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Invited review

A survey on problems and methods in generalized assembly line balancing

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Abstract

Assembly lines are traditional and still attractive means of mass and large-scale series production. Since the early times of Henry Ford several developments took place which changed assembly lines from strictly paced and straight single-model lines to more flexible systems including, among others, lines with parallel work stations or tasks, customer-oriented mixed-model and multi-model lines, U-shaped lines as well as unpaced lines with intermediate buffers.

In any case, an important decision problem, called assembly line balancing problem, arises and has to be solved when (re-) configuring an assembly line. It consists of distributing the total workload for manufacturing any unit of the product to be assembled among the work stations along the line.

Assembly line balancing research has traditionally focused on the simple assembly line balancing problem (SALBP) which has some restricting assumptions. Recently, a lot of research work has been done in order to describe and solve more realistic generalized problems (GALBP). In this paper, we survey the developments in GALBP research.

Keywords: Assembly line balancing; Mass-production; Literature survey; Production process

1. Introduction

Assembly lines are flow oriented production systems which are still typical in the industrial production of high quantity standardized commodities and even gain importance in low volume production of customized products. Among the decision problems which arise in managing such systems, assembly line balancing problems are important tasks in medium-term production planning.

An *assembly line* consists of (*work*) *stations* $k = 1,\dots,m$ arranged along a conveyor belt or a similar mechanical material handling equipment. The workpieces (jobs) are consecutively launched down the line and are moved from station to station. At each station, certain operations are

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repeatedly performed regarding the *cycle time* (maximum or average time available for each workcycle). The decision problem of optimally partitioning (balancing) the assembly work among the stations with respect to some objective is known as the *assembly line balancing problem* (ALBP).

Manufacturing a product on an assembly line requires partitioning the total amount of work into a set of elementary operations named *tasks* $V = \{1, \ldots, n\}$. Performing a task j takes a *task time* t_j and requires certain equipment of machines and/or skills of workers. Due to technological and organizational conditions *precedence constraints* between the tasks have to be observed.

These elements can be summarized and visualized by a *precedence graph*. It contains a node for each task, node weights for the task times and arcs for the precedence constraints. Fig. 1 shows a precedence graph with $n = 10$ tasks having task times between 1 and 10 (time units). The precedence constraints for, e.g., task 5 express that its processing requires the tasks 1 and 4 (*direct predecessors*) and 3 (*indirect predecessor*) be completed. The other way round, task 5 must be completed before its (direct and indirect) *successors* 6, 8, 9, and 10 can be started.

Any type of ALBP consists in finding a feasible *line balance*, i.e., an assignment of each task to a station such that the precedence constraints and further restrictions are fulfilled (see Section 2). The set S_k of tasks assigned to a station k (=1, ..., m) constitutes its *station load*, the cumulated task time $t(S_k) = \sum_{j \in S_k} t_j$ is called *station time*. When a fixed common *cycle time c* is given (paced line; cf. Section 2), a line balance is feasible only if the station time of neither station exceeds c. In case of $t(S_k) < c$, the station k has an *idle time* of $c - t(S_k)$ time units in each cycle.

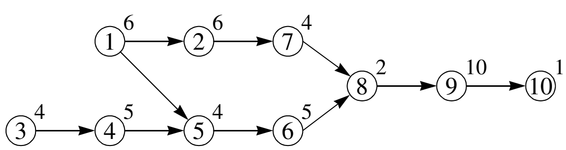

Fig. 1. Precedence graph.

For the example of Fig. 1, a feasible line balance with cycle time $c = 11$ and $m = 5$ stations is given by the station loads $S_1 = \{1,3\}$, $S_2 = \{2,4\}$, $S_3 = \{5,6\}$, $S_4 = \{7,8\}$, $S_5 = \{9,10\}$. While no idle time occurs in stations 2 and 5, stations 1, 3, and 4 show idle times of 1, 2, and 5, respectively.

The installation of an assembly line is a long-term decision and usually requires large capital investments. Therefore, it is important that such a system is designed and balanced so that it works as efficiently as possible. Besides balancing a new system, a running one has to be re-balanced periodically or after changes in the production process or the production program have taken place. Because of the long-term effect of balancing decisions, the used *objectives* have to be carefully chosen considering the strategic goals of the enterprise. From an economic point of view *cost and profit related objectives* should be considered (cf. Section 4). However, measuring and predicting the cost of running a line over months or years and the profits achieved by selling the products assembled is rather complicated and error-prone. A usual surrogate objective consists in maximizing the line utilization which is measured by the *line efficiency* as the productive fraction of the line's total operating time and directly depends on the cycle time c and the number of stations m (cf. Section 3).

2. Characteristics of assembly line systems

Because of very different conditions in industrial manufacturing, assembly line systems and corresponding ALBPs are multifaceted. In the following, we shortly characterize the most relevant properties for classifying assembly lines. For more detailed classifications and overviews on balancing issues we refer to, e.g., Buxey et al. (1973), Baybars (1986), Shtub and Dar-El (1989), Ghosh and Gagnon (1989), Erel and Sarin (1998), Scholl (1999, Chapter 1) as well as Rekiek et al. (2002b). Furthermore, see Rekiek and Delchambre (2001).

In case of a *paced assembly line*, the station time of every station is limited to the *cycle time c* as a maximum value for each workpiece. Since tasks are indivisible work elements, c can be no smaller