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EVALUATION OF MULTI CRITERIA ASSEMBLY LINE BALANCING BY MCDM APPROACHES: A CONCEPTUAL REVIEW

Abstract: *This research paper gives an up-to-date review and discusses the development of the multi criteria assembly line balancing (ALB) and also gives a detailed list of different criteria for the purpose of comparing different assembly line balancing techniques. This paper is structured in six sections. Section one is introduction which gives the details of basic contributions of different researchers. Section two gives basic problem of assembly line balancing and its detailed classifications. In Section three objectives (criteria's) are shown in tabulated manner with reference as a result of extensive literature survey. Section four portrays assembly line balancing techniques for the solution of ALB Problems. Section five gives the information about the gaps in the literature for prioritizing different assembly line balancing techniques. Finally Section six, concludes the research work and gives information about possible future implications.*

Keywords: *Multiple Objective Criteria, Assembly Line Balancing Techniques, MCDM Approaches*

1. Introduction

An assembly line is a flow-oriented production system where the productive units performing the operations, referred to as stations, are aligned in a serial manner. The work pieces visit stations successively as they are moved along the line usually by some kind of transportation system, e.g. a conveyor belt (Boysen *et al.*, 2006a). The fundamental line balancing problem is to assign the tasks to an ordered sequence of stations, such that the precedence relations are satisfied and some measure of effectiveness is optimized (e.g. minimize the number of stations or minimize the idle time) **(**Becker and Scholl, 2006). Moreover, practitioners might be provided with valuable advices on how to use already existing models and procedures, for that purpose already existing ALB models and procedures are identified for the different types of real-world assembly systems and future research challenges are recognized (Boysen *et al.*, 2006).

2. Assembly Line Balancing Problem (ALBP)

2.1. Basic problem of ALB

An assembly line consists of workstations arranged along a conveyor belt or a similar mechanical material handling equipment. The work pieces (jobs) are consecutively launched down the line and are moved from station to station. At each station, certain operations are repeatedly performed regarding the cycle time (maximum or average time available for each workstation).

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The decision problem of optimally partitioning (balancing) the assembly work among the stations with respect to some objective is known as the assembly line balancing problem (ALBP). Due to technological and Organizational conditions precedence constraints between the tasks have to be observed. These elements can be summarized and visualized by a precedence graph. It contains a node for each task, node weights for the task times and arcs for the precedence constraints. Figure 1 shows a precedence graph (Boysen *et al.*, 2006a).

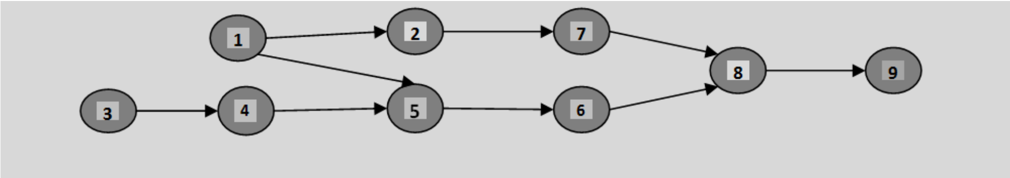

Figure 1. Precedence Diagram (Boysen *et al.*, 2006a)

2.2. Basic problem of ALB

Figure 3 shows the five bases of classification of Assembly line balancing problem. There brief description is given below and further classification is shown in Figure 4.

2.2.1. ALB in dependency of number of models

Single-model assembly lines: If only one product is assembled and all work pieces are identical the assembly line is known as single-model assembly line (Yano and Bolat, 1989; Sumichrast and Russel, 1990; Sumichrast *et al.*, 1992; Bard *et al.*, 1992; Merengo *et al.*, 1999).

Mixed-model assembly lines: Mixed-model line produces the units of different models in an arbitrarily intermixed sequence (Bukchin *et al.*, 2002). As shown in Figure 2.

Multi-model assembly lines: Multi-model line produces a sequence of batches with intermediate setup operations. (Burns and Daganzo, 1987; Dobson and Yano, 1994).

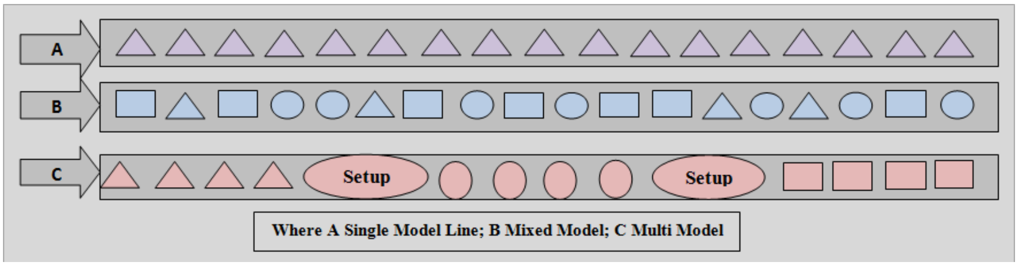

Figure 2. Assembly Lines for Single and Multiple Products **(**Becker and Scholl, 2003)

