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Assembly Line Balancing: A Review of Developments and Trends in Approach to Industrial Application

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ASSEMBLY LINE BALANCINGA REVIEW OF DEVELOPMENTSAND TRENDS IN APPROACH TO INDUSTRIAL APPLICATION

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Assembly Line Balancing: A Review of Developments and Trends in Approach to Industrial Application

Naveen Kumar [α] & Dalgobind Mahto [σ]

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I. Introduction

Line Balancing means balancing the production line, or any assembly line. The main objective of line balancing is to distribute the task evenly over the work station so that idle time of man of machine can be minimized. Lime balancing aims at grouping the facilities or workers in an efficient pattern in order to obtain an optimum or most efficient balance of the capacities and flows of the production or assembly processes.

Assembly Line Balancing (ALB) is the term commonly used to refer to the decision process of assigning tasks to workstations in a serial production system. The task consists of elemental operations required to convert raw material in to finished goods. Line Balancing is a classic Operations Research optimization technique which has significant industrial importance in lean system. The concept of mass production essentially involves the Line Balancing in assembly of identical or interchangeable parts or components into the final product in various stages at different workstations. With the improvement in knowledge, the refinement in the application of line balancing procedure is also a must. Task allocation of each worker was achieved by assembly line balancing to increase an assembly efficiency and productivity.

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a) Definitions of Related Terms

i. *Line Balancing*

Line Balancing is leveling the workload across all processes in a cell or value stream to remove bottlenecks and excess capacity. A constraint slows the process down and results if waiting for downstream operations and excess capacity results in waiting and absorption of fixed cost.

ii. *Single-Model Assembly Line*

In early times assembly lines were used in high level production of a single product. But now the products will attract customers without any difference and allows the profitable utilization of Assembly Lines. An advanced technology of production which enables the automated setup of operations and it is negotiated time and money. Once the product is assembled in the same line and it won't variant the setup or significant setup and it's time that is used, this assembly system is called as Single Model Line.

iii. *Mixed Model Assembly Line*

In this model the setup time between the models would be decreased sufficiently and enough to be ignored. So this internal mixed model determines the assembled on the same line. And the type of assembly line in which workers work in different models of a product in the same assembly line is called Mixed Assembly Line.

iv. *Multi Model Assembly Line*

In this model the uniformity of the assembled products and the production system is not that much sufficient to accept the enabling of the product and the production levels. To reduce the time and money this assembly is arranged in batches, and this allows the short term lot-sizing issues which made in groups of the models to batches and the result will be on the assembly levels.

The model of different assembly lines and levels of activities are presented below in Fig. 1, Fig. 2 and Fig. 3

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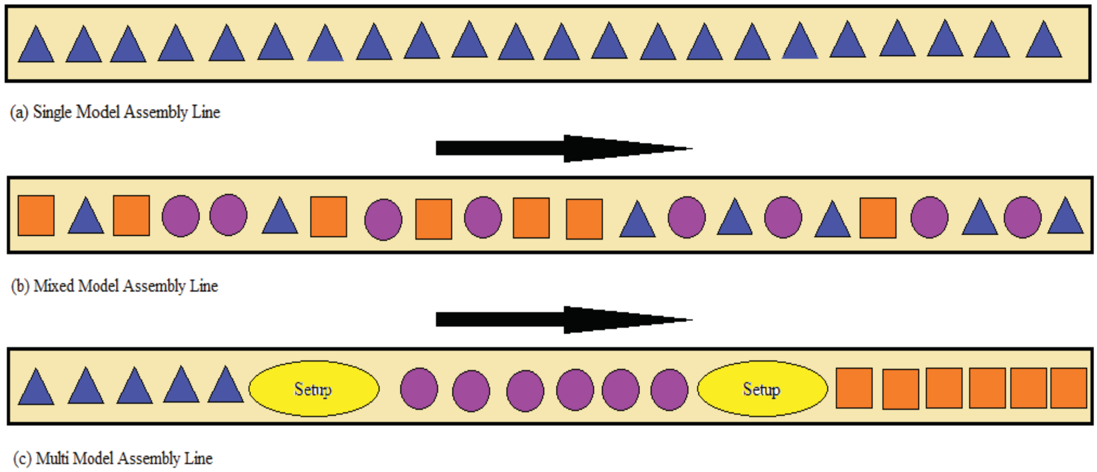

Figure 1 : Assembly lines for single and multiple products

Number of models	Single Model	Mixed Model	Multi Model
Line control	Paced	Unpaced asynchronous	Unpaced synchronous
Frequency	First-time installation		Reconfiguration
Level of automation	Manual Lines		Automated Lines
Line of business	Automobile Production		Further example

Figure 2 : Investigated kinds of Assembly Line Balancing [ALB]

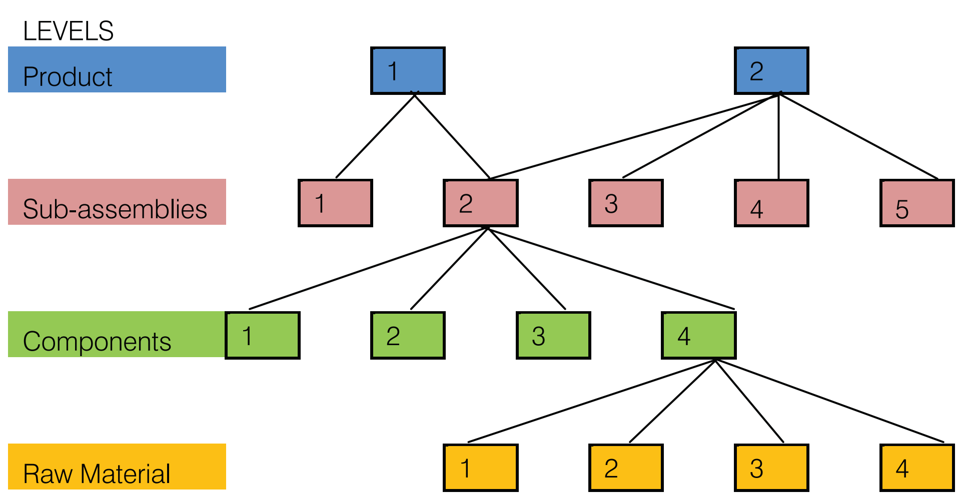

Figure 3 : Production levels in a typical manufacturing environment

v. *Non Value Added Costs*

a. *Cost from Overproduction*

Production costs money. There is no need to produce such products which cannot be sold. This is the most deceptive waste in today's time and resources utilization is to be maximized. Overproduction includes making more than what is required and making products earlier than required.

b. *Excess Inventory Cost*

Higher inventory cost is not beneficial for any company in today's variable demand business climate. Costs which are associated with the inventory are space, obsolescence, damage, opportunity cost, lagged defect detection and handling. In the case of obsolete inventory, all costs invested in the production of a part are wasted. Excessive inventory should be eliminated.

c. *Processing Cost*

Efforts that add no value to the desired product from a customer's point of view are considered as non-value added processing. Non value added operations should be eliminated. Vague picture of customer requirements, communication flaws, inappropriate material or machine selection for the production are the reasons behind this type of waste.

d. *Defective Products*

Companies give much emphasis on defects reduction. However defects still remain the major contributors towards the non-value added cost. Cost associated with this is quality and inspection expenditure, service to the customer, warranty cost and loss of customer fidelity.

e. *Transportation Cost*

Cost associated with material movement is a significant factor in the non-value added cost function. In a well designed system work and storage areas should be near to its point of use. This consumes huge capital investment in terms of equipment required for material movement, storage devices, and systems for material tracking. Transportation does not add value towards the final product.

f. *Motion*

Any motion that does not add value to the product or service comes under non-value added cost. Motion consumes time and energy and includes man or machine movement. Time spent by the operators looking for a tool, extra product handling and heavy conveyor usage are the typical example of the motion waste.

