Ergonomics in the assembly line design problem

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1 Introduction

Assembly lines are production systems designed for the final assembly of a manufacturing product, this mode of production is suitable for mass production, or mass customization. Assembly lines are composed of workstations connected between them with conveyors, semi-finished products are transported in a constant speed (takt time) between the different workstations where the parts are added in sequence to form the final finished product. To maximize the profit, a cost-effective approach should be adopted to design assembly systems [6]. Optimization problems related to the design of the assembly systems are the combinatorial problem of assigning different tasks to workstations to assemble a product, denoted the Assembly Line Balancing Problem (ALBP) [3]. Moreover, in the design stage of assembly systems, a relevant problem is the equipment selection problem, when we select equipment to assign to different workstations in order to execute the different tasks, with the optimization of the design cost. The joint problem of equipment selection and line balancing will be referred to as the Assembly Line Design Problem (ALDP) [4].

Due to the repetitive aspect of work in assembly lines, the manipulation of loads and heavy tools, industrial workers are exposed to work-related musculoskeletal disorders (MSDs). MSDs are the major source of disease and absenteeism among industrial workers, affecting the economics of the production system and resulting in high compensation and absenteeism costs with a decrease in the overall system productivity. Equipment to improve the efficiency of the work and/or the ergonomics of the workstation are costly. Hence, designers should consider the trade-off between the cost of equipment and their effects on ergonomics. There is a wide type of equipment to improve the work efficiency and ergonomics load, ranging from industrial lifts, tool balancers and mechanical manipulators up to new technological equipment such as augmented reality, collaborative robot (cobot) that interact with workers in a shared workspace and assistive exoskeleton technology.

Advantages of considering ergonomics in the design stage are greater flexibility in balancing the workload and lower costs of interventions on existing lines. For designers, it is of primary importance to dispose of information on the trade-off between the investment and the ergonomics level; the selection of equipment involves cost related to the purchase, the powering with electrical energy, air powering, cost of maintenance and worker’s training and formation. The expected level of ergonomics in the line is also of great importance since equipment could enhance the ergonomics but decrease the execution time, or vice-versa. Costly equipment comes with an improvement, either fastening the execution time, or decreasing the load of the execution of tasks, or both.
2 The proposed approach

In the literature, the ALDP is considered aside from ergonomics, although the assignment of tasks and equipment influences the ergonomics of assembly systems and the design cost. In this work, we propose an approach for the ALDP with the consideration of ergonomics. In order to consider the numerous possible alternatives, we examine the problem with a bi-objective approach. The first objective is the total design cost, and the second one is an ergonomics criterion that considers the fatigue and recovery of workers and determines the adequate work-rest schedules [2, 1].

In order to generate the Pareto front of the problem described above, we firstly propose a mixed-integer linear programming (MILP) formulation. The ergonomics criterion is linearized in the MILP and the ALDP is defined with a new linearization of the assignment of equipment and tasks to reduce the size of the model, with suitable valid inequalities.

Thereafter, we propose a dichotomic search algorithm to solve the ALDP with the ergonomics criterion, and we integrate the former in an $\epsilon$-constraint algorithm to obtain the Pareto front. We fix the cost in the $\epsilon$-constraint algorithm, then the dichotomic search algorithm is initialized with a starting solution and the interval of search is reduced until proving the Pareto optimal point. The $\epsilon$-constraint algorithm is executed in such a way to keep only the efficient solutions.

3 Performance evaluation and perspectives

We implemented the algorithm with C++, with Cplex as a linear solver for the MILP formulation, the preliminary results on instances inspired from a real industrial case study are promising. We also propose to test our approach on instances from the literature, with a discussion of the results.

For future works, we will compare our approach for ALDP with formulations from the literature to assess the performance of the approach we proposed, furthermore, the dichotomic search and $\epsilon$-constraint algorithm could be compared to the generic bi-objective branch-and-bound algorithm in [5].

Références


