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Balancing of parallel assembly lines with mixed-model product

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Abstract— **The single-model assembly line is not efficient for today's competitive industry because to respond the customer's expectation, companies need to produce mixed-model products. This research takes advantages of the parallel assembly lines to balance mixed-model in parallel assembly line and allocating tasks of models to workstations to reduce the cycle times. To solve the problem, the meta-heuristic algorithms was developed and coded in MATLAB®. This research shows the modification of the mixed-model production into parallel assembly line and an algorithm can be used for more than two products together with different cycle times. In addition, now the modification allows Mixed-Model Parallel Assembly Line Balancing (MMPALB) becomes a useful tool to allocate all tasks of the mixed-model in the parallel lines, and balances with the minimum cycle time for each model.**

Keywords-component; mixd-model product, parallel assembly lines, artifitial intelegent, tabu search

I. INTRODUCTION

An assembly line consists of workstations that produce a product as it moves successively from one workstation to the next along the line, which this line could be straight, u-line or parallel until completed. To balance an assembly line, some methods have been originally introduced to increase productivity and efficiency. These objectives are achieved by reducing the amount of required manufacturing time to produce a finished product, by reduction in number of workstations or both of them. The Assembly Line Balancing Problem (ALBP) has been extensively studied [1], but it is still an important problem which many researchers try to create new design and balance for the ALBP to achieve more efficiency especially in new assembly line design like parallel assembly lines. The arrangement of tasks in workstation of an assembly line are followed by two main objectives [2-3]. The first one is type I problem that is related to determine the minimum number of required workstations to achieve the specified cycle time and the second one is type II for allocating the tasks to the workstations in such a way the maximum required time for the assembly at any given workstation be minimum in the all-available workstations. Comprehensive surveys of related researches have been appeared in [4-7] Many publications are available concerning the design, balancing and scheduling for Single, Multi and Mixed-Product lines.

The mixed-model production defined as the products, which differ from each other with respect to size, color, material, or equipment, are manufactured on the same line [8]. This situation presents further challenges since tasks, processing times and precedence constraints vary from model to model.

The Mixed-Model Assembly Line (MMAL) is a more complex to balance in which several types of the products are assembled simultaneously on the line which considering to the shape of line which in single line all tasks allocate in one and in parallel assembly line in more than one line. In addition, it entails the additional considerations of the interactions between the assembled models [9]. The importance of the MMAL Balancing Problem (MMALBP) in the modern industry encouraged several researches in the last few years. (e.g. Erel and Gökçen [10], Esmaeilian et al. [11-13], Gökçen and Erel [14], Jin and Wu [15], Kurashige et al. [16], Matanachai and Yano [17], Merengo et al. [18], Özcan and Toklu [19], Song et al. [20], and Vilarinho and Simaria [21]).

In the other hand, Parallel Assembly Lines (PALs) are considered as production system, which consists of a number of assembly lines in parallel status. On the each line, a certain number of product(s) considering to type of product(s) manufactured observing a cycle time. By arranging the lines in a favorable style, it is possible to increase efficiency of the production system by combining workstations of neighbor lines during balancing the lines [12-13, 22-23].

Studies on the parallel lines are quite few [23]. In designing the PAL, Süer and Dagli [24] suggested heuristic procedures and algorithms to determine the number of lines and the line configuration dynamically. Gökçen et al. [23] suggested heuristic procedures and a mathematical model for the multiple or parallel assembly line balancing problem.

Lusa [25] described the parallelization of the assembly lines is a strategy that may provide numerous advantages to both the company and the workers. The main advantages of PALs over a single line are firstly to improve the balance of the overall production system and productivity [5, 26]. Also, PALs increase the system flexibility [26-28], and reduces failure sensitivity [26-28]. Therefore, with considering the benefits of parallel assembly line the complexity of MMAL will be reduced. Successful Mixed Model Parallel Assembly Line (MMPAL[11, 13]) requires solutions to the following problems (see Figure 1). The goal of this paper is to present a heuristic procedure to assign MMAL's tasks to PALs and create an initial balancing of the MMPAL for using as the initial solution of meta-heuristic method.

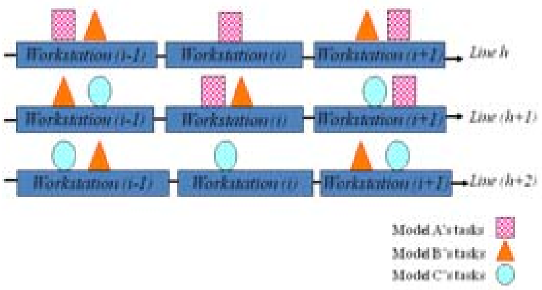


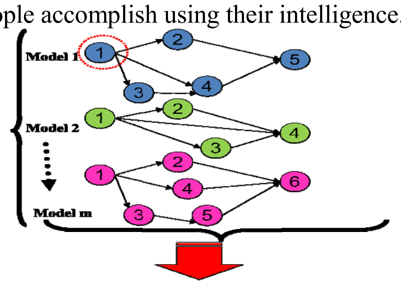
Figure 1. Mixed-model parallel assembly lines