g. *Waiting*

If line is not properly balanced and inappropriate material flow selection are the reasons behind waiting time. The time spent on waiting for raw material, the job from the preceding work station, machine down-time, and the operator engaged in other operations and schedules are the major contributors in the waiting time.

b) *Terms In Line Balancing Technique*

In assembly line balancing system, there is various term normally used.

i. *Cycle Time*

Cycle time is the Maximum amount of time allowed at each station. This can be found by dividing required units to production time available per day.

$$Cycle\ time = \frac{Production\ \ Time\ per\ day}{Unit\ required\ \ per\ day} \qquad \text{(eq.1)}$$

ii. *Lead Time*

Summation of production times along the assembly line.

$$Lead\ time = \sum Production\ Time\ along\ the\ assembly\ time \qquad \text{(eq.2)}$$

iii. *Bottleneck*

Delay in transmission that slow down the production rate. This can be overcome by balancing the line.

iv. *Precedence*

It can be represented by nodes or graph. In assembly line the products have to obey this rule. The product can't be move to the next station if it doesn't complete at the previous station. The products flow from one station to the other station. A typical precedence diagram is mentioned in Fig.4 below to represent the activities.

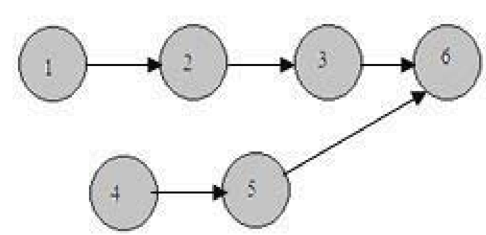

Figure 4 : Example of Precedence Diagram

v. *Idle Time*

Idle time is the time specified as period when system is not in use but is fully functional at desired parameters.

vi. *Productivity*

Define as ratio of output over input. Productivity is depends on several factors such as workers skills, jobs method and machine used.

$$Productivity = \frac{Output}{Labour * Production\ \ time\ per\ day\,(hour)} \qquad \text{(eq.3)}$$

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vii. *Smoothness Index*

This is the index to indicate the relative smoothness of a given assembly line balance. A smoothness indeed is zero indicates perfect balance.

$$SI = \sqrt{\sum_{i=1}^{k}(STmax - STi)^2} \quad \text{(eq.4)}$$

Where,

STmax - maximum station time (in most cases cycle time),

STi - station time of station i.

viii. *Balance Delay*

This is the ratio of total station time to the product of cycle time and the number of workstations.

$$BD = \left[\left\{(K) * (CT) - \left(\sum_{I=1}^{K} STi\right)\right\} \Big/ \{(K) * (CT)\} * 100\%\right] \quad \text{(eq.5)}$$

II. Aims And Objectives Of The Work

The aim of this is to minimizing workloads and workers on the assembly line while meeting a required output.

The aims and objectives of the present study are as follows:-

- To reduce production cost and improve productivity
- To determine number of feasible workstation.
- To identify the location of bottleneck and eliminate them.
- To determine machinery and equipment according to assembly mechanism.
- To equally distribute the workloads among workmen to the assembly line.
- To optimize the production functions through construction of mix form of automation assembly and manual assembly.
- To minimize the total amount of idle time and equivalently minimizing the number of operators to do a given amount of work at a given assembly line speed.

III. Literature Review

Lean and agile manufacturing is a very vast field and Line Balancing in industries is also very important. Many times in conferences this is main topic of discussion and many students and scholars also publish their work on this topic. Amen (2000) **[1]** 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.

A survey on heuristic methods for cost-oriented assembly line balancing was presented by Amen (2000) **[2]**. 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.

A work on new heuristic method for mixed model assembly line balancing problem was published by Jin and Wu (2002) **[3]**. 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 with little more computation overhead.

Fleszar and Hindi (2003) **[4]** 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.

A work on assembly line balancing in a mixed-model sequencing environment with synchronous transfers was presented by Karabati and Sayin (2003) **[5]**. An assembly line balancing problem was

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considered in a mixed-model line which was operated under a cyclic sequencing approach. Study of the problem was done in an assembly line environment with synchronous transfer of parts between the stations. They formulated the assembly line balancing problem with the objective of minimizing total cycle time by incorporating the cyclic sequencing information. They showed that the solution of a mathematical model that combines multiple models into a single one by adding up operation times constitutes a lower bound for this formulation. An alternative formulation was proposed that suggested minimizing the maximum sub cycle time.

A work was presented by Simaria and Vilarinho (2004) [6] on genetic algorithm based approach to the mixed-model assembly line balancing problem of type II. According to them mixed-model assembly lines allow for the simultaneous assembly of a set of similar models of a product. A mathematical programming model was presented in this work and an iterative genetic algorithm based procedure for the mixed-model assembly line balancing problem with parallel workstations, in which the goal was to maximize the production rate of the line for a predetermined number of operators.

A fuzzy logic approach to assembly line balancing work was presented by Fonseca et al. (2005) [7]. This work deals with the use of fuzzy set theory as a viable alternative method for modeling and solving the stochastic assembly line balancing problem. Variability and uncertainty in the assembly line balancing problem had traditionally been modeled through the use of statistical distributions. Fuzzy set theory allowed for the consideration of the ambiguity involved in assigning processing and cycle times and the uncertainty contained within such time variables. COMSOAL and Ran-ked Positional Weighting Technique were modified to solve the balancing problem with a fuzzy representation of the time variables. The work showed that the new fuzzy methods capabilities of producing solutions similar to, and in some cases better than, those reached by the traditional methods.

Gokcen (2005) [8] presented a work on shortest route formulation of simple U-type assembly line balancing problem. A shortest route formulation of simple U-type assembly line balancing (SULB) problem was presented. This model was based on the shortest route model developed in for the traditional single model assembly line balancing problem. Agpak and Gokcen (2005) [9] presented their work on assembly line balancing: Two resource constrained cases. A new approach on traditional assembly line balancing problem was presented. The proposed approach was to establish balance of the assembly line with minimum number of station and resources and for this purpose, 0–1 integer-programming models were developed.

A work was presented by Bukchin and Rabinowitch (2006) [10] on branch and bound based solution approach for the mixed-model assembly line-balancing problem for minimizing stations and task duplication costs. A common assumption in the literature on mixed model assembly line balancing is that a task that is common to multiple models must be assigned to a single station. In this work a common task to be assigned to different stations for different models. The sum of costs of the stations and the task duplication was to be minimized. An optimal solution procedure based on a backtracking branch and bound algorithm was developed and evaluates its performance via a large set of experiments. For solving large-scale problems branch and bound based heuristic was developed.

Levitin et al. (2006) [11] works on genetic algorithm for robotic assembly line balancing. Flexibility and automation in assembly lines can be achieved by the use of robots. The robotic assembly line balancing (RALB) problem was defined for robotic assembly line, where different robots may be assigned to the assembly tasks, and each robot needs different assembly times to perform a given task, because of its capabilities and specialization. The solution to the RALB problem includes an attempt for optimal assignment of robots to line stations and a balanced distribution of work between different stations. It aims at maximizing the production rate of the line. Gokcen and Agpak (2006) [12] presented their work on goal programming approach to simple U-line balancing problem. A goal programming model for the simple U-line balancing (ULB) problem was developed. The proposed model which was the multi criteria decision making approach to the U-line version provides increased flexibility to the decision maker since several conflicting goals can be simultaneously considered.

A work on heuristic solution for fuzzy mixed-model line balancing problem was presented by Hop (2006) [13]. This work addresses the mixed-model line balancing problem with fuzzy processing time. A fuzzy binary linear programming model was formulated for the problem. This fuzzy model was then transformed to a mixed zero one program. Due to the complexity nature in handling fuzzy computation, new approximated fuzzy arithmetic operation was presented. A fuzzy heuristic was developed to solve this problem based on the aggregating fuzzy numbers and combined precedence constraints. The general idea of our approach was to arrange the jobs in a sequence by a varying-section exchange procedure. Then jobs were allocated into workstations based on these aggregated fuzzy times with the considerations of technological constraint and cycle time limit. Promising results were obtained by experiments.