2.2.2. ALB in dependency of line control

Paced line: In a paced assembly production system typically a common cycle time is given which restricts process times at all stations? The pace is kept up by a continuously advancing material handling device, e.g. a conveyor belt, which forces operators to finish their operations before the work piece has reached the end of the respective station (Gökcen and Baykoc, 1999; Henig, 1986; Kottas and Lau, 1981; Lau and Shtub, 1987; Lyu, 1997). Unpaced asynchronous line: In un paced lines, work pieces are transferred whenever the required operations are completed, rather than being bound to a given time span. Under asynchronous movement, a work piece is always moved as soon as all required operations at a station are completed and the successive station is not blocked anymore by another work piece (Buzacott, 1968; Suhail, 1983; Baker *et al.*, 1990; Hillier and So, 1991; Hillier *et al.*, 1993; Malakooti, 1994; Powell, 1994; Dolgui *et al.*, 2002). Unpaced synchronous line: Under synchronous movement of work pieces, all stations wait for the slowest station to finish all operations before work pieces are transferred at the same point in time (Lau and Shtub, 1987; Buzacott and Shantikumar, 1993; Kouvelis and Karabati, 1999).

2.2.3. ALB with regard to its frequency

First time installation: Whenever an assembly production system is installed for the first time, ALB problem is solved by the survey of all alternative processes which lead to the desired product(s), which are hence passed on to the balancing problem. It gives a better overall solution and is especially suitable for a first time installation (Pinto *et al.*, 1983; Pinnoi and Wilhelm, 1998; Bukchin and Tzur, 2000).

Reconfiguration: A reconfiguration becomes necessary whenever there is a substantial change in the structure of the production program, e.g., a permanent shift in the demand for models (Falkenauer, 2005).

2.2.4. ALB and the level of automation

Manual lines: Where work pieces are fragile or if work pieces need to be gripped frequently, as industrial robots often lack the necessary accuracy manual lines are used. (Abdel-Malek and Boucher, 1985).

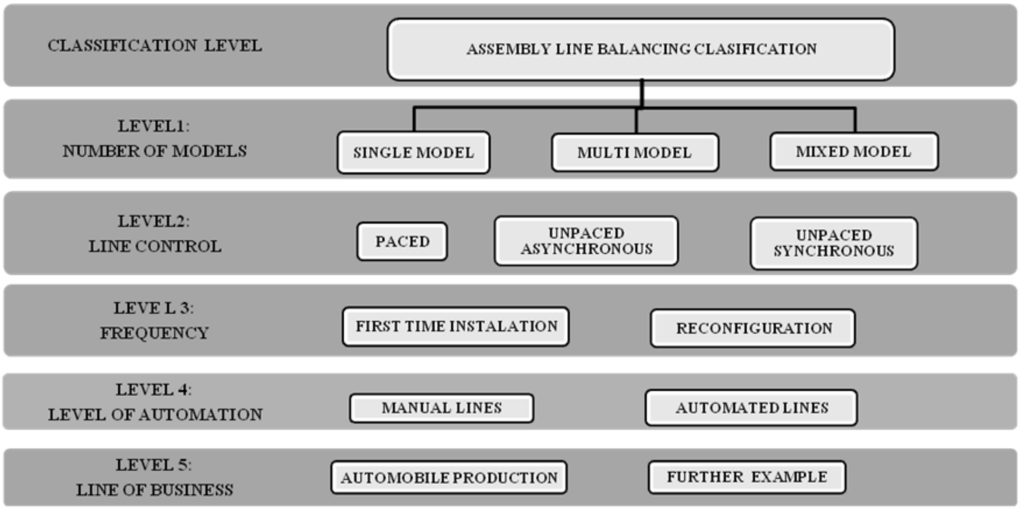

Figure 3. Invested Kinds of Assembly Line Balancing (Boysen *et al.*, 2006a)

Automated lines: Fully automated lines are mainly implemented wherever the work environment is in some form hostile to human beings or where industrial robots are able to perform tasks more economically and with a higher precision (e.g. metal processing tasks) (Pinnoi and Wilhelm, 1998; Bukchin and Tzur, 2000).

2.2.5. Line of business specific ALB

Automobile production: The final assembly of cars is mainly carried out on paced, mixed model lines with a high proportion of manual labor (Meyr, 2004). Further examples: As electronic devices usually consist of a number of electronic subassemblies, which need to be assembled them, (Hautsch *et al.*, 1972; Lapierre and Ruiz, 2004; Bautista and Pereira, 2002)

