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A disassembly line balancing problem with fixed number of workstations

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ABSTRACT

In this study, a Disassembly Line Balancing Problem with a fixed number of workstations is considered. The product to be disassembled comprises various components, which are referred to as its parts. There is a specified finite supply of the product to be disassembled and specified minimum release quantities (possible zero) for each part of the product. All units of the product are identical, however different parts can be released from different units of the product. There is a finite number of identical workstations that perform the necessary disassembly operations, referred to as tasks. We present several upper and lower bounding procedures that assign the tasks to the workstations so as to maximize the total net revenue. The computational study has revealed that the procedures produce satisfactory results.

1. Introduction

The environmental regulations, customer awareness and recent advances in technology all together have shifted the product recovery process from the act of disposing to the act of remanufacturing and recycling. Recycling preserves the material content of the discarded (used) products via some manufacturing and disassembly operations. Remanufacturing, on the other hand, keeps the functional content of the used products and improves their quality up to a desired usable level via disassembly operations and some manufacturing.

Disassembly is the first important step of product recovery activities (McGovern and Gupta, 2011) and it is methodical extraction of valuable parts, operations involve the separation of the reusable parts from the discarded products. The parts are either subject to some remanufacturing process or sold to suppliers. Disassembly operations are usually performed on a disassembly line that consists of a number of serial workstations. The first workstation takes the product to be disassembled. The cycle terminates, i.e., the product leaves the line, whenever all its required parts are disassembled.

The Disassembly Line Balancing Problem (DLBP) assigns the set of tasks to each workstation for each product to be disassembled. The problem is critical in minimizing the use of valuable resources (such as time and money) invested in disassembly, and maximizing the level of automation of the disassembly process and the quality of the parts or materials recovered.

This study considers a DLBP with a fixed number of workstations. It is assumed that there is a specified supply for the products to be disassembled. For each part, a defined minimum release quantity must be met. The amount in excess of the minimum release quantity can also be sold in the market. Hence the excess quantity is produced, provided that the part is profitable, and that there is enough supply. The aim is to assign the tasks to the disassembly workstations so as to maximize the total net revenue of the parts, while meeting their specified minimum release quantities, and without exceeding the specified cycle time. To satisfy the minimum release quantities, different parts may be released from different units of the product. The challenge is to use different line balances, hence use different task assignments to the already mounted workstations, while disassembling different units of the product. To the best of our knowledge, the study is the first attempt to solve the DLBP with minimum release quantities and fixed number of workstations.

Our study will have a direct impact on the industries that experience continuous advances in their technology. These advances naturally affect the function and fashion oriented expectations of the consumers. One such application area that we take our motivation from is the electrical and electronic equipment industry. The consumers of the personal computers, televisions or cellular phones, replace their products within a few months to a few years, even when the products (thereby their parts) are functioning properly. Electrical and electronic equipments consist of many different substances some of which may contain hazardous components and valuable parts (Capraz, Polat, & Güngör, 2015). As the used products have proper conditions, their valuable parts (like memories, CPUs, valuable metals) can be used in manufacturing new models. The minimum release quantities for these parts (that we define in our models) are

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associated to the demands from the third party like the producers of the new models. Moreover, as we assume, the amount released excess of the minimum release quantities of the valuable parts can be stored in the inventory for future orders. Another application area is the automotive industry where the consumers of the luxurious cars replace their not-so-much-used cars with new brands that make use of the most recent technology.

The rest of the study is organized as follows. Section 2 reviews the disassembly process and literature on the DLBP whereas Section 3 defines our problem. In Section 4 the mathematical models and their use in finding optimal solutions are discussed. In Section 5, we present upper bounds together with the mechanisms used to strengthen them and present a heuristic procedure. The computational experiment is discussed in Section 6 and the study is concluded in Section 7.

2. Disassembly process & the related literature

Güngör and Gupta (2001b) defined disassembly as a systematic process of separating a product into its constituent parts, components, subassemblies or other groupings. The issues in the area of disassembly can be classified into two broad categories as design and operational. Crowther (1999) considered a design for disassembly issue and mentioned that a life cycle model that incorporates the stages of a disassembly strategy can highlight the environmental advantages of designing for disassembly, showing how it can extend service life and thereby improve sustainability. As a practical application, he discussed the construction industry and mentioned that experience gained from disassemblable buildings can be used to create guidelines for other products. As discussed in Brennan, Gupta, and Taleb (1994), the design aspects for disassembly have being recognized by the industries that generate huge amount of ferrous and plastic waste like motor cars and appliance sectors.

When the old products come to disassembly plant so that their components can be recovered in the assembly plant or re-used, operational problems arise. The operational problems that are likely to arise are layout, resource allocation, process sequencing and disassembly line balancing. As mentioned by Brennan et al. (1994), the operational problems have environmental concerns that are even forced by the governments like the recycling regulations, and limitations on the energy consumptions. These regulations affect the operating costs as extra costs are incurred for covering the expenses related to the environmental matters.