Gamberini et al. (2006) [14] presented their work on a new multi-objective heuristic algorithm for solving the stochastic assembly line re-balancing problem. In this work a new heuristic for solving the assembly line rebalancing problem was presented. The method was based on the integration of a multi-attribute decision making procedure, named technique for order preference by similarity to ideal solution (TOPSIS), and the well known Kottas and Lau heuristic approach. The proposed methodology was focused on rebalancing an existing line, when some changes in the input parameters (i.e. product characteristics and cycle time) occur. Hence, the algorithm deals with the assembly line balancing problem by considering the minimization of two performance criteria: (i) the unit labor and expected unit incompletion costs, & (ii) tasks reassignment.

A work was presented by Song (2006) [15] on recursive operator allocation approach for assembly line-balancing optimization problem with the consideration of operator efficiency. An optimization model was used for assembly line balancing problem in order to improve the line balance of a production line under a human centric and dynamic apparel assembly process. An approach was proposed to balance production line through optimal operator allocation with the consideration of operator efficiency. Two recursive algorithms were developed to generate all feasible solutions for operator allocation. Three objectives i.e. the lowest standard deviation of operation efficiency, the highest production line efficiency and the least total operation efficiency waste were rearranged to find out the optimal solution of operator allocation. The performance comparison demonstrated that the proposed optimization method outperforms the industry practice.

Dolgui et al. (2006) [16] works on special case of transfer lines balancing by graph approach. In their work for paced production they considered a balancing problem lines with workstations in series and blocks of parallel operations at the workstations. Operations of each workstation were partitioned into blocks. All operations of the same block were performed simultaneously by one spindle head. All blocks of the same workstation were also executed simultaneously. The operation time of the workstation was the maximal value among operation times of its blocks. The line cycle time was the maximal workstation time. A method for solving the problem was based on its transformation to a constrained shortest path problem.

A survey on problems and methods in generalized assembly line balancing was presented by Becker and Scholl (2006) [17]. 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.

Kim et al. (2006) [18] presented his work on endo symbiotic evolutionary algorithm for the integration of balancing and sequencing in mixed-model U-lines. A new evolutionary approach in mixed model U-shaped lines was proposed to deal with both balancing and sequencing problems. The use of U-shaped lines was an important element in Just-In-Time production. For an efficient operation of the lines, it is important to have a proper line balancing and model sequencing. A new genetic approach was proposed to solve the two problems of line balancing and model sequencing called endosymbiotic evolutionary algorithm.

Peeters and Degraeve (2006) [19] works on linear programming based lower bound for the simple assembly line balancing problem. The simple assembly line balancing problem was a classical integer programming problem in operations research. A set of tasks, each one being an indivisible amount of work requiring a number of time units, must be assigned to workstations without exceeding the cycle time. They presented a new lower bound, namely the LP relaxation of an integer programming formulation based on Dantzig–Wolfe decomposition. A column generation algorithm was proposed to solve the formulation and a branch-and-bound algorithm also proposed to exactly solve the pricing problem.

A work on optimal piecewise-linear program for the U-line balancing problem with stochastic task times was published by Urban and Chiang (2006) [20]. The utilization of U-shaped layouts in place of the traditional straight-line configuration has become increasingly popular. This work examines the U-line balancing problem with stochastic task times. A chance-constrained, piecewise linear, integer program was formulated to find the optimal solution. Various approaches were used to identify a tight lower bound. Computational results showed that the proposed method was able to solve practical sized problems.

Hirotani et al. (2006) [21] works on analysis and design of self-balancing production line. In a self-balancing production line each worker was assigned work dynamically. In this work, they examine other less restrictive conditions that can achieve the same self-balancing effect, and furthermore, characteristics of this line were analyzed by deriving the imbalance condition and analyzing the influence of initial position. In addition, a method for designing a self-balancing line based on our results was proposed.

A work was presented by Dimitriadis (2006) [22] 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.

Lapierre et al. (2006) **[23]** presented his work on balancing assembly lines with tabu search. Balancing assembly lines is a crucial task for manufacturing companies in order to improve productivity and minimize production costs. Despite some progress in exact methods to solve large scale problems, software's implementing simple heuristics are still the most commonly used tools in industry. Here a new tabu search algorithm was presented and discussed. Its performance was then evaluated on Type I assembly line balancing problem. They discuss the flexibility of the meta-heuristic and its ability to solve real industrial cases.

For productivity improvement Gokcen et al. (2006) **[24]** 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.

Amen (2006) **[25]** 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.

Azar et al. (2006) **[26]** presented their work on load balancing of temporary tasks in the l_p norm. In this on-line load balancing problem has been considered on m identical machines. Jobs arrive at arbitrary times, where each job had a weight and duration. A job had to be assigned upon its arrival to exactly one of the machines. The duration of each job was known only on completion. Once a job has been assigned to a machine it cannot be reassigned to another machine. Focus was to minimize the maximum over time of the sum (over all machines) of the squares of the loads, instead of the traditional maximum load.

A state-of-the-art exact and heuristic solution procedure for simple assembly line balancing was presented by Scholl and Becker (2006) **[27]**. Whenever a line has to be configured or redesigned the assembly line balancing problem arises there and had to be solved. It can be distributing of the total workload for manufacturing. In this work, they an up-to-date and comprehensive survey of simple assembly line balancing problem research with a special emphasis on recent outstanding and guiding contributions to the field had been given.

A balancing method and genetic algorithm for disassembly line balancing was developed by McGovern and Gupta (2007) **[28]**. Disassembly active-ties take place in various recovery operations i.e. in re-manufacturing, recycling and disposal. Returned pro-ducts need to be automatically. It is therefore important that the disassembly line be designed and balanced for maximum works efficiently. In this work the problem was mathematically defined and proven NP-complete. Also, a new formula for quantifying the level of balancing was proposed. A first-ever set of a priori instances to be used in the evaluation of any disassembly line balancing solution technique was then developed and a genetic algorithm was presented for obtaining optimal solutions for disassembly line balancing problems.

Agpak and Gokcen (2007) **[29]** discussed a chance constrained approach to stochastic line balancing problem. In this work, chance constrained 0–1 integer programming models for the stochastic traditional and U-type line balancing (ULB) problem were developed. These models were solved for several test problems that are well known in the literature and the computational results were given. Also, a goal programming approach was presented in order to increase the system reliability, which was arising from the stochastic case. A classification of assembly line balancing problems was presented by Boy sen and Flie dner (2007) **[30]**. Assembly lines are special flow-line production systems which are of great importance in the industrial production and assembly lines even gained importance in low volume production of customized products. A classification scheme of assembly line balancing was provided for the ease communication between re-searchers and practitioners.

Ant algorithms were also developed by Bautista and Pereira (2007) **[31]** 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.

A station-oriented enumerative algorithm for two-sided assembly line balancing was developed by Xia-o-feng et al. (2008) **[32]**. A station-oriented enumerative algorithm for two-sided assembly lines balancing was proposed in this work. Firstly the time transfer function was defined and combined with the precedence relation to compute the earliest and the latest start time of tasks. With the direction and cycle time constraints, a station-oriented procedure based on the start time was designed to assign tasks, starting from the left station to the right station of the position. The proposed algorithm was integrated with the Hoffmann heuristic to develop a system for solving two-sided assembly lines balancing problems. The test was per-formed on the well known benchmark set of problem instances. Experimental results demonstrate that the proposed procedure is efficient.

