Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-12 (2016) 921–925

Resource Constrained Disassembly Line Balancing Problem

Süleyman Mete[a], Zeynel Abidin Çil[b], Eren Özceylan[a], Kürşad Ağpak[a]

[a]*Department of Industrial Engineering, University of Gaziantep, 27310, Gaziantep, Turkey*
(e-mails: smete@gantep.edu.tr,erenozceylan@gmail.com,agpak@gantep.edu.tr)
[b] *Department of Manufacturing Engineering, University of Batman, 72060, Batman, Turkey*
(e-mail: cilzeynelabidin@gmail.com)

Abstract: The disassembly line balancing (DLB) problem is the process of allocating a set of disassembly tasks to an ordered sequence of workstations in such a way that optimizes some performance measures (e.g., number of stations, hazardous components number, cycle time and work load). When disassembly operations are done on disassembly line, sometimes they need specific resources such as a robot, equipment, material, specific machine or qualified staff while working at the workstation. This issue also raises resource constrained disassembly line balancing (RCDLB) problem. Therefore, in this study, a mathematical model is presented for DLB problem by considering resource constraints. The objective is to minimize the number of resources and workstations under determined cycle time. The mathematical model is solved by using a mathematical programming package called as GAMS-CPLEX. Two examples from literature are solved and analyzed in order to test validity of the proposed model.

Keywords: Disassembly line, mathematical model, resource constrained

1. INTRODUCTION

Disassembly operation is a systematic approach that removes a part, or a group of parts or a subassembly from a product or separating a product into all of its parts for a given objective (Güngör and Gupta, 2001). Disassembly operations can be performed at a single workstation, in a disassembly cell or on a disassembly line. Although a single workstation and disassembly cell are more flexible, the highest productivity rate is provided by a disassembly line and hence balancing a disassembly line is the best choice for disassembly processes (Kalaycı and Gupta, 2014). DLB problem deals with the assignment of disassembly tasks to a set of ordered disassembly workstations while considering the disassembly precedence constraints to satisfy some performance indicators. The first published scientific study related with DLB belonged to Güngör and Gupta (2001) and for more than a decade, many studies were made on this subject. During this period various new balancing problem concepts such as straight (Altekin et al. 2008; Koç et al. 2009; Altekin and Akkan, 2012), U-type (Avikal and Mishra, 2012; Avikal et al. 2013), parallel (Aydemir and Türkbey, 2013; Hezer and Kara, 2015), mixed-model (Agrawal and Tiwari, 2008; Paksoy et al. 2013) etc., and solution algorithms such as exact solutions (Koç et al. 2009; Bentaha et al. 2015), ant colony optimization (Agrawal and Tiwari, 2008; Ding et al. 2010; Kalaycı and Gupta, 2013), genetic algorithm (McGovern and Gupta, 2007; Kalaycı et al. 2015), tabu search (Kalaycı and Gupta, 2014) for those problems have been produced. The common thing for all these problems is using both the operator and the machine in the most efficient way. However, due to nature of disassembly line conditions such as hazardous, explosive materials and precision tools, some special resources are needed. As a result of these situations usage of special equipment and/or professional workers, which are able to perform more than one process, is required. In order to benefit from disassembly lines more, these equipment and workers must be added to the line in a way by which high efficiency measures (maximum usage, minimum the number of workstations) can be achieved. Although resource constraints are considered in assembly line balancing problems by Pinnoi and Wilhelm (1997), Ağpak and Gökçen (2005), Corominas et al. (2010), and Mete and Ağpak (2013), this issue is not handled – to the best knowledge of the authors – in DLB problems. In this paper, DLB problem is studied with resource constraints. Efficient usage of resources that perform disassembly line operations has been aimed by balancing the line with the minimum number of workstations. The paper is organized as follows: after the introduction and literature review in this section, the second part will address the DLB formulation for the resource constrained cases. In the third part, the solutions of the resource constrained DLB problem on numerical examples are given, and discussed. In the last part, conclusion and suggestions for future studies are addressed.

