

Balancing disassembly lines under consideration of tool requirements and limited space

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Abstract: One of the factors that can enable a shift towards a circular economy is the efficient organization of product disassembly. To this end, we study the disassembly line balancing problem, i.e., the assignment of disassembly tasks to workstations and extend it by practical aspects. We present a profit oriented optimization model, specifically taking into account the resource needs to carry out each task, and the limited space at workstations. The model is applied to a case study from literature and, by means of a sensitivity analysis, we demonstrate the impact of various problem specific parameters on the objective value and solution characteristics.

Keywords: Decision Support System, Closed-loop Supply Chains, Line Design and Balancing, Integer linear programming

1. INTRODUCTION

During the last decade, research on disassembly lines has grown in importance due to several reasons. The ever-increasing consumption and shortening product life cycles give rise to the environmental awareness by both consumers and producers. The subsequent product stewardship shifts the responsibility for limiting the ecological impact for a great extent to the producer. Furthermore, environmental legislation is becoming more stringent. The extended manufacturer responsibility draws attention to reverse production systems to make a closed loop supply chain. Disassembly is often an elementary requirement for a more desirable end-of-life option such as remanufacturing, reusing, and recycling (Jia and Shuwei, 2017). In addition to environmental aspects, there are some economic reasons to support disassembly as well. That is, a possible reduction of production cost or lead times.

Research on disassembly can be grouped in several categories. On the one hand, research is concerned with the design for disassembly (DFD) concept. This product design process takes the end-of-life options into account such that products can be easily and rapidly taken apart (Alting, 1992). On the other hand, research focuses on the execution of disassembly, which again can be divided into three subareas. First, it involves disassembly scheduling. This deals with the problem of determining the quantity and timing of product disassembly to satisfy part demand over a planning horizon (Kim et al., 2007). Second, sequencing captures the selection of the optimal order of operations in the separation for a given product on a single station (Lambert, 2003). Lastly, and subject of this study, is the disassembly line balancing problem (DLBP) which deals with the assignment of disassembly tasks to workstations. Although a single workstation or a disassembly cell is more

flexible, disassembly lines are preferred in terms of higher productivity rates and their potential for automation.

Installing a disassembly line requires a large capital investment for the workstations and the material-handling systems. In consequence, running the disassembly line should be as efficient as possible, which can be achieved by balancing the disassembly line. By increasing the efficiency of the disassembly process and reducing the used resources, assembly lines can be designed to be more competitive. The DLBP is a relatively young research area in contrast to the assembly variant. So far, research on disassembly covers the base problem with limited extensions. Thus, further development of the DLBP-approach is desirable. We propose a new model for the DLBP adopting a profit oriented approach that takes tool requirements into account and considers that space at workstations is limited.

The profit oriented approach can be motivated by the revenue structure of the problem. The revenues of disassembly depend on the released parts by several tasks throughout the disassembly process. For each released part, the revenues obtained by selling differ from the corresponding disposal costs. This contrasts assembly line balancing problems, where revenues mainly depend on amount of finished end products. Therefore, partial assembly is undesirable, as the revenues are only obtained when the product is fully assembled. On the contrary, disassembly can be either partial or complete. The partial option is either required because of technical limitations such as non reversible connections or it can be motivated by economic desirability. For example, for recycling, disassembling two parts, made from the same material, is not needed. Therefore, the problem at hand, considers the trade-off between the task revenues and the costs of workstations, tasks, and tools. This results in an optimum degree of disassem-

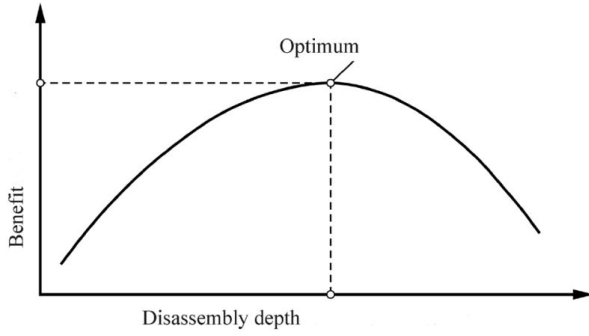


Figure 1. Trade-off between degree of disassembly and benefits (Opalić et al., 2010)

bly, which mostly does not cover all disassembly tasks. A common observed trade-off is illustrated in Figure 1. Disassembling further than the optimal degree may result in higher costs for smaller gains (Opalić et al., 2010). In case components are obliged to be disassembled by legislation, e.g., hazardous materials, the desired degree of disassembly is influenced. Even though partial disassembly complicates the problem, it should be considered as it allows to optimize the disassembly depth.