Further Classification of Assembly Line Balancing (as shown in the Figure 4) involves the Single Model Deterministic (SMD): Where the task times are known deterministically and an efficiency criterion is to be optimized. Single Model Stochastic (SMS): With the introduction of stochastic task times many other issues become relevant, such as station times exceeding the cycle time and many more. Multi/Mixed Model Deterministic (MMD): An assembly line producing multiple products with deterministic task times. Multi/Mixed Model stochastic (MMS): Problem perspective differs from its MMD counterpart in that stochastic times are allowed. SALBP: Straight single product assembly lines where only precedence constraints between tasks are considered.SALBP-1: Minimize the number of stations for a given production rate (fixed cycle time). SALBP-2: Minimize cycle time (maximize the production rate) for a given number of stations. SALBP-E: maximizing the line efficiency thereby simultaneously minimizing number of stations and cycle time and considering their interrelationship. SALBP-F: whether or not a feasible line balance exists for a given combination of number of stations and cycle time. GALBP: all problem types which generalize or remove some assumptions of SALBP are called generalized assembly line balancing problems (GALBP). MALBP and MSP: Mixed model assembly lines produce several models of a basic product in an intermixed sequence. MSP: It has to find a sequence of all model units to be produced such that inefficiencies (work overload, line stoppage, off-line repair etc) are minimized (Bard *et al.*, 1992; Scholl *et al.*, 1998). UALBP: The U-line balancing problem considers the case of U-shaped (single product) assembly lines, where stations are arranged within a narrow U. As a consequence, worker is allowed to work on either side of the U, i.e. on early and late tasks in the production process simultaneously. Therefore, modified precedence constraints have to be observed (Urban, 1998; Scholl and Klein, 1999).

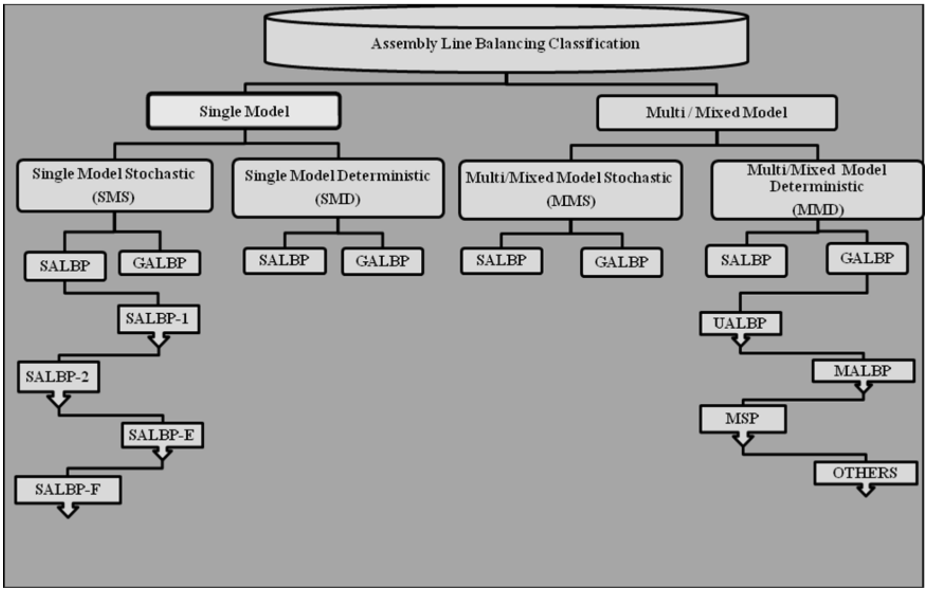

Figure 4. Classification of Assembly Line Balancing Problem (Ghosh and Gangnon, 1989; Scholl and Becker, 2006; Becker and Scholl, 2006)

3. Various (objectives) criteria's of assembly line balancing

Finally, the optimization of ALB will be guided by some objectives which evaluate solutions. In the case of multi-objective optimization more than a single objective can be selected. Various Technical and Economic Objective Criteria (as shown in the Table.2) have been used in the ALB literature, Ghosh and Gagnon (1989). In the literature, usually only one objective is used, while other goals are formulated as constraints. Only few references deal with multiple objective assembly line balancing problems, namely, (Baybars, 1985; Shtub and Dar-El, 1990; Deckro and Rangachari, 1990; Malakooti, 1991; Malakooti, 1994; Malakooti and Kumar, 1996).

