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Coupling a genetic algorithm approach and a discrete event simulator to design mixed-model un-paced assembly lines with parallel workstations and stochastic task times

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ABSTRACT

In the paper, an innovative approach to deal with the Mixed Model Assembly Line Balancing Problem (MALBP) with stochastic task times and parallel workstations is presented. At the current stage of research, advances in solving realistic and complex assembly line balancing problem, as the one analyzed, are often limited by the poor capability to effectively evaluate the line throughput. Although algorithms are potentially able to consider many features of realistic problems and to effectively explore the solution space, a lack of precision in their objective function evaluation (which usually includes a performance parameter, as the throughput) limits in fact their capability to find good solutions. Traditionally, algorithms use indirect measures of throughput (such as workload smoothness), that are easy to calculate, but whose correlation with the throughput is often poor, especially when the complexity of the problem increases. Algorithms are thus substantially driven towards wrong objectives. The aim of this paper is to show how a decisive step forward can be done in this filed by coupling the most recent advances of simulation techniques with a genetic algorithm approach. A parametric simulator, developed under the event/object oriented paradigm, has been embedded in a genetic algorithm for the evaluation of the objective function, which contains the simulated throughput. The results of an ample simulation study, in which the proposed approach has been compared with other two traditional approaches from the literature, demonstrate that significant improvements are obtainable.

1. Introduction

The design of an assembly line is a complex problem that, as many other industrial problems, has to take into account two fundamental aspects: performances and costs. Performances of an assembly line are mainly related to its throughput, i.e. to the number of products that can be completed in the unit time. Costs are related to the amount of resources (labor and equipment) needed to complete all the tasks. The assembly line balancing problem is fundamentally a trade-off problem between these two factors. There are many ways to formulate Assembly Line Balancing Problems (ALBPs), as it will be described in the next paragraph. However, both these aspects have to be taken into account in some way, or in the objective function or in the problem constraints.

One of the main issues while solving ALBPs is that is difficult to evaluate the throughput of a complex assembly line. While costs of a determined line configuration can be easily calculated from the amount of resources employed, it is often not easy to calculate its throughput with an acceptable degree of precision. This difficulty is correlated to the features considered in the ALBP. It is low for simple lines, with a limited number of tasks, deterministic completion times, and where only one product can be produced. However, when more realistic features are considered it becomes much higher. So for example if a large number of tasks have to be considered, with stochastic times of completion, and/or when multiple products have to be assembled in a mixed-model way, with a specified sequence, or with the possibility to utilize parallel workstations in each workcentre, then it becomes very challenging to predict the throughput of a determined line configuration. In this context, it becomes consequently very difficult to compare different design alternatives on the basis of their performances.

As Bukchin (1998) outlined in his study, the only way to accurately evaluate the throughput of complex assembly lines would be to perform a simulation study. However, this is unfortunately very time consuming, because it requires to build a simulation model each time a different design alternative has to be evaluated. This does not fits with the most part of solving

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methods presented in literature, which provide the evaluation of a large number of possible solutions to find the final one.

For this reason until now, researchers have utilized indirect 'measures' of the throughput, which can be easily calculated from a determined line configuration, without the need to perform a simulation run. These measures are based upon the assumption that the way workloads are allocated to workstations (in terms of variability inside each workstation and among different workstations) can have a direct influence on the line throughput. Unfortunately, the correlation between the effective throughput and these measures are often poor. Furthermore, the more the complex is the line, the more is expected this correlation to be low.

So at this stage of research, advances in solving more realistic and complex assembly line balancing problem are limited by the poor capability to effective evaluate the line throughput. Although algorithms are potentially able to consider many features of realistic problems and to effectively explore the solution space, a lack of precision (or a sort of bias) in their objective function evaluation limits in fact their capability to find good solutions. In summary, algorithms are driven towards wrong objectives.

The aim of this paper is to show how a decisive step forward can be done in this filed by coupling the most recent advances of simulation techniques with a genetic algorithm approach. In particular, the adoption of event and object oriented simulation approaches has recently allowed to build parametric simulation models that can be embedded in genetic algorithms procedures for the effective evaluation of their objective function (Tiacci, 2012).

In the paper one of the most complex problem in assembly lines is considered: mixed-model lines, with stochastic task times of completion and parallel workstations allowed. There are few algorithms presented in literature capable to deal with all these features at the same time. In this work we introduce a new genetic algorithm approach in which a parametric simulator is embedded, and compare it with other two methods, namely a Simulation Annealing (SA) approach and a Genetic Algorithm (GA) approach, that on the contrary utilize indirect measures of throughput in their objective functions. The results of an ample simulation study, reported in Section 6, demonstrate the radical improvements obtainable by the proposed approach.

The paper is organized as follows. In the next section, a literary review on assembly line balancing problems and the related operational objectives is carried out. In Section 3 the particular problem taken into consideration is described in detail. The GA algorithm approach, coupled to the parametric simulator for the objective function evaluation, is described in Section 4. Section 5 is dedicated to the design of experiment for the evaluation of the proposed approach, which is also compared with other two approaches from the literature. In Section 6 results are reported and discussed.

2. Literary review

In this paper we focus our attention to a very complex assembly line balancing problem (described in detail in Section 3), which provides the following features: mixed-model un-paced line, with parallel workstations, stochastic task times of completion; the objective takes into consideration equipment and labor cost. The literary review is organized in two sections. Section 2.1 is related to assembly line balancing problems that fit with our case. Section 2.2 is related to how the objectives of this type of problem have been approached in literature.

2.1. Assembly line balancing problems

The Assembly Line Balancing Problem (ALBP) consists in assigning tasks to workstations, while optimizing one or more objectives without violating any restriction imposed on the line (e.g. precedence constraints among tasks). The basic version is the so-called Simple Assembly Line Balancing Problem (SALBP) and provides a single-model, paced line with fixed cycle time and deterministic task times. For an overview of exact methods and heuristics developed to solve the SALBP, see Scholl and Becker (2006). One of the most restricting assumptions of SALBP is related to the production of a single model. In fact, pressure for manufacturing flexibility, due to the growing demand for customized products, has led to a gradual replacement of simple assembly lines with mixed-model assembly lines, in which a set of similar models of a product can be assembled simultaneously.

The related problem that arises is the so called MALBP (Mixed-model Assembly Line Balancing Problem), that is much more complicated because of the variability of assembly times of different models assigned to a specific workstation. In mixed-model production, set-up times between models could be reduced sufficiently enough to be ignored and usually all models are variations of the same base product and only differ in specific customizable product attributes (Boysen et al., 2008). Studies published in the last years utilize different approaches to solve it, such as: simulated annealing (McMullen and Frazier, 1998; Simaria and Vilarinho, 2001; Vilarinho and Simaria, 2002), Ant techniques (McMullen and Tarasewich, 2003; McMullen and Tarasewich, 2006; Yagmahan, 2011), genetic algorithms (Akpinar and Bayhan, 2011; Haq et al., 2006; Simaria and Vilarinho, 2004; Tiacci et al., 2006; Zhang and Gen, 2011), and other heuristics (Askin and Zhou, 1997; Bukchin et al., 2002; Jin and Wu, 2003; Karabati and Sayin, 2003; McMullen and Frazier, 1997; Merengo et al., 1999).

The MALBP can be seen as a particular case of the more general GALBP (Generalized Assembly Line Balancing Problem), which embrace many features related to more realistic problems, such as cost functions, equipment selection, paralleling, stochastic task times. For a comprehensive classification of the possible features of the GALBP see Becker and Scholl (2006) and Boysen et al. (2007).

Stochastic task times in particular are a difficult issue to deal with. Tasan and Tunali (2008), in their survey on genetic algorithms applied to ALBP, outlined that only one article (Suresh and Sahu, 1994), out of the 29 analyzed, dealt with stochastic processing times. Non deterministic task times in fact complicate the prediction of line performances, because blocking and starvation phenomena are accentuated. Furthermore, blocking and starvation are also induced by the variability of task times of different models assigned to a specific workstation. Thus, the combination among mixed-model lines and stochastic task times is particularly challenging.

Another feature characterizing many real assembly lines configuration is the possibility to implement some type of parallelism, for example utilizing parallel workstations performing the same task set. The aim of using parallel stations is often to perform tasks with processing time larger than the desired cycle time. However, also if any given task time does not exceed cycle time, the possibility to replicate workstations may be desirable, because it enlarges the space of feasible solutions of the balancing problem, including many feasible and potentially better balanced configurations (Tiacci et al., 2006; Vilarinho and Simaria, 2002).

There are not many algorithm in literature that takes into consideration the same amount of modeling options as our case at the same time, such as, in particular, stochastic task times, multiple products produced in a mixed-model way, parallel workstations (without limits regarding the maximum number of replicas per work centre), and a fitness function that considers cycle time performance as well as total labor and equipment costs. In fact, the one considered is a realistic industrial setting, which differs