Assembly Line Balancing – A Review

Vrittika Pachghare[1], R. S. Dalu[2]

[1]M.Tech. Student, Production Engineering, Govt. College of Engineering, Amravati, Maharashtra, India

[2]Associate Professor, Mechanical Engineering Department, Govt. College of Engineering, Amravati, Maharashtra, India

Abstract: ***Assembly line balancing is the method of assigning tasks to workstations by optimizing a performance measure while satisfying precedence relations between tasks and cycle time restrictions. Many exact, heuristic and Meta heuristic approaches have been proposed for solving simple straight and U-shaped assembly line balancing problems. Worker heterogeneity leads to a problem called the assembly line worker assignment and balancing problem (ALWABP). This paper presents the reviews of assembly line balancing methods and tries to find out latest developments and trends available in industries in order to minimize production time.***

Keywords: Assembly line balancing, Assembly line balancing methods, Exact Methods, Heuristic Methods, Meta heuristic Methods.

1. Introduction

Assembly lines are the most important components of mass production systems. The improved labor productivity is their essential significance for producers who have to produce high volume products in a fast and cost effective manner. An assembly line consists of several successive workstations in which a group of assembly operations (tasks) are performed in a limited duration (cycle time). The productivity level of an assembly line generally depends on balancing performance. Assembly line balancing (ALB) is the problem of assigning tasks to successive workstations by satisfying some constraints and optimizing a performance measure. This performance measure is usually the minimization of the number of workstations utilized over the assembly line. The assignments should guarantee that each task is assigned to at least and at most one workstation (assignment constraints), all precedence relations among these tasks are satisfied (precedence constraints) and the work content of a workstation does not exceed the predetermined cycle time (cycle time constraints). The cycle time is determined by means of demand rate of the product in a planning horizon. Assembly lines can be categorized into several groups with regard to their shapes and number of different products produced on the line. By means of the line shape, they are classified as 'traditional straight' and 'Ushaped' assembly lines. 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 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 and exact methods to solve the ALB problems. 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 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 assembly line balancing methods and summary of the future research suggestions from the review articles.

- Type 1 (SALBP-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 inter-relationship.
- 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*.

The number of stations or time cycle is a performance measurement to be optimized. Regarding the number of products, the assembly lines can be classified into three basic types Single-model assembly line used in mass production of a single product, as in Figure 1a. Mixed-model assembly line: used to produce several models of a basic product, without the need to setup .Figure 1b shows an example of this type of line. Multi model assembly line used when there are significant differences in the production processes of each model. To minimize the inefficiency of the setup time between models, batches are used, and it originates the batch sizing problem. This line type is illustrated in Figure 1c.

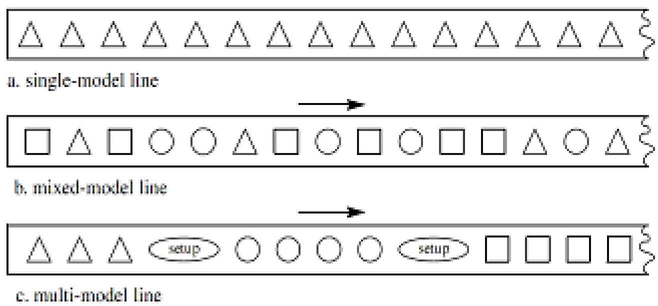

Figure 1: Assembly lines for single and multiple products

1.1 Procedures to Solve Assembly Line Balancing Problems

Numerous procedures have been developed to solve assembly line balancing problems. Due to the NP-hard nature of this type of combinatorial problem, few exact methods have been developed to solve SALBP, in particularly SALBP-1. Habitually, although guaranteeing an optimum so methods have a problem size limitation, measured in terms of computing time; therefore, they can only be applied to problem instances with small or medium number of assembly tasks. Approximate methods (i.e., heuristics and Meta heuristics) have been developed in order to overcome such a limitation, and aiming at providing good solutions that are as near as possible of the optimal solution.