Boysen and Fliedner (2008) **[33]** presented a versatile algorithm for assembly line balancing. In this work discusses a two stage graph-algorithm, which was designed to solve line balancing problems including practice relevant constraints, such as parallel work stations and tasks, cost synergies, processing alter-natives, zoning restrictions, stochastic processing times or U-shaped assembly lines. A work on Assembly Line Balancing in Clothing Company was developed by Eryuruk et al. (2008) **[34]**. In this two heuristic assembly line balancing techniques known as the Ranked Positional Weight Technique developed by Helgeson and Birnie, and the Probabilistic Line Balancing Technique developed by El-Sayed and Boucher, were applied to solve the problem of multi-model assembly line balancing in a clothing company for two models.

Boysen et al. (2008) **[35]** in 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. Balancing and scheduling tasks in assembly was done by Andres et al. (2008) **[36]** lines with sequence-dependent setup times. According to them the classical Simple Assembly Line Balancing Problem (SALBP) has been widely enriched over the past few years with many realistic approaches and much effort has been made to reduce the distance between the academic theory and the industrial reality. The problem presented in this work adds sequence-dependent setup time considerations to the classical SALBP and when-ever a task is assigned next to another at the same workstation, a setup time must be added to compute the global workstation time. After formulating a mathematical model for this innovative problem and showing the high combinatorial nature of the problem, eight different heuristic rules and a GRASP algorithm were designed and tested for solving the problem in reasonable computational time.

Miralles et al. (2008) **[37]** works on Branch and bound procedures for solving the Assembly Line Worker Assignment and Balancing Problem: Application to Sheltered Work centers for Disabled. In this work a new problem called Assembly Line Worker Assignment and Balancing Problem (ALWABP) was introduced. The problem consists of providing a simultaneous solution to a double assignment: (1) tasks to stations; and (2) available workers to stations. After defining the mathematical model for this problem, a basic Branch and Bound approach with three possible search strategies and different parameters was presented. They also proposed the use of a Branch and Bound-based heuristic for large problems and analyzed the behavior of both exact and heuristic methods through experimental studies.

Simple and U-type assembly line balancing problems with a learning effect was presented by Toksari et al. (2008) **[38]**. In this reported work, they introduced learning effect into assembly line balancing problems. In many realistic settings, the produced worker(s) or machine(s) develops continuously by repeated the same or similar activities. Therefore, the production time of product shortens if it is processed later. They showed that polynomial solutions can be obtained for both simple assembly line balancing problem and U-type line balancing problem with learning effect. A dynamic programming based heuristic for the assembly line balancing problem was presented by Bautista and Pereira (2009) **[39]**. The simple assembly line balancing problem was the simplification of a real problem associated to the assignment of the elementary tasks required for assembly of a product in an assembly line. The present work proposes a new procedure to solve the problem named Bounded Dynamic Programming. This use of the term Bounded was associated not only with the use of bounds to reduce the state space but also to the reduction of such space based on heuristics.

Choi (2009) **[40]** presented a work on goal programming mixed-model line balancing for processing time and physical workload. They present a new mathematical model of line balancing for processing time and physical workload at the same time. According to them line balancing was the problem to assign tasks to stations while satisfying some managerial viewpoints. Comparing the pay offs between the two overloads, test results showed that well balanced job allocation was able to be obtained through the proposed model. And they conclude that the model may be very useful for the operation managers to make decisions on their job scheduling efforts.

A mathematical model and a genetic algorithm for two-sided assembly line balancing were presented by Kim (2009) [41]. A two-sided assembly line is a type of production line where tasks are performed in parallel at both sides of the line. The line is often found in producing large products such as trucks and buses. In this they presented a mathematical model and a genetic algorithm (GA) for two-sided assembly line balancing. The mathematical model can be used as a foundation for further practical development in the design of two-sided assembly lines.

An ant colony optimization algorithm for balancing two-sided assembly lines was presented by Simaria and Vilarinho (2009) [42]. Two-sided assembly lines are a special type of assembly lines in which workers perform assembly tasks in both sides of the line. The highlighted approach of this work is to address the two-sided mixed-model assembly line balancing problem. First, a mathematical programming model, then, an ant colony optimization algorithm

An efficient approach was presented by Gao (2009) [43] for type II robotic assembly line balancing problems. This study presented a type II robotic assembly line balancing problem, in which the assembly tasks had assigned to workstations, and each workstation needs to select one of the available robots to process the assigned tasks with the objective of minimum cycle time. An innovative genetic algorithm (GA) hybridized with local search was proposed for the problem. Sabuncuoglu et al. (2009) [44] presented an ant colony optimization for the single model U-type assembly line balancing problem. An assembly line is a production line in which units move continuously through a sequence of stations.

Ege et al. (2009) [45] works on Assembly line balancing with station paralleling. In their study they assume an arbitrary number of parallel workstations can be assigned to each stage. Every task requires a specified tooling/equipment, and this tooling/equipment should be available in all parallel workstations of the stage to which the task was assigned. Their objective was to find an assignment of tasks to stages so as to minimize sum of station opening and tooling/equipment costs. They propose two branch and bound algorithms: one for optimal solutions and one for near optimal solutions. Becker and Scholl (2009) [46] worked on balancing assembly lines with variable parallel workplaces: Problem definition and effective solution procedure. Assembly line balancing problems (ALBP) arise whenever an assembly line is configured, redesigned or adjusted. In this work an extension of the basic ALBP to the case of flexible parallel workplaces products were considered. The problem was defined and modeled as an integer linear program. As a solution approach a branch and bound procedure was proposed which also can be applied as a heuristic.

Balancing of mixed-model two-sided assembly lines was presented by Ozcan and Toklu (2009) [47]. A new mathematical model and a simulated annealing algorithm for the mixed model two-sided assembly line balancing problem had been presented. The proposed mathematical model minimizes the number of mated-stations as the primary objective and minimizes the number of stations as a secondary objective for a given cycle time. In the proposed simulated annealing algorithm, two performance criteria considered were maximizing the weighted line efficiency and minimizing the weighted smoothness index.

A binary fuzzy goal programming approach was presented by Kara et al. (2009) [48] for single model straight and U-shaped assembly line balancing. Assembly line balancing generally requires a set of acceptable solutions to the several conflicting objectives. In this study, a binary fuzzy goal programming approach was applied to assembly line balancing. Models for balancing straight and U-shaped assembly lines with fuzzy goals were proposed. An illustrative example was presented to demonstrate the validity of the proposed models and to compare the performance of straight and U-shaped line configurations.

A comparison of exact and heuristic methods for a transfer line balancing problem was presented by Guschinskaya and Dolgui (2009) [49]. Transfer line balancing problems (TLBP) deal with the optimization of serial machining lines. At every machine, the operations were performed by blocks. The operations within each block were executed simultaneously by the same multi-spindle head. In the lines considered here, the spindle heads of each machine are activated sequentially. The objective of TLBP was to group the operations into blocks and to assign the blocks to machines in order to minimize the total amount of the required equipment.

Che et al. (2009) [50] have explained on cooperator selection and industry assignment in supply chain network with line balancing technology.

Integrating assembly planning and line balancing using precedence diagram was presented by Abdul-Hassan (2009) [51]. According to them, assembly planning and assembly line balancing are considered as two independent tasks. Assembly planning represents a fundamental step in the operation of a manufacturing system that involves product assembly while line balancing represents one of the biggest technical problems in designing and operating a manual assembly line. A methodology called COMSOAL-PLB (Computer Method of Sequencing Operations for Assembly Lines of Assembly Planning and Line Balancing) was developed to incorporate making decisions on process planning and production planning for assembly product.