Table 1. Revealed characteristics and the three models of innovation

S.No	Category (Objective) Criteria	Assembly Line Balancing (Objective) Criteria	Optimization	ALB Layout	References/Sources
1.	Technical	West Ratio (WR)	Maximize West Ratio	SALBP	Dar-El (1975)
2.	Technical	Task Time Intensity (TTI)	Maximize Task Time Intensity	SALBP	Scholl (1999)
3.	Technical	Task Time Distribution (TTD)	Minimize Task Time Distribution	SALBP	Scholl (1999)
4.	Technical	Balance Delay(BD)	Minimize Balance Delay	SALBP	Kildbridge and Wester (1961)
5.	Technical	Smoothness Index(SI)	Minimize Smoothness Index	SALBP/ ULBP	Moodie and Young (1965); Driscoll& Thilakawardana (2001)
6.	Technical	Line Time	Minimize Line Time	SALBP	
7.	Technical	Balance Efficiency(BE)	Maximize Line Efficiency	SALBP/ ULBP	Moodie And Young (1965)
8.	Technical	Productivity Level Index(PLI)	Maximize Productivity Level Index	ULBP	Hami *et al.* (2012)
9.	Technical	Worker Crossover Index(WOCI)	Maximize Worker Crossover Index	ULBP	Hami *et al.* (2012)
10.	Technical	No of Workstations (M)	Minimize Number of Stations	ULBP/ (TSALB P)	Malakooti (1994); Malakooti, and Kumar (1996); Chica *et al.* (2011)
11.	Technical	No. of Temporary Worker (TW)	Minimize No. of Temporary Worker	ULBP	Hami *et al.* (2012) Widyadana and Juni (2009)
12.	Technical	Cycle Time (CT)	Minimize Cycle Time	TSALBP	Malakooti(1994); Malakooti, and Kumar, (1996); Widyadana and Juni, (2009); Chica *et al.* (2011)
13.	Technical	Production Rate (PR)	Maximize Production Rate	Batch-Model	Malakooti and Kumar (1996); Kabir and Tabucanon (1995)
14.	Economic	Net Profit (Pr)	Maximize Profit	SALBP	Scholl (1999)
15.	Technical	Total Idle Time (IT)	Minimize Total Idle Time along	SALBP	Ghosh And Gagnon (1989)

			the Line		
16.	Technical	Buffer Size (b)	Minimize Buffer Size	SALBP	Malakooti, (1994); Malakooti and Kumar (1996)
17.	Economic	Total cost of operation with buffers (TC)	Minimize total cost of operation	SALBP	Malakooti (1994)
18.	Technical	Crew Size/Number of Workers Required for the Solution (W)	Minimization of Required Workers	SALBP	Mcmullen and Tarasewichz (2006)
19.	Technical	System Utilization/ Utilization of Assembly Line Layout (U)	Maximize Utilization of Assembly Line Layout	SALBP	Mcmullen and Tarasewichz (2006); Askin and Zhou (1997); Gocken and Erel (1998); Vilarinho and Simaria (2002)
20.	Technical	Probability of All Work Centers Completing Work On Time (P)	Maximize Probability of All Work Centers Completing Work On Time	SALBP	Merengo *et al.* (1999)
21.	Economic	Design Cost of Assembly Line Layout (Cost)	Minimize Design Cost	SALBP	Askin and Zhou (1997); Rekiek *et al.* (2000); Bukchin *et al.* (2002)
22.	Technical	Variety (V)	Maximize Variety	Batch-Model	Kabir and Tabucanon (1995)
23.	Technical	Minimum Distance (D)	Minimize Distance	Batch-Model	Kabir and Tabucanon (1995)
24.	Technical	Division Labor (L)	Minimize Division Labor	Batch-Model	Kabir and Tabucanon (1995)
25.	Technical	Quality (Q)	Maximize Quality	Batch-Model	Kabir and Tabucanon (1995)
26.	Technical	Area of Stations (A)	Minimize Area of Stations	TSALBP	Chica *et al.* (2011)
27.	Technical	Station Times (Stat, Line)	Station Times are to be Smoothed	SALBP	Boysen *et al.* (2006)
28.	Technical	Number of Work Piece Position Changes.	Minimize or Maximize	SALBP	Boysen *et al.* (2006)
29.	Technical	Overall Facility or Line Length	Minimize Overall Facility or Line Length	SALBP	Ghosh and Gagnon (1989)
30.	Technical	Throughput Time	Minimize The Throughput Time	SALBP	Ghosh and Gagnon (1989)
31.	Technical	Minimizing the work load deviation	Minimizing work load deviation	SALBP	
32.	Economic	Combined Cost of Labor, Ws. And	Minimize Combined	SALBP	Kottas and Lau (1973); Ghosh and Gagnon (1989)

		Product Incompleteness	Cost of Labor, Ws. and Product Incompleteness		
33.	Economic	Labor Cost/Unit	Minimize Labor Cost/Unit	SALBP	Ghosh and Gagnon (1989)
34.	Economic	Total Penalty Cost for Inefficiencies	Minimize Total Penalty Cost	SALBP	Ghosh and Gagnon (1989)
35.	Economic	Inventory, Set Up And Idle Time Cost	Minimize Inventory, Set Up and Idle Time Cost	SALBP	Ghosh and Gagnon (1989)
36.	Economic	Total In-Process Inventory Costs	Minimize Total In-Process Inventory Costs	SALBP	Ghosh and Gagnon (1989)
37.	Economic	Penalty Costs	Minimize Penalty Costs	SALBP	
38.	Economic	Inventory And Set-Up Costs	Minimize Inventory and Set-Up Costs	SALBP	Caruso (1965)
39.	Technical	Number of Workers (M)	minimize the number of workers	SALBP	Sirovetnukul and Chutima (2009)
40.	Technical	Deviation of Operation times of Workers (DOW)	Minimize the Deviation of Operation times of Workers	SALBP	Sirovetnukul and Chutima (2009)
41.	Technical	Walking Time (WT)	Minimize the Walking Time	SALBP	Sirovetnukul and Chutima (2009)

