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The Assembly Line Balancing Problem : Review articles*

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ABSTRACT

The assembly line balancing problem (ALBP) consists of assigning tasks to an ordered sequence of stations such that the precedence relations among the tasks are satisfied and some performance measure is optimized. In this survey paper we give an up-to-date review and discuss the development of the classification of the assembly line balancing problem (ALBP) which has attracted attention of researchers and practitioners of research for almost half a century. We also present suggestions and summaries for future research directions of the literature review.

Keywords : Assembly line balancing problem (ALBP), Literature review, Optimization problem

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Introduction

The fundamental of line balancing problems is to assign the tasks to an ordered sequence of stations, such that the precedence relations are satisfied and some measurements of effectiveness are optimized. (e.g. minimize the balance delay or minimize the number of work stations; etc)

The first published paper of the assembly line balancing problem (ALBP) was made by Salveson (1955) who suggested a linear programming solution. Since then, the topic of line balancing has been of great interest to researchers. However, since the ALB problem falls into the NP hard class of combinatorial optimization problems (Gutjahr and Nemhauser, 1964), it has consistently developed the efficient algorithms for obtaining optimal solutions. Thus numerous research efforts have been directed towards the development of computer-efficient approximation algorithms or heuristics (e.g. Kilbridge and Wester, 1961; Helgeson and Birnie, 1961; Hoffman, 1963; Mansoor, 1964; Arcus, 1966; Baybar, 1986a) and exact methods to solve the ALB problems. (e.g. Jackson, 1956; Bowman, 1960; Van Assche and Herroelen, 1978; Mamoud, 1989; Hackman et al., 1989; Sarin et al., 1999)

In addition, with the growth of knowledge on the ALB problem, review articles are necessary to organize and summarize the finding for the researchers and practitioners. In fact, several articles (e.g. Kilbridge and Wester, 1962; Mastor, 1970; Johnson,1981; Talbot et al.,1986; Baybars, 1986b; Ghosh and Gagnon, 1989; Erel and Sarin, 2001) have reviewed the work published on this problem. Recently two articles by Scholl and Becker (2006); Becker and Scholl (2006) provide the state-of-the-art exact and heuristic solution procedures for simple assembly line balancing (SALB) and a survey on problems and methods in generalized assembly line balancing (GALB) respectively. In this paper, we give an up-to-date review, discuss about the development of the classification of the ALBP and summary of the future research suggestions from the review articles.

A Definition of Assembly Line Balancing (ALB)

Basic problem of ALB

An assembly line consists of work stations $k = 1,\ldots, m$ usually arranged along a conveyor belt or a similar material handling equipment. The jobs are consecutively launched down the line and are moved from station to station. At each station, certain operations are repeatedly performed regarding the cycle time. In general, the line balancing problem consists of optimally balancing the assembly work among all stations with respect to some objective. For this purpose, the total amount of work necessary to assemble a work piece (job) is split up into a set $V = \{1,\ldots, n\}$ of elementary operations named *tasks*. Performing a task j takes a *task time* t_j and requires certain equipment of machines and/or skills of workers. The total workload necessary for assembling a work piece is measured by the sum of task times $\sum t$. These elements can be summarized by a *precedence diagram*. It contains a node for each task, node weights for the task times, arcs the direct and paths for the indirect precedence constraints. Figure 1 shows a precedence diagram with n = 9 tasks having task times between 2-9 in time unit.