II. MIXED-MODEL PARALLEL ASSEMBLY LINES BALANCING PROBLEM

This research has focused on allocating tasks to balance the mixed-model parallel assembly lines. This model, which is called Mixed-Model Parallel Assembly Line Balancing (MMPALB), is a new problem in ALBP. Therefore, the research problem defined as a set of different models (Nm) must be assembled simultaneously in parallel assembly lines. Each model has its own set of precedence requirements. Each task (i) of the models has a processing time (tim) which models may be different from number of tasks (Im), cycle time (Cm), and minimum number of workstations. Consequently, the main aim of this research is to assign the i-th task of the m-th model to the k-th workstation on the h-th parallel line to minimize the cycle time (Ch) for each product (type II) formulated in a mathematical model (see Figure 2).

III. DEVELOPED METAHEURISTIC ALGORITHM

Xhafa and Abraham [29] defined meta-heuristic methods as an Artificial intelligence (AI) way to survey the solution space. On the other hand, AI is a field of study concerned with designing and programming machines to accomplish tasks that people accomplish using their intelligence.



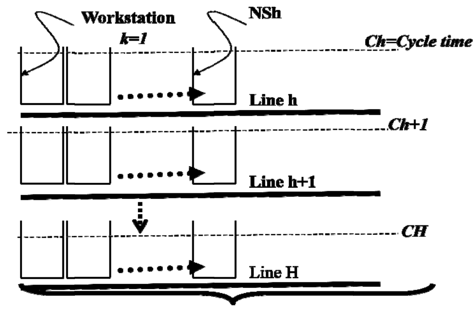


Figure 2. Mixed-model parallel assembly lines balancing problem

Based on the ALBPs, the best performing methods to solve the ALBPs optimally are those, which include systems such as local search techniques. These techniques are embedded within meta strategies that overcome local optimality by accepting non improving moves and thus poorer solutions [29]. Since the ALBP is NP-hard, most authors proposed meta-heuristic procedures to solve ALBP.

Tabu Search (TS) is a repetitive improvement algorithm based on neighborhood search methods, which uses various types of memories and strategies to direct this search. TS was firstly presented by Glover [30-34] as an approach for solving combinatorial optimization problems. This method was designed to move from one solution in a search space to another solution iteratively with the function of discovering a global optimum for a combinatorial optimization problem.

The search to find solution of the MMPALBP consists of two stages: the initial solution program that generates a feasible initial solution, and the TS improvement that takes an initial solution and improves upon it.

The TS heuristic algorithm cannot generate an initial solution, in that it can only improve initial solutions. To generate an initial solution, a composite heuristic decision rule is used in this research to determine the initial number of workstations for each line, to assign tasks to specific workstations, and to calculate the sum of total tasks time in each workstation [13].

The basic idea of the TS heuristic is to regulate some (most recent) moves to prevent cycling and accept non-improving moves to escape from a local optimum in search of the global optimum.

A. *Tabu length*

If the process of TS algorithm is not guided by some rules, it will be leaded to a local optimal solution. TS introduces a memory structure that forbids or penalizes certain moves that would return to a recently visited solution. This memory structure plays an essential role in the search process. In the assembly line balancing problems, the flexible memory is defined as set of tabu moves from given tasks and workstations.

Tabu Length (TL) presents the number of tabu, which will be put on the tabu set. This memory structure plays an essential role during the search process. In the TMMPALB, the flexible memory is defined as a set of tabus from tasks, lines and workstations, which its length has been identified as 10 (see Equation 1).

$$\{(task, line, workstation)_j \mid j = 0,...,10\} \rightarrow Tabu\_l = 10 \quad (1)$$

The main idea of develop TS meta-heuristic for mixed-model parallel assembly lines is to find the best solution (or move) in the neighborhood of the current solution and thus to proceed to the best solution. Therefore, all possible exchanges in each period are considered. Each exchange is defined as a move because of change the solutions. The TS searches all the candidate moves in the neighborhood of the current solution, and selects the best move with maximum improvement to exchange. The candidate moves for the mixed-model parallel lines are the exchange of tasks from one workstation to other workstations. Next, the total improvement for each move is computed, and finally the best admissible move is selected considering to high index of improvement. A best admissible move is a move that is either non-tabu or push the solution to obtain the best result. In other words, the total improvement of the neighboring solution obtained by performing the move is better than the best solution found so far by following the aspiration criterion. The best admissible move is the most beneficial acceptable move.

To find better solution spaces, TS requires some additional rules to make it more intelligent. The flexible memory is used to a short-term horizon. That is to remember the most recent moves to avoid being trapped in local optimum. Whether the good solutions visited up to now have some common characteristics, usually it is valuable to observe. This surveillance can later be used to lead the neighborhood in the search process to prefer solutions with characteristics that have occurred often in good solutions previously visited. This creates an intensification strategy for the search. It can be used to encourage solutions to satisfy such properties and discourage solutions that violate them [31-32].

