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Review

# A review of cost and profit oriented line design and balancing problems and solution approaches

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ABSTRACT

This review paper presents the state of the art on the problems, approaches and analytical models for assembly and transfer line design and balancing that addresses explicitly cost and profit oriented objectives. The discussions aim to facilitate identifying open problems and research areas that have wide practical applications and that necessitate further investigations. Moreover, they might serve as a foundation for developing decision support systems (DSS) that aid managers in planning and designing profitable or cost efficient assembly and transfer lines.



## 1. Introduction

Assembly and transfer lines contain serially located workstations in which the operations are continuously carried out. They have been installed in various industries such as the automotive, home appliance or electronics, where the major goal is to efficiently produce and deliver large amounts of standardized products. As a consequence of efficiency pursuit of these industries, modeling and solving line balancing problems have gained importance. A rich assembly and transfer line balancing literature, which covers numerous optimization problems, emerged.

These problems require development of capacity or cost-based modeling and use of effective solution techniques. For more details on line balancing problems, modeling and solution methods, we refer to the survey papers, such as Ghosh and Gagnon (1989), Erel and Sarin (1998), Rekiek, Dolgui, Delchambre, and Bratcu (2002), Becker and Scholl (2006), Scholl and Becker (2006), Boysen, Fliedner, and Scholl (2008a) and Rashid, Hutabarat, and Tiwari (2012). We also cite Boysen, Fliedner, and Scholl (2007) and Battaia and Dolgui (2013) for classification of the problems.

Although these interesting surveys present a broad range of line balancing problems and methods, they do not provide an in-depth analysis of some important branches of line design and balancing literature. This lack is noticeable for cost and profit based models, despite their recognized importance (see, e.g., Falkenauer, 2005). One possible explanation could be the scarcity (at the time these surveys were written) of publications on this topic, in comparison with other branches which had produced an abundant literature. Even though capacity oriented approach is more common in the literature, models where costs and profits are explicitly calculated and optimized in all phases of product life cycle are taking attention of researchers. Studies on this field have been rapidly increasing recently (almost half of the papers cited in this review were published during the last 8 years).

We concentrate on this particular branch and provide an in-depth analysis of cost and profit based line design and balancing models. Such a detailed study allows us to investigate the use of optimization tools in the design of production facilities, to explain their needs in planning and control of activities, from product and process design to recycling, and to clarify their characteristics and importance for product life cycle management (PLM).

It should also be noted that most of the models presented in this survey require various data on costs in order to produce cost-efficient line balance. It might not be always possible to have reliable cost figures at the point in time line balancing is performed. Thus, often researchers fall back on simple performance criteria of the capacited

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models, which are available, e.g., the number of stations or the cycle time. Moreover, under specific premises some simple line balancing problems also minimize costs, e.g., the capacity oriented Simply Assembly Line Balancing Problem of type 1 (SALBP-1) leads to a cost minimum, whenever any station costs the same. Also minimizing the cycle time for the capacity oriented Simply Assembly Line Balancing Problem of type 2 (SALBP-2) could maximize profit in specific circumstances.

However, nowadays many companies can reach to accurate data, they are more and more seeking to use this information and generate more effective designs. We also note that cost and profit based models are usually used at advanced stages of the design process. At the initial stages, a set of possible configurations is selected by using capacity oriented models. Cost- or profit- oriented approach is employed afterwards.

Considering the increase in the number of publications on cost- and profit-oriented models, we believe that it has become necessary to structure this field and develop a more detailed classification. Moreover, we make a concerted effort to present research gaps and explicitly list promising areas. We discuss the possible research perspectives. The discussion could help to identify open problems and research areas that have wide practical applications and need further investigation.

This article is an expanded and improved version of the paper presented at the 19th World Congress of the International Federation of Automatic Control in Cape Town, South Africa (Hazir, Delorme, & Dolgui, 2014).

Section 2 will introduce the classification and then review and discuss the main publications in each class. Section 3 will present a synthesis of this review and provide some discussions on future research directions.

## 2. Literature review

Cost based models minimize long-term investment or short term operating costs, whereas in profit based models revenues hence price and production volumes are also incorporated. Main relevant cost categories that should be examined are wages, material and inventory expenses, equipment procurement and maintenance, setup and idle time costs and the penalties of delays.

Some cost or profit based models optimize objective functions that include components concerning productivity or efficiency, which are the major concerns of the capacity approach. Indeed these models could be classified as “composite”, since they implicitly or explicitly optimize capacity as well as the cost. For instance, maximizing the profits require optimizing production quantity/capacity and costs at the same time. Therefore, in our survey, these composite models are grouped into another subcategory, which covers cost of idleness and profit optimization. Fig. 1 illustrates the classification that we use in this study. Note that the capacity oriented models are not detailed, since they are out of the scope of this review.

