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Remedial actions for disassembly lines with stochastic task times

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ABSTRACT

We suggest the incorporation of remedial actions for profit-oriented disassembly lines with stochastic task times. When task times are stochastic, there is a probability that some of the tasks are not completed within the predefined cycle time. For task incompletions in disassembly lines, pure remedial actions of stopping the line and offline disassembly are proposed along with the hybrid line which is a combination of the two pure remedial actions. The remedial actions have a significant effect on the expected cycle time as well as the expected profit due to line stoppages and offline disassembly, which together make up the incompletion costs. Stopping the line allows the line to be stopped until all incomplete tasks are completed, while in offline disassembly, incomplete tasks are completed in an offline disassembly area after the core leaves the line. The approaches used in assembly lines for quantifying the associated costs with stopping the line and offline repair for a given line balance are modified and used. Hybrid lines can implement both pure remedial actions for two different task classes: The line is stopped for Finish (F-) tasks and offline disassembly is executed for Pass (P-) tasks. For hybrid lines, we formulate the problem for given line balance so as to maximize the expected profit as a Mixed Integer Programming model. A full enumeration scheme is proposed to derive the hybrid line solution. As partial disassembly is allowed, for offline disassembly and hybrid line, we also formulate and solve the task selection problem so as to determine which incomplete P-tasks to execute during offline disassembly. Our computational study aims to show the significance of incompletion costs, analyze the effect of the base cycle time and demonstrate that hybrid lines are capable of improving the expected profit as well as expected cycle time compared to the pure remedial actions. Stopping the line and hybrid line on average yield 26% higher expected profits compared to offline disassembly.

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1. Introduction

Over the last three decades, environmental concerns, governmental legislations as well as economic benefits have facilitated the design of reverse logistics systems and closed loop supply chains so as to accomplish material and product recovery. Hence, the end-of-use or end-of-life products are collected, disassembled and tested, and then redistributed for further reprocessing with different recovery options such as reuse, repair, recycling, refurbishing and remanufacturing.

Disassembly involves the separation of the collected products into their constituent parts, components, subassemblies or other groupings (Gupta & Taleb, 1994) and is a crucial stage in both material and product recovery. Depending on the recovery option, disassembly may be complete so as to fully disassemble the product or partial due to economic or technical constraints hindering full disassembly of the product (Lambert, 2002). Disassembly lines are considered to be the most efficient way to disassemble products in large quantities (Güngör & Gupta, 2002).

Due to prominent physical and operational differences between assembly and disassembly such as significant variation in the input flow due to uncertainties in the quantity, quality, and arrival times of the collected products; allowing partial disassembly; failures of disassembly tasks; existence of different precedence relationship types between tasks; and large variation in task times, researchers have been developing distinct solution methods for design problems of disassembly lines. The efficiency of the designed disassembly lines is highly affected by their balance. Hence, the disassembly line balancing problem (DLBP) focuses on the determination of the line balance by assigning the disassembly tasks to an ordered sequence of stations so that a measure of effectiveness is optimized and the precedence relations among the disassembly tasks are met. In the DLBP literature, various objective functions such as

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minimizing number of stations, minimizing cost, maximizing profit and smoothing the workload among the stations are considered.

DLBP has initially assumed deterministic disassembly task times. McGovern and Gupta (2007b) provide a proof for the NP-completeness of the decision version of DLBP. The solution approaches proposed for DLBP include heuristics (Avikal, Jain, & Mishra, 2013; Avikal, Mishra, & Jain, 2014; Duta, Filip, & Henrioud, 2007; Güngör & Gupta, 2002), mathematical programming based techniques (Altekin, Kandiller, & Ozdemirel, 2008; Koc, Sabuncuoglu, & Erel, 2009; Paksoy, Güngör, Özceylan, & Hancilar, 2013) and metaheuristics (Ding, Feng, Tan, & Gao, 2010; Kalayci & Gupta, 2013a, 2013b, 2013c, 2014; Kalayci, Polat, & Gupta, 2014; McGovern & Gupta, 2006, 2007a, 2007b).

Uncertainties associated with task failures during disassembly (Altekin & Akkan, 2012; Güngör & Gupta, 2001), collected products (Tripathi, Agrawal, Pandey, Shankar, & Tiwari, 2009), cycle time (Liu, Chen, & Huang, 2013) and variations in demand of end-of-life products (Tuncel, Zeid, & Kamarthi, 2014) have also been incorporated into DLBP. The uncertainty associated with the task times in manual lines arise due to changes in product and station characteristics as well as operator effectiveness, which depends on the line pace, operator proficiency, and motivation (Battaïa & Dolgui, 2013). The variability associated with the task times in disassembly is much higher compared to assembly. Even when similar units are disassembled, reported coefficient of variations in disassembly task times reach to a value of five (Guide, 2000), while high variability in assembly task times corresponds to coefficient of variation values that are between 0.25 and 0.6 (Erel, Sabuncuoglu, & Sekerci, 2005; Guerriero & Miltenburg, 2003).

