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Comparison of Multiobjective Algorithms for the Assembly Line Balancing Design Problem

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Abstract: The proposed article presents a planning method for a mixed-model line under consideration of product, processes and resources alternatives and addresses shortcomings in the current literature. In order to compare product and process alternatives and the impact of the line balancing and equipment selection, a detailed cost model is developed. Four resolution methods, belonging to the family of evolutionary algorithms and swarm intelligence, are proposed. Based on the fine tuning of their parameter values through a Design of Experiment, all algorithms are compared in order to highlight their strengths and weaknesses.

Keywords: Computer-aided manufacturing system design, Algorithms, Multiobjective optimisations, Optimization problems, Economic design

1. INTRODUCTION

Since product mass customization became a viable strategy in the mid-1990s, there has been tremendous market pressure on companies to deliver personalized products and services to customers with mass production efficiency, costs and quality. These requirements are, in this paradigm, addressed by developing product platforms that leverage on commonality, modularity and standardization across different product and process platforms by accommodating flexibility and reusability of the production systems.

Assembly lines, which meet these costs and efficiency requirements and are the most commonly used assembly systems, allow the assembly of products by workers with limited training and by dedicated machines and/or robots. Due to the high investment and running costs involved, the design and re-design of such lines is highly important. A number of crucial decisions have to be made in the design of assembly lines, including product design, process selection, line layout configuration and line balancing. Due to their complexity, these problems are usually considered at one time (Battaia und Dolgui 2013).

Changeable, dynamic and uncertain markets forces companies to regularly renew their product and process platforms through new production technologies and also factory infrastructure in order to fit explicitly the requirements of individual customers. This consistently affects the complexity of various life cycles activities, especially assembly planning tasks, which are seen as increasingly dynamic and difficult to control. These characteristics features are mostly related to the choice of the right level of automation (e.g. fully and semi-automatic or manual) and equipment regarding technical data and engendered product costs. Although the majority of product costs are determined in early design stage, many decisions about the design are made during this stage with little knowledge of the effect on downstream cost centres, e.g. assembly. The implication is that design decision determine the majority of product costs and that early design decisions are much more significant than later manufacturing decisions (Barton et al. 2001). While some authors state that the design decisions determine about 70% (Farineau et al. 2001) or more of product costs, others are more specific and state that manufacturing decisions can only affect 10-25% of product costs. However, compared to the cost responsibility, manufacturing costs represent about 70% of product costs and design costs about, regarding authors, between 6 and 12% (Shehab und Abdalla 2002).

In the view of significant uncertainty, the ability to plan the most flexible and economic assembly system with known uncertainty by taking product and process alternatives into consideration is highly important. This article presents a planning method for a mixed-model line under consideration of product, processes and resources alternatives, aiming at both optimizing capacity- and cost-oriented objectives. The next chapter will present an overview of similar work carried on this topic, followed by the description of the developed cost model. In the last chapters, the parameter values of four optimization methods will be optimally defined. Finally, the developed optimization methods will be compared on a set of 11 benchmark problems.

2. ASSEMBLY LINE BALANCING PROBLEM

Due to different conditions in industrial manufacturing, assembly line systems and corresponding Assembly Line Balancing Problem (ALBPs) have been extensively studied and different classification schemes and state-of-the-art have been proposed in the literature. A common classification scheme distinguishes between the: (i) Simple Assembly Line Balancing Problem, and the (ii) Generalized Assembly Line

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Balancing Problem (GALBP). In the former case, only one single product is processed, and the problem is restricted by precedence relations and cycle time constraints. In the latter case, problems involving e.g. parallel workstations, parallel tasks, unequally equipped workstations, problems involving sequence-dependent or stochastic processing times and problems considering mixed and multi-model lines can be found. In order to better identify the increasing variety of real-world balancing problems, Boysen et al. (Boysen et al. 2007) provided a classification scheme of ALBP, based on a tuple-notation $[\alpha|\beta|\gamma]$, where α, β, γ respectively represent the precedence graph characteristics, the station and line characteristics, and the objectives to be optimized. Battaia and Dolgui (Battaia und Dolgui 2013) provided a taxonomy of ALBPs. ALBPs can also be classified into (i) capacity-oriented objectives and (ii) cost-oriented objectives. Hazir et al. (Hazir et al. 2014) extended the classification of Boysen et al. by incorporating cost and profit aspects.