To develop the classification, we make use of the scheme of Boysen et al. (2007). However we detail the cost optimization category (see Fig. 1). Instead of using a single notation to represent the cost minimization objective, i.e. $\gamma = Co$, we propose to use a more specific notation, $\gamma = Equ$, $\gamma = Lab$, $\gamma = Inv$, $\gamma = Set$, $\gamma = Inc$, $\gamma = Rec$, $\gamma = Idl$, for models optimizing the equipment, labor, inventory, setup, incompletion, reconfiguration and idle time costs, respectively. As profit functions include cost components, we use only the notation $\gamma = Pr$ as suggested by Boysen et al. (2007) for profit maximizing studies, and do not to write down the constituting cost components additionally. In our classification study, we require that cost figures are known or could be explicitly assigned, and the objective function includes a cost component related to the corresponding category.

### 2.1. Cost based models

#### 2.1.1. Equipment costs

This category includes cost of procuring, operating and maintaining machinery, tools and corresponding supplies.

In industry, flexible manufacturing systems (FMS) have been developing rapidly, as a result, numerous processing and equipment alternatives become feasible to perform the tasks. This makes choosing the equipment/station and assigning tasks to stations interrelated. To take these decisions, investment and operating costs are evaluated; however usually there is a trade-off between those cost categories. Graves and Lamar (1983) were among the first to examine line balancing problem with work station selection. Nicosia, Pacciarelli, and Pacifici (2002) also studied this combined problem and proposed a dynamic programming algorithm. Addressing the assignment of heterogeneous resources, Corominas, Ferrer, and Pastor (2011) formulated a general model that minimizes the total cost, which includes cost of stations and the different resource types.

Bukchin and Tzur (2000) optimized the equipment costs for simple model lines. Later, Bukchin and Rabinowitch (2006) extended the study for mixed models; the assumption that a common task of different models is assigned to a single station was relaxed. Task duplications were penalized by integrating cost of duplications in the objective function. For solution, a branch and bound algorithm was developed. Models developed in these two studies have been further studied. Following a multi-criteria approach, Pekin and Azizoglu (2008) generalized the work of Bukchin and Tzur (2000). They optimized the total equipment cost and the number of workstations simultaneously. Barutcuoglu and Azizoglu (2011) fixed the number of stations and added the assumption that operation time and equipment cost are correlated so that the cheaper equipment never produces a shorter operation time.

Kazemi, Ghodsi, Rabbani, and Tavakkoli-Moghaddam (2011) extended the model of Bukchin and Rabinowitch (2006) for U-type lines. Compared to conventional straight lines, U-type lines offer more options to group the operations, hence they are more flexible, but more difficult to balance. The authors used genetic algorithms (GA) to solve the balancing problem. GA were also used to produce solutions for FMS planning (Chen & Ho, 2005). Making use of Pareto dominance relationships, Chen and Ho (2005) addressed four criteria: total flow time, machine workload unbalance, greatest machine workload and total tool cost.

An other relevant engineering optimization area that focuses on equipment selection is transfer line balancing. This problem has been studied by Dolgui et al. (Battaia & Dolgui, 2012; Battaia, Dolgui, Guschinsky, & Levin, 2012, 2014a, 2014b; Belmokhtar, Dolgui, Guschinsky, & Levin, 2006; Borisovsky, Dolgui, & Kovalev, 2012; Delorme, Dolgui, & Kovalyov, 2012; Dolgui, Finel, Guschinsky, Levin, & Vernadat, 2006a; Dolgui, Guschinsky, & Levin, 2006c, 2012), see also the recent article by Osman and Baki (2014). In transfer lines, stations can be equipped with changeable units such as multi-spindle heads. These units that operate in parallel or sequentially at a station are called blocks. Each block executes several operations simultaneously. The major problem is to define the optimum number of stations and block assignments while minimizing the total line investment cost. In addition to precedence relations, operations and block compatibility constraints are important.

When assembly line balancing and equipment selection problems are simultaneously treated, the resulting more complex problem is called assembly system design problem (ASDP). Fixed cost of installing the equipment in the stations and the station dependent variable cost of operations are optimized (Gadidov & Wilhelm, 2000; Pinnoi & Wilhelm, 1997a, 1998, 2000, 1997b; Wilhelm, 1999; Wilhelm & Gadidov, 2004). A relevant interesting problem is multi-criteria ASDP. To solve this problem, Ozdemir and Ayag (2011) first generated line