2. MATHEMATICAL MODEL FOR RESOURCE CONSTRAINED DISASSEMBLY LINE BALANCING PROBLEM

In this study, resource constraints are considered when DLB problem is solved. The objective of this study is to present a solution method for being able to solve DLB problem considering resource constraints. For this reason, a mathematical model is presented. The proposed model is developed by combining the approaches of Ağpak and Gökçen (2005) which is resource constraint for simple assembly line balancing problem and of Koç et al. (2009) integer programming formulation for DLB. The objective of the model is to minimize number of resources that is assigned to workstations. These resources expressed in illustration may be robots, limited number of workers or

2405-8963 © 2016, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.07.893

limited number of specific machines. In this study, each of tasks is performed by only one resource (resource R1 or R2). For example, resource R1 can perform {1, 5, 7, 3, 9} tasks and resource R2 can perform {2, 6, 8, 4} tasks for 9 task DLB problem. Therefore, intersection of tasks is empty cluster (Ağpak and Gökçen, 2005). Model assumptions and notations for the proposed mathematical model of RCDLB problem are given as follows:

2.1 Model Assumptions

These assumptions are shared for mathematical model. In this study, the resource constraint disassembly lines consider to operate under the following assumptions:

- Each disassembly task times are known.
- A disassembly task may result in extracted of one or more parts.
- Each task is assigned to only one workstation.
- The total processing time of the assigned tasks for each workstation must be less than the cycle time.
- Precedence relations between tasks must be satisfied.

2.2. Notations

Notations are introduced for the proposed model. The following notations and equations will be used to describe the problem characteristics.

Indices

I	Task number for	i= 1…N (task)
J	Workstation number	j=1…M (station)
r	Types of resources for	r=1…R
T	Cycle time	

Parameters

d_{Bi}	It is the task time of normal node (B_i)
A_k	It is the artificial nodes in transformed AOG
B_i	It is the normal nodes in transformed AOG
$P(A_k)$	It is the immediate predecessor set of A_k
$P(B_i)$	It is the immediate predecessor set of B_i
$S(A_k)$	It is the immediate successor set of A_k
$S(B_i)$	It is the immediate successor set of B_i

Decision Variables

H_{jr} 1, if there is resource *"r"* in workstation *"j"*; 0 otherwise

S_{jr} It is the set of tasks that can be fulfilled in workstation *"j"* with resource *"r"*

X_{ij} 1, if task B_i is assigned to workstation *"j"*; 0 otherwise

F_j 1, If workstation *"j"* is opened; 0 otherwise

Z_i 1, If task B_i is performed; 0 otherwise

Basic structure integer programming formulation of RCDLB problem is as follows:

Objective function

$$Min\ \sum_{r=1}^{R}\sum_{j=1}^{M} H_{jr} \qquad (1)$$

Subject To

$$\sum_{i\in S_{jr}} X_{ij} - \| S_{jr} \| H_{jr} \le 0, \qquad r = 1, \dots R \qquad (2)$$

$$\sum_{i:B_i\in S(A_k)} Z_i = 1 \qquad \forall_{k=0} \qquad (3)$$

$$\sum_{i:B_i\in S(A_k)} Z_i = \sum_{i:B_i\in P(A_k)} Z_i \qquad \forall_{k=1,2,\dots,h} \qquad (4)$$

$$\sum_{j=1}^{J} X_{ij} = Z_i \qquad \forall_{i=1,2,\dots,I} \qquad (5)$$

$$\sum_{i:B_i\in P(A_k)} \sum_{j=1}^{v} X_{ij} \le \sum_{i:B_i\in S(A_k)} X_{iv} \qquad \forall_{k=1,2,\dots,K} \qquad (6)$$

$$\sum_{i=1}^{I} X_{ij} d_{Bi} \le TF_j \qquad \forall_{j=1,2,\dots,J} \qquad (7)$$

$$X_{ij}, F_j, Z_{i,} H_{jr} \in \{0,1\} \qquad \forall_{i=1,2,\dots,I;j=1,2,\dots,J} \qquad (8)$$

The objective function is to minimize the number of resources that is assigned to workstations. Constraint (2) provides that if at least one task is done in workstation *"j"* with resource *"r"* and then resource *"r"* is used in workstation *"j"*, H_{jr} value takes 1. Exactly one of the OR-successors is selected with constraints (3) and (4). Constraint (5) assures that selected task is assigned to at most one workstation. Constraint (6) handles the precedence relations between the normal nodes: Since exactly one of the OR-successors and one of the OR-predecessors of an artificial node will be chosen, Constraint (6) makes sure that the successor selected among the OR-successors will be assigned to the higher-indexed workstation than the predecessor chosen among the OR-predecessors is assigned. Constraint (7) is the cycle time constraint that sum of task times assigned to each workstation does not exceed the cycle time. Last constraint (8) is the binary restrictions.

3. NUMERICAL EXAMPLE

Two examples which are 23-task and 30-task test problems from literature are solved to illustrate efficiency of model in this part. The proposed model is formulated with GAMS/CPLEX (General Algebraic Modeling System), and experiments are conducted on a computer Intel Xeon 4 Core 2.40 GHz processor with 8 GB RAM. Cycle time is used as 25 and 35 second for radio example and sample product respectively. Maximum number of workstation of sample product and radio are determined as the same, 5 workstations. Two resource types (R1 and R2) are considered in this study. Resources for each task are determined randomly using mainly the same approach with Ağpak and Gökçen (2005). Task time and resource required for each task of sample product is shown Table 1.

The transformed AOG (TAOG) of the sample product with 23-tasks is shown in Fig. 1. In Table 1 the resources and task times are presented. The problems are solved for two cases, which are with/ without resource constraints.

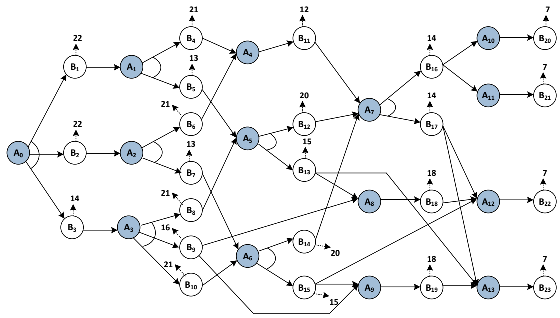

Figure 1: TAOG of the sample product (Koç et al. 2009)

Table 1: Task times and required resources of Sample product

Tasks	*Task Time*	*Resource Type*
1	22	R1
2	22	R2
3	14	R1
4	21	R2
5	13	R2
6	21	R2
7	13	R1
8	21	R2
9	16	R1
10	21	R2
11	12	R1
12	20	R2
13	15	R2
14	20	R1
15	15	R1
16	14	R2
17	14	R1
18	18	R1
19	18	R2
20	7	R1
21	7	R2
22	7	R2
23	7	R1

Table 2 indicates the results acquired when the proposed model is run without resource constrained. In first case, the objective is to minimize number of workstations for a given cycle time.

Table 2: Results of balanced DLB example problem without resource constraits

Opened station	Assigned task	Required resource	Idle Time
1	1-5	R1+R2	0
2	13	R2	20
3	18-22-23	R1+ R2	3
Total		2*R1+3*R2	23

When same problem is solved using RCDLB model, we get the results of Table 3.

Table 3: Results of balanced DLB example problem with resource constraits

Opened station	Assigned task	Required resource	Idle Time
1	1	R1	13
2	5-13	R2	7
3	18-22-23	R1+R2	3
Total		2*R1+2*R2	23

Same total idle time and number of workstations are achieved from two cases. In Table 2 and 3, two case models are compared according to required resources for 23-task test problem. First case, for balancing of the DLB problem three workstations and 5 resources (2 units of R1 type and 3 units of R2 type) are being used in the DLB model without resource constraints.

On the other hand, the objective of the second case is to minimize the resources that are assigned to workstations. This case, which is considering resource constrained model, three workstations and 4 resources (2 unit of R1type and 2 unit of R2 type) are used. Thus, 1 unit of resource (resource R2) is saved. Therefore, this solution is the best according to number of resources; the best workstations number is also reached.