Ozcan and Toklu (2009) [52] works on Multiple-criteria decision-making in two-sided assembly line balancing: A goal programming and a fuzzy goal programming model. They presented a mathematical model, a pre-emptive goal programming model for precise goals and a fuzzy goal programming model for imprecise goals for two-sided assembly line balancing. The mathematical model minimizes the number of mated–stations as the primary objective and it minimizes the number of stations as a secondary objective for a given cycle time. A work on MIP approach for balancing transfer line with complex industrial constraints was presented by Essafi et al. (2010) [53]. According to them at least one CNC machine is to be installed at each workstation. The objective was to assign a given set of operations required for the machining of the part to a sequence of workstations while minimizing the total number of machines used. This problem was subject to precedence, exclusion and inclusion constraints.

Toksari et al. (2010) [54] works on assembly line balancing problem with deterioration tasks and learning effect. In this simultaneous effects of learning and linear deterioration were introduced into assembly line balancing problem. In many realistic settings, although the actual task time of a task is modeled as an increasing function of its starting time due to deterioration effects the produced worker develops continuously by repeated the same or similar activities. The objective of problem was to minimize the station number and a mixed nonlinear integer programming model was developed. A research work on assembly line balancing to minimize balancing loss and system loss was published by Roy and Khan (2010) [55]. Assembly Line production is one of the widely used basic principles in production system. The main aim was to redefine the objective of the Assembly Line Balancing Problem and sequentially handle Balancing Loss and System Loss.

Fan et al. (2010) [56] published their work on balancing and simulating of assembly line with overlapped and stopped operation on the subject modeling and simulation of assembly line with overlapped and stopped operation, builds mathematical model for the assembly line both under certainty and uncertainty environment.

Essafi et al. (2010) [57] worked on balancing lines in CNC machines based on heuristic method of line balancing. The optimization of production systems is an important stage for manufacturers to minimize costs and remain competitive. However, in the current economic context, with market volatility and fluctuation in demand, industrials manufacturers need more flexible production systems. Thus, new types of lines were created; i.e. flexible and reconfigurable transfer lines. The flexibility or the recon figurability of a line is obtained through the use of special machines, a developed control system for the line, a specific architecture, etc. The use of Computer Numerical Control (CNC) machines is a common way to add more flexibility or reconfigurability to a machining line. Such machines are highly automated and use computer programs to define the different tools to use for a specific part. Therefore they correspond to standard and interchangeable units in which a new program can be loaded to change the production.

Ozcan (2010) [58] published their finding on balancing stochastic two-sided assembly lines: A chance-constrained, piecewise-linear, mixed integer program and a simulated annealing algorithm. In this type of a production line, both left-side and right-side of the line are used in parallel. The problem of balancing twosided assembly lines with stochastic task times was considered in this work. A chance-constrained, piece wise linear, mixed integer program was proposed to model and solve the problem. A work on multi objective constructive heuristics for the 1/3 variant of the time and space assembly line balancing problem: ACO and random greedy search was reported by China et al. (2010) [59]. Two new multi objective proposals based on ant colony optimization and random greedy search algorithms was presented to solve a classical industrial problem: time and space assembly line balancing. Some variants of these algorithms had been compared in order to find out the impact of different design configurations and the use of heuristic information.

Yeh and Kao (2010) [60] reported on a new bidirectional heuristic for the assembly line balancing problem. According to them, Assembly line balancing problem (ALBP) is one of the well-known NP-hard layout planning problems for mass production systems. Similarly, a work on simultaneous balancing and scheduling of flexible mixed model assembly lines with sequence-dependent setup times was published by Ozturk et al. (2010) [61]. They have considered simultaneous balancing and scheduling of flexible mixed model assembly lines with sequence-dependent setup times. They have proposed alternate Mixed Integer Programming and Constraint Programming formulations.

Likewise, in the field of application of genetic algorithm the important works have been performed by Taha (2011) [62] Akpinar and Bayhan (2011) [63] and Chica et al. (2011) [64].

Ozbakir and Tapkan (2011) [65] published their work on bee colony intelligence in zone constrained two-sided assembly line balancing problem. In this study two-sided assembly line balancing problem with zoning constraint was solved by bees algorithm so as to minimize the number of stations for a given cycle time. Likewise, a work on bi-criteria assembly line balancing by considering flexible operation times was presented by Hamta et al. (2011) [66].

Kilincci (2011) [67] worked on firing sequences backward algorithm for simple assembly line balancing problem of type 1 and published their work on the same. The objective of simple assembly line balancing problem type-1 (SALBP-1) was to minimize the number of workstations on an assembly line for a given cycle time. A new heuristic algorithm was presented to solve the problem. The presented algorithm makes an order of firing sequence of transitions from Petri net model. Task was assigned to a workstation using this order and backward procedure.

A work was published by Chica et al. (2011) [68] which shows their work on different kinds of preferences in a multi-objective ant algorithm for time and space assembly line balancing on different Nissan scenarios. The main focus of this was to study influence of incorporating user preferences based on Nissan automotive domain knowledge to guide the multi-objective search process with two different aims. First, to reduce the number of equally preferred assembly line configurations and second, to only provide the plant managers with configurations of their contextual interest in the objective space based on real-world economical variables.

Otto and Scholl (2011) [69] worked on discrete optimization incorporating ergonomic risks into assembly line balancing. In manufacturing, control of ergonomic risks at manual workplaces is a necessity commanded by legislation, care for health of workers and economic considerations. In this work it has been shown that even though most ergonomic risk estimation methods involve nonlinear functions, they can be integrated into assembly line balancing techniques at low additional computational cost. Their computational experiments indicate that re-balancing often leads to a substantial mitigation of ergonomic risks. Line balancing analysis of tuner product manufacturing was published by Sihombing et al. (2011) [70]. In the tuner production line, number of operator, production tools/equipment, and production process are three significant factors related to productivity through using of line balancing method. This study performed the line balancing method through simulation model in order to reduce the line unbalancing causes and relocate the workforce associated to idle time, eliminating the bottleneck, and at the same time maintaining/ improving the productivity.

Yag mahan (2011) [71] presented mixed-model assembly line balancing using a multiobjective ant colony optimization approach. This work deals with the mixed-model assembly line balancing problem and objective for this problem was to minimize the number of stations for a given cycle time. To solve this problem a multi-objective ant colony optimization algorithm was proposed. To prove the efficiency of the proposed algorithm, a number of test problems were solved. The results showed that the MOACO algorithm is an efficient and effective algorithm which gives better results than other methods compared.

Multi-objective optimization of a stochastic assembly line balancing: A hybrid simulated annealing algorithm was published by Cakir et al. (2011) [72]. This work deals with multi-objective optimization of a single-model stochastic assembly line balancing problem with parallel stations. The objectives were as follows: (1) minimization of the smoothness index and (2) minimization of the design cost. Ozbakira et al. (2011) [73] works on Multiple-colony ant algorithm for parallel assembly line balancing problem. Assembly lines are designed as flow oriented production systems which perform operations on standardized products in a serial manner. In this work, a novel multiple colony and algo rithm was developed for balancing by objective parallel assembly lines. The proposed approach was extensively tested on the benchmark problems and performance of the approach is compared with existing algorithms.

Blum and Miralles (2011) [74] works on solving the assembly line worker assignment and balancing problem via beam search. In this work they deal with a specific assembly line balancing problem that was known as the assembly line worker assignment and balancing problem (ALWABP). This problem arises in settings where tasks must be assigned to workers, and workers to work stations. In this work an algorithm based on beam search was introduced for solving the ALWABP with the objective of minimizing the cycle time when given a fixed number of work stations, respectively, workers.

Hou and Kang (2011) [75] presented their work on online and semi-online hierarchical scheduling for load balancing on uniform machines. In their work they consider online and semi-online hierarchical scheduling for load balancing on m parallel uniform machines with two hierarchies. The procedures for the time and space constrained assembly line balancing problem was presented by Bautista and Pereira (2011) [76]. The Time and Space constrained Assembly Line Balancing Problem (TSALBP) is a variant of the classical Simple Assembly Line Balancing Problem that additionally accounts for the space requirements of machinery and assembled parts. The present work proposed an adaptation of the Bounded Dynamic Programming (BDP) method to solve the TSALBP variant with fixed cycle time and area availability.