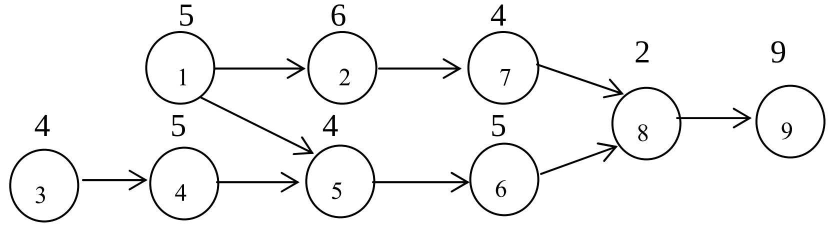

Figure 1. *Precedence diagram*

A feasible line balance, i.e. an assignment of tasks to stations has to ensure that no precedence relationship is violated. The set S_k of tasks assigned to a station k constitutes its station load or work content, the cumulated task time $t(S_k) = \sum_{j \in Sk} t_j$ is called station time. When a fixed cycle time c is given (paced line), 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 unit in each cycle. For example in Figure 1, a feasible line balance with cycle time c =11 and number of station , m = 5 stations is given by stations loads ; S1 ={1,3}, S2 ={2,4}, S3 = {5,6}, S4 = {7,8} , S5 = {9} A usual objective consists in maximizing the line utilization which is measured by the line efficiency E 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. In the most simple case, the line efficiency is defined as follows : $E = \sum t/(m*c)$

Classification of ALBP

In this section, we provide characteristics of balancing problems considered in the literature and give some classification schemes (c.f., e.g., Ghosh and Gagnon, 1989; Scholl and Becker, 2006; Becker and Scholl, 2006)

1 Ghosh and Gagnon (1989) classified the ALBP into four categories; as shown in Figure 2

(1) Single Model Deterministic (SMD) (2) Single Model stochastic (SMS)
(3) Multi/Mixed Model Deterministic (MMD) (4) Multi/Mixed Model stochastic (MMS)

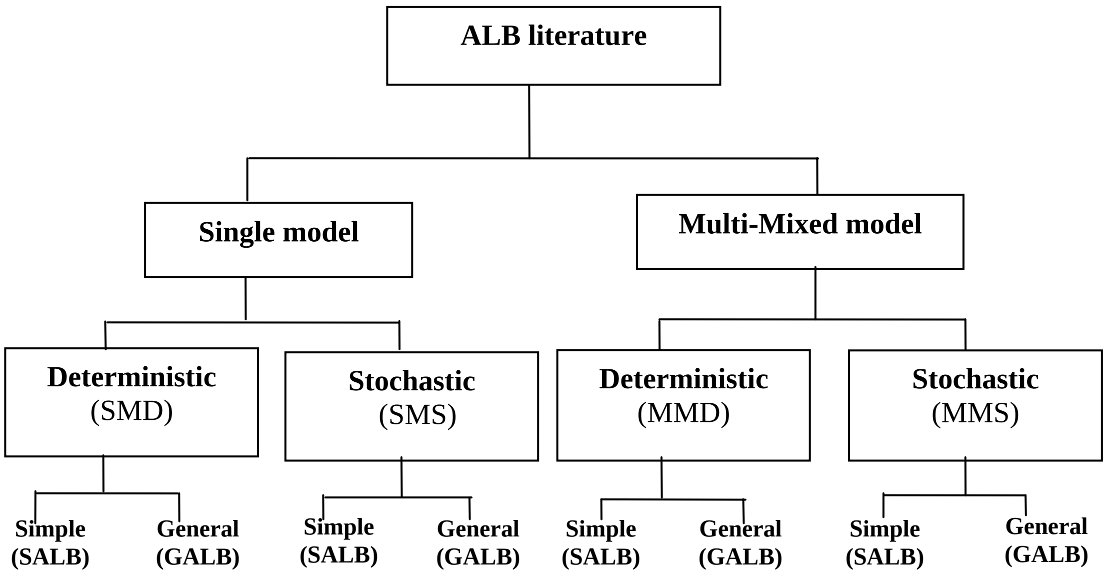

Figure 2. *Classification of assembly line balancing literature (Ghosh and Gagnon, 1989)*

The **SMD** version of the ALB problem assumes dedicated, single model assembly lines where the task times are known deterministically and an efficiency criterion is to be optimized. This is the original and simplest form of the assembly line balancing problem (SALB). Introduce other restrictions or factors(e.g. parallel stations, zoning restrictions) into the model and the problem becomes the General Assembly Line Balancing Problem (GALB)

The **SMS** problem category introduces the concept of task-time variability. This is more realistic for manual assembly lines, where workers' operation times are seldom constant. With the introduction of stochastic task times many other issues become relevant, such as station times exceeding the cycle time (and perhaps the production of defective or unfinished parts), pacing effects on workers' operation times, station lengths, the size and location of inventory buffers, launch rates and allocation of line imbalances.