Radio example also is solved for considering without/with resource constrained. Transferred AND/OR graph of the radio example is given Figure 2 and required resources for each task is given Table 4.

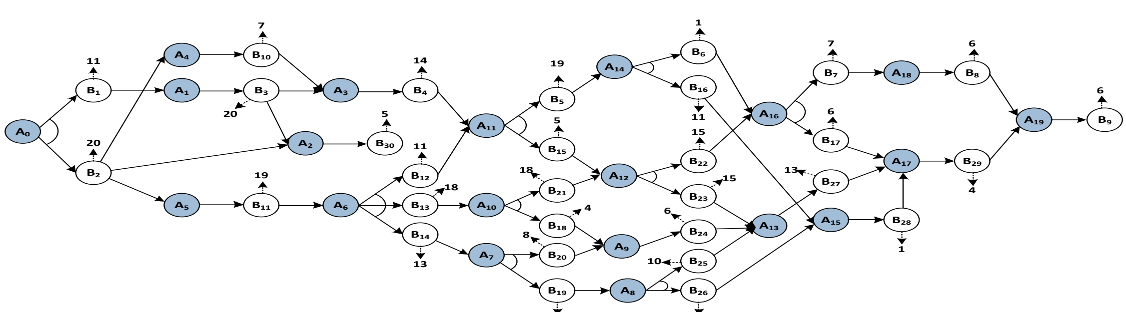

Figure 2: TAOG of the radio example (Altekin and Akkan, 2012)

Table 4: Task times and required resources of radio example

Tasks	*Task Time*	*Resource Type*
1	11	R2
2	20	R2
3	20	R1
4	14	R2
5	19	R1
6	1	R2
7	7	R1
8	6	R1
9	6	R1
10	7	R2
11	19	R1
12	11	R2
13	18	R1
14	13	R1
15	5	R1
16	11	R2
17	6	R1
18	4	R1
19	6	R2
20	8	R1
21	18	R2
22	15	R2
23	15	R1
24	6	R1
25	10	R1
26	20	R2
27	13	R2
28	1	R2
29	4	R1
30	5	R1

Results of the model without resource constraints case are presented in Table 5. According to Table 5, 4 units of R1 type and 3 units of R3 type resources are used to done disassembly tasks. In the first and second case (with/without resource constrained), same number of workstation is opened.

Table 5: Results of balanced DLB radio example without resource constraints

Opened station	Assigned task	Required resource	Idle Time
1	1	R2	14
2	3-30	R1	-
3	4-15	R1+R2	6
4	23	R1	10
5	27-29-9	R1+R2	2
Total		4*R1+3*R2	32

On the other hand, second case 4 units of R1 type and 2 units of R2 type resources are used (see Table 6). In this case one resource (one unit of R2 type) is preserved when compared with first case.

Table 6: Results of balanced DLB radio example with resource constraints

Opened station	Assigned task	Required resource	Idle Time
1	1	R1	14
2	3-30	R1	-
3	4	R2	11
4	5-6	R1+R2	5
5	7-8-9	R1	6
Total		4*R1+2*R2	36

The main objective of the proposed model, when disassembly tasks are being assigned to the workstations, the tasks that can be performed by the same resource should be assigned to the same workstation. In this way, less resource will be used as shown on Table 3 and Table 6 for the second case (with resource constraints).

4. CONCLUSIONS

To the best of our knowledge, this study is the first attempt to solve RCDLB problem. In real life application, some resources such as specific machines, limited number of workers or robots are restricted to perform a disassembly task. These conditions also expose the problem of resource constraint. To achieve this aim, a mathematical model by combining the approaches of Ağpak and Gökçen (2005) and Koç et al. (2009) is adapted to RCDLB problem. The objective of proposed approach is to establish DLB with minimum resources and workstations number. This approach provides resource saving or use of resources efficiently as much as possible. Results of model show that the proposed method is efficient.

For future, proposed approach can be applied to other types of DLB problems such as parallel, two-sided, U-type and etc. Different resource scenario can be considered like two or more than and generalized resources cases in future research. Heuristic algorithms can be developed for the RCDLB problem.

