A bibliographic review of production line design and balancing under uncertainty

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Abstract: This bibliography reviews the solution methods developed for the design and balancing problems of production lines such as assembly and disassembly lines. The line design problem aims in determining the number of workstations along with the corresponding assignment of tasks to each workstation, while the line balancing problem seeks an assignment of tasks, to the existing workstations of the line, which ensures that the workloads are as equal as possible among the workstations. These two optimisation problems can be also integrated and treated as a multi-objective optimisation problem. This review considers both deterministic and stochastic formulations for disassembly lines and is limited to assembly line design and balancing under uncertainty. This bibliography covers more than 90 publications since 1976 for assembly and 1999 for disassembly.

Keywords: Assembly, Disassembly, Line design and balancing, Uncertainty.

1. INTRODUCTION

A production line can be defined as a succession of workstations where tasks are performed sequentially at each station. The design or balancing of such a system can be reduced to an optimization problem which minimizes or maximizes certain objectives under specified constraints. The design problem aims in determining the number of workstations and the corresponding assignment of tasks to each station. The balancing problem seeks an assignment of tasks, to the existing workstations of the line, which ensures workstations' workloads to be as equal as possible. These two problems can be studied separately or simultaneously using multiobjective optimization tools and techniques.

Throughout this article, we review papers dealing with the design and balancing problems in assembly and disassembly lines. Since the first study on disassembly line balancing appeared in 1999 (Güngör and Gupta (1999)), both deterministic and stochastic formulations are considered for disassembly lines, respectively in Sections 2 and 3. In the latter, the main papers dealing with the assembly line design and balancing under uncertainty are also presented. Comprehensive surveys on deterministic assembly line design and balancing can be found in the literature, e.g. Scholl and Klein (1999); Becker and Scholl (2006); Scholl and Becker (2006); Boysen et al. (2007); Battaïa and Dolgui (2013). Future research directions are given in Section 4.

2. DETERMINISTIC DISASSEMBLY LINE DESIGN AND BALANCING

2.1 Heuristic and metaheuristic solution approaches

For the problem of the minimization of the number of workstations in the single-product disassembly line, different heuristics have been developed in Güngör and Gupta (1999); Duta et al. (2008); Avikal et al. (2013, 2014). Tang et al. (Tang et al. (2001)) presented a heuristic to design a multi-products disassembly line.

Duta et al. (Duta et al. (2005)) applied an equal piles approach to design a disassembly line with the objective to maximize its profit taking into account parts failures. For this problem, Tang and Zhou (2006) used a heuristic approach based on Petri nets.

Güngör and Gupta (2002) introduced a set of relevant optimization criteria for the design of the disassembly lines, such as: idle time minimization, maximization of the disassembly priority of hazardous parts and maximization of the disassembly priority of highly demanded parts. Different multi-objective approximate approaches considering these objectives lexicographically have been proposed in the following studies: a probabilistic distributed intelligent agents and an uninformed deterministic search (McGovern and Gupta (2005)), ant colony algorithm (McGovern and Gupta (2006); Zhu et al. (2014)), genetic algorithms (McGovern and Gupta (2007b)), greedy/hill-climbing, greedy/2-opt hybrid heuristics and hunter-killer heuristic (McGovern and Gupta (2007a)) to deal with the line design problem. A multi-objective heuristic with the same optimization criteria has been proposed by Avikal et al. (2013) for the U-shaped disassembly line design.

Ding et al. (Ding et al. (2009, 2010b,a)) developed a multi-objective ant colony algorithm to deal with the disassembly line design problem where the optimization criteria mentioned above were considered simultaneously. For the same problem, a simulated annealing metaheuristic has been proposed in Kalayci et al. (2012).

Different metaheuristic approaches have been developed in order to integrate line design and sequencing problems: a

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heuristic approach based on partial branch and bound concept (Lambert and Gupta (2005)), river formation dynamics (Kalayci and Gupta (2013d)), tabu search (Kalayci and Gupta (2014)), ant colony optimisation approach (Kalayci and Gupta (2013b)) and simulated annealing (Kalayci and Gupta (2013c,a)).