The stochastic version of DLBP has been recently formulated using stochastic programming (Bentaha, Battaïa, & Dolgui, 2013b, 2013c, 2014a, 2014b, 2014c, 2014d, 2015; Bentaha, Battaïa, Dolgui, & Hu, 2014, 2015) and chance constrained programming (Bentaha, Battaïa, & Dolgui, 2013a, 2014d) with different objective functions that include cost minimization, profit maximization and smoothing the workloads among the stations. In addition to the part revenues involved in profit-oriented studies (Bentaha et al., 2013a, 2013b, 2014b, 2014c, 2015; Bentaha, Battaïa, Dolgui, & Hu, 2014, 2015), all of these studies include station operating costs and some of them incorporate costs for treating hazardous materials (Bentaha et al., 2013a, 2014b, 2014c, 2014d, 2015; Bentaha, Battaïa, Dolgui, & Hu, 2015). Penalty costs for exceeding cycle time is also included in Bentaha et al. (2013b, 2013c, 2014a) and Bentaha, Battaïa, Dolgui, and Hu (2014). Both complete disassembly and partial disassembly have been addressed in different studies. Several studies in this field assume that disassembly task times follow Normal distribution (Agrawal & Tiwari, 2008; Aydemir-Karadag & Turkbey, 2013; Bentaha et al., 2013a, 2014d, 2015; Bentaha, Battaïa, Dolgui, & Hu, 2015) while the remaining ones assume the disassembly task times to be random variables with known probability distributions.

Proposed solution approaches for stochastic DLBP include metaheuristics (Agrawal & Tiwari, 2008; Aydemir-Karadag & Turkbey, 2013), Lagrangian relaxation (Bentaha et al., 2014c), second order cone programming (Bentaha et al., 2013a, 2014d, 2015; Bentaha, Battaïa, Dolgui, & Hu, 2015), piecewise linear approximation (Bentaha et al., 2014d, 2015; Bentaha, Battaïa, Dolgui, & Hu, 2015), Monte Carlo sampling techniques (Bentaha et al., 2013b, 2014b, 2014c, 2014e; Bentaha, Battaïa, Dolgui, & Hu, 2014), and L-shaped algorithm (Bentaha et al., 2013b, 2013c, 2014a). Majority of these studies use a combination of these solution approaches. Note that Bentaha, Battaïa, and Dolgui (2015) and Bentaha, Battaïa, Dolgui, and Hu (2015) also analyze the efficiency of the proposed approach using instances from the stochastic assembly line balancing (SALB) literature.

Except Bentaha et al. (2013b, 2013c, 2014a) and Bentaha, Battaïa, Dolgui, and Hu (2014), the proposed solution approaches aim at reducing the probability of exceeding the cycle time without providing corrective actions and quantification of the relevant costs. Bentaha et al. (2013b, 2013c, 2014a) and Bentaha, Battaïa, Dolgui, and Hu (2014), acknowledge the fact that a corrective action is needed each time the duration of tasks assigned to a station exceeds the given cycle time, hence, they incorporate a penalty cost for exceeding the cycle time in the objective function. By Bentaha et al. (2014), only the maximum amount the cycle time is exceeded over all stations is penalized. Bentaha et al. (2013b, 2013c, 2014a) penalize the total expected time that the cycle time is exceeded in all stations. Bentaha et al. (2014a) point out the computational difficulty in calculating this expectation even for a given line balance, as it involves multivariate numerical integration of implicitly defined probability density functions (p.d.f.) of the variables representing the amount the cycle time is exceeded for each station. Exact evaluation of the expectation term is possible while its optimization presents severe complexity (Birge, 1997; Santoso, Ahmed, Goetschalckx, & Shapiro, 2005).

In order to explore corrective actions and quantify associated costs, several remedial actions have been proposed in the SALB literature. Proposed remedial actions include stopping the line (Lyu, 1997; Shin & Min, 1991; Silverman & Carter, 1986), offline repair (Carter & Silverman, 1984; Gökçen & Baykoç, 1999; Kottas & Lau, 1973, 1976, 1981; Sarin & Erel, 1990; Sarin, Erel, & Dar-El, 1999; Shin, 1990), hybrid lines (Lau & Shtub, 1987), multiple manning (Shtub, 1984; Vrat & Virani, 1976) and using inspection and repair points between stations. Each remedial action leads to additional costs as more time and labor are required, and hence costs associated with them should be included.

Among these remedial actions, the two commonly used ones are stopping the line and offline repair. Stopping the line refers to the case, when the total duration of the tasks assigned to a station exceeds the predefined cycle time (base cycle time), the line is stopped and the cycle time is extended to finish all incomplete tasks. As soon as no incomplete task remains, end of the cycle is reached and the workpieces are sent to next stations. When the offline repair remedial action is used, each cycle ends once the given cycle time is elapsed. Thus, some of the tasks may not be completed at the end of the cycle leading to time-related incompletions. Other tasks at a station may not be even started, as they might be followers of tasks, which were not completed in upstream stations leading to precedence-related incompletions. Kottas and Lau (1976) express that the expected cost associated with task incompletions has to be considered when designing lines, and they propose a three stage process to evaluate the expected incompletion cost of a given line balance. They also note that such costs for precedence-related incompletions are difficult to represent due to the work dependencies among stations.

So as to combine the stopping the line and offline repair remedial actions, Lau and Shtub (1987) propose hybrid lines for assembly systems. In hybrid lines, the tasks are classified into two: Finish (F-) tasks and Pass (P-) tasks. Once the given base cycle time is elapsed, the line is stopped to finish all F-tasks online in the stations. However, for P-tasks the line is not stopped when the base cycle time is elapsed, and offline repair is performed for incomplete tasks at the end of a cycle. Using given balances, given set of P- and F-tasks and simulation, Lau and Shtub (1987) demonstrate cost savings can be achieved via hybrid lines over offline repair.

Hybrid lines offer several advantages for disassembly systems. First of all, since uncertainty in disassembly task times is higher, the expected costs associated with task incompletions should be significant. Thus, cost savings and profit improvements might be possible via hybrid lines. Hybrid lines also provide operational flexibility in case of task incompletions as both offline disassembly and

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