1.2 Exact Procedures

Generally, (mixed) integer linear programming models have been used to formally describe assembly line balancing problems, which may facilitate designers and decision makers to have a better understanding of different assembly systems. However, most often solving such models optimally has not practical relevance because standard solvers proved to be inefficient when considering real-world scaled problems. Therefore, most exact method considered in the literature to solve ALBP are based on dynamic programming and branch-and-bound procedures. Dynamic Programming (DP) procedures basically transform the problem into a multi-stage decision process by breaking it into smaller sub problems, which in turn are solved recursively; then the optimal solutions of the sub problems are used to construct the optimal solution of the original problem. Branch-and-bound (B&B) is an enumeration technique, which finds the optimal solution by exploring subsets of feasible solutions. Sub-regions are formed by branching the solution space. A bounding process is recursively used to find lower or upper bounds of the optimal solution within each sub-region, using different searching strategies (e.g. depth first search, minimal lower bound, best first search or minimal local lower bound). Some effective B&B methods developed to solve SALBP-1 include FABLE.

1.3 Heuristic Methods

A common methodology used is the greedy approach, where, at each step of the procedure, one element of the solution is chosen according to a given criteria until a complete solution is obtained. The simplest method randomly generates solutions, evaluates each one of them and keeps the best of all solutions obtained. Basically, constructive methods are based on priority rules, most of which are measured considering the number of predecessors and successors, and the task processing times. One of the first proposed heuristic was Ranked Positional Weight (RPW) in which tasks are ranked in descending order of the positional weight (the summation of the task time and the processing times of all its successors). Other well-known priority rules include maximum task time, maximum total number of successors, minimum earliest and latest workstation and minimum slack. Some heuristics combine several priority rules; such as, for example, TTS which considers the maximum task time divided by the total number of successors. Priority-rule based methods create a ranked list of the assignable tasks. A task is assignable if all of its predecessors have already been assigned and if its time plus the current workstation time does not exceed the cycle time. Then, tasks are selected and assigned to the workstations considering one of the two following strategies.

1. Station-oriented strategy starts with one workstation and then others are consecutively considered one at a time. With each iteration, tasks are orderly selected from the ranked list and assigned to the current workstation. Once the current workstation is fully loaded (the ranked list is empty) a new workstation is opened.
2. Task-oriented strategy, the first task in the rank list (the one with the highest priority) is selected and assigned to the earliest workstation to which the task can be assigned. Task-oriented methods are further divided into immediate-update-first or general-first-fit methods depending on whether the ranked list is immediately updated after a task has been assigned or after all tasks in the ranked list have already been assigned, respectively

1.4 Meta heuristics

Falling in a local optimum is a main drawback of classical heuristic methods. Therefore, in the last years a group of methods, referred to as metaheuristics have been developed to overcome such a limitation. The term metaheuristic was first introduced by Glover (1996). These procedures are based in constructive methods to find an initial solution (or a population of initial solutions) and local search algorithms to move to an improved neighbour solution. In contrast to local search approaches, metaheuristics do not stop when no improving neighbour solutions can be found. They allow movements to worsening solutions in order to avoid premature convergence to a local optimum solution. Metaheuristics use different concepts derived from artificial intelligence, evolutionary algorithms inspired from mechanisms of natural evolution. GRASP (Greedy Randomized Adaptive Search Procedure) is an iterative process in which each iteration consists of two phases the construction phase, which generates an initial solution; and the improving phase, which uses a local optimization procedure to find a local optimum. The initial solution is generated by probabilistically selecting the next element to be incorporated in a partial solution from a restricted candidate list (RCL). Tabu search (TS) is a local search metaheuristic based on memory structures that prevents returning and keeping trap in a local optimum solution. To escape from a local optimum moves to worse solutions are allowed. A tabu list is used to avoid cycling back to recently visited solutions. The size of the list, a key parameter, determines the number of iterations during which a given solution is prevented to reoccur. The procedure finishes, for example, when a number of search movements have been performed and no further improvement

