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Second order conic approximation for disassembly line design with joint probabilistic constraints

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ABSTRACT

A problem of profit oriented disassembly line design and balancing with possible partial disassembly and presence of hazardous parts is studied. The objective is to design a production line providing a maximal revenue with balanced workload. Task times are assumed to be random variables with known normal probability distributions. The cycle time constraints are to be jointly satisfied with at least a predetermined probability level. An AND/OR graph is used to model the precedence relationships among tasks. Several lower and upper–bounding schemes are developed using second order cone programming and convex piecewise linear approximation. To show the relevance and applicability of the proposed approach, a set of instances from the literature are solved to optimality.

1. Introduction

Disassembly process plays a crucial role in material and product recovery. It is a required condition for an efficient treatment of end-of-life (EOL) products (Ilgin & Gupta, 2010, 2012). The objective of disassembly is to separate EOL products subassemblies and components for recycling, remanufacturing and reuse. To carry out disassembly operations with higher productivity rate, disassembly lines are used (Güngör & Gupta, 2002).

From practical point of view, disassembly process is more complex than assembly. In fact, in a disassembly environment, a product is broken down into several components and subassemblies whose quality, quantity and reliability cannot be controlled as in an assembly environment. The structure and quality of EOL products are strongly uncertain and even the number of components in such products can not be predicted. Moreover, an EOL product may contain certain hazardous material which necessitates special handling at a workstation of a disassembly line. Due to technical or economic restrictions such as irreversible connections of components of a product and low revenue obtained from retrieved parts, disassembly is usually a partial process (Lambert, 2002).

Because of the peculiarities given above, the design and balancing of disassembly lines (known as DLBP: disassembly line balancing problem), is a hard optimization problem and needs adapted solution methods. A disassembly line consists of an ordered sequence of workstations connected by a material handling system which is used to transport work–pieces from one workstation to another. As aforementioned, certain parts or subassemblies may be hazardous and require a particular treatment incurring a supplementary cost.

The studied optimization problem consists in assigning a given set of disassembly tasks (of an EOL product) to an ordered sequence of workstations, while respecting precedence and cycle time constraints. Cycle time constraints are to be jointly satisfied with at least a certain probability level $(1-\alpha)$ fixed by the decision maker. Task times are assumed to be independent random variables with known normal probability distributions. The main objective is to maximize the profit produced by the line by optimizing the number of needed workstations of the line and the depth of the disassembly process. Subsequently, the idle times at workstations should be as smooth as possible.

Although the main purpose of this paper is to study stochastic DLBP, it is also shown that the obtained results remain valid for stochastic assembly line design and balancing problem (ALBP).

The paper is organized as follows: Section 2 provides an overview of the relevant literature on disassembly and assembly line design and balancing under uncertainty. A formal description of the studied problem is given in Section 3. Section 4 presents the developed solution approach. Numerical experiments and optimization results

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are presented in Section 5. Section 6 concludes the paper with future research directions.

2. Literature review

In this section, papers dealing with line design and balancing under uncertainty of the task processing times for both disassembly and assembly are discussed. In addition, problems that have studied the case of disassembly/assembly processing alternatives are reviewed.

2.1. Disassembly line design and balancing

Only limited studies in the literature have taken into account the task processing times variability that characterizes the disassembly context in DLBP. A fuzzy colored Petri net model with a heuristic solution method was proposed in Turowski and Morgan (2005) to study the human factors that cause uncertainty of task times. A collaborative ant colony algorithm for stochastic mixed–model U–shaped DLBP was developed in Agrawal and Tiwari (2006). Task times were assumed to be stochastic with known normal probability distributions. A binary bi–objective non linear program was developed in Aydemir-Karadag and Turkbey (2013) for DLBP under uncertainty of the task times. Task times were assumed to be independent random variables with known normal probability distributions.

Several mathematical models have also been developed for DLBP under uncertainty of task processing times. In Bentaha, Battaïa, and Dolgui (2014a), uncertainty was modeled using the notion of recourse cost and a sample average approximation method was developed to solve the studied optimization problem. In Bentaha, Battaïa, Dolgui, and Hu (2014d), uncertainty was modeled using workstation expectation times. In Bentaha, Battaïa, and Dolgui (2014b), a stochastic program was developed for the joint problem of disassembly line balancing and sequencing under uncertainty. In Bentaha, Battaïa, and Dolgui (2014c), a Lagrangian relaxation was proposed to maximize the disassembly line profit under task times variability where workstation expectation times are considered.

To model the possible disassembly process alternatives and precedence relationships among tasks, some of the existing papers have used directed graphs called AND/OR graphs. There are two types of such graphs: AND/OR graphs constituted of tasks and AND/OR graphs constituted of tasks and subassemblies. The first type is considered in (Altekin & Akkan, 2012; Altekin, Kandiller, & Ozdemirel, 2008; Güngör & Gupta, 2001, 2002), the second in (Bentaha et al., 2014a, 2014b, 2014c, 2014d; Koc, Sabuncuoglu, & Erel, 2009; Lambert, 1999). The latter which includes an explicit representation of subassemblies as well as tasks, is used in this paper. It is explained in detail in Section 3.