2.2 Exact solution approaches

Mathematical programming formulations and exact solution approaches have been also proposed for the disassembly line design and balancing. Altekin et al. (Altekin et al. (2008)) developed an integer programming formulation with profit maximization for the case of partial disassembly. They proposed a lower and upper-bounding scheme based on linear programming relaxation. An and/or graph was used to model the precedence relationships among disassembly tasks. Koc et al. (Koc et al. (2009)) considered the objective of minimizing the number of workstations. Two exact approaches were developed based respectively on mixed integer and dynamic programs. It was shown that a dynamic programming approach was capable of providing exact solutions for larger problem instances.

Other papers, recently, are interested in integrating closed loop supply chain network design and disassembly line balancing problems. Two mixed linear programming formulations have been proposed in Özceylan and Paksoy (2013); Özceylan et al. (2014) to model the problem.

3. NON-DETERMINISTIC PRODUCTION LINE DESIGN AND BALANCING

3.1 Uncertain assembly task processing times

Modeling with known probabilistic distributions

The major part of the literature studying uncertainty of assembly task processing times belongs to this subcategory.

To design then balance an assembly line under random task processing times of symmetric known distributions, a heuristic and exact solution approach have been proposed, respectively, in Raouf and Tsui (1982) and Betts and Mahmoud (1989). However, the most frequent model used for assembly task processing times as random variables is the Gaussian distribution. For this model and straight assembly lines, heuristic solution methods (Kao (1979); Carter and Silverman (1984); Silverman and Carter (1986); Chakravarty and Shtub (1986); Shin (1990); Lyu (1997); Fazlollahtabar et al. (2011)), metaheuristics (Erel et al. (2005); Cakir et al. (2011)) and exact algorithms (Kao (1976); Henig (1986); Sarin et al. (1999)) have been elaborated. The case of a line with workstations paralleling has been studied in McMullen and Frazier (1997). The optimization of U-lines has been conducted in Guerriero and Miltenburg (2003); Chiang and Urban (2006); Baykasoğlu and Özbakır (2007); Bagher et al. (2011); Özcan et al. (2011). Two heuristic approaches for the line re-balancing have been developed in Gamberini et al. (2006, 2009). In Liu et al. (2005), the authors studied the cycle time minimization (or maximization of the line pace).

Exact and heuristic methods have been also proposed to solve the assembly line design with disjoint probabilistic constraints, respectively, for U-lines in Urban and Chiang (2006); Ağpak and Gökçen (2007) and two-sided lines in Özcan (2010).

Modeling with closed intervals

We suppose that a processing time of an assembly task belongs to an interval of the form $[a, b]$, $a < b$, $a, b \in \mathbb{R}_+^*$. The values of a and b are respectively the minimum and maximum values that a task processing time can take. No probability distribution is associated with the interval $[a, b]$.

Papers dealing with such uncertainty in assembly line design exist already. The authors in Hazır and Dolgui (2013); Gurevsky et al. (2013a), presented formulations and exact solution methods. Stability analysis of feasible and optimal solutions of assembly line design problem and its generalized version, along with exact and heuristic approaches allowing processing time variations of some tasks, have been developed respectively in Gurevsky et al. (2012) and Gurevsky et al. (2013b).

Modeling with fuzzy sets or scenarios

A task processing time is called fuzzy if its value belongs to a fuzzy subset $\tilde{\Upsilon} \subseteq \Omega$. This subset is defined with its characteristic or membership function $\mu\colon \Omega \to [0, 1]$; Ω is an uncountably infinite set. For example, for a given value υ, $\mu_{\tilde{\Upsilon}}(\upsilon)$ represents the membership degree of υ in $\tilde{\Upsilon}$. Such a type of uncertainty of the task processing times has been studied in Zacharia and Nearchou (2012); Hop (2006); Tsujimura et al. (1995).

In the second case of uncertainty, the task processing times are defined with scenarios (with no associated probabilities) which are predetermined by a certain planning in a given period. This kind of uncertainty of the task processing times has been studied in Dolgui and Kovalev (2012); Xu and Xiao (2011, 2009).

