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A Simulated Annealing algorithm for a mixed model assembly U-line balancing type-I problem considering human efficiency and Just-In-Time approach

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A B S T R A C T

This research deals with balancing a mixed-model U-line in a Just-In-Time (JIT) production system. The research intends to reduce the number of stations via balancing the workload and maximizing the weighted efficiency, which both are considered as the objectives of this research paper.

After balancing the line and determining the number of stations, the labor assignment policy should be set. In this study, it was assumed that there are two types of operators: permanent and temporary. Both types can work in regular and overtime periods. Based on their skill levels, workers are classified into four types. The sign at each work station indicates types of workers allowed to work at that station. An alert system using the hybrid kanban systems was also considered. To solve this problem, a Simulated Annealing algorithm was applied in the following three stages. First, the balancing problem was solved and the number of stations was determined. Second, workers were assigned to the workstations in which they are qualified to work. Following that, an alert system based on the kanban system was designed to balance the work in the process inventory. This was achieved by defining control points based on the processing time and making control decisions to minimize the number of kanban cards. In the proposed SA algorithm, two methods for the temperature cooling schedule were considered and two methods were defined for determining the number of neighborhood search. The initial temperature was considered equal to the cost of the initial solution to reach the convergence situation as soon as possible. Five problems were solved in small size using the GAMS software. The results obtained from the GAMS software were compared with those obtained from the SA algorithm to determine the performance difference. The computational results demonstrated that the SA algorithm is more consistent with the answers obtained. Also seven large scale problems were solved. The results showed that the SA algorithm still have better reliability. To show the efficiency of the proposed SA algorithm, an axel assembly company was studied. To satisfy demands and reduce backlogging, a mixed model assembly line was designed for this case study. The results showed that the mixed model assembly line designed using the SA algorithm had good efficiency.

1. Introduction

Mixed-Model Assembly Line (MMAL) is a type of production line where a variety of models similar in product property are assembled to consider the diversity of customer's demands. Several researchers have studied MMAL balance problems and proposed many mathematical models and optimization algorithms. Helgeson and Birninie (1961) used a ranked positional weight technique to solve the assembly line balancing problem. Erel and Gokcen (1999) provided a shortest-route formulation to minimize the processing time for different models considering precedence constraints. Erel and Gokcen (1998) developed a binary integer formulation for the mixed-model assembly line balancing problem.

The MMAL balance is affected by many factors which should be comprehensively considered. In this paper, a new mathematical model in which two factors are integrated is introduced. The factors include the number of workstations and assembly line efficiency. Based on workforce efficiency, a new mathematical model is presented to minimize workforce costs. Until now, extensive research has been carried out on pull control-based production systems as one aspect of lean manufacturing (Askin & Krishnan, 2009). An alert system based on the kanban system is presented in Section 3. Askin et al. (2009) reached conditions ensuring the optimality of a single buffer in a multistage pull system for producing a single product type with known service times and deterministic lead times. A Simulated Annealing (SA) algorithm is developed to find optimal solutions of the problems.

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This paper is organized in nine sections. Section 1 is focused on the introduction; Section 2 provides a literature review for the assembly line balancing problem, human allocation problem and kanban system. The problem description is dealt with in Section 3. In Section 4, the objective function for the balance problem is defined. A mathematical model is presented in Sections 5 and 6 provides the specification of the novel Simulated Annealing algorithm. Section 7 deals with the experimental design and parameters setting of the proposed algorithm. Section 8 is allocated to the application of the SA algorithm for designing a mixed model assembly line for a company. Finally, Section 9 puts a conclusion on the findings of this research and introduces some directions for future research.

2. Literature review

Many studies on the assembly line balancing (ALB) problems consisting exact solution methods, heuristics and meta-heuristic approaches have been reported in the literature. The comprehensive reviews of such studies have been given by Baybars (1986) and Ghosh and Gagnon (1989), Erel and Gokcen (1998) and more by Becker and Scholl (2006). Although many surveys have been conducted for straight ALB problems, the U-line ALB problem has been studied considerably by researchers as well.

Lee, Kim, and Kim (2001) developed an assignment procedure for ALB-I and ALB-II problems with two performance criteria: work relatedness and work slackness. Baykasoglu and Dereli (2006) presented an ant colony optimization considering heuristic algorithm to solve the ALB-I problem with zoning constraints. Hu, Wu, and Jin (2008) presented a station-oriented enumerative algorithm for the ALB-I problem. Kim, Song, and Kim (2009) developed a mathematical formulation and a genetic algorithm for the ALB-II problem. Wu, Jin, Bao, and Hu (2008) presented a formal ALB-I problem, and they also developed a branch-and-bound algorithm to solve the problem. Mixed-model assembly lines are also used in a range of industries to improve the flexibility to adapt the changes in market demand.

Several studies on the mixed-model straight line assembly line balancing problem have been reported in the literature (Dar-El & Cother, 1975; Erel & Gokcen, 1999; Jin & Wu, 2002; Karabati & Sayin, 2003; Macaskill, 1972; McMullen & Frazier, 1998; Merengo, Nava, & Pozzetti, 1999; Simaria & Vilarinho, 2004; Thomopoulos, 1970; Vilarinho & Simaria, 2002, 2006. Simaria and Vilarinho (2009) addressed the MMALB problem and proposed a mathematical programming model to formally describe the problem. They presented an ant colony optimization algorithm to solve the problem as well. The mathematical programming model proposed by Simaria and Vilarinho (2009) is a complex model so that the optimal solutions are not reached. In this paper, a hybrid non-linear and mixed integer programming (MIP) models are developed to solve the MMALB-I problem. The presented mathematical model is based on the mathematical formulation of MMALB-I presented by Simaria and Vilarinho (2009). Also, a Simulated Annealing (SA) approach is developed for the MMALB-I problem especially for large-sized problems.

Workforce planning has an important role in realizing the objectives of lean manufacturing.

Hax and Candea (1984) have developed several alternative production planning options that can be applied to deal with changing demand patterns, considering use of variable workforce, overtime, seasonal inventory and planned backlogs. Some authors presented several classical LP models incorporating the production, manpower and inventory related tradeoffs in each of the options mentioned above (Rohit, Venkataramanaiah, & Anand, 2003). Silva, Lisboa, and Huang (2000) presented an aggregate production-planning model that was considered a constant level of employment.

Using explicit costs for overtime and inventory holding from a real life case study, the researchers showed that the model could achieve cost savings of 8.1% when applied to a construction material firm in Portugal. Lagodimos and Leopoulos (2000) proposed a mixed integer programming based greedy heuristic for the manpower shift-planning problem. The objective of this problem was to determine the minimum number of workers needed to work in each available period to meet pre-specified production targets.

The JIT manufacturing system has the goal of continuously reducing and ultimately removing all forms of wastes (Brown & Mitchell, 1991; Ohno, 1988; Sugimori, 1977). Based on this principle, Japanese companies are operating with very low level of inventory and recognizing exceptionally a high level of productivity (Greene James, 1987; Tersine, 1994). The JIT is based on“ zero concept”, which aims to achieve zero defects, zero queues, zero breakdown, zero inventories and so on. It ensures the supply of right parts in the right quantity in the right place and at the right time. Hence, the old system of material acquisition and buyer–seller relationships are adjusted to this new revolutionary concept, (Womack et al., 1991; Womack and Jones, 1994).

3. Problem description

To deal with a competitive situation, a make-to-order environment is assumed for the problem definition. In such a condition, there are various kinds of products which are ordered by different customers. To satisfy all customers a mixed model assembly line should be used to prepare customer's orders on their due date. By applying a MMAL, all the products can be produced simultaneously. A mixed model assembly line makes a simpler production system; for instance, with fewer workers and lower WIP (Bukchine, Ezey, & Jacob, 2002). In a MTO, the goals such as zero defects, zero queues, zero inventories and zero breakdowns are so significant. These goals are considered in the Just-In-Time philosophy. The JIT is a strategy developed by Taiichi Ohno. In the Toyota Motor company, Taiichi Ohno and Shigeo Shingo began to incorporate Ford production and other techniques into an approach called Toyota Production System or Just-In-Time. They recognized the central role of inventory. In this regard, a JIT pull production system may be used to realize the objectives of lean manufacturing. Based on the survey undertaken by Sendil Kumar and Panneerselvam (2007), a pull system was defined. In this pull system, from the current workstation (j), each task is withdrawn by its succeeding workstation ($j + 1$). In fact, the task is pulled by a successive workstation instead of being pushed by its preceding workstation. The flow of different parts throughout the product line is controlled by kanban cards which are divided into two categories (see Fig. 1):

1. **Single-card system** in which the distance between two constructive workstations is very short and a single buffer is available between the workstations.
2. **Two-card system** in which the distance between two consecutive workstations is much longer. In this system, each station will have an inbound buffer and an outbound buffer.

Where POK, WS and WK are the production order kanban, the index of workstation and the index of the withdrawal kanban, respectively.

Based on Chan (2001), the hybrid pull system was defined. The hybrid kanban manufacturing system is a combination of the push- and pull-type modes. In this study the raw materials are pushed from station r to station r' and this process is continued to the last production station. This type of manufacturing system differs from