Currently, the disassembly process is rather labor intensive. Nevertheless, to reach higher productivity levels and cope with increasing labor costs, disassembly plants urge to invest in process automation. In addition, precision tools are frequently needed for disassembly operations. If a product contains hazardous or explosive materials, there may be a need for additional special tools and resources (Mete et al., 2016). The tools should be added to the line in an efficient way avoiding unnecessary costs, i.e., it should be assured that only the optimal amount of tools are acquired and positioned efficiently.

Finally, in order to obtain solutions that are feasible in practice, space constraints have to be taken into account. Both the resources (tools and machines), and the increasing number of disassembled parts in a mass customization era, require space at the border of the line. Considering space may lead to a different optimal assignment of tasks to workstations. This has already been proven in assembly lines (Bautista and Pereira, 2007) but to the best of our knowledge, it has not been investigated in disassembly systems yet.

The remainder of this paper is organized as follows: First, we review related literature in the next section. Next, we propose the optimization model in Section 3 before presenting the results of applying the model to a case study in Section 4. We end the text with a conclusion and directions for future research.

2. LITERATURE

The basic DLBP can be defined as “the assignment of disassembly tasks to workstations such that all the disassembly precedence relations are satisfied and some measure of effectiveness is optimized” (Ding et al., 2010). Although the assembly line balancing problem (ALBP) has been extensively studied in the literature, the literature considering the DLBP is relatively sparse (Battaia and

Dolgui, 2013). This last study summarized the line balancing problem literature into an extensive taxonomy and states that mathematical models, developed for assembly and machining lines, are not directly applicable to the disassembly variant.

Gungor and Gupta (1999) first described the complications of the DLBP. They developed a simple heuristic using candidate tasks and a priority function to solve it. It is described as a problem with multiple weighted objectives. A matrix was proposed as alternative representation for the precedence relationships, which they later generalized as the disassembly precedence matrix (DPM) in Güngör and Gupta (2001). Uncertainties in the quality of the parts were considered in the extension of this model to task failures resulting in complications such as early-leaving, skipping and revisiting workpieces (Güngör and Gupta, 2001).

Later, Altekin et al. (2008) proposed a profit-oriented approach in which products can be partially disassembled. A mixed-integer formulation was developed to simultaneously determine which tasks to complete, which demand of parts needs to be fulfilled, the number of workstations to open, the cycle time and the disassembly line balance. Koc et al. (2009) utilized a transformed AND/OR-graph to ensure the feasibility of the precedence relationships and proposed an integer mathematical formulation minimizing the amount of workstations opened.

Kalayci and Gupta (2013b) researched the sequence-dependent DLBP (SDDLBP) where the task times of two tasks may interact when precedence relations are absent. Sequence-dependent time increments are included based on the order in which these tasks are performed. An artificial bee colony algorithm was proposed as suitable approach and proved to outperform other meta-heuristics. Liu and Wang (2017) presented an improved discrete artificial bee colony algorithm for solving the SDDLBP.

Similar to the earlier mentioned Altekin et al. (2008), the partial profit-oriented optimization problem was described by Bentaha et al. (2014) and Kalaycilar et al. (2016). In addition, they included task time uncertainty and minimum release quantities in respective order. Altekin et al. (2016) approached the stochastic profit-oriented DLBP by involving remedial actions, among which the line is interrupted and disassembly is activated offline.

Although straight lines for single-model product disassembly dominate the research, there are a few articles on other types. Hezer and Kara (2015) and Agrawal and Tiwari (2008) investigated multi-product parallel and U-type disassembly lines respectively. Also in Paksoy et al. (2013) the disassembly line is focused on mixed-model products and incorporates the fuzziness of targeted goals.

Li et al. (2020) study the disassembly line balancing problem with AND/OR precedence, minimising the number of stations. They propose a branch, bound and remember algorithm.