Ant colonies algorithms, basically model the behaviour of ants searching an optimal path (e.g. for food or real ants) which connects two different positions. The selection of paths is stochastic and it is influenced by both the quantity of pheromone that other ants have put on a path (i.e. desirability) and the local values of the objective function that can be determined if the path is selected (i.e. visibility). Simulated Annealing (SA) is a technique inspired from the physical annealing of solids. It models how the molecular structure of metals is disordered at high temperatures and ordered and crystalline at low temperatures. A problem instance is formulated in such a way that it resembles disordered material. The temperature is gradually lowered such that ordered states correspond to good solutions of the problem. SA methods avoid getting trap in a local optimum by allowing uphill moves based on a model of the annealing process in the physical world.

Genetic algorithms (GA) closely simulate biological evolution as they map programs and data into DNA-like structures that express some notion of fitness. GA uses a set of initial solutions, i.e. individuals, each of which represents a point in the search space of potential solutions to a particular problem. A given number of individuals conforms a population of potential solutions. The population is evolved by employing crossover and mutation operators along with an objective function (i.e. the fitness function) that determines how likely individual are to be reproduced.

2. Review

Literature review is categorized in three different groups as follows.

1. Assembly line balancing and problems
2. Assembly line balancing methods(Exact and Heuristic)
3. Metaheuristic methods.

2.1 Assembly line balancing and problems

Becker et al (2006) A survey on problems and methods in generalized assembly line balancing was presented 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 un paced lines with intermediate buffers. Assembly line balancing research had traditionally focused on the simple assembly line balancing problem which had some restricting assumptions. Recently, a lot of research work had been done in order to describe and solve more realistic generalized problems. M Amen (2006) works on cost-oriented assembly line balancing in which model formulations, solution difficulty, upper and lower bounds was also considered. Cost oriented assembly line balancing was discussed in this work. First focus was on special objective function and a formal problem statement. Then they concentrate on general model formulations that can be solved by standard optimization tools and introduce several improvements to existent models. These models were designed for either general branch-and-bound techniques with LP-relaxation or general implicit enumeration techniques. Further they discuss the solution difficulty of the problem and showed that the maximally-loaded station rule had to be replaced by the two-station rule.

Dimitriadis (2006) A work was presented by on assembly line balancing and group working: A heuristic procedure for workers groups operating on the same product and workstation. In this work they examined an assembly line balancing problem that differs from the conventional one in the sense that there were multi-manned workstations, where workers groups simultaneously perform different assembly works on the same product and workstation. The proposed approach here results in shorter physical line length and production space utilization improvement, because the same number of workers can be allocated to fewer workstations. A heuristic assembly line balancing procedure was thus developed and illustrated. Finally, experimental results of a real-life automobile assembly plant case and well known problems from the literature indicate the effectiveness and applicability of the proposed approach in practice.

Gokcen et al (2006) for productivity improvement published a work on balancing of parallel assembly lines. Productivity improvement in assembly lines is very important because it increases capacity and reduces cost. If the capacity of the line is insufficient, one possible way to increase the capacity is to construct parallel lines. In this study, new procedures and a mathematical model on the single model assembly line balancing problem with parallel lines were proposed.

Nils Boysen et al (2007) their work on assembly line balancing problems classification. Accordingly, this attracted attention of many researchers, who tried to support real-world configuration planning by suited optimization models (assembly line balancing problems). In spite of the enormous academic effort in assembly line balancing, there remains a considerable gap between requirements of real configuration problems and the status of research. To ease communication between researchers and practitioners, we provide a classification scheme of assembly line balancing. This is a valuable step in identifying remaining research challenges which might contribute to closing the gap.