In their review paper McGovern and Gupta (2011) discussed many aspects of the operational problems with an emphasis on the disassembly sequencing problem and the DLBP. The disassembly line sequencing problem decides on the disassembly process sequence of a specified disassembly product and the DLBP decides on the assignment of the tasks to each disassembly workstation.

Lambert (2003) provided a review of the disassembly sequencing literature. Some noteworthy studies on disassembly sequencing are due to Lambert (1997), Navin-Chandra (1994) and Lambert (2002). Navin-Chandra (1994) used a modified traveling salesman problem so as to minimize total costs while meeting obligatory reclamation of definite parts. Lambert (1997) proposed a graph based method so as to maximize the economic performance of the disassembly process within given technical and environmental constraints. Both methods were applicable to the disassembly of complex consumer products like automotive vehicles, consumer electronics and mechanical assemblies and were applied to a headlamp and ballpoint pen disassembly products. Lambert (2002) proposed a linear programming based solution procedure for the minimum cost disassembly sequence of an electronic equipment. His method was applicable all products having hierarchical modular structures.

The DLBP was first introduced in Güngör and Gupta (2001b). Güngör and Gupta (2001a) mentioned several complications like early leaving, self-skipping, skipping, disappearing and revisiting work pieces that could be faced in disassembly line practices. To reduce the effects of the complications on the disassembly process, they proposed a shortest path based solution algorithm. McGovern and Gupta (2007a) showed that the decision version of the DLBP is NP-complete. McGovern and Gupta (2007b) considered a DLBP to minimize the number of workstations while balancing the idle times between the workstations. They proposed an exhaustive search method that returns optimal solutions for small sized problem instances and a genetic algorithm that finds high quality solutions, for the large sized problem instances.

Güngör and Gupta (2002) proposed a heuristic procedure for the DLBP under complete disassembly. They assumed an infinite supply of a single product and considered the efficient utilization of the resources while satisfying the minimum release quantity. They illustrated the proposed heuristic on an eight task personal computer disassembly example. Koc, Sabuncuoglu, and Erel (2009) considered a complete disassembly DLBP so as to minimize the number of workstations. They introduced AND/OR graphs and proposed Integer and Dynamic Programming formulations.

Altekin, Kandiller, and Özdemirel (2008) studied the DLBP under partial disassembly and an infinite supply of a single product. They formulated their net revenue maximization model as a mixed-integer linear program and used its relaxations to find lower and upper bounds. They stated that their approach could be used in designing and operating remanufacturing systems where large volumes of similar products should be disassembled. Altekin and Akkan (2012) proposed a predictive–reactive approach based on a mixed-integer model to improve the profitability of the disassembly line. A predictive balance was created and then given a failure, the line was rebalanced. They stated that their algorithm could be used as a guide by the disassembly workers about how to proceed in case of a task failure.

The recent disassembly lines research considered the uncertainty of the task times and product quality. Bentaha, Battaïa, and Dolgui (2014a, 2014b, 2014c, 2015) and Bentaha, Battaïa, and Dolgui (2014d) studied complete and partial disassembly models, respectively. Bentaha et al. (2014a) modeled uncertainty using the notion of resource cost and proposed a sample average approximation method. Bentaha et al. (2014b) studied the joint problem of disassembly line balancing and sequencing. Bentaha et al. 2014c proposed a lagrangian relaxation approach to maximize the total profit. Bentaha et al. (2015) considered the problem of minimizing the workstation operation costs and additional costs for handling the hazardous parts. They developed several lower and upper bounding mechanisms. Bentaha et al. (2014d) addressed workload balancing problem with fixed number of workstations. They developed a stochastic binary program.

Ding, Feng, Tan, and Gao (2010) stated that a successful disassembly line often requires an integrated consideration of many objectives and proposed an ant colony algorithm to generate the efficient set. They tested their algorithm with three objectives: number of the workstations, workload balancing between the workstations and demand rating. They illustrated the heuristic on a 25 task cellular phone disassembly example. Paksoy, Güngör, Özceylan, and Hancilar (2013) mentioned that in real world applications the objectives could be fuzzy due to incomplete information and proposed fuzzy goal programming and fuzzy multi-objective programming. They considered three objectives: number of the workstations, workload balancing between the workstations and cycle time. The approaches were applied on 10 tasks flash light and 30 tasks radio examples. Hezer and Kara (2014) introduced parallel line dissassembly balancing problem and proposed a network model based approach for its solution. For more information on the dissassembly line balancing and planning, one may refer to Ullerich (2014).

The most closely related published work to ours is Altekin et al. (2008)'s study. Our problem environment differs from theirs in the