2.2. Assembly line design and balancing

Even if uncertainty level is lower in assembly, however, different sources from the assembly environment may cause the task time variations, as for example, non qualified operators, machine failures, complex assembly tasks, etc. To deal with this uncertainty, the following models were proposed in the literature. Task times were assumed to be random variables with either known continuous probability distributions (Zhao, Liu, Ohno, & Kotani, 2007), or known or unknown symmetric probability distributions (Betts & Mahmoud, 1989; Raouf & Tsui, 1982), or known independent normal probability distributions. This third case has received quite some attention: earlier papers have focused on optimizing straight assembly lines where heuristic (Carter & Silverman, 1984; Chakravarty & Shtub, 1986; Fazlollahtabar, Hajmohammadi, & Es'haghzadeh, 2011; Kao, 1979; Lyu, 1997; Shin, 1990; Silverman & Carter, 1986), metaheuristic (Cakir, Altiparmak, & Dengiz, 2011; Erel, Sabuncuoglu, & Sekerci, 2005) and exact solution methods (Henig, 1986; Kao, 1976; Sarin, Erel, & Dar-el, 1999) were proposed. The case of ALBP with station paralleling was studied in (McMullen & Frazier, 1997). Optimization of U–lines was investigated in (Bagher, Zandieh, & Farsijani, 2011; Baykasoğlu & Özbakır, 2007; Chiang & Urban, 2006; Guerriero & Miltenburg, 2003; Özcan, Kellegöz, & Toklu, 2011). Two heuristic approaches to the assembly line re-balancing problem were developed in (Gamberini, Gebennini, Grassi, & Regattieri, 2009; Gamberini, Grassi, & Rimini, 2006). In Liu, Ong, and Huang (2005), the authors studied the problem of minimizing the cycle time of the line to be designed.

Robust balancing of assembly lines with interval task times and stability analysis of optimal solutions for ALBP have been proposed, respectively, in (Gurevsky, Hazır, Battaïa, & Dolgui, 2013b; Hazır & Dolgui, 2015) and (Gurevsky, Battaïa, & Dolgui, 2013a; Sotskov, Dolgui, & Portmann, 2006). Robust balancing of an assembly line with uncertain demand has been presented in Chica, Óscar Cordón, Damas, and Bautista (2013). For cycle time minimization, two robust models and exact solution method for ALBP with interval uncertainty for task times have been proposed in (Hazır & Dolgui, 2013).

Particularly, for the case of task times following known normal probability distributions, exact and heuristic approaches were designed to solve integer linear programs with disjoint probabilistic constraints, for straight and U–lines (Ağpak & Gökçen, 2007; Urban & Chiang, 2006) and two–sided lines (Özcan, 2010).

Modeling of process alternatives and precedence relationships among tasks for assembly line balancing is undertaken in (Capacho & Pastor, 2006, 2008). The authors introduced and defined a new graph using the notion of Alternative Subgraphs. To solve this problem, an exact approach has been proposed in Scholl, Boysen, and Fliedner (2009) and heuristic approaches in Capacho, Pastor, Dolgui, and Guschinskaya (2007). It should be noted that Alternative Subgraphs graph is exclusively constituted of tasks and does not represent the possible subassemblies as does AND/OR graph used in this study.

As it can be seen, joint satisfaction of cycle time constraints with a certain probability level has not been considered neither for DLBP nor for ALBP. The next section presents the developed formulation for the former problem that with some reduction can be also applied for latter problem.

3. Problem statement

The aim is to assign disassembly tasks from set I to an ordered sequence of workstations from set J, while satisfying precedence and cycle time constraints under uncertainty of the task processing times. The value of $|J|$ represents the worst case for the number of workstations of the line. For a given problem instance, $|J|$ corresponds to the number of tasks of the longest disassembly process alternative (longest in terms of number of tasks). The goal is to design a line providing the maximal profit and resulting in a number of stations $\mathtt{m}^* \leqslant |J|$. Cycle time ($C_t$) constraints for all workstations have to be jointly respected with at least a probability level $(1-\alpha)$ fixed by the decision maker; C_t is the amount of time allocated to each station to complete its assigned tasks. It is the ratio of the planning period length to the number of products that need to be disassembled in order to meet the demand.

The following assumptions are used. A single type discarded product has to be partially (or completely) disassembled on a straight paced line. All received EOL items contain all initial parts with no addition or removing of components. Certain components of the EOL products are hazardous. A task can be performed at any workstation but cannot be split between two workstations. Task processing times are independent from the order in which the tasks are performed. Each component or subassembly has a certain non negative resale value but can be 0. A fixed cost per operating a time unit of an opened workstation and an additional fixed cost per operating a time unit for treating a hazardous part are given.