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Review

A taxonomy of line balancing problems and their solution approaches

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ABSTRACT

Line balancing belongs to a class of intensively studied combinatorial optimization problems known to be NP-hard in general. For several decades, the core problem originally introduced for manual assembly has been extended to suit robotic, machining and disassembly contexts. However, despite various industrial environments and line configurations, often quite similar or even identical mathematical models have been developed. The objective of this survey is to analyze recent research on balancing flow lines within many different industrial contexts in order to classify and compare the means for input data modelling, constraints and objective functions used. This survey covers about 300 studies on line balancing problems. Particular attention is paid to recent publications that have appeared in 2007–2012 to focus on new advances in the state-of-the-art.

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1. Introduction

A flow line consists of a sequence of workstations performing repetitive sets of tasks on products. Such lines are used in many manufacturing contexts such as machining, assembly, or disassembly. Because of the high investment and running costs involved, the design (or re-design) of such lines is of considerable practical importance (Askin and Standridge, 1993; Nof et al., 1997; Scholl, 1999; Dolgui and Proth, 2010). A number of crucial decisions have to be made in flow line design, including product design, process selection, line layout configuration and line balancing. Usually these problems are considered one at a time because of their complexity (Kimms, 2000; Zhang et al., 2002; Battaïa et al., 2012a).

The first two steps – product design and process selection – provide the information about the work that must be done in the flow line being designed, i.e., a set of indivisible tasks related by some constraints. The sources of these constraints can be the technology used, economic and environmental considerations or ergonomic factors for the workforce. The next step deals with the choice of the line layout (straight, U-shaped, with circular transfer, asymmetric, etc.). This defines how the workstations will be situated on the line as well as what flow directions and rules are to be used. Finally, the last and crucial step is line balancing. Here tasks are assigned to the workstations and resources that will be deployed on the line. This is a complex combinatorial problem. Its solution determines for the most part the efficiency of the line designed.

This paper surveys the contemporary research literature on line balancing and presents a taxonomy for the wide range of models and solution approaches proposed for these problems to enable researchers and practitioners to understand better the current state of this domain. The goal is to help to find the nearest known models and possible methods for future line balancing problems. Unlike the majority of other state of the art studies, our study is not limited to assembly lines but considers diverse line balancing problems from different contexts – machining, assembly, disassembly and other industries – within a common modelling framework.

This article emphasises the topics being intensively studied for the last decade. More than 267 papers have been published in major refereed international journals since the last comprehensive review (Boysen et al., 2008) became available online in 2006. This significant amount of publications shows that this subject continues to hold an important place in production research. The current article is especially focused on these most recent publications. Nevertheless, it highlights also key issues identified in the past but which have unfortunately remained undeveloped and still require additional academic research.

The first known formulation of an assembly line balancing problem has been made by Salveson (1955). It assigned a set of tasks $I=\{1,2,\ldots,i,\ldots,|I|\}$ to linearly ordered workstations $M=\{1,2,\ldots,k,\ldots,m\}$. Order relations among the tasks are given by a precedence graph G, where an arc (i,j) exists if task j cannot be started before the end of task i. The tasks assigned to workstation k, i.e., set I_k, are performed sequentially, i.e., workstation processing time, $T_k=\sum_{i\in I_k} t_i$, where t_i is the processing time of task i. The cycle time constraint requires that workstation processing times do not exceed a given value c referred to as line cycle time (also known as takt time), i.e., $T_k \le c$, $\forall k \in M$. The objective is to assign all given tasks with respect to precedence and cycle time constraints while minimizing the number of workstations required. This problem was referred to by Baybars (1986) as the Simple Assembly Line Balancing Problem (SALBP). SALBP is known to be NP-hard in general (Wee and Magazine, 1986). Several indicators have been suggested to evaluate the computational complexity of particular SALBP instances (for more details, see Bhattacharjee and Sahu, 1990; Driscoll and Thilakawardana, 2001; Hoffmann, 1990; Scholl, 1999).

SALBP has been intensively studied in the literature. As a result, numerous operational research techniques have been applied to solve this problem to optimality or approximately. Several evaluations of heuristics (Boctor, 1995; Ponnambalam et al., 1999; Talbot et al., 1986) and exact methods (Baybars, 1986; Erel and Sarin, 1998; Scholl, 1999; Scholl and Becker, 2006) have been presented. However, a number of recent publications show that SALBP is still a challenging topic for researchers (e.g., Bautista and Pereira, 2009; Blum, 2008; Ho and Emrouznejad, 2009; Kilincci, 2010, 2011; Kilincci and Bayhan, 2008; Liu et al., 2008; Nearchou, 2007; Özcan and Toklu, 2009a; Pastor and Ferrer, 2009; Sewell and Jacobson, 2012; Sheu and Chen, 2008).

Recently, an algorithm called "Branch, Bound, and Remember" was presented by Sewell and Jacobson (2012). It provided optimal solutions for 269 test-bed instances referenced in the literature in less than half a second per problem, on average. This is an excellent result. Nevertheless, this does not signify that the research on SALBP is now definitively over. It is known that for combinatorial problems there exist always examples for which enumeration algorithms are not efficient enough. Thus, the search for new and more difficult SALBP benchmarks is an interesting path for future research.

The SALBP considers a single straight assembly line for only one type of product. This problem was generalized for other line configurations, manufacturing contexts and performance requirements. Each novel formulation involved new decisions, constraints or/and optimization objectives. As a result, a great number of definitions have appeared for the so-called Generalized Assembly Line Balancing Problem (GALBP), Disassembly Line Balancing Problem (DLBP) and Transfer Line Balancing Problem (TLBP). However, similarities can be observed amongst them, e.g., both assembly and disassembly lines can have a U-layout, multiple workplaces or employ workers with different skills. Precedence constraints with standard and exclusive (OR-) relations can be appropriate for machining, assembly, and disassembly processes. As a consequence, when only looking at the mathematical model of a line balancing problem, often one cannot identify if the model has been developed for assembly, disassembly or machining line. Thus, our survey aims to present a novel taxonomy, more general and common for several manufacturing environments where flow lines are used.

Taking into account the ever growing number of articles on generalisations of SALBP, the previous comprehensive surveys on GALBP (Ghosh and Gagnon, 1989; Gagnon and Ghosh, 1991; Rekiek et al., 2002; Becker and Scholl, 2006), while still valuable in themselves have not covered the numerous current issues and the large body of recently published research.

The survey of Boysen et al. (2007) has proposed the first and very interesting classification of line balancing problems in the form of the tuple-notation. The tuples corresponded to: