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A heuristic approach for U-shaped assembly line balancing to improve labor productivity [☆]

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ABSTRACT

The assembly line balancing problem is a non deterministic polynomial type planning problem for mass production. Layout design changes constitute a major decision that yields investment for assembly operations and numerous heuristics have been reported in the literature for solving the line balancing problems. U-shaped assembly layout offers several benefits over traditional straight-line layout in implementation of lean manufacturing and Just-In-Time technology. In the paper an attempt has been made to evaluate labor productivity in U-shaped line system and straight line system. A Critical Path Method (CPM) based approach for U-shaped assembly line has been applied for assigning the task to the work stations for assembly line layout. Results show that the CPM based U-shaped approach performs better and improve the labor productivity of assembly line layout.

1. Introduction

An assembly line is generally used for mass production and has been a matter of concern of researchers for a long time. A straight line balancing may be defined as processes of assigning tasks to the workstations in such a manner that all workstations have approximately the equal amount of work assigned to them. During assignment of the tasks to the workstations precedence relations among these tasks should not be violated. Many heuristics have been reported for the assembly line balancing (ALB) (Chiang & Urban, 2006).

In recent years, many manufactures have adopted Just-in-Time (JIT) approach for manufacturing, as it is capable to improve productivity, profits and product quality. JIT is beneficial for companies that are engaged in job shop, repetitive types of jobs and process manufacturing. An important change resulting from JIT implementations is the replacement of the traditional straight lines with U-shaped production lines (Aase, Olson, & Schniederjans, 2004).

The U-shaped assembly line has become an amicable alternative for assembly production system since operator may perform more than one task located to different places of assembly line. Moreover, the U-type line disposition allows for more possibilities on how to assign the tasks to the workstations therefore the number of workstations needed for a U-shaped line layout is never more than the number of workstations needed for the traditional straight assembly line. In the traditional ALB, for a given cycle time (the time interval between two successive outputs), the set of possible assignable tasks is confirmed by those tasks whose predecessors have already been assigned to workstations, whereas in the U-type line balancing problems, the sets of assignable tasks is determined by all those tasks whose predecessors and successors have already been assigned (Liu, Ong, & Huang, 2003).

One of the important characteristics that make U-shaped assembly lines different from straight assembly lines is that the entrance and the exit of these lines are at the same position (Monden, 1993). Products enter the U-shaped assembly line at the front-side and exit from the back-side of the line. The lengths of front-side and back-side of the U-shaped assembly line are equal and operators work inside of the U-shaped assembly line. Studies on U-shaped assembly lines provide evidence for their potential to improve visibility and communication skills between operators, reduce operator requirements, increase quality, reduce work-in-process inventory, and facilitate problem-solving and efforts to adjust to changes in the external environment of the firm (Aase et al., 2004; Kara, Özgüven, Yalçın, & Atasagun, 2011; Miltenburg, 1998, 2001). Cheng, Miltenburg, and Motwani (2000) have listed the following factors that enhanced the wider acceptance of U-shaped lines:

I. *Volume flexibility*: The production rate of a line in a JIT environment changes frequently. In such an environment, a U-shaped is preferred to a straight line because of its volume

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flexibility. By increasing or decreasing the number of operators on the line, a company can adjust the production rate as required. This level of volume flexibility is harder to obtain with a straight line.

II. *Operator flexibility*: Since walking distance is shorter in a U-shaped than on a straight line, it is easier for an operator to oversee on several work station.

III. *Number of workstations*: The number of workstations required for a U-shaped is never more than, that required on a straight line. There are more possibilities for grouping tasks into workstations on a U-line.

IV. *Material handling*: A U-line eliminates the need for special material-handling equipment such as conveyors and other special material-handling operators those are necessary in straight line. Instead, production operators move products from machine to machine.

V. *Visibility and teamwork*: In a straight line layout operators are spread out along a long line and may be separated by walls of inventory. The compact size of a U-line improves visibility and communication. This enhances teamwork, gives a sense of belonging, and increases responsibility and ownership compared to a straight line.

VI. *Rework*: In a U-line, the distance to return the defective product is short. It is easier to correct a quality problem quickly by returning a defective product to the station where product was produced. This is in contrast to the traditional policy of sending the defective product to a separate rework area.

In this paper an analysis of labor productivity for U-shaped line and traditional straight has been carried out using bi-directional assignments and with a CPM based approach. In Section 2, the relevant literature has reviewed, while Section 3 depicts precise description of the U-shaped and traditional straight-line layout. In Section 4, the applied approach has been described and in Section 5 a practical example and computational results have been shown with the conclusion in Section 6.

2. Literature review

Assembly line balancing problem has become a matter of concern for academicians and researchers for a long time. Many heuristics, exact algorithms and optimization techniques have been deployed for the assignment of the tasks to workstations. However, majority of the past studies has been focused on the traditional straight assembly line layouts.

Baybars (1986) has developed a single pass heuristic for single-model deterministic line balancing, for different priority rules. Gokcen, Agpak, Gencer, and Kizilkaya (1997) have proposed a non-linear integer program as a model for mixed model line balancing problems with parallel workstations. Fleszer and Hindi (2003) have proposed a bidirectional heuristic for assembly line balancing problem with a reduction technique. Liu et al. (2003) have proposed two heuristics for solving the assembly line balancing. The proposed algorithm first generates an initial solution by a bi-directional assignment procedure, thereafter improves the solution by swapping tasks among workstations. Liu, Ong, and Huang (2005) have proposed a bi-directional heuristic to solve the single-model stochastic assembly line balancing problem and then smoothed the workload by swapping tasks among workstations. Dolgui, Guschinsky, and Levin (2006) have presented a solution for a special case of transfer lines balancing by graph approach. Becker and Scholl (2006) presented a survey on problems and methods for generalized assembly line balancing. Yeh and Kao (2009) have proposed a bi-directional heuristic based on critical path method. Bautista and Pereira (2009) have proposed a dynamic programming based heuristic for the assembly line balancing problems. Guschinskaya and Dolgui (2009), described transfer line balancing problems with an objective to group the operations into blocks and to assign the blocks to machines in order to minimize the total amount of the required equipment. They also presented a comparison of exact and heuristic methods for a transfer line balancing problems. Battaïa and Dolgui (2012) have presented a survey with an objective to analyze research on balancing flow lines within different industrial contexts in order to classify and compare the means for input data modeling, constraints and objective functions used.

Nakase, Yamada, and Matsui (2002) have proposed a management design approach for stochastic task time and have evaluated the cost and lead time under demand fluctuation. Khan and Day (2002) have proposed a knowledge based design methodology to optimize the mixed model assembly line for real life problem with stochastic task times. Kumar, Kumar, Shankar, and Tiwari (2003) presented an Expert Enhanced Colored Stochastic Petri Net and its application in assembly/disassembly with the focus on facilitates. The process planning activities of assembly/disassembly are also analysed. Simaria and Vilarinho (2004) have used genetic algorithm to minimize the cycle time for mixed model problem with parallel workstations. Kilincci and Bayhan (2006) have proposed an algorithm based on Petri-Net approach for minimization of number of workstations. Bautista and Pereira (2007) have proposed an Ant algorithm for time and space constrained assembly line balancing.

Miltenburg and Wijngaad (1994) have introduced U-line balancing to overcome the limitations of the traditional straight line balancing. They used a dynamic programming formulation to solve small problem instances. Sparling and Miltenburg (1998) studied the mixed model U-lines (MMULs) and developed a procedure for line balancing. Urban (1998) presented an integer linear programming formulation to solve small to medium size U-line balancing problems via standard mathematical programming software. Scholl and Klein (1999) have developed a branch and bound procedure to solve, problems with 297 tasks. Ajenblit and Wainweight (1998) have developed a genetic algorithm for assembly line balancing. Miltenburg (2002) has solved the dual problem of balancing and scheduling using a genetic algorithm. Cheng et al. (2000) have analyzed the effect of the straight line layout and U-shaped line layout on the product quality. Erel, Sabuncuogl, and Aksu (2001) have proposed simulated annealing as solution methodology for large U-lines. A study containing the analysis of procedures followed for the balancing of U-line was carried out by Aase, Schniederjans, and Olson (2003) which detailed various design elements that should be included into the solution methodologies for solving the U-shaped assembly line balancing problem. Later Aase et al. (2004) found the impact of U-shaped assembly line layout on the labor productivity. Some hypothesis and variable on which the labor productivity depends have been described. Gokcen, Agpak, Gencer, and Kizilkaya (2005) have proposed a new model based on the finding the shortest route in a directed network for simple U-shaped assembly line balancing problems. Kim, Kim, and Kim (2006) have proposed an evolutionary algorithm for the mixed-model U-line balancing and scheduling that utilized the endosymbiotic principles of evolution. Chiang and Urban (2006) have proposed a heuristic based on the first-fit assignment approach and the priority based approach with stochastic task time. Nakade and Nishiwaki (2008) have presented an optimization problem for finding an allocation of workers to the line that minimizes the overall cycle time under the minimum number of workers satisfying the demand. Toksari, İşleyen, Güner, and Baykoç (2008) have proposed an algorithm for simple and U-shaped assembly line with learning effect for minimization of number of workstations.