The DLBP was shown by McGovern and Gupta (2007) to be an NP-complete problem. Two main streams, namely exact solution and (meta-)heuristic approaches, are observed to optimize the DLBP. Mixed-integer (Altekin

et al., 2008) and multi-objective models are frequently used for exact solution approaches. Also integer programming (Koc et al., 2009) and goal programming (Paksoy et al., 2013) are often researched. For metaheuristics, genetic algorithm (McGovern and Gupta (2007), Kalayci et al. (2016)) and ant colony optimization (McGovern and Gupta (2006), Kalayci and Gupta (2013a)) are popular in research. Research methodologies for the DLBP are far less explored than for the ALBP. Recently, an extensive review on all model categories as well as on all solution methodologies in the DLBP-research was published in Deniz and Ozcelik (2019).

The aspects of the extensions targeted in this study, namely space and tool constraints, can only be found to a limited extent in the literature. These were studied in the ALBP, as in Bautista et al. (2013) and Ağpak and Gökçen (2005) respectively. Mete et al. (2016) did a first attempt to include resource constraints in the DLBP, in which the number of resources used in workstations is minimized.

For a thorough and recent review of the disassembly line balancing problem we refer the reader to Özceylan et al. (2019).

3. THE OPTIMIZATION MODEL

In this section, the model is formally described. Before doing so, the notation is presented in Table 1.

Table 1. Model notation

Sets	
$\mathcal{I}$	Set of tasks
$\mathcal{K}$	Set of workstations
$\mathcal{R}$	Set of resources
$\mathcal{P}_i$	Set of immediate predecessors of task i
$\mathcal{P}'_i$	Set of possible immediate predecessors of task i
$\mathcal{I}_r$	Set of tasks that need tool r
Variables	
$x_{ik} = \begin{cases} 1, & \text{if task } i \text{ is assigned to workstation } k \\ 0, & \text{otherwise} \end{cases}$	
$y_k = \begin{cases} 1, & \text{if workstation } k \text{ is opened} \\ 0, & \text{otherwise} \end{cases}$	
$z_{rk} = \begin{cases} 1, & \text{if resource } r \text{ is assigned to workstation } k \\ 0, & \text{otherwise} \end{cases}$	
Parameters	
t_i	Task time of task i
r_i	Net revenue generated from task i
s_i	Space required to store parts originating from task i
s_r	Space required to store resource r
c_r	Cost for 1 unit of resource r per cycle
S	Space available at every workstation
C	Cycle time
F	Cost for setting up a workstation

In the following, the main assumptions are given:

- The model applies to cases where one type of product is disassembled.
- A paced line is considered.
- Disassembly can be either partial or complete. The rationale of this choice is discussed in section 1.
- Task preemption (interruptions) is not allowed.
- The parameters used in the model are assumed to be deterministic, known and independent of the assigned workstation.
- The cycle time and the available area in each workstation is assumed to be greater than all individual task times and task areas, respectively.
- The available area in a workstation is the area that can be used to store parts and tools, consequently without working space and moving area.
- Precedence relations of type AND, OR and AND/OR, typical for disassembly, are incorporated (see Güngör and Gupta (2001)).

Minimize:

$$\sum_{k \in \mathcal{K}} F y_k + \sum_{r \in \mathcal{R}} \sum_{k \in \mathcal{K}} c_r z_{rk} - \sum_{i \in \mathcal{I}} \sum_{k \in \mathcal{K}} r_i x_{ik} \quad (1)$$

subject to:

$$\sum_{k \in \mathcal{K}} x_{ik} \leq 1 \quad \forall i \in \mathcal{I} \quad (2)$$

$$\sum_{i \in \mathcal{I}} t_i x_{ik} \leq C y_k \quad \forall k \in \mathcal{K} \quad (3)$$

$$\sum_{i \in \mathcal{I}_r} x_{ik} \leq M z_{rk} \quad \forall k \in \mathcal{K} \quad \forall r \in \mathcal{R} \quad (4)$$

$$\sum_{i \in \mathcal{I}} s_i x_{ik} + \sum_{r \in \mathcal{R}} s_r z_{rk} \leq S \quad \forall k \in \mathcal{K} \quad (5)$$

$$x_{ik} - \sum_{k' \in \mathcal{K}: k' \leq k} x_{jk'} \leq 0 \quad \forall i \in \mathcal{I} : |\mathcal{P}_i| > 0 \quad \forall j \in \mathcal{P}_i \quad \forall k \in \mathcal{K} \quad (6)$$