The **MMD** problem formulation assumes deterministic task times, but introduces the concept of an assembly line producing multiple products. Multi-model lines assemble two or more products separately in batches. In mixed-model lines single units of different models can be introduced in any order or mix to the line. Multi-mixed model lines introduce various issues that are not present in the single-model case. Model selection, model sequencing and launching rate(s) and model lot sizes become more critical issues here than in the single model case.

The **MMS** problem perspective differs from its MMD counterpart in that stochastic times are allowed. However, these issues become more complex for the MMS problem because factors such as learning effects, worker skill level, job design and worker task time variability become more difficult to analyze because the line is frequently rebalanced for each model assembled.

2 Scholl and Becker (2006); Becker and Scholl (2006)

They have classified the main characteristics of assembly line balancing problems considered in their several constraints and different objectives as shown in Figure 3. It has illustrated the classification of assembly line balancing problems.

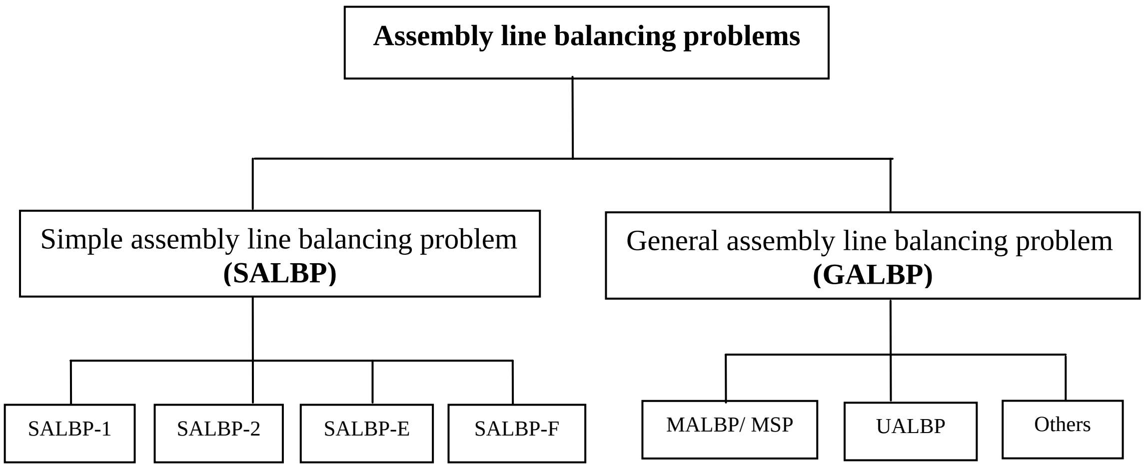

Figure 3. *classification of assembly line balancing problems*

(1) SALBP : The simple assembly line balancing problem is relevant for straight single product assembly lines where only precedence constraints between tasks are considered (for a survey see Scholl and Becker, 2006)

- Type 1 (SALB-1) of this problem consists of assigning tasks to work stations such that the number of stations *(m)* is minimized for a given production rate (fixed cycle time, *c*).

- Type 2 (SALBP-2) is to minimize cycle time (maximize the production rate) for a given number of stations *(m)*.

- Type E (SALBP-E) is the most general problem version maximizing the line efficiency *(E)* thereby simultaneously minimizing *c* and *m* considering their interrelationship.

- Type F (SALBP-F) is a feasibility problem which is to establish whether or not a feasible line balance exists for a given combination of *m* and *c*.

(2) GALBP : In the literature, all problem types which generalize or remove some assumptions of SALBP are called generalized assembly line balancing problems (GALBP). This class of problems (including UALBP and MALBP) is very large and contains all problem extensions that might be relevant in practice including equipment selection, processing alternatives, assignment restrictions etc. (for a survey see Becker and Scholl, 2006).

