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The stochastic U-line balancing problem: A heuristic procedure

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Abstract

Many heuristics have been proposed for the assembly line balancing problem due to its computational complexity and difficulty in identifying an optimal solution. Still, the basic line balancing model fails to consider a number of realistic elements. The implementation of a Just-In-Time manufacturing system generally entails the replacement of traditional straight assembly lines with U-shaped lines. An important issue in the U-line balancing problem is the consideration of task time variability due to human factors or various disruptions. In this paper, we consider the stochastic U-line balancing problem. A hybrid heuristic is presented consisting of an initial feasible solution module and a solution improvement module. To gain insight into its performance, we analyze the heuristic under different scenarios of task time variability. Computational results clearly demonstrate the efficiency and robustness of our algorithm.

Keywords: Line balancing; Heuristics; Facilities planning and design

1. Introduction

The assembly line balancing (ALB) problem was first published in mathematical form by Salveson in 1955. Due to the computational complexity of the problem—ALB is known to be an NP-hard problem (Karp, 1972)—optimal solution methodologies have limited potential for solving practical problems (see Baybars (1986) for a review of exact procedures). Therefore, a great deal of research has recently been directed in the development of efficient heuristic algorithms. Talbot et al. (1986) classified existing heuristics into one of four categories: single-pass, composite, backtracking, or optimal-seeking. Since then, intelligent metaheuristic approaches, such as tabu search, genetic algorithms, and simulated annealing (Leu et al., 1994; Chiang, 1998; McMullen and Frazier, 1998), have been proposed for the problem. Heuristics for the line balancing problem have also

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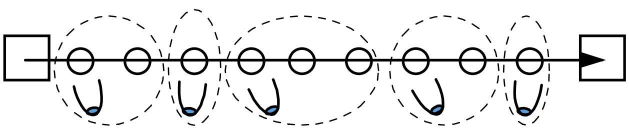
been extended to incorporate zoning restrictions (Schofield, 1979), mixed-model production lines (Askin and Zhou, 1997; Vilarinho and Simaria, 2002), two-sided assembly lines (Bartholdi, 1993), among other generalizations.

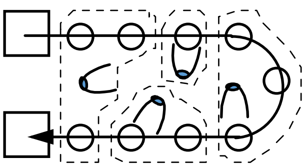
In recent years, many manufacturers have adopted a Just-in-Time (JIT) approach to manufacturing, finding that it improves their productivity, profits, and product quality. JIT is beneficial for companies engaged in repetitive, job shop, or process manufacturing. One of the important changes resulting from JIT implementation is the replacement of the traditional straight lines with U-shaped production lines; Fig. 1 provides a comparison between a traditional line and a U-line. The main benefits of the U-line as compared to a straight line include reduction in the wasted movement of operators and work-in-process inventory, improved productivity (Hirano, 1988), easier implementation of zero-defects campaign, higher flexibility in workforce planning in the face of changing demand (Monden, 1983), and improvement in material handling (Sekine, 1992). Several authors, including Sekine (1992), provide an explanation of U-shaped production lines and how they operate, as well as the benefits realized by their implementation.

The U-line balancing problem was introduced by Miltenburg and Wijngaard (1994); they used a dynamic programming formulation to solve small problem instances. Urban (1998) presented an integer linear programming formulation to solve small- to medium-sized U-line balancing problems via standard mathematical programming software (CPLEX). Scholl and Klein (1999) developed a branch-and-bound procedure to solve, either optimally or suboptimally, problems with up to 297 tasks. Aase et al. (2003) have recently developed a branch-and-bound procedure found to be more efficient than previously-developed exact procedures for the U-line balancing problem. Ajenblit and Wainwright (1998) developed a genetic algorithm, and Erel et al. (2001) proposed simulated annealing as solution methodologies for larger U-lines.

Another important topic in assembly line balancing is the consideration of task time variability. "Considerable variations, which are mainly due to the instability of humans with respect to work rate, skill and motivation as well as the failure sensitivity of complex processes, require considering stochastic task times" (Becker and Scholl, 2006). In addition to the inherent variability of human operators, other factors that may dictate the use of stochastic line balancing include the "inevitable disruptions such as disposing of an empty case... sealing a full tote" (Bartholdi et al., 2001), "difficulty in fitting together the parts to be assembled" (Buzacott and Shanthikumar, 1993), or any "variability from sources that have not been explicitly called out (e.g., a piece of dust in the operator's eye)" (Hopp and Spearman, 1996). Even in automated processes, "there is always some natural variability. For instance, in machining operations, the composition of material might differ, causing processing speed to vary



(a)



(b)

Fig. 1. (a) An example of a traditional assembly line and (b) an example of a U-Line conversion.