$$x_{ik} - \sum_{k' \in \mathcal{K}: k' \leq k} \sum_{j \in \mathcal{P}'_i} x_{jk'} \leq 0 \quad \forall i \in \mathcal{I} : |\mathcal{P}'_i| > 0 \quad \forall k \in \mathcal{K} \quad (7)$$

$$y_k \leq y_{k-1} \quad \forall k \in \mathcal{K} \setminus 1 \quad (8)$$

$$x_{ik} \in \{0, 1\} \quad \forall i \in \mathcal{I} \quad \forall k \in \mathcal{K} \quad (9)$$

$$y_k \in \{0, 1\} \quad \forall k \in \mathcal{K} \quad (10)$$

$$z_{rk} \in \{0, 1\} \quad \forall r \in \mathcal{R} \quad \forall k \in \mathcal{K} \quad (11)$$

The proposed model minimizes the net costs, which is similar to maximizing the net revenue. It simultaneously determines which workstations will be opened (y_k), which resources will be used at which workstation (z_{rk}), and which tasks will be executed. If a task is executed, it is assigned to a workstation (x_{ik}) such that the line is balanced as good as possible. By using a cost- and revenue-based objective, the opening of workstations and use of resources is not minimized, but balanced in an economic sense. Constraint (2) states that each task can be assigned to at most one workstation. This implies the possibility of partial disassembly which distinguishes the problem from assembly problems. If a task must definitely be carried out, for instance because of the hazardous character, the inequality sign must be replaced by an equality sign for that task. Constraint (3) deals with the cycle time limit.

Tasks can only be assigned to a certain workstation as long as the total duration of the assigned tasks to that workstation does not exceed the cycle time. Besides, it ensures that assigning a task leads to the use of that workstation. Constraint (4) ensures that if at least one task requires resource r and is assigned to workstation k , that specific resource is allocated to that workstation. This is done by means of a big-M constraint, with $M = |\mathcal{I}_r|$. A resource can be used for several tasks at the same workstation and should only be assigned once. In this model, a task may require several resources and the same type of resource can be used in multiple workstations. Constraint (5) includes space limitations into the model. The space needed at a specific workstation cannot exceed the available space. This includes both the space to store parts that are released at that workstation and space that is occupied by the resources assigned to the workstation. Due to simplicity, it is assumed that each workstation has the same amount of available space. However, the model can easily be adapted to accommodate specific values. The following two constraints ensure the satisfaction of precedence relations. Constraint (6) incorporates the AND-precedence relationships. A task i cannot be assigned to a workstation k that is before any of the workstations of its AND-predecessors j . Constraint (7) implies that task i can only be assigned to a workstation k if at least one of its OR-predecessors is already assigned to a station before k or to station k itself. Constraint (8) deals with opening the workstations in the right order. Workstation k can only be opened if the prior one is already opened. This is rather a technical constraint reducing symmetry in the model. Lastly, Constraints (9), (10), and (11) define the domains of the decision variables.

4. COMPUTATIONAL STUDY

The number of dataset available in the DLBP-literature is very limited. Furthermore, there are no data sets available for the DLBP with the considered extensions. In the following subsection we describe how we supplemented existing data with the required information on space, tools, costs and revenues. Thereafter, we present some results.

4.1 Case study

We apply the model to a case study of a cellular telephone instance consisting of $n = 25$ components. The case study and the associated data has originally been described by Kalayci and Gupta (2013a) and we will refer to it as KG13. The space requirements, tool assignments, and the information about cost and revenue structure was added as follows. The spatial attributes were created following a discrete binomial distribution with a minimum of 0 and maximum of 20 space units. The workstation space was fixed at this maximum of 20 space units. The workstation cost was fixed at 10 for each workstation. Besides, the number of resource types $|\mathcal{R}|$ was selected by drawing a number between 1 and 4 from a uniform distribution. For each of the resources, the number of tasks needing that resource was generated between 1 and 5. Tasks were drawn with a uniform probability and assigned to these resources. Consequently, there are in between 1 and 20 distinct resource requirements. The resource space and cost was

derived from uniform distributions with a minimum of 1 and a maximum of 5 and 10 respectively. Lastly, the net revenue for each task was generated following a discrete distribution between -5 and 20.

