



RESEARCH ARTICLE

Two sided assembly line balancing with parallel allowed performance

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Abstract

Two-sided assembly line balancing (ALB) problems usually occur in plants which are producing large-sized high-volume products, such as buses, trucks, locomotives and domestic products. This paper considers the two sided line with new approach on parallel performing capability of tasks by bolding the real world locomotive production plant problem. The introduced problem is modeled by the linear integer mathematical formulation.

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Introduction and literature review

Assembly lines can be categorized in to several types such as traditional and base straight one side, U-shape one side, multi level lines, two sided and etc. The two sided assembly lines are designed usually for the plants with big size of products or products which are need to operate on both left and right sides

of them such as buses, trucks and locomotives as emphasizes in this paper. This kind of assembly line includes straight ordered workstations with tasks operating in them on the both sides along the product transport path (Figure 1).

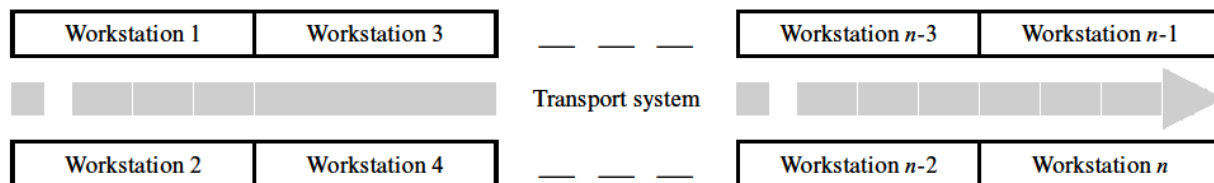


Fig.1. Two sided assembly line.

Two-ALB is mainly distinguished from traditional one sided assembly line balancing (one-ALB) in that tasks have restrictions on the operation directions. Some assembly operations prefer one of the two sides, while others can be performed at either side of the line. That is the tasks are classified into three types: L (left); R (right) ; and E (either) type tasks.

The two sided assembly lines are considered in the literature on the both solution methodology approach and the problem definition. In the literature the two-ALB has not been studied and considered as its importance in comparison with the traditional one sided one. Bartholdi, [1] is the first researcher who addressed the two sided ALB problems in a real case. He suggested a simple assignment rule which is

based on the first-fit-rule (FFR), and a major focus is placed on the development and use of an interactive program assisting humans in building solutions quickly and incrementally, the FFR heuristic considered the minimizing the number of workstations as the objective function. After that, Kim et al [2] developed a genetic algorithm to solve two-sided ALB problems. Lee et al [3] generated an assignment procedure for two-sided ALB problems, in order to maximize work relatedness and slackness. Lapierre and Ruiz [4], presented an enhanced priority-based heuristic that is developed to solve a specific two-sided ALB problem. In the case of mathematical formulations, Kim et al [1], developed the first base model considering the minimization of number of stations for a given cycle time. Then this model used by the authors for many problems of two-ALB as a base pattern. Ozcan[5], Ozcan and Toklu(a)[6] and Ozcan and Toklu(b)[7] used the base model with changing in the objective function to minimizing cycle time. Ozcan and Toklu(c) [8] also categorized these two-ALB problems on base of the objective of number of stations minimization and cycle time as TALBP-I and TALBP-II, respectively. In the case of problem definition, there are several constraints which are regularly considered in most two-ALB problems as zoning constraints, synchronous constraints and positioning constraints. Zoning constraints relates to a group of tasks to assign or not assign in same zone of production line (simaria and Vilarinho[9]), synchronous constraints describes same starting of the determined paired tasks in a mated station and positioning constraints determines tasks specific stations to be assigned or not. Wu et al [10], presented a branch and bound algorithm for TALBP-I which minimizes the length of the line and solved the TALBP-I optimally up to 148 tasks problem of Bartholdi [1]. Baykasoglu and Dereli [11] presented an ant colony optimization meta-heuristic algorithm for the two-ALB where the zoning constraint is introduced for the first time in two-ALBPs. Xiaofeng et al [12] proposed a heuristic algorithm for solving the TALBP-I where the tasks assigned to the new open stations based on the direction and the cycle time considering the earliest and latest start time of the tasks can be processed. Ozcan and According to the problem's literature the parallel tasks performance feature has not been seen and considered also the TALBP-II is the least considered objective function by the authors. In the next section the comprehensive introduced problem description is clarified by depicting local locomotive production plant considered problem. Next the problem is modeled mathematically in a linear mixed integer structure. Then the designed heuristic

algorithm is presented. The advantages, disadvantages and computational out comings are resulted in final part of the paper.

1. Two sided assembly line balancing with parallel task performance capability

This paper introduces the effects of parallel performing of paired tasks in paired mated stations in a two-sided assembly line balancing problem. Not considering of this interaction effect of parallel performing tasks is not reasonable and not acceptable, because the performance of every tasks in single direct of the line absolutely in the most situations is under the effect of paired parallel task on the other side. This effect can be in positive good trend or negative direction or in rare situations with no sense. This truth of the two-sided lines has not been seen in the literature so far and only the synchronous constraint is considered, which performs just like a precedence relation graph and not even close to the current considered problem. Parallel performance of two paired tasks in mated stations may have positive effects on cost or tasks times. Such as in local locomotive production plant, assume that the two tasks are performing in each sides of the line which both need the same quality inspector; the inspector needs equipments to check out the quality and these equipments should be transfer to station, so if these two tasks perform in parallel, the inspector can do the tests only by one transferring and one visitation, which reduces the total wasted time and transferring costs. This fact is significantly important while the equipments are heavy, big and also having the space and transferring usage limitations. After fixing longitudinal bars to fixtures, the all welding spots of small parts on longitudinal bars that prepared in previous stations should be welded. Welding is performed first on the left longitudinal bar (task A) then after smoothing the welding spots, the welding inspector enters to station with his needed equipments, next equipments should be gathered and removed from station, next the hole task of welding of right bar (task B) starts and the inspector enters with all equipments, then tests the right bar's welding quality. But as told if these both tasks of welding (tasks A and B) perform simultaneously in parallel, the inspector just comes for a single time.

Parallel performing of known paired tasks may consequently have negative effects on each other. For example, assume that the two paired parallel performing tasks, which one of them needs accuracy and attention but the other one however has no physical interference with the other one but mentally ruins the accuracy of the parallel performing task's operator which leads to reworking or low quality or

breaking down of the task. In some situations these interactions are negligible and don't need to be considered. The main focus of this paper is on mentioned first situation, which occurs frequently a lot in similar parallel tasks in locomotive assembly line's stations.

In this paper the positive effects of tasks are considered in the model of the basic two-ALB problem, where several paired tasks are determined that can perform simultaneously in parallel lines and this implementations lead to the tasks times reduction that consequently leads to total reduction of cycle time and increment in production rate. According to the sample problem in locomotive production, simultaneously implementations of the tasks of welding need additional operators whom have the same ability to perform simultaneously on the other

side, which means additional costs. To the problem considered in this paper the parallel performance of tasks limits by these costs and the costs seen in the number of parallel performances. The following section describes the above introduced problem by linear mixed integer programming formulations.

2. Mathematical Formulation

In this paper the two-sided assembly line balancing problem with additional new concept of parallel performance properties of tasks are considered and formulated as following equations. The all parameters, sets and variables are noted as follows:

Sets:

$I = \{1, 2, \dots, i, \dots, n\}$	Set of tasks
$J = \{1, 2, \dots, j, \dots, n\}$	Set of mated stations
$A_L \subset I$	Set of tasks should be done on left side
$A_R \subset I$	Set of tasks should be done on right side
$A_E \subset I$	Set of tasks don't have operational direction
$P(i)$	Set of immediate predecessors of task i
$P'(i)$	Set of immediate successors of task i
$S'(i)$	Set of successors of task i
$p_0 = \{i \in I \mid P(i) = \emptyset\}$	Set of tasks don't have any predecessors
$C(i) = \begin{cases} A_L & \text{if } i \in A_R \\ A_R & \text{if } i \in A_L \\ \emptyset & \text{if } i \in A_E \end{cases}$	Set of tasks with opposing operational direction with task i
$CC(i) = \begin{cases} A_L & \text{if } i \in A_L \\ A_R & \text{if } i \in A_R \\ \emptyset & \text{if } i \in A_E \end{cases}$	Set of tasks with same operational direction with task i
$I'(i) = \{h \mid h \in I - (P'(i) \cup P(i) \cup S'(i) \cup CC(i))\}$	Set of tasks can perform in parallel with task i
$R(i) = \{p \mid p \in I - (P'(i) \cup P(i) \cup S'(i) \cup S(i) \cup C(i))\}$	Set of tasks with no relation with task i