4. Techniques for the solution of assembly line balancing problem

The large combinational complexity of the ALB problem has resulted in enormous computational difficulties. To achieve optimal or at least acceptable solutions, various solution methodologies have been explored. These methods are organized in Figure5.Refers to two research studies which combined priority ranking procedures with simulation programs. Despite recent advances in problem formulation and solution procedure efficiency, mathematical Programming / network-based optimization techniques are still computationally prohibitive beyond limited problem dimensions. Heuristic and Meta heuristic techniques (Simulated Annealing (SA), Tabu Search (TS), Genetic Algorithm (GA) and Ant Colony Optimization (ACO), etc.) still remain the only computationally efficient and sufficiently flexible methodologies capable of addressing large-scale, real-world ALB situations, particularly for the multi/mixed model and GALBP categories.

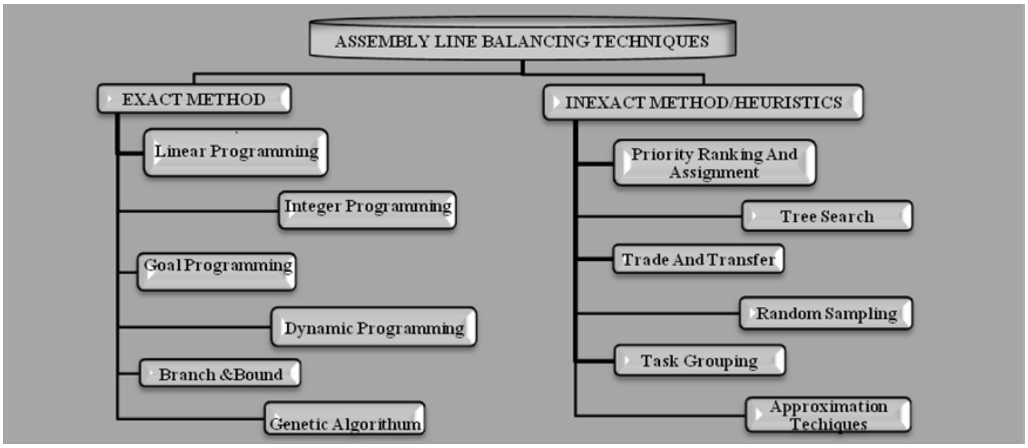

Figure 6. ALB Methodological Techniques (Ghosh and Gagnon, 1989)