In the mixed-model parallel assembly lines balancing method, the idea is to allocate as much time as possible to each workstations of parallel lines, so that the cycle time for each line is minimized. The intensification and diversification strategies can be achieved by introducing a function, which is called IDS, and adding into the objective function. Therefore, the objective function can be calculated with the following equation (2).

The objective function value is

$$= \text{New objective function value - old objective function value} + IDS \quad (2)$$

The stopping criterion for the proposed tabu search heuristic is defined based on the number of iterations, which should be greater than 1000 iterations.

IV. NUMERICAL EXAMPLE

The Merten's test problem (downloadable under www.assembly-line-balancing.de) was selected to check the performance of proposed algorithm and to illustrate how the proposed heuristic works. The data set which is well-known as Merten data set includes three models (M=3) and each model is assembled through 7, 6, and 8 tasks (see Figure 3).

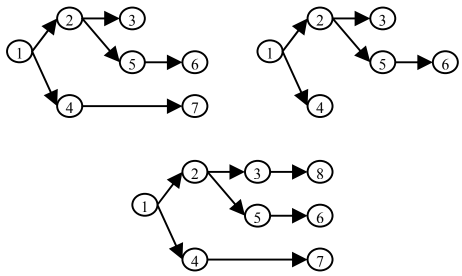


Figure 3. Merten data set precedence diagrams[23]

Table I present the operation time of each task for Merten data set. In the Merten's test problem, the initial heuristic is started with 9, 11, and 13 (t.u.) as the initial cycle times for models 1, 2, and 3 respectively with 6, 5, and 5 as the minimum number of workstation in case of independent assembly lines (Gökçen [23]).

TABLE I. MERTEN DATA SET TASKS PROCESSING TIME (T.U.)[23]

i	1	2	3	4	5	6	7	8	9	10
t_{i1}	1	5	4	3	5	6	5	--	--	--
t_{i2}	1	5	4	3	5	6	--	--	--	--
t_{i3}	1	5	4	3	5	6	5	4	--	--

By considering that TMMPALB procedure, it is attempted to find the minimum cycle time for each parallel line by changing the arrangement of tasks in the parallel assembly line's workstations. The results presented in Table II shows that the tasks of each model in which workstation have been assigned in index. As an example, "X(3,1,1,2)=1" represent that the 3rd task of the 1st model has been assigned to the 1st line in the 2nd workstation.

TABLE II. FINAL BALANCING ARRANGEMENT

*** *Line=1* ***	*** *Line=2* ***	*** *Line=3* ***
X(1,1,1,1)=1 *X(2,1,1,1)=1* *X(1,2,1,1)=1* *X(3,1,1,2)=1* *X(5,1,1,2)=1* *X(7,1,1,3)=1* *X(3,2,1,3)=1* *X(6,1,1,4)=1* *X(4,2,1,4)=1*	*X(4,1,2,1)=1* *X(2,2,2,1)=1* *X(5,2,2,2)=1* *X(4,3,2,2)=1* *X(6,2,2,3)=1*	*X(1,3,3,1)=1* *X(2,3,3,1)=1* *X(3,3,3,1)=1* *X(5,3,3,2)=1* *X(7,3,3,2)=1* *X(6,3,3,3)=1* *X(8,3,3,3)=1*

The results of TMMPALB procedure is presented in the Table III. As it appeared from Table III, the acceptable smoothness and imbalanced in the parallel assembly lines workstations have been achieved.

TABLE III. FINAL ST (T.U.) AND C (T.U.) FOR THE 1ST TEST PROBLEM

		H		
		STk1	STk2	STk3
k	1	9	8	10
	2	9	8	10
	3	8	8	10
	4	6	0	0
Ch		9	8	10

The results present the unchanged cycle time for the 1st model and the improved cycle time for the 2nd line from 11 to 8 (t.u.) and for the 3rd line from 13 to 10 (t.u.).

V. Computational Result

The performance of the proposed meta-heuristic mixed-model parallel assembly lines is tested on the 4 test problems which are taken from Merten in the ALB literature. Each problem consists of a same number of tasks, same task times, and same precedence relations but in case of different cycle times. This problem is located in small size test problem. In this test problem, Gökçen's data test [23], four test prolems have been created and by TMMPALB tried to balance them in parallel assembly lines (see Table IV).

TABLE IV. Computational Result

Test Problem	Independent assembly line						Mixed-model parallel assembly lines						Cycle times improvement (%)		
	NS			C			NS			C					
	1	2	3	1	2	3	1	2	3	1	2	3			
1	6	5	5	9	11	13	4	3	3	9	8	10	0.00	27.27	23.08
2	5	5	4	11	13	17	3	2	2	11	12	16	0.00	7.69	5.88
3	5	4	6	13	17	9	3	2	4	10	11	9	23.08	35.29	0.00
4	4	6	5	17	9	11	2	3	4	16	6	10	5.88	33.33	9.09

VI. Conclusion

A meta-heuristic method was presented for allocating and balancing of the mixed-model products through the parallel assembly lines. The experiment showed that by using TMMPALB it is possible to allocate more than one model (Mixed-Model) in the parallel assembly lines and balance them without any limitation in the number of models, number of parallel assembly lines, and number of tasks for each model.

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