Nils Boysen et al (2008) their work on assembly line balancing tried to make understand that which model to use when. This work structures the vast field of assembly line balancing according to characteristic practical settings and highlights relevant model extensions which were required to reflect real world problems and open research challenges were identified.

Purnomo et al (2013) A work on two-sided assembly lines balancing with assignment restrictions . Two-sided assembly line is a set of sequential workstations where task operations can be performed in two sides of the line. In this work a mathematical model was proposed for two-sided assembly line type II. The aim of the model was minimizing the cycle time for a given number of workstations and balancing the workstation simultaneously.

Naveen Kumar et al (2013) Assembly line balancing is to know how tasks are to be assigned to workstations, so that the predetermined goal is achieved. Minimization of the number of workstations and maximization of the production rate are the most common goals. This paper presents the reviews of different works in the area of assembly line balancing and tries to find out latest developments and trends available in industries in order to minimize the total equipment cost and number of workstation.

2. 2 Assembly line balancing methods

M Amen (2000) A survey on heuristic methods for cost-oriented assembly line balancing was presented. In this work main focus was on cost-oriented assembly line balancing. This problem mainly occurs in the final assembly of automotives, consumer durables or personal computers, where production is still very labor-intensive, and where the wage rates depend on the requirements and qualifications to fulfill the work. In this work a short problem description was presented along with classification of existent and new heuristic methods for solving this problem. A new priority rule called best change of idle cost was proposed. This priority rule differs from the existent priority rules because it was the only one which considers that production cost were the result of both, production time and cost rates.

M Amen (2000) presented work on an exact method for cost-oriented assembly line balancing. Characterization of the cost oriented assembly line balancing problem had been shown by without loading the stations maximally the cost-oriented optimum. According to him criterion two stations-rule had to be used. An exact backtracking method was introduced for generating optimal solutions in which the enumeration process was limited by modified and new bounding rules. Results of an experimental investigation showed that the new method finds optimal solutions for small and medium-sized problem instances in acceptable time.

Jin et al (2002) A work on new heuristic method for mixed model assembly line balancing problem was published A goal chasing method was presented which is a popular algorithm in JIT system for the mixed model assembly line balancing problem. In this work, definition of good parts and good remaining sequence were provided and analyze their relationship with the optimal solutions objective function value. A new heuristic algorithm was also develop called 'variance algorithm' the numerical experiments showed that the new algorithm can yield better solution.

Fleszar et al (2003) presented a work on enumerative heuristic and reduction methods for the assembly line balancing problem. They presented a new heuristic algorithm and new reduction techniques for the type 1 assembly line balancing problem. The new heuristic was based on the Hoffmann heuristic and builds solutions from both sides of the precedence network to choose the best. The reduction techniques aimed at augmenting precedence, conjoining tasks and increasing operation times. A test was carried out on a well-known benchmark set of problem instances; testify to the efficacy of the combined algorithm, in terms of both solution quality and optimality verification, as well as to its computational efficiency.

Olga Battaia et al (2012) A heuristic-based guidance for enumeration process was included as an efficient component of the algorithm as well works on reduction approaches for a generalized line balancing problem. The objective of the work was to minimize the cost of the line being designed. This work presented effective pre-processing methods which can reduce the size of the initial problem in order to shorten the solution time required.

3. Metaheuristic Methods

Ponnambalam etl (2000) "A Multi-Objective Genetic Algorithm for Solving Assembly Line Balancing Problem", a multi-objective genetic algorithm to solve assembly line balancing problems is proposed. The performance criteria considered are the number of workstations, the line efficiency, the smoothness index before trade and transfer, and the smoothness index after trade and transfer. The developed genetic algorithm is compared with six popular heuristic algorithms, namely, ranked positional weight, Kilbridge and Wester, Moodie and Young, Hoffmann precedence matrix, immediate update first fit, and rank and assign heuristic methods. For comparative evaluation, 20 networks are collected from open literature, and are used with five different cycle times. All the six heuristics and the genetic algorithm are coded in C++ language. It is found that the proposed genetic algorithm performs better in all the performance measures than the heuristics. However, the execution time for the GA is longer, because the GA searches for global optimal solutions with more iteration.