5. Literature review of Mcdm approaches in the field of Assembly line balancing

A brief review of the literature survey in the area of Multi Criteria Decision Making (MCDM) techniques is given below. Jolai *et al*. (2009), proposes a data envelopment analysis (DEA) approach to solve an assembly line balancing problem. A computer-aided assembly line balancing tool as flexible line balancing software is used to generate a considerable number of solutions alternatives as well as to generate quantitative decision-making unit outputs. The quantitative performance measures were considered in this article. Then DEA was used to solve the multiple-objective assembly line balancing problem. An illustrative example shows the effectiveness of the proposed methodology. In this article, the evaluation criteria are West Ratio (Dar-El, 1975), Task Time Intensity, Task Time Distribution (Scholl, 1999), Balance Delay (Kildbridge and Wester, 1961), Smoothness Index (Moodie and Young, 1965) and Balance Efficiency. Farkhondeh *et al.* (2010), propose a model, using multi-objective decision making approach to the U-shaped line balancing problem, to offer enhanced decision maker flexibility, by allowing for conflicting goals. The assembly line operation efficiency is the most significant aim in our study, and this efficiency relates to management of resources and the solution of line balancing problem. First, the U-shaped line balancing problem is solved considering the model's goals. Then, the index function of assembly line balancing is determined and the efficiencies of the optimal solution outputs are evaluated using Data Envelopment Analysis (DEA). In this article, the47evaluation criteria are Smoothness Index (SI) (Driscoll and Thilakawardana, 2001), Temporary Worker (TW), No. of Workstations (M), Productivity Level Index (PLI), Worker Crossover Index (OCI), Balance Efficiency (BE) (Widyadana and Juni, 2009). In this research, U-type line balancing using goal programming for multi objective model with two goals, i.e., minimized the Number of Temporary Workers and Cycle Time in each station. Different amount of time for temporary worker to accomplish their tasks were generated. The cycle time in each station goal and the number of temporary workers goal are conflicting goals. When one goal has a higher priority, then the other one will be unsatisfied. The result also shows that in some cases U-line balancing model has better performance than straight line balancing model and in some cases both of them are equal. This study shows that the U-line balancing has more benefit than the straight line balancing, but the U-line balancing could not be interesting since it needs more walking time. Finally, An example to illustrate the model, as well as some analyses is presented. Kabir and Tabucanon (1995), developed a multi attribute-based approach to determine the number of workstations. At first, a set of feasible number of workstations which are balanced for each product model are generated. A procedure is then developed to compute the changeover time for each configuration (number of workstation), and finally, a multi attribute evaluation model is developed to select the number of workstations considering production rate, variety, minimum distance moved, division of labor and quality using the analytic hierarchy process and simulation. The methodology is then applied to a real-life batch-model assembly line for printing calculators. Shtub and Dar-El (1990) developed a methodology for selecting the type of assembly system through the analytic hierarchy process of Saaty, (1980)...They considered four factors which influence the decision and these are division of labor and specialization, work flow, interchangeability of parts and minimum distance moved. The alternatives taken were the type of assembly systems - manual, automatic or semiautomatic. This work looked into the problem in a macroscopic aspect, i.e. the assembly system as a whole. Kriengkorakot and Pianthong (2007), give an up-to-date review and discuss the development of the classification of the assembly line balancing problem (ALBP) which has attracted attention of researchers and practitioners of research for almost half a century. We also present various technical and economical objective criteria been used in the ALB literature Ghosh and Gagnon (1989). The seven technical criteria's discussed are No. of Workstations, Cycle Time, Total Idle Time, Balance Delay, Overall Facility or Line Length, Throughput Time, No. of work stations that will exceed the cycle time and six economical criteria found in the literature are Combined Cost of Labour, Workstations and Product Incompleteness, Labour Cost/Unit, Total Penalty Cost for Inefficiencies, Inventory, Set Up And Idle Time Cost, Total In-Process Inventory Costs, Net Profit. Within the technical category, minimizing the number of work stations has been the most chosen. And economical criteria typically relate to assembly line operating cost or profitability measures, all the economical criteria consider labor cost or labor idleness cost, the most popular criterion and the apparent trend is to include other cost such as product in completions Kottas and Lua, (1973), penalty costs**,** and inventory and set-up costs Caruso (1965). The technical criteria have been the classical dominant choice, while economic criteria have gained rapid attention of researcher since the mid-1970s. Mcmullen and Frazier (1998) presents a technique for comparing the results of different assembly line balancing strategies by using Data Envelopment Analysis (DEA). Initially, several heuristics— which can be thought of as assembly line balancing strategies were used to solve seven line-balancing problems. The resulting line balance solutions provided two pieces of information that were of particular interest: the Number of Workers needed and the Amount of Equipment needed. These two items were considered inputs for DEA. The different line balance solutions were then used as layouts for simulated production runs. From the simulation experiments, several output performance measures were obtained which were of particular interest and were used as outputs for DEA. The analysis shows that DEA is effective in suggesting which line balancing heuristics are most promising. In this work, DEA is used to compare different line balancing heuristics using two output performance measures (Cycle Time performance and percentage of on-time completions within cells). Malakooti (1994), One of the problems in the design of multi station lines is the allocation of different work elements to various work stations. This problem is called Assembly Line Balancing (ALB). The failure of workstations and other unforeseen circumstances can result in unnecessary idling of the production line. In order to improve the production rate of such systems, buffer storage of certain capacities can be allocated between each pair of workstations. In this work, ALB with buffers is formulated as a single criteria decision making as well as a multiple criteria decision making problem. In the single objective problem, the cycle time is given and the optimal number of workstations and the buffer sizes is obtained to minimize the total cost. In the multiple criteria problem, several criteria (objectives) are defined. These objectives are the number of workstations, their buffer sizes, the cycle time, and the total cost of operation with buffers. Malakooti (1994), also describes how the best alternative can be selected through the use of existing interactive multiple criteria methods. Several examples are solved and the results of computation experiments are provided. When an assembly line operates without internal buffer storage space, the workstations are independent. This means that if one station break down all other stations will be affected. Either immediately or by the end of a few cycles of operation (Groover, 1987; Dar-El, 1975**;** Sharp, 1977**;** Buxley *et al.*, 1973). The other workstations will be forced to stop as either a starving station where the workstation cannot continue to operate because no parts are arriving to the line or a blocking station where parts are prevented from being passed to the next station because the next station is down. When an automated flow line is divided into stages and each stage has a storage buffer, the overall efficiency and production rate of the line are improves (Melloy and Soyster, 1990; Smith and Daskalki, 1988**).** Malakooti and Kumar, (1996)**,** design and developed a knowledge based system that solve multi objective assembly line balancing problems to obtain an optimal assignment of a set of assembly tasks to a sequence of work stations. The formulations and solutions currently employed by managers and practitioners usually aims at optimizing one objective (i.e, number of work stations or cycle time), thus ignoring the multi dimensional nature of the overall objectives of the manager. Furthermore in practice ALBPs are ill-defined and ill-structured, making it difficult to formulate and solve them by mere mathematical approaches. This work present a knowledge based multi objective approach to ALBPs. It demonstrates how such a system can be constructed and how a variety of assembly line balancing methods can be used in a uniform structure to support the decision maker (DM) to formulate, validate the formulation, generate alternatives and choose the best alternative. The goal, ideally (Malakooti, 1990**,** Malakooti 1994) is to optimize several objectives of the assembly operation. In this paper it is assumed that factors such as work design, ergonomics, working conditions, technological sequence of tasks, task time, etc have been brought to optimal levels and that the decisions under investigation are only those relate to the assignment of tasks to workstations and their impact on profit. Despite their frequent occurrence, development and implementation of Assembly Line Balancing solutions suffer from several drawbacks. Three of them are outlined below: In practice as well as in literature, ALBPs are mostly formulated as a single objective problem (Salveson, 1955**;** Bowman, 1960**;** White, 1961**;** Ramsing and Dowing, 1970**;** Pattorson and Albracht, 1975**;** Baybars, 1986**;** Henig, 1986**;** Talbot and Patterson, 1984), and many others. Due to the multidimensional character of the overall assembly objectives (such as production rate, cost of operation, buffer space) single objective formulations are inadequate. Assembly Line Balancing Problems, even with the single objective, are shown to be NP hard problems. Therefore, the computer time taken to develop exact solutions grows exponentially in problem size and soon becomes exorbitant. For this reason, numerous heuristic procedures (Helgeson and Birnie, 1961; Kilbridge and Wester 1961; Moodie and Young, 1965; Arcus, 1966; Ramsing and Dowing, 1970), Sphicas and Silverman (1976), and also some recent works by Batts and Mahmoud (1990), and Bhattacharjee and Sahu (1990), have been presented in literature. None of these methodologies can be said to be universally superior in terms of the quality of solution, although each will perform well (in the sense of proximity to optimal solution) for certain problem structures. Due to technicalities involved, practitioners (equivalently, users or decision makers, henceforth) are often unable to determine the solution methodology that will yield the best solution. In practice, it may be necessary to optimize more than one conflicting objectives simultaneously to obtain effective and realistic solutions. Driscoll (1999), within this work a compound set of assembly line problem measures has been introduced and these are Order Strength (OS) (Mastor, 1970), Flexibility Ratio (FR), West Ratio (WR) (Dar-El, 1973) and Time Interval (TI) (Wee and Magazine, 1981). And two traditional assessment parameters, Balance Delay and Smoothness Index (Moodie and Young, 1965) investigated. Two new measures of solution quality have been created to support balancing model studies. Line Efficiency and Balance Efficiency. Initially introduced four measures of difficulty are calculated, then grouped into two key indices, and precedence Index and task time index, from which an overall index of difficulty is obtainable. The precedence diagram for an individual product represents the engineering constraints on the sequence of assembly. The 'precedence' order has been found to be a major influence on the ease or difficulty of balancing and must therefore contribute in an assessment of problem difficulty. Two aspects of individual problem have been selected for inclusion in an overall Precedence Index; Precedence Strength (Ps) and Precedence Bias (Pb). While the task time index includes Task Time Intensity (Ti).and Task Time Distribution (Td). Sirovetnukul and Chutima (2009), developed the multi-objective worker allocation problems of single and mixed-model assembly lines having manually operated machines in several fixed U-shaped layouts. Three objective functions are simultaneously minimized, i.e. Number of Workers, Deviation of Operation Times of Workers, and Walking Time. Chica *et al.* (2011), Presented Time and space assembly line balancing which considers realistic multi objective versions of the classical assembly line balancing industrial problems involving the joint optimization of conflicting criteria such as the Cycle Time, The Number of Stations, And/or Area of Stations. In addition to their multi-criteria nature, the different problems included in this field inherit the precedence constraints and the cycle time limitations from assembly line balancing problems, which altogether make them very hard to solve. Therefore, time and space assembly line balancing problems have been mainly tackled using multi objective constructive meta heuristics. Global search algorithms in general and multi objective genetic algorithms in particular have shown to be ineffective to solve them up to now because the existing approaches lack of a proper design taking into account the specific characteristics of this family of problems. The aim of this contribution is to demonstrate the latter assumption by proposing an advanced multi objective genetic algorithm design for the 1/3 variant of the time and space assembly line balancing problem which involves the joint minimization of the number and the area of the stations given a fixed cycle time limit. This novel design takes the well known NSGA-II algorithm as a base and considers the use of a new coding scheme and sophisticated problem specific operators to properly deal with the said problematic questions. A detailed experimental study considering 10 different problem instances (including a real-world instance from the Nissan plant in Barcelona, Spain) will show the good yield of the new proposal in comparison with the state-of-the-art methods Mcmullen and Frazier (2006). A technique derived from ant colony optimization is presented that addresses multiple objectives associated with the general assembly line-balancing problem. The specific objectives addressed are Crew Size, System Utilization, The Probability of Jobs Being Completed Within a Certain Time Frame And System Design Costs. These objectives are addressed simultaneously, and the obtained results are compared with those obtained from single-objective approaches. Comparison shows the relative superiority of the multi-objective approach in terms of both overall performance and the richness of information.