Weida and Tianyuan (2011) [77] work on strategic robust mixed model assembly line balancing based on scenario planning. Assembly line balancing involves assigning a series of task elements to uniform sequential stations with certain restrictions. Decision makers found that a task assignment which is optimal with respect to a deterministic or stochastic/fuzzy model gain poor performance in reality. In real environments, assembly line balancing robustness was a more appropriate decision selection guide. A robust model based on α worst case scenario was developed to

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compensate for the drawbacks of traditional robust criteria.

A genetic algorithm based approach for simultaneously balancing and sequencing of mixed-model U-lines with parallel workstations and zoning constraints was presented by Hamzadayi and Yildiz (2012) **[78]**. A Priority-Based Genetic Algorithm based method was presented for the simultaneously tackling of the mixed-model U-shape assembly line line balancing/model sequencing problems with parallel workstations and zoning constraints and allows the decision maker to control the process to create parallel workstations and to work in different scenarios. In this, simulated annealing based fitness evaluation approach was developed to be able to make fitness function calculations easily and effectively.

Cheshmehgaz (2012) **[79]** worked on accumulated risk of body postures in assembly line balancing problem and modeling through a multi-criteria fuzzy-genetic algorithm. A novel model of assembly line balancing problem was presented that incorporates assembly worker postures into the balancing. Also a new criterion of posture diversity was defined and contributes to enhance the model. The proposed model suggests configurations of assembly lines via the balancing and the assigned workers gets the opportunities of changing their body postures, regularly.

Mahto and Kumar (2012) **[80]** works on an empirical investigation of assembly line balancing techniques and optimized implementation approach for efficiency improvements. The concept of mass production essentially involved the assembly of identical or interchangeable parts of components into the final product at different stages and workstations. The relative advantages and disadvantages of mass or flow production were a matter of concern for any mass production industry. How to design an assembly line starting from the work breakdown structure to the final grouping of tasks at work stations had been discussed in this work using two commonly used procedures namely the Kilbridge-Wester Heuristic approach and the Helgeson-Birnie Approach. Line Balancing was a classic, well-researched Operations Research optimization problem of significant industrial importance. The core objectives of this work was to optimize crew size, system utilization, the probability of jobs being completed within a certain time frame and system design costs. These objectives were addressed simultaneously, and the results obtained were compared with those of single-objective approaches.

A work on assembly line balancing in garment industry was presented by Chen et al. (2012) **[81]**. A grouping genetic algorithm (GGA) was developed for ALBP of sewing lines with different labor skill levels. GGA can allocate workload among machines as evenly as possible for different labor skill levels, so the mean absolute deviations can be minimized. Real data from garment factories and experimental design were used to evaluate GGA's performance.

Rabbani et al. (2012) **[82]** works on mixed model U-line balancing type-1 problem. In this a new approach to balance a mixed model U-shaped production system independent was developed for any product sequences. This approach was based on minimization of crossover workstations. In balancing mixed model assembly lines in U-shaped line layouts was more complicated than that of straight lines.

A model was developed in which minimizing the number of crossover workstations and maximizing the line efficiency were considered at same time.

Mixed-model assembly line balancing in the make-to-order and stochastic environment using multi-objective evolutionary algorithms was stated by Manavizadeh et al. (2012) **[83]**. A multi-objective genetic algorithm (MOGA) was present to solve a mixed-model assembly line problem (MMALBP), considering cycle time (CT) and the number of stations simultaneously. In this work, a mixed-model assembly line had been put forth in a make-to-order (MTO) environment according to the stochastic environment of production systems. Also a MOGA approach was presented to solve the corresponding balancing problem and the decision maker was provided with the subsequent answers to pick one based on the specific situation.

Modeling and solving constrained two-sided assembly line balancing problem via bee algorithms was presented by Tapkana et al. (2012) **[84]**. A fully constrained two-sided assembly line balancing problem was addressed in this research work. A mathematical programming model was presented in order to describe the problem formally. Due to the problem complexity, two different swarm intelligence based search algorithms are implemented to solve large-sized instances. Bees algorithm and artificial bee colony algorithm had been applied to the fully constrained two-sided assembly line balancing problem so as to minimize the number of workstations and to obtain a balanced line.

Chutima and Chimklai (2012) **[85]** works on multi-objective two-sided mixed-model assembly line balancing using particle swarm optimisation with negative knowledge. Particle swarm optimisation (PSO) is an evolutionary metaheuristic inspired by the swarming behavior observed in flocks of birds. A PSO algorithm was presented with negative knowledge (PSONK) to solve multi-objective two-sided mixed-model assembly line balancing problems. Instead of modelling the positions of particles in an absolute manner as in traditional PSO, PSONK employed the knowledge of the relative positions of different particles in generating new solutions.

Multi objective memetic algorithms for time and space assembly line balancing were presented by Chica et al. (2012) **[86]**. Three proposals of multi-objective

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memetic algorithms were presented to solve a more realistic extension of a classical industrial problem: time and space assembly line balancing. These three proposals were, respectively, based on evolutionary computation, ant colony optimization, and greedy randomized search procedure. An efficient branch and bound algorithm for assembly line balancing problem with parallel multi-manned workstations was presented by Kellegoz and Toklu (2012) [87]. Assembly lines with parallel multi-manned workstations and one of their balancing problems were addressed, and a branch and bound algorithm was proposed. The algorithm was composed of a branching scheme, some efficient dominance and feasibility criteria based on a problem-specific knowledge. A heuristic-based guidance for enumeration process was included as an efficient component of the algorithm as well. Battaia and Dolgui (2012) [88] 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. Rule-based modeling and constraint programming based solution of the assembly line balancing problem was discussed by Topaloglu et al. (2012) [89]. The assembly line balancing problem employs traditional precedence graphs to model precedence relations among assembly tasks. This work proposed to model assembly constraints through the well known If-then rules, and to solve the rule-based model through constraint programming (CP), as CP naturally models logical assertions. It has been also shown that how to map a rule-based model to a CP or an integer programming (IP) model. The result of experiments showed that CP was more effective and efficient than IP.

Simultaneous solving of balancing and sequencing problems with station-dependent assembly times for mixed-model assembly lines was presented by Mosadegha et al. (2012) [90]. In this work Mixed-Model Assembly Line (MMAL) was considered and studied for balancing and sequencing problems as well as solved. A new Mixed-Integer Linear Programming (MILP) model was developed to provide the exact solution of the problem with station-dependent assembly times. Yoosefelahi et al. (2012) [91] published a work on type II robotic assembly line balancing problem: An evolution strategies algorithm for a multi-objective model. The aim of the study was to minimize the cycle time, robot setup costs, robot costs and a procedure was also proposed to solve the problem. In addition, a new mixed-integer linear programming model was developed.

A hybrid PSO algorithm for a multi-objective assembly line balancing problem with flexible operation times, sequence-dependent setup times and learning effect was published by Hamta et al. (2013) [92]. In this a multi-objective (MO) optimization of a single-model assembly line balancing problem (ALBP) considered where the operation times of tasks were unknown variables and the only known information was the lower and upper bounds for operation time of each task. Three objectives were simultaneously considered as follows: (1) minimizing the cycle time, (2) minimizing the total equipment cost, and (3) minimizing the smoothness index. A new solution method was proposed which is based on the combination of particle swarm optimization (PSO) algorithm with variable neighborhood search (VNS) to solve the problem.