Bautista et al (2007) Ant algorithms were also developed for a time and space constrained assembly line balancing problem. This work mainly focused on the application of a procedure based on ant colonies to solve an assembly line balancing problem. Time and Space constrained Assembly Line Balancing Problem was also presented and a basic model of one of its variants. An ant algorithm was presented that offered good results with simple balancing problems. Finally, the validity of the proposed algorithms was tested by means of a computational experience with reference instances.

4. Future Scope

From the literature survey following points are needs to be discussed:-

- A new improvement in priority rule is discussed which shows that production cost is the result of both production time and cost rates.
- Numerical experiments on a newly developed heuristic algorithm i.e. variance algorithm shows better solution with more calculations ahead.
- New cost reduction techniques are developed which focus precedence, conjoining tasks and increasing operation times; combined algorithms are tested for both solution quality and optimality verification, as well as to its computational efficiency.
- A mathematical programming model presents an iterative genetic algorithm based on the mixed model assembly line balancing problem with parallel workstations which maximize the production rate of the line for a predetermined number of operators.
- Backtracking branch-and-bound algorithm is developed and evaluates its performance via a large set of experiments and large-scale problems.
- For maximizing the production rate of the line robot assembly line balancing problems are solved for optimal assignment of robots to line stations and a balanced distribution of work between different stations.

- Three terms i.e. the lowest standard deviation of operation efficiency, the highest production line efficiency and the least total operation efficiency waste are studied to find out the optimal solution of operator allocation.
- A new genetic approach called endo symbiotic evolutionary algorithm is developed for solving the problems of line balancing and model sequencing.
- Experiment on a new heuristic assembly line balancing in real-life automobile assembly plant case results in shorter physical line length and production space utilization improvement, because the same number of workers can be allocated to fewer workstations.
- A new Tabu search algorithm is evaluated on Type-I assembly line balancing problem which shows the flexibility of the metaheuristic and its ability to solve real industrial cases.
- Experimental results of algorithm integrated with the Hoffmann heuristic shows the proposed procedure are more efficient.
- An ant colony optimization algorithm is proposed to solve the assembly problem in which two ants work simultaneously one at each side of the line to build a balancing solution which verifies the precedence, zoning, capacity, side and synchronism constraints of the assembly process.
- The generic algorithm mathematical model based on the assembly line balancing technology is adopted and results of real cases show that quickly and effectively than normal mathematical model.
- New genetic algorithm is proposed to find the optimum solutions within a limited number of iterations.
- A bi-criteria nonlinear integer programming model is developed for minimizing the cycle time and minimizing the machine total costs.
- Simulation tools such as Fact- Model, to modeling the production line and the works estimated are used to reduce the line unbalancing causes and relocate the workforce associated to idle time, eliminating the bottleneck and improving the productivity.

5. Conclusion

The literature highlights the contributions of various assembly line balancing methods such as Exact method, Heuristic method And Metaheuristic method for global optimum solution and gaps in literature which discuss point have more attention From the study of assembly line balancing it is found that assembly lines are flow-line production systems, where a series of workstations, on which interchangeable parts are added to a product. The product is moved from one workstation to other through the line, and is complete when it leaves the last workstation. It has been also observed that equipment costs, cycle time, the correlation between task times and equipment costs and the flexibility ratio needs a great attention.

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Author Profile

Vrittika Pachghare received B Tech degree in Mechanical Engineering from Government college of Engineering, Amravati (Maharashtra). She is now perusing M. Tech in Production Engineering (Final Year) from Government college of Engineering, Amravati (Maharashtra).