Parameters:

t'_i	Normal processing time of task i
t_i	Processing time of task i after parallel performance with determined paired task.
$\ I'(i)\ $	The number of tasks can perform in parallel with task i
$UBP = \left[\sum_{i \in I} \ I'(i)\ / n \right]$	Upper bound of the number of total determined paired tasks parallel performances
ct	Cycle time
SS	
$K(i) = \begin{cases} \{1\} & \text{if } i \in A_R \\ \{2\} & \text{if } i \in A_L \\ \{1,2\} & \text{if } i \in A_E \end{cases}$	Shows the direction of tasks

Variables:

x_{ijk}	If task i assigns to mated station j in direction k 1, otherwise 0
y_{ih}	If tasks i and h perform in parallel 1, otherwise 0
t_i^f	Finish time of task i
Z_{ip}	If task i perform earlier than task p 1, other wise 0

Formulation

$$\sum_{j \in J} \sum_{k \in k(i)} x_{ijk} = 1, \forall i \in I \tag{1}$$

$$\sum_{g \in J} \sum_{k \in k(h)} g x_{hgk} - \sum_{j \in J} \sum_{k \in k(i)} j x_{ijk} \leq 0, \forall i \in I - p_0, h \in p(i) \tag{2}$$

$$t_i^f - t_h^f + \mu \left(1 - \sum_{k \in k(h)} x_{hjk} \right) + \mu \left(1 - \sum_{k \in k(i)} x_{ijk} \right) \geq t_i \tag{3}$$

$\forall i \in I - p_0, h \in p(i), j \in J$

$$\sum_{h \in I'(i)} y_{ih} \leq 1, \forall i \in I \tag{4}$$

$$y_{ih} = y_{hi}, \forall i, h \in I \tag{5}$$

$$\sum_{i \in I} \sum_{h \in I'(i)} y_{ih} \leq UBP \tag{6}$$

$$\sum_{i \in I} \sum_{h \in \{I-I'(i)\}} y_{ih} = 0 \quad (7)$$

$$-\mu \left(2 - \sum_{k \in k(i)} x_{ijk} - \sum_{\substack{g \in J \\ g \neq j}} \sum_{k \in k(h)} x_{hgk} \right) + y_{ih} \leq 0 \quad (8)$$

$$\forall i \in I, h \in I'(i), j \in J$$

$$-\mu(2 - x_{ijk} - x_{hjk}) + y_{ih} \leq 0 \quad (9)$$

$$\forall i \in I, h \in I'(i), j \in J, k \in k(i) \cap k(h)$$

$$-\mu(1 - \sum_{h \in I'(i)} y_{ih}) + t_i \leq t'_i, \forall i \in I \quad (10)$$

$$\mu(1 - \sum_{h \in I'(i)} y_{ih}) + t_i \geq (4/5)t'_i, \forall i \in I \quad (11)$$

$$-\mu \left(\sum_{h \in I'(i)} y_{ih} \right) + t_i \leq t'_i, \forall i \in I \quad (12)$$

$$\mu \left(\sum_{h \in I'(i)} y_{ih} \right) + t_i \geq t'_i, \forall i \in I \quad (13)$$

$$t_p^f - t_i^f + \mu(1 - x_{pj}) + \mu(1 - x_{ijk}) + \mu(1 - z_{ip}) + \mu.y_{ipj} \geq t_p \quad (14)$$

$$\forall i \in I, p \in R(i), j \in J, k \in K(i) \cap K(p)$$

$$t_i^f - t_p^f + \mu(1 - x_{pj}) + \mu(1 - x_{ijk}) + \mu.z_{ip} + \mu.y_{ipjk} \geq t_i \quad (15)$$

$$\forall i \in I, p \in R(i), j \in J, k \in K(i) \cap K(p)$$

$$z_{ip} = 1 - z_{pi}, i \in I, p \in R(i) \quad (16)$$

$$t_i^f - t_h^f + t_h - t_i - \mu(1 - y_{ih}) \leq 0, \forall i \in I, h \in I'(i) \quad (17)$$