Suwannarongsri and Puangdownreong (2008), proposes a novel intelligent approach for solving the assembly line balancing (ALB) problems. The adaptive tabu search (ATS) method and the partial random permutation (PRP) technique are combined to provide optimal solutions for the ALB problems. In this work, the multiple objectives including the Workload Variance, the Idle Time, and the Line Efficiency, are proposed and set as the objective function. The proposed approach is tested against three benchmark ALB problems and one real-world ALB problem. Obtained results are compared with results obtained from the single-objective approach. As results, the proposed multiple-objective approach based on the ATS and the PRP is capable of producing solutions superior to the single-objective. A work on bi-criteria assembly line balancing by considering flexible operation times was presented by Hamta *et al*. (2011). Hamta *et al*, (2011)**,** addresses a novel approach to deal with Flexible task Time Assembly Line Balancing Problem (FTALBP). In this work, machines are considered in which operation time of each task can be between lower and upper bounds. These machines can compress the processing time of tasks, but this action may lead to higher cost due to cumulative wear, erosion, fatigue and so on. This cost is described in terms of task time via a linear function. Hence, a bi-criteria nonlinear integer programming model is developed which comprises two inconsistent objective functions: minimizing the Cycle Time and minimizing the Machine Total Costs. Moreover, a genetic algorithm (GA) is presented to solve this NP-hard problem and design of experiments (DOE) method is hired to tune various parameters of our proposed algorithm. The computational results demonstrate the effectiveness of implemented procedures. Hamta *et al.*, (2011), addresses multi-objective optimization of a single-model assembly line balancing problem where the processing times of tasks are unknown variables and the only known information is the lower and upper bounds for processing time of each task. Three objectives are simultaneously considered as follows: (1) minimizing the Cycle Time, (2) minimizing the Equipment Cost, and (3) minimizing the Smoothness Index. In order to reflect the real-world situation adequately, we assume that the task time is dependent on worker(s) (or machine(s)) learning for the same or similar activity and also sequence-dependent setup time exists between tasks. Furthermore, a solution method based on the combination of two multi-objective decision-making methods, weighted and min-max techniques, is proposed to solve the problem. Finally, a numerical example is presented to demonstrate how the proposed methodology provides Pareto optimal solutions. Cakir *et al*. (2011), deals with multi-objective optimization of a single-model stochastic assembly line balancing problem with parallel stations. The objectives are as follows: (1) minimization of the Smoothness Index and (2) minimization of the Design Cost. To obtain Pareto-optimal solutions for the problem, we propose a new solution algorithm, based on simulated annealing (SA).The effectiveness of new solution algorithm is investigated comparing its results with those obtained by another SA (using a weight-sum approach) on a suite of 24 test problems. Computational results show that new solution algorithm with a multinomial probability mass function approach is more effective than SA with weight-sum approach in terms of the quality of Pareto-optimal solutions. Ozcan and Toklu (2009), worked 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. Ozcan and Toklu (2009), proposed goal programming models which are the first multiple-criteria decision-making approaches for two-sided assembly line balancing problem with multiple objectives. The Number of Mated-Stations, Cycle Time and the Number of Tasks Assigned per Station are considered as goals. An example problem is solved and a computational study is conducted to illustrate the flexibility and the efficiency of the proposed goal programming models. Based on the decision maker's preferences, the proposed models are capable of improving the value of goals. This work presents 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. The zoning constraints are also considered in this model, and a set of test problems taken from literature is solved. Gamberini *et al*. (2006), 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.