A Simulated Annealing algorithm for a mixed model assembly U-line balancing type-I problem considering human efficiency and Just-In-Time approach was presented by Manavizadeh et al. (2013) [93]. This work deals with balancing a mixed-model U-line in a Just-In-Time (JIT) production system. The research tries to reduce the number of stations via balancing the workload and maximizing the weighted efficiency. In this study two types of operators were assumed: permanent and temporary. Both types can work in regular and overtime periods. Based on their skill levels, workers were classified into four types. The sign at each work station indicated types of workers allowed to work at that station. An alert system using the hybrid kanban systems was also considered. A Simulated Annealing algorithm was applied in the following three stages for solving this problem. First, the balancing problem was solved by determining number of stations; secondly workers were assigned to the workstations in which they were qualified to work and finally an alert system based on the kanban system was designed to balance the work in the process inventory.

A simulated annealing algorithm for multi-manned assembly line balancing problem was presented by A bdolreza et al. (2013) [94]. In this work a simulated annealing heuristic was proposed for solving assembly line balancing problems with multi-manned workstations. The line efficiency, line length and the smoothness index were considered as the performance criteria. A work on an iterative genetic algorithm for the assembly line worker assignment and balancing problem of type-II was published by Mutlu et al. (2013) [95]. In this study, they considered the assembly line worker assignment and balancing problem of type-II (ALWABP-2). ALWABP-2 arises when task times differ depending on operator skills and concerns with the assignment of tasks and operators to stations in order to minimize the cycle time. An iterative genetic algorithm (IGA) was developed to solve this problem.

Tuncel and Topaloglu (2013) [96] works on assembly line balancing with positional constraints, task assignment restrictions and station paralleling: A case in an electronics company. A real-life Assembly Line Balancing Problem was discussed in this for an electronics manufacturing company. The main characteristics of the problem were as follows: (i) a set of operations are related to the front part of the workpiece and others are related to the back part of the workpiece, which in turn makes all tasks dependent on the position of the workpiece, (ii) some of the tasks must be executed on the same station and no other tasks should be assigned to this station due to technological restrictions, (iii) parallel stations are allowed to increase the line efficiency at the required production rate and to overcome the problem of assigning tasks with operation times that exceed the cycle time. Initially, the problem was formulated as a 0–1 integer programming model and solved using CPLEX solver. Then, the effect of alternative work schedules such as multiple shifts and overtime on the expected labor cost of the line was analyzed.

A work on hybridizing ant colony optimization via genetic algorithm for mixed-model assembly line balancing problem with sequence dependent setup times between tasks was presented by Sener et al. (2013) **[97]**. This work presented a new hybrid algorithm, which executes ant colony optimization in combination with genetic algorithm (ACO-GA), for type I mixed-model assembly line balancing problem (MMALBP-I) with some particular features of real world problems such as parallel workstations, zoning constraints and sequence dependent setup times between tasks.

A work on stability measure for a generalized assembly line balancing problem was published by Gurevsky et al. (2013) **[98]**. A generalized formulation for assembly line balancing problem (GALBP) was considered, where several workplaces were associated with each workstation. The objective of this work was to assign all given tasks to workstations and workplaces while minimizing the line cost estimated as a weighted sum of the number of workstations and workplaces. The goal of this article was to propose a stability measure for feasible and optimal solutions of this problem with regard to possible variations of the processing time of certain tasks. A heuristic procedure providing a compromised between the objective function and the suggested stability measure was developed and evaluated on benchmark data sets.

A work on two-sided assembly lines balancing with assignment restrictions was presented by Purnomo et al. (2013) **[99]**. 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 mated-workstations and balancing the workstation simultaneously.

Mozdgira et al. (2013) **[100]** published their work using the Taguchi method to optimize the differential evolution algorithm parameters for minimizing the workload smoothness index in simple assembly line balancing. An assembly line is a flow-oriented production system in which the productive units performing the operations, referred to as stations, are aligned in a serial manner. In this work the SALBP is further classified into SALBP-1, SALBP-2, SALBP-E and finally SALBP-F. In this work, a differential evolution algorithm was developed to minimize workload smoothness index in SALBP-2. Also, the algorithm parameters were optimized using the Taguchi method.

IV. Summary of Literature Survey

The summery research done by experts in the area of line balancing have been presented in Table 1 in the ascending order of year and classification are given in Fig.5. Ironically, there are ample works and have been performed by researchers on SALB, GALB and MALB, before 2000 among them the noted works were carried out by Falkenauer, Delchamber, Anderson, Ferris, Tsujimura, Kim and Rekiek et al.etc.

Table 1 : Summary of the developments in line balancing based on literature survey

Reference No.	Author Name (Year)	Investigated Problem Type
1,2	Amen (2000), (2000)	Cost-oriented assembly line balancing
3	Jin and Wu (2002)	Mixed model assembly line balancing
4	Fleszar and Hindi (2003)	Heuristic and reduction methods for the ALB
5	Karabati and Sayin (2003)	ALB in mixed-model sequencing environment
6	Simaria and Vilarinho (2004)	MMALB balancing problem of type II
7	Fonseca et al. (2005)	Fuzzy logic approach to assembly line balancing
8	Gokcen (2005)	Simple U-type assembly line balancing
9	Agpak and Gokcen (2005)	Assembly line balancing
10	Bukchin and Rabinowitch (2006)	MMALB problem for minimizing stations
11	Levitin et al. (2006)	Robotic assembly line balancing
12	Gokcen and Agpak (2006)	Simple U-line balancing problem
13	Hop (2006)	Fuzzy mixed-model line balancing
14	Gamberini et al. (2006)	Assembly line re-balancing

15	Song (2006)	Assembly line-balancing
16	Dolgui et al. (2006)	Transfer lines balancing
17	Becker and Scholl (2006)	Assembly line balancing
18	Kim et al. (2006)	Mixed-model U-lines
19	Peeters and Degraeve (2006)	Simple assembly line balancing
20	Urban and Chiang (2006)	U-line balancing problem
21	Hirotani et al. (2006)	Self-balancing production line
22	Dimitriadis (2006)	Assembly line balancing
23	Lapierre et al. (2006)	Balancing assembly lines with tabu
24	Gokcen et al. (2006)	Balancing of parallel assembly lines
25	Amen (2006)	Cost-oriented assembly line balancing
26	Azar et al. (2006)	Load balancing of temporary tasks
27	Scholl and Becker (2006)	Simple assembly line balancing
28	McGovern and Gupta (2007)	Disassembly line balancing
29	Agpak and Gokcen (2007)	Stochastic line balancing
30	Boysen and Fliedner (2007)	Assembly line balancing problem
31	Bautista and Pereira (2007)	Time and space constrained assembly line balancing
32	Xia-o-feng et al. (2008)	Two-sided assembly line balancing
33	Boysen and Fliedner (2008)	Assembly line balancing
34	Eryuruk et al. (2008)	Assembly line balancing
35	Boysen et al. (2008)	Assembly line balancing
36	Andres et al. (2008)	Balancing and scheduling tasks in assembly
37	Miralles et al. (2008)	Assembly line worker assignment and balancing
38	Toksari et al. (2008)	Simple and U-type assembly line balancing
39	Bautista and Pereira (2009)	Assembly line balancing problem
40	Choi (2009)	Mixed-model line balancing
41	Kim (2009)	Two-sided assembly line balancing
42	Simaria and Vilarinho (2009)	Balancing two-sided assembly lines
43	Gao (2009)	Type II robotic assembly line balancing
44	Sabuncuoglu et al. (2009)	Single model U-type assembly line balancing
45	Ege et al. (2009)	Assembly line balancing with station paralleling
46	Becker and Scholl (2009)	Assembly lines with variable parallel workplaces
47	Ozcan and Toklu (2009)	Mixed-model two-sided assembly lines
48	Kara et al. (2009)	Single model straight and U-shaped assembly line balancing
49	Guschinskaya and Dolgui (2009)	Transfer line balancing
50	Che et al. (2009)	Supply chain network with line balancing technology
51	Abdulhasan (2009)	Assembly planning and line balancing
52	Ozcan and Toklu (2009)	Multiple-criteria decision-making in two-sided assembly line balancing
53	Essafi et al. (2010)	Transfer line with complex industrial constraints
54	Toksari et al. (2010)	Assembly line balancing problem
55	Roy and Khan (2010)	Assembly line balancing
56	Fan et al. (2010)	Balancing and simulating of assembly line
57	Essafi et al. (2010)	Balancing lines with CNC machines
58	Ozcan (2010)	Balancing stochastic two-sided assembly lines
59, 64,68, 86	Chica et al. (2010), (2011), (2011), (2012)	Time and space assembly line balancing problem
60	Yeh and Kao (2010)	Assembly line balancing

