA index or other postural assessment methods in ALBP could be found in Otto and Battaia (2017). Moreover, future applications of the model to real cases with a larger data set are needed to derive general guidelines and frameworks.

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