6. Gaps in the literature

The field of assembly line balancing has been vigorously researched in recent decades. Recently, innovations addressing some of the more complicating features of the problem. Some of these innovations include parallel treatment of workers, tasks with stochastic durations, multiple objectives optimization, and mixed-models for JIT systems. Among these complicating features addressed here, Multiple Objectives Optimization (as shown in table 2) should be of value to decision-makers needing to run the line smoothly and to design efficient, productive and competitive assembly lines. From the literature review it is very clear that the Multiple Objectives (criteria's) Optimization of any line balancing problem by applying multi criteria decision making (MCDM) approaches is very less. And to evaluate an assembly line of any manufacturing industry through MCDM approaches will give more precise results since by applying these methods multiple objectives will optimize simultaneously and also will be helpful in prioritizing the solution methodologies. In future work, we hope to apply the multi criteria decision making (MCDM) approaches to the extensions of the SALBP, such as u-shaped line balancing problem, mixed-model assembly lines balancing problem, etc. further more in the future researches, these approaches could be developed towards considering both of quantitative (technical and economic) and qualitative (criteria's related to workers) criteria's.

7. Conclusion

This study addresses the evaluation of assembly line balancing solutions obtained through the assembly line balancing techniques from both category (i.e. Exact and Inexact). Based on the MCDM approaches to optimize multiple objectives. Decision makers could use Multi Criteria decision making to select best alternatives that have been generated with software package effectively. In the future researches, this approach could be developed towards considering both of quantitative and qualitative criteria.

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