61	Ozturk et al. (2010)	Balancing and scheduling of flexible mixed model assembly lines
62	Taha (2011)	Two-sided assembly line balancing
63	Akpinar and Bayhan (2011)	Mixed model assembly line balancing problem with parallel workstations
65	Ozbakir and Tapkan (2011)	Two-sided assembly line balancing
66	Hamta et al. (2011)	Bi-criteria assembly line balancing
67	Kilincci (2011)	Simple assembly line balancing problem of type I
69	Otto and Scholl (2011)	Assembly line balancing
70	Sihombing et al. (2011)	Line balancing analysis
71	Yagmahan (2011)	Mixed-model assembly line balancing
72	Cakir et al. (2011)	Stochastic assembly line balancing
73	Ozbakira et al. (2011)	Multiple-colony ant algorithm for parallel assembly line balancing problem
74	Blum and Miralles (2011)	Assembly line worker assignment and balancing problem
75	Hou and Kang (2011)	Scheduling for load balancing on uniform machines
76	Bautista and Pereira (2011)	Time and space constrained assembly line balancing
77	Weida and Tianyuan (2011)	Mixed model assembly line balancing based on scenario planning
78	Hamzadayi and Yildiz (2012)	Balancing and sequencing of mixed-model U-lines with parallel workstations
79	Cheshmehgaz (2012)	Body postures in assembly line balancing
80	Mahto and Kumar (2012)	Assembly line balancing techniques
81	Chen et al. (2012)	Assembly line balancing
82	Rabbani et al. (2012)	Mixed model U-line balancing type-I
83	Manavizadeh et al. (2012)	Mixed-model assembly line balancing
84	Tapkana et al. (2012)	Two-sided assembly line balancing
85	Chutima and Chimklai (2012)	Two-sided mixed-model assembly line balancing
87	Kellegoz and Toklu (2012)	Assembly line balancing problems with parallel multi-manned workstations
88	Battaia and Dolgui (2012)	Generalized line balancing
89	Topaloglu et al. (2012)	Assembly line balancing
90	Mosadegha et al. (2012)	Assembly times for mixed-model assembly lines
91	Yoosefelahi et al. (2012)	Robotic assembly line balancing type II
92	Hamta et al. (2013)	Multi-objective assembly line balancing
93	Manavizadeh et al. (2013)	Mixed model assembly U-line balancing type-I
94	Abdolreza et al. (2013)	Multi-manned assembly line balancing
95	Mutlu et al. (2013)	Assembly line worker assignment and balancing problem of type-II
96	Tuncel and Topaloglu (2013)	Assembly line balancing with positional constraints
97	Sener et al. (2013)	Mixed-model assembly line balancing
98	Gurevsky et al. (2013)	Assembly line balancing problem
99	Purnomo et al. (2013)	Two-sided assembly lines balancing
100	Mozdgira et al. (2013)	Simple assembly line balancing

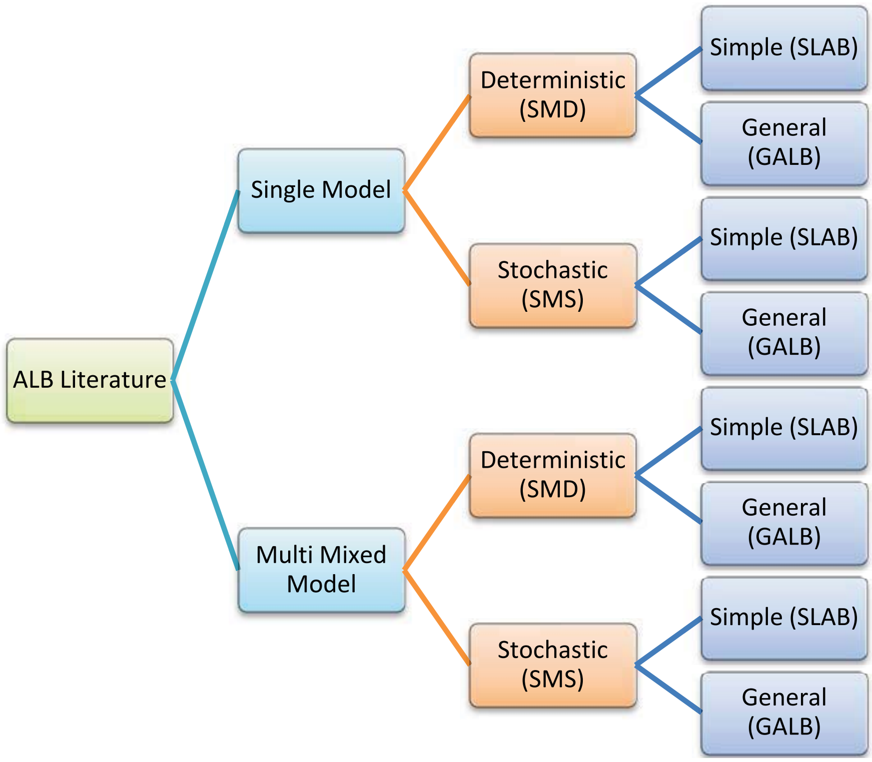

Figure 5 : Classification of assembly line balancing literature

V. Discussion

From the review of literatures it is found that Assembly line balancing can be used almost all types of industries. From the literature survey following points are needs to be discusse:-

- Experiments in line balancing show that optimal solutions for small and medium-sized problem are possible in acceptable time.
- 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.
- Different mathematical models that combines multiple models into a single one by adding up operation times and that suggested minimizing the maximum sub cycle time.
- 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 single-model U-type assembly line balancing problem are solved by ant colony algorithms and showed very competitive performance.
- 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.
- A simulation prototype system is developed for effective and correct assembly line balancing problem.
- Two-sided assembly lines with stochastic task times are considered for task time variation due to two-sided assembly lines with stochastic task times.
- 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.
- Parallel assembly lines provide some opportunities in improving increasing system flexibility, reducing failure sensitivity, improving system balance and productivity when the capacity of production system is insufficient.
- Bounded Dynamic Programming is adopted to solve the Time and Space constrained Assembly Line Balancing Problem variant with fixed cycle time and area availability.
- Priority-Based Genetic Algorithm is used for tackling of the mixed-model U-shape assembly line balancing/model sequencing problems with parallel workstations.
- New criterion of posture diversity is defined which assigned workers encounter the opportunities of changing their body postures regularly.
- Bees algorithm and artificial bee colony algorithm is applied to the fully constrained two-sided assembly line balancing problem so as to minimize the number of workstations and to obtain a balanced line.
- Genetic algorithm and iterative first-fit rule are used to solve the problem and experiments shows finding the best position over many workstations and the genetic algorithm provided more flexible task assignment.

VI. Conclusion

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. Ultimately, we have to work for assigning the workstations so that predetermined goal is achieved. This can be done by minimization of the number of workstations and maximization of the production rate as studied in the literature survey.

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.

- A heuristic procedure for solving larger size of problems can be designed.
- Paralleling of workstations and tasks may be studied to improve the line efficiency.
- To select a single equipment to perform each task from a specified equipment set.
- Bee and ant colony algorithm to be adopted for finding number of workstations.

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