4.2 Results

The presented mathematical model is implemented in CPLEX 12.8 on a computer with 8 GB Ram and an Intel Core i5-7200U processor with 2.50GHz. We carried out a one-factor-at-a-time (OFAT) analysis to get insight in the influence of a parameter change on the objective value and the three main outputs, i.e., the number of opened workstations, the number of assigned tasks and the number of assigned resources.

Space

As described above, workstations are limited in space. In this section, the impact of changing available workstation space (per unit) is tested. Figure 2 shows the results with the available space on the x-axis. The objective function value is displayed on the right y-axis. The number of opened workstations, assigned tasks and assigned resources may be read from the left y-axis.

As can be seen in Figure 2, a decrease of space worsens the objective value, which can be expected as the problem is more constrained. When the decision variables in the solution change, the objective function logically adapts unless the effects neutralise each other. If the space is too small, obviously no task is assigned at all. Despite some tasks exist that need less space than the limit, those tasks are not assigned if their revenue cannot bear the workstation cost or their predecessors require more space than what is available. Here, this is the case for S between 0 and 6. These solutions are also depicted, as not conducting any disassembly is a feasible solution. When it becomes economically viable, workstations are opened and tasks are assigned to workstations such that the objective value improves rapidly. The steep increase in workstation openings and assignments is followed by a fluctuating development and stabilizes, starting from S equal to 31. At this point the cycle time constraint completely dominates spatial constraints. Nevertheless, these results show that the consideration of space heavily impacts the profitability and design of a disassembly line.

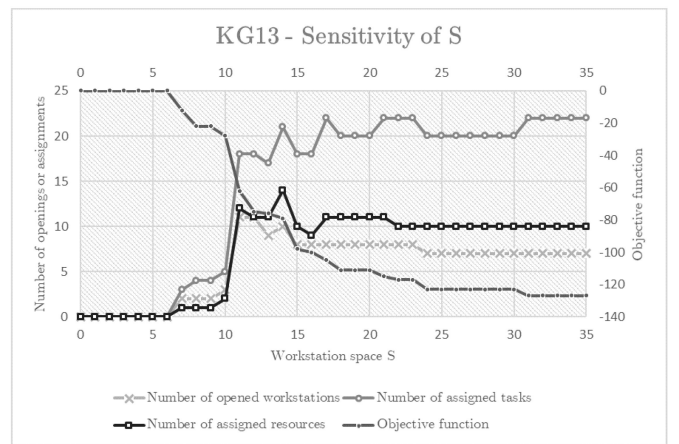


Figure 2. Impact of space S

Workstation cost

A similar graph is shown in Figure 3, displaying the results per unit change of the workstation cost F . The higher the workstation cost, the higher (and thus worse) the objective value. However, the pace, at which the objective function worsens, decreases with increasing workstation costs. This is logical as the objective value deteriorates with the amount of opened workstations times the change in the workstation cost. As more workstations are closed with increasing costs, the net costs change gets smaller. Breakpoints can be observed. At a breakpoint, one or more workstations are closed until none of them operates. Consequently, the number of assigned tasks and resources also diminish at that point. Between two breakpoints, these remain at the same amount and the objective value varies proportionately. Note that a workstation cost of 0 is not realistic in practice.

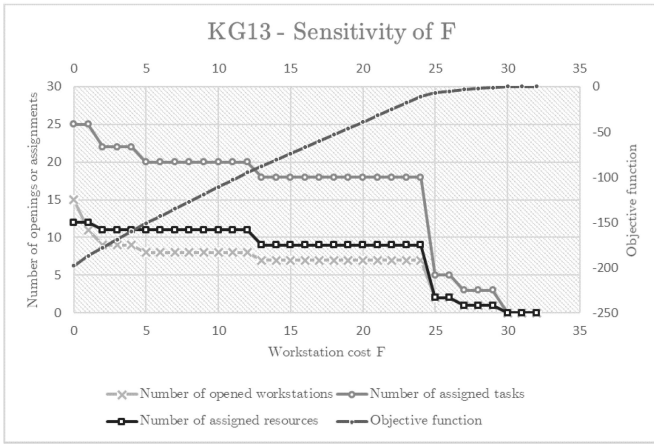


Figure 3. Impact of work station cost F

Resource costs

Figure 4 represents the results for varying resource costs c_r . All resource costs were systematically increased or decreased with 2% percentage change steps upon its starting value. Again, there is a step-like pattern in the number of task assignments and station openings. The net costs increase with a diminishing pace at every breakpoint. As one can see, a resource cost of 0 leads to the use of more resources than needed. This indicates that spatial considerations may not circumvent the placement of superfluous resources and only the introduction of resource costs does.