Two different approaches have been proposed to incorporate processing alternatives into ALBP. The former one is known as the equipment selection problem and is based on the assumption that there is a fixed set of equipment (exactly one of each) that has to be selected and assigned to a station. The latter consists in assigning processes to tasks. In addition to line balancing, for each task exactly one processing alternative has to be chosen out of a set of possible ones. These alternatives are determined through task requirements concerning either technological alternatives (e.g. gluing, clinching) or resource alternatives (e.g. machines or manpower). Corominas et al. (Corominas et al. 2011) formulated a general model with resource alternatives that minimizes the total cost, which includes the fixed station costs and unit cost of different resource types. Pekin and Azizoglu (Pekin und Azizoglu 2008) addressed the assembly line design problem with several equipment alternatives for each task. They minimized the total equipment cost and the number of workstations. Agpak and Gokcen (Ağpak und Gökçen 2005) presented an industrial problem of assembly line balancing with the simultaneous assignment of equipment and tasks to workstations. In this problem, a limited number of specific machines and workers has to be selected. Capacho and Pastor (Capacho und Pastor 2008) considers alternative variants that an assembly process may admit. Each assembly variant is represented by a subgraph and determines the tasks required to assemble a part of a particular product. Up to now, the problem has been defined and modelling in a restricted version and an extended version (Capacho und Pastor 2008). This problem, also known as the Alternative Subgraphs Assembly Line Balancing Problem (ASALBP) considers alternative assembly precedence subgraphs that involve either the same or different set of tasks. Not only heuristic methods have been developed and tested comprehensively by Capacho et al. (Capacho et al. 2009; Capacho et al. 2006) but also an exact method (Scholl et al. 2009). Scholl et al. (Scholl et al. 2009) proposed a formal representation of the ASALBP using an (X)-OR graph. Another line of research indirectly considers processing alternatives by equipping stations with different machinery and tools which have different abilities and speeds to perform the tasks (Bukchin und Tzur 2000). A similar approach was proposed by Oesterle and Amodeo (Oesterle und Amodeo 2014) in order to solve the line balancing and equipment selection problem.

Despite the huge amount of research done over the last years, there is still a vast bridge between the methods provided by the literature and the current industrial problems and market features, engendering a difficult practical use of these methods. Indeed, the requirement of quality engenders the need to not only select and plan the most reliable system, with e.g. low maintenance effort, low material waste and a low number of deficient products but also the most economic one. While most of the studies consider equipment costs on a high level, other product costs elements (e.g. breakdowns, quality) are not examined. Furthermore, most of the studies previously listed, only optimize either one capacity-oriented or cost-oriented objective. However, since most real-life decision and planning situations involve multiple conflicting criteria that should be considered simultaneously, a multi-criteria optimization model that consider both time and cost based criteria, conjugated with a robust cost model, would better reflect the current industrial needs. To solve this model, we propose two evolutionary algorithms, one ant colony algorithm and one particle swarm optimization algorithm.

3. PRODUCT COST ESTIMATION TECHNIQUES

In order to assess manufacturing costs, four techniques can be used, namely intuitive, analogical, parametric and analytical methods. Analytical methods are based on a detailed analysis of product design, its features and corresponding manufacturing processes. In this category, methods such as: (i) operation-based cost models, (ii) break-down cost models, (iii) cost tolerance models, feature-based cost models, (iv) activity-based models, and process-based models can be found. The Process-based cost modelling (PBCM) (Field et al. 2007) postulates that costs can be regarded as a function of technical factors and models the material flow to and from each process step and calculates the cost of processing material at each step. Since this method can project manufacturing or assembly costs based on part and process characteristics, it is suitable for our requirements for evaluating different product, process and resource alternatives. Fig. 1 shows the break-down of the manufacturing costs based on engineering, technological and scientific principles. This sub-model relates final product or part characteristics such as size, shape and material to the technical parameters of the process required to produce that product. These parameters can be associated to cycle time, downtime, reject rate, equipment and tooling requirements or material used. The second sub-model uses the processing requirements in order to scale them into the total amount of equipment, labour, floor space and energy consumption.

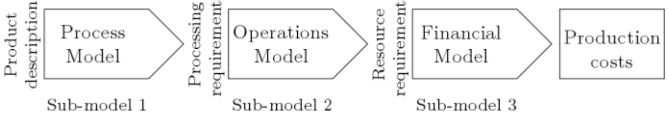

Fig. 1 Process-based cost modelling framework