- MALBP and MSP : Mixed model assembly lines produce several models of a basic product in an intermixed sequence. Besides the mixed model assembly line balancing problem (MALBP), which has to assign tasks to stations considering the different task times for the different models and find a number of stations and a

cycle time as well as a line balance such that a capacity- or even cost-oriented objective is optimized (cf. Scholl, 1999, Chapter 3.2.2). However, the problem is more difficult than in the single-model case, because the station times of the different models have to be smoothed for each station (*horizontal balancing*; cf. Merengo et al., 1999). The better this horizontal balancing works, the better solutions are possible in the connected short-term *mixed model sequencing problem* (MSP). MSP has to find a sequence of all model units to be produced such that inefficiencies (work overload, line stoppage, off-line repair etc.) are minimized.
(e.g. Bard et al., 1992 and Scholl et al., 1998)

- UALBP : The U-line balancing problem (UALBP) considers the case of U-shaped (single product) assembly lines, where stations are arranged within a narrow U. As a consequence, worker are allowed to work on either side of the U, i.e. on early and late tasks in the production process simultaneously. Therefore, modified precedence constraints have to be observed. By analogy with SALBP, different problem types can be distinguished. (cf. Miltenburg and Wijngaard, 1994; Urban , 1998; Scholl and Klein,1999; Erel et al., 2001)

Objective criteria and methodological techniques

Objective criteria

1 Ghosh and Gagnon (1989)

Various technical and economic objective criteria have been used in the ALB literature ,Ghosh and Gagnon (1989). As can be seen in Table 1, the seven technical criteria, which relate to throughput operational efficiency, have in aggregate been the more commonly employed (58:13). Within the technical category, minimizing the number of work stations has been the most chosen.

Economic criteria typically relate to assembly line operating cost or profitability measures. Table 1 lists six economic criteria found in the literature, all the economic criteria consider labor cost or labor idleness cost, the most popular criterion and the apparent trend is to include other cost such as product incompletions (Kottas and Lau, 1973), penalty costs (Dar-El, 1977) and inventory and set-up costs (Caruso, 1965). While the technical criteria have been the classical dominant choice, economic criteria have gained rapid attention of researcher since the mid-1970s.

Type of objective criteria		**Frequency of use**				
		SMD	**SMS**	**MMD**	**MMS**	**total**
1. <u>Technical</u>						
-min. the no. of work st.(given cycle time)		**16**	**2**	**2**	**1**	**21**
-min. the cycle time (given no. of ws.)		**13**	**1**	**2**	**0**	**16**
-min. the total Idle time along the line		**9**	**0**	**3**	**0**	**12**
-min. the balance delay		**2**	**0**	**1**	**0**	**3**
-min. the overall facility or line length		**0**	**0**	**2**	**0**	**2**
-min. the throughput time		**0**	**0**	**1**	**0**	**1**
-min. the probability that one or more work stations will exceed the cycle time		**0**	**1**	**1**	**1**	**3**
	total	**40**	**4**	**12**	**2**	**<u>58</u>**
2. <u>Economic</u>						
-min. the combined cost of labour, ws. and product incompleteness		**0**	**3**	**0**	**1**	**4**
-min. the labour cost/unit		**3**	**1**	**0**	**0**	**4**
-min. the total penalty cost for a no. of inefficiencies		**0**	**0**	**2**	**0**	**2**
-min. the inventory, set up and idle time cost		**0**	**0**	**1**	**0**	**1**
-min. the total in-process inventory costs		**0**	**1**	**0**	**0**	**1**
-max. the net profit		**1**	**0**	**0**	**0**	**1**
	total	**4**	**5**	**3**	**1**	**<u>13</u>**

Table 1 : *ALB objective criteria (Ghosh and Gagnon, 1989)*

2 Scholl (1999) (Chapter 1.3.10)

From literature, he has mainly classified the objective criteria into two categories; capacity oriented goals and cost oriented goals.

• Capacity oriented goals. Most commonly, ALBP contain the objective of *maximizing the capacity utilizatio*n of the line which is measured by the *line efficiency (E).* In case of deterministic operation times and single-model production, the line efficiency only depends on the cycle time and the number of stations. The simpler objectives are often considered :

- minimize the number of stations for a given cycle time.
- minimize the cycle time for a given number of stations.
- minimizing the balance delay time (sum of idle times) and the balance delay (percentage of idle times) over all stations, etc.