Task revenues

Lastly, the influence of the tasks' revenues was tested (see Figure 5). To this end, their revenues were adjusted in relation to their starting value, per 2%. When task revenues decline, some tasks are not assigned anymore. This concerns tasks whose resource and workstation costs are larger than the revenue that can be generated. This can be seen as fewer workstations are opened and fewer resources are assigned. Consequently, one would not assign any task if revenues are very low. The assignments stabilize when all tasks are performed or when all workstations are filled. The objective value is ever-increasing with the task revenues.

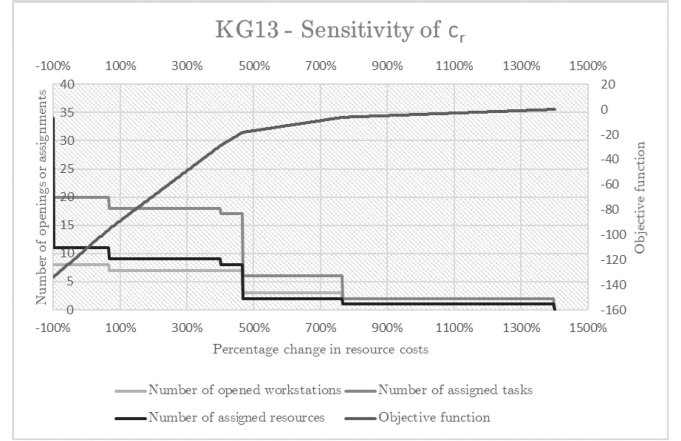


Figure 4. Impact of resource costs c_r

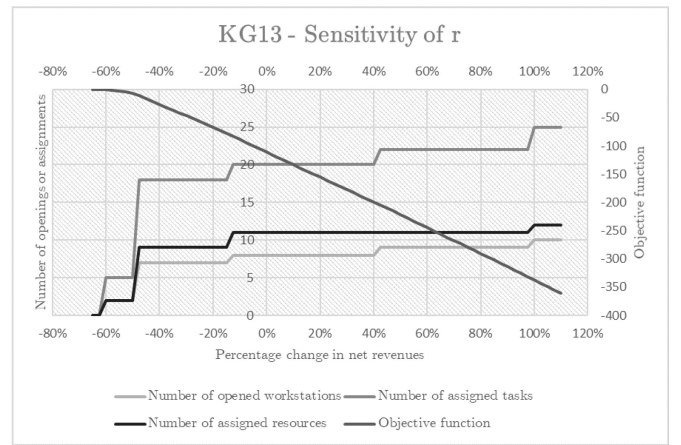


Figure 5. Impact of task revenues r_i

5. CONCLUSION

In this research, we proposed to optimize disassembly line balancing while considering tool and space requirements. Disassembly is gaining importance as a result of environmental awareness and legislation, and in this study important practical considerations are added. A profit-oriented integer mathematical program was proposed to model its characteristics. This way it reflects real-world decision-making problems. The model was tested for a case study from literature and the impact of various parameters has been analyzed extensively.

In future research, the analysis should be extended to other problem instances to validate the results. This may include the investigation of various probability distributions in the data generation. As mentioned before, a limited number of problem instances are available in literature and they are small-sized. Testing on larger sized data instances is desirable. For this, research should also be targeted at improving the computational solution approach, as larger instances will be more computationally demanding to solve.