3.2 Uncertain disassembly task processing times

Few studies, in the literature, have investigated the disassembly line design and balancing under uncertainty of the task processing times.

A fuzzy colored Petri net model with a heuristic solution method have been proposed in Turowski and Morgan (2005) to study the human factors that cause uncertainty of task processing times. in this study, task times were determined according to a learning process. A collaborative ant colony algorithm for stochastic mixed-model U-shaped disassembly line balancing has been developed in Agrawal and Tiwari (2008). To analyze and compute a global idle time of a mixed disassembly line, with random independent task processing times of identical distributions, the authors in Zhao et al. (2007) presented a modeling and solution approaches using Markov chains. Task times were assumed to be random variables with known normal probability distributions. A binary bi-objective non linear program has been presented in Aydemir-Karadag and Turkbey (2013) for disassembly line design and balancing under uncertainty of the task times. Disassembly task times were assumed to be independent random variables with known normal probability distributions. Mathematical programming based approaches have been also conducted in Özceylan and Paksoy (2014a,b) to deal with fuzzy task processing times.

In Bentaha et al. (2013e,c,b, 2014e, 2013d,a, 2015, 2014c,d,b,a), mathematical models and exact solution approaches for designing a disassembly (or assembly) line under uncertainty of the task processing times have been developed. Partial disassembly has been taken into account and complex and/or precedence relationships among tasks have been integrated.

First, in Bentaha et al. (2013e,c,b, 2014e), uncertainty was modeled using the notion of recourse cost and a sample average approximation method was developed to solve the studied optimization problem. In other words, these studies aimed in minimizing the line stoppage costs caused by the task processing times uncertainties. Second, in Bentaha et al. (2013d,a, 2015), the goal was to guarantee a certain operational level defined by the designer. Uncertainty was modeled using joint probabilistic cycle time constraints. Third, in Bentaha et al. (2014c,d,b,a), uncertainty was modeled using workstation expectation times. In Bentaha et al. (2014c), the joint problem of disassembly line design and tasks sequencing was studied. In Bentaha et al. (2014d), a Lagrangian relaxation was proposed to maximize the disassembly line profit. In Bentaha et al. (2014a), the line balancing problem has been undertaken under the assumption of the fixed number of workstations.

Some existing articles in the literature treated other kinds of uncertainty which characterize the disassembly lines. The authors in Güngör and Gupta (2001) proposed a heuristic to deal with task failures caused by defective parts of the end of life products to be disassembled. A fuzzy optimization model was proposed in Tripathi et al. (2009) with the objective to maximize the net revenue of the disassembly process under uncertainty of the quality of end of life products. A mixed integer programming based predictive-reactive approach to deal with task failures has been also presented in Altekin and Akkan (2011) with the objective to maximize the profit generated by a disassembly line. The authors in Tuncel et al. (2012) used a Monte Carlo-based reinforcement learning technique to solve the multi-objective line design under demand variations of the end of life products. Uncertainty of end of life products demand has been conducted in Chica et al. (2013). Cycle time uncertainty has been studied in Liu et al. (2013). To deal with the imprecise or fuzzy nature of decision-makers targeted goals in line design and help to find the criteria priority in multi-objective line design, fuzzy multi-objective programming and fuzzy AHP approaches have been, respectively, proposed in Paksoy et al. (2013) and Avikal et al. (2014).

4. CONCLUSION

In this article, we referenced most of the existing papers (about 90 publications) dealing with the assembly and disassembly line design and balancing under uncertainty. Deterministic models for disassembly lines have been also discussed.

This study shows that for non-deterministic production line design and balancing, most of the referenced papers modeled the task processing times as independent normal variables with known probability distributions. The most frequently, such optimization problems have been addressed by heuristic and metaheuristic approaches. Since the design of production lines is a strategic problem of high importance, defining the production costs over a large planning horizon, more effort has to be allocated to the development of efficient exact methods. In the case of the disassembly lines, more attention has to be paid to the high uncertainty of end-of-life product quantity and quality as well as to the environmental impact of such lines.

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