• Cost oriented goals. An important objective is to minimize the total costs of line including long-term investment costs and short-term operating costs. Assembly line production systems may concern the following *cost categories* (i.e. costs of machinery and tools, wage costs, material costs, etc. (for detail see Scholl, 1999, Chapter 1.3.10 pp.21-22) which are mainly influenced by the cycle time and the number of stations (cf. Deckro, 1989; Rosenberg and Ziegler, 1992; Amen, 2000 a, 2000b, 2001 and Scholl and Becker, 2003). In the literature, usually only one objective is used, while other goals are formulated as constraints. Only few references deal with multiple objective assembly line balancing problems, namely, Baybars (1985), Shtub and Dar-El (1990), Deckro and Rangachari (1990), Malakooti (1991,1994) and Malakooti and Kumar (1996).

Methodological techniques

The large combinational complexity of the ALB problem has resulted in enormous computational difficulties. To achieve optimal or at least acceptable solutions, various solution methodologies have been explored. These methods are organized and their use analyzed in Table 2.

ALB techniques	**Frequency of use**				
	SMD	**SMS**	**MMD**	**MMS**	**total**
1. Exact methods					
- Linear Programming (LP)	**1**	**0**	**0**	**0**	**1**
- Integer Programming (IP)	**7**	**0**	**1**	**0**	**8**
- Dynamic Programming (DP)	**4**	**2**	**0**	**0**	**6**
- Goal Programming (GP)	**1**	**0**	**0**	**0**	**1**
- Shortest-path tech. (SP)	**2**	**0**	**2**	**0**	**4**
- Maximal-path tech. (MP)	**1**	**0**	**0**	**0**	**1**
- Branch and bound (BB)	**11**	**1**	**0**	**1**	**13**
			total		**34**
2. Inexact methods or heuristic					
- Priority ranking and assignment	**10**	**5**	**7**	***2+sim**	**24**
- Tree search (heuristic BB)	**8**	**1**	**0**	**0**	**9**
- Trade and transfer	**1**	**2**	**1**	**0**	**4**
- Random sampling	**3**	**1**	**0**	**0**	**4**
- Others ; task grouping, approximation tech.	**5**	**3**	**1**	***2+sim**	**11**
			total		**52**

Table 2 : *ALB methodological techniques (Ghosh and Gagnon, 1989)*

***** Refers to two research studies which combined priority ranking procedures with simulation programs.

Despite recent advances in problem formulation and solution procedure efficiency, mathematical programming/network-based optimization techniques are still computationally prohibitive beyond limited problem dimensions. It is also unlikely that computational efficiency will progress sufficiently in the near term to allow the use of even the most efficient exact techniques to obtain optimal solutions to realistically sized GALB problems. Therefore, heuristic and metaheuristic techniques (e.g. Simulated Annealing (SA), Tabu Search (TS), Genetic Algorithm (GA) and Ant Colony Optimization (ACO), etc.) still remain the only computationally efficient and sufficiently flexible methodologies capable of addressing large-scale, real-world ALB situations, particularly for the multi/mixed model and GALBP categories.

Conclusion and future research

In the literature survey, it shows that research has made significant algorithm developments in solving simple problems (SALBP). Though SALBP is a class of NP-hard optimization problems, effective exact and heuristic algorithms are available which solve small and medium-size instances of problems. Nevertheless, further algorithmic improvement is necessary for solving large-scale problems.

Recently, assembly line balancing research evolved towards formulating and solving generalized problem (GALBP) with different additional characteristics such as cost functions, paralleling, equipment selection, u-line layout and mixed-model production. In the literature survey on GALBP (cf. Becker and Scholl, 2006) shows that a lot of relevant problems have been identified and modeled but development of sophisticated solution procedures has just begun. Then, additional research is necessary to adopt state-of-the-art solution concepts like metaheuristics and highly developed algorithms for SALBP to the variety of GALBP. Moreover, standardized and realistic test beds are required for testing and comparing methodical enhancements.

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