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REFERENCES

- Agrawal, S. and Tiwari, M. (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.
- Altekin, F.T., Bayındır, Z.P., and Gümüşkaya, V. (2016). Remedial actions for disassembly lines with stochastic task times. *Computers & Industrial Engineering*, 99, 78–96.
- Altekin, F., L., K., and N., O. (2008). Profit oriented disassembly balancing. *International Journal of Production Research*, 46:10(312), 2675–2693.
- Alting, L. (1992). Design for assembly and disassembly, Keynote Paper. *Annals CIRP*, 41(1), 625.
- Ağpak, K. and Gökçen, H. (2005). Assembly line balancing: Two resource constrained cases. *International Journal of Production Economics*, 96(1), 129–140.
- Battaia, O. and Dolgui, A. (2013). A taxonomy of line balancing problems and their solution approaches. *International Journal of Production Economics*, 142(2), 259–277.
- Bautista, J., Batalla, C., and Alfaro, R. (2013). Incorporating ergonomics factors into the tsalbp. *IFIP Advances in Information and Communication Technology*, 397(PART 1), 413–420.
- Bautista, J. and Pereira, J. (2007). Ant algorithms for a time and space constrained assembly line balancing problem. *European journal of operational research*, 177(3), 2016–2032.
- Bentaha, M.L., Battaia, O., and Dolgui, A. (2014). Disassembly line balancing and sequencing under uncertainty. *Procedia CIRP*, 15, 239–244.
- Deniz, N. and Ozcelik, F. (2019). An extended review on disassembly line balancing with bibliometric & social network and future study realization analysis. *Journal of Cleaner Production*.
- 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.
- Gungor, A. and Gupta, S.M. (1999). Disassembly line balancing. *Proceedings of the 1999 Annual Meeting of the Northeast Decision Sciences Institute*, 193–195.
- Güngör, A. and Gupta, S.M. (2001). Disassembly sequence plan generation using a branch-and-bound algorithm. *International Journal of Production Research*, 39(3), 481–509.
- Hezer, S. and Kara, Y. (2015). A network-based shortest route model for parallel disassembly line balancing problem. *International Journal of Production Research*, 53(6), 1849–1865.
- Jia, L. and Shuwei, W. (2017). A proposed multi-objective optimization model for sequence-dependent disassembly line balancing problem. *Proceedings of the 3rd International Conference on Information Management (ICIM)*, 421–425.
- Kalayci, C.B. and Gupta, S.M. (2013a). Ant colony optimization for sequence-dependent disassembly line balancing problem. *Journal of Manufacturing Technology Management*, 24(3), 413–427.
- Kalayci, C.B. and Gupta, S.M. (2013b). Artificial bee colony algorithm for solving sequence-dependent disassembly line balancing problem. *Expert Systems with Applications*, 40(18), 7231–7241.
- Kalayci, C.B., Polat, O., and Gupta, S.M. (2016). A hybrid genetic algorithm for sequence-dependent disassembly line balancing problem. *Annals of Operations Research*, 242(2), 321–354.
- Kalaycilar, E.G., Azizoglu, M., and Yeralan, S. (2016). A disassembly line balancing problem with fixed number of workstations. *European Journal of Operational Research*, 249(2), 592–604.
- Kim, H.J., Lee, D.H., and Xirouchakis, P. (2007). Disassembly scheduling: Literature review and future research directions. *International Journal of Production Research*, 45(18-19), 4465–4484.
- Koc, A., Sabuncuoglu, 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 (Institute of Industrial Engineers)*, 41(10), 866–881.
- Lambert, A.J. (2003). Disassembly sequencing: A survey. *International Journal of Production Research*, 41(16), 3721–3759.
- Li, Z., Çil, Z., Mete, S., and Kucukkoc, I. (2020). A fast branch, bound and remember algorithm for disassembly line balancing problem. *International Journal of Production Research*, 58(11), 3220–3234.
- Liu, J. and Wang, S. (2017). Balancing disassembly line in product recovery to promote the coordinated development of economy and environment. *Sustainability (Switzerland)*, 9(2).
- McGovern, S.M. and Gupta, S.M. (2006). Ant colony optimization for disassembly sequencing with multiple objectives. *The International Journal of Advanced Manufacturing Technology*, 30(5-6), 481–496.
- 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., Abidin Çil, Z., Özceylan, E., and Ağpak, K. (2016). Resource Constrained Disassembly Line Balancing Problem. *IFAC-PapersOnLine*, 49(12), 921–925.
- Opalić, M., Kljajin, M., and Vučković, K. (2010). Disassembly layout in weee recycling process. *Strojarstvo*, 52(1), 51–58.
- Özceylan, E., Kalayci, C., Güngör, A., and Gupta, S. (2019). Disassembly line balancing problem: a review of the state of the art and future directions. *International Journal of Production Research*, 57(15/16), 4805–4827.
- 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.