REFERENCES

Agrawal, S. and Tiwari, M. K. (2008). A collaborative ant colony algorithm to stochastic mixed-model U-shaped disassembly line balancing and sequencing problem. *International Journal of Production Research,* 46 (6), 1405–1429.

Ağpak, K. and Gökçen H. (2005). Assembly line balancing: Two resource constrained case. *International Journal of Production Economics*, 96, 129–140.

Altekin, F.T., Kandiller, L., and Ozdemir, N.E. (2008). Profit-oriented disassembly-line balancing. *International Journal of Production Research*, 46 (10), 2675–2693.

Altekin, F.T. and Akkan, C. (2012). Task-failure-driven rebalancing of disassembly lines. *International Journal of Production Research*, 50 (18), 4955–4976.

Aydemir, A.K. and Türkbey, O. (2013). Multi-objective optimization of stochastic disassembly line balancing with station paralleling. *Computers & Industrial Engineering*, 65 (3), 413–425.

Avikal, S., and Mishra, P.K. (2012). A new U-shaped heuristic for disassembly line balancing problems. *Pratibha: International Journal of Science, Spirituality, Business and Technology*, 1 (1), 2277—7261.

Avikal, S., Jain, R. and Mishra, P. (2013). A heuristic for U-shaped disassembly line balancing problems. *MIT International Journal of Mechanical Engineering*, 3 (1), 51–56.

Bentaha, M.L., Battaïa, O. and Dolgui, A. (2015). An exact solution approach for disassembly line balancing problem under uncertainty of the task processing times. *International Journal of Production Research*, 53 (6), 1807–1818.

Corominas A., Ferrer L. and Pastor R. (2010). Assembly line balancing: general resource- constrained case. *International Journal of Production Research*, 49 (12), 3527-3542.

Ding, L.P., Feng, Y.X., Tan, J.R. and Gao, Y.C. (2010). A new multi-objective ant colony algorithm for solving the disassembly line balancing problem. *The International Journal of Advanced Manufacturing Technology*, 48 (5-8), 761–771.

Güngör, A. and Gupta, S. M. (2001). “A Solution Approach to the Disassembly Line Balancing Problem in the Presence of Task Failures.” *International Journal of Production Research* 39 (7): 1427–1467.

Hezer, S. and Kara, Y. (2014). A network-based shortest route model for parallel disassembly line balancing problem. *International Journal of Production Research*, 53 (6), 1849–1865.

Kalayci, C.B. and Gupta, S.M. (2013). Ant colony optimization for sequence-dependent disassembly line balancing problem. *Journal of Manufacturing Technology Management*, 24 (3), 413–427.

Kalaycı C.B. and Gupta, S.M. (2014). A Tabu Search Algorithm for Balancing a Sequence-dependent disassembly line. *Production Planning & Control: The Management of Operations*, 25 (2), 149-160.

Kalaycı, C.B., Polat, O. and Gupta, S.M. (2015). A hybrid genetic algorithm for sequence-dependent disassembly line balancing problem. *Annals of Operations Research*, doi: 10.1007/s10479-014-1641-3.

Koç, A. Sabuncuoğlu, I., And Erel, E. (2009). Two exact formulations for disassembly line balancing problems with task precedence diagram construction using an AND/OR graph. *IIE Transactions*, 41 (10), 866–881.

McGovern, S.M. and Gupta, S.M. (2007). A balancing method and genetic algorithm for disassembly line balancing. *European Journal of Operational Research*, 179 (3), 692–708.

Mete, S. and Ağpak, K. (2013). Multi objective generalized resource constrained two sided assembly line balancing problem and computational analaysis. [In Turkish.] *Journal of the Faculty Engineering and Architecture of Gazi University,* 28 (2): 567–576.

Paksoy, T., Güngör, A., Özceylan, E. and Hancilar, A. (2013). Mixed model disassembly line balancing problem with fuzzy goals. *International Journal of Production Research*, 51 (20), 6082–6096.

Pinnoi, A., Wilhelm, W.E. (1997). A family of hierarchical models for assembly system design. *International Journal of Production Research,* 35 (1), 253–280.