$$t_i^f \leq ct, \forall i \in I \quad (18)$$

$$t_i^f \geq t_i, \forall i \in I \quad (19)$$

The above model minimizes cycle time for a given number of stations (TALBP-II). Constraint (1) describes that every task should assign only to one station. Constraint (2) assures the precedence relations. Constraint (3) controls the precedence relations of tasks in both sides of station. Constraint (4) limits the number of parallel performing tasks to 2. Constraint (5) controls the number of parallel performing of a task. As told in previous section, the parallel performances lead to more costs and these costs seen in the number of parallel performances, and so the total number of performances of these paired tasks is limited by Constraint (6). Constraints (7), (8) and (9) declare the pair of tasks that cannot

perform together in parallel. Constraints (10) and (11) describes that if the two paired tasks perform in parallel their process times reduce to assumed lower time, in this paper this value is assumed 80 percent of the normal time. Constraints (12) and (13) declare the processing time of non parallel performed paired tasks as normal times. Constraints (14) and (15) describe the tasks finish times on the basis of their assignments in stations. Constraint (16) declares that every two tasks perform earlier or later than each other, of course considering the non parallel tasks. Constraint (17) assures the parallel simultaneous starting of two paired tasks. Constraint (18) calculates the cycle time of the line. Constraint (19)

provided with the aim of correct calculation of first assigned task's finish time in stations.

2.1. Model solution CPU time

Above model is solved by the Lingo.11 mathematical optimization software and ran on the PC with 2.2 GHz processor. The runs of the model for several small examples of standard TALBP-II and also TALBP-II with parallel performances demonstrates the way differences of problems complexity between these two problems. These differences of the both problems solutions are depicted as column chart in Figure 2.

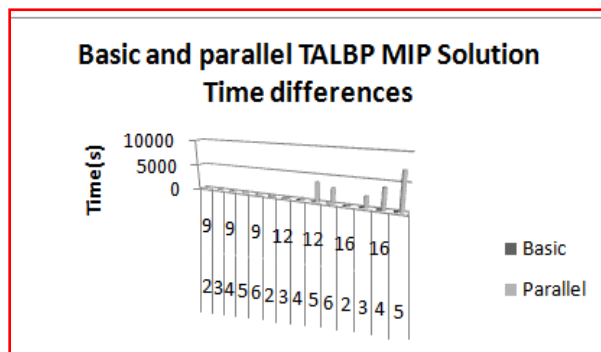


Fig.2. Basic and Parallel TALBP MIP solution time differences

Above chart shows that the solution times of the simple TALBP are negligible in comparison with TALBP with parallel performing properties and this difference shows the complexity of the considered problem.

3. Computational Results

In this section the results of mathematical formulation are depicted. Set of standard problems with 9, 12 and 16 tasks are considered as small size problems and the results and comparisons are shown in Table.1 in both the parallel and non-parallel basic format of the problem.

problem	No. of mated stations	\bar{ct}_1	\bar{ct}_2	UBP	MIP with parallel		MIP basic	
					ct	Time(s)	ct	Time(s)
P9	2	8.2	9.25	2	9	8	10	1
	3	5.47	6.17	2	7.2	21	9	2
	4	4.1	4.625	2	5	17	6	1
	5	3.28	3.7	2	4.8	33	6	1
	6	2.73	3.083	2	4.8	21	6	1
P12	2	5.45	6.25	3	6	39	7	5
	3	3.63	4.17	3	4.4	186	5	5
	4	2.725	3.125	3	3.6	491	4	9
	5	2.18	2.5	3	3	3772	3	3
	6	1.82	2.083	3	2.4	3002	3	2
P16	2	18.4	20.5	3	20.2	120	22	13
	3	12.27	13.7	3	14	2194	16	98
	4	9.2	10.25	3	12	4061	15	123
	5	7.36	8.2	3	9.6	7208	11	141

4. Conclusions and future research proposals

Two-sided assembly line balancing (ALB) problems usually occur in plants which are producing large-sized high-volume products, such as buses, trucks, locomotives and domestic products. This paper considers the two sided line with new approach on parallel performing capability of tasks by bolding the real world locomotive production plant problem. The introduced problem is modeled by the linear integer mathematical formulation. The solution time for parallel and non parallel basic format of TALB problems shows that the complexity level of these two type of problems are very different, since the solution times of model for basic format are about several minutes, but for the case of parallel they are about several hours.

For the future studies this paper suggests the more powerful searching based algorithms with initial solutions of the final result of a very simple and applicable algorithm.

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