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EVALUATION OF ASSEMBLY LINE BALANCING METHODS USING AN ANALYTICAL HIERARCHY PROCESS (AHP) AND TECHNIQUE FOR ORDER PREFERENCES BY SIMILARITY TO IDEAL SOLUTION (TOPSIS) BASED APPROACH

Abstract: *Assembly lines are special flow-line production systems which are of great importance in the industrial production of high quantity standardized commodities. In this article, assembly line balancing problem is formulated as a multi objective (criteria) problem where four easily quantifiable objectives (criteria's) are defined. Objectives (criteria's) included are line efficiency, balance delay, smoothness index, and line time. And the value of these objectives is calculated by five different heuristics. In this paper, focus is made on the prioritization of assembly line balancing (ALB) solution methods (heuristics) and to select the best of them. For this purpose, a bench mark assembly line balancing problem is solved by five different heuristics and the value of objectives criteria's (performance measures) of the line is determined. Finally the prioritization of heuristics is carried out through the use of AHP- TOPSIS based approach by solving an example.*

Keywords: *Simple Assembly Line Balancing (SALB), Pair Wise Comparison Scale, Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)*

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. An assembly line consists of a conveyor belt. Each station repeatedly has to perform a set of tasks on consecutive productunits moving along the line at constant speed. Because of the uniform movement of theline each product unit spends the same fixed time interval, called the cycle time CT, in everywork station. As a consequence, the cycle time CT determines the production rate which is *1/*CT. Tasks or operations are indivisible elements of work which have to be performed toassemble a product. The execution of each of n tasks j=1...n requires a fixed timeinterval, the task time *tj* which is assumed to be integral. Due to technological restrictionsprecedence constraints partially

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specifying the sequence of tasks have to be considered.These constraints can be represented by a precedence graph containing nodes for all tasksand arcs (i, j) if task i has to be completed before task j can be started.The Simple Assembly Line Balancing Problem (SALBP) can be stated as follows (Baybars, 1986; Domschke *et al.*, 1993). Each task has to be assignedto exactly one station of the assembly line such that no precedence constraint is violated. The assembly line balancing problem (ALBP) is one of the classic problems in industrial engineering and is considered as the class of NP-hard combinatorial optimization problems (Amen, 2006). Therefore, heuristic methods have become the most popular techniques for solving such problems. (Arcus, 1965; Helgeson and Birnie, 1961; Khaw and Ponnambalam, 2009). This paper is organized as follows. Section 2 discusses the literature review on multi objective (criteria) assembly line balancing problems. Section 3 addresses the heuristics for the solution of assembly line balancing problem. While section 4 presents the performance measures (objectives criteria's) of assembly line balancing problem.Section 5 presents the MCDM approaches-AHP and TOPSIS. Section 6 methodology adapted. Section 7 result. Section 8 conclusion and scope for the future research.

2. Literature review on multi objective (criteria) assembly line balancing problems

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 (Kumar, 2006), Smoothness Index (Moodie and Young, 1965) and Balance Efficiency. (Fanrkhondeh *et al.*, 2011), 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, the 47evaluation 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). Gede Agus Widyadana (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, minimumdistance 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 (1989) 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, interchangeabilityof 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 Pianthog, (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 (Ramsing and Downing, 1970), penalty costs (Dar-El and Curry, 1977) 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 sincethe mid-1970s. Mastor (1970) 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 (1991), 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 totalcost of operationwith buffers. Malakooti (1991) 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; Scholl, 1999; Buxey *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: (Elsayed, 1994; Kabir and Tabucanon, 1995; Shtub and Dar-El, 1989; Kilbridge and Wester, 1961), 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, 1994; Malakooti, 1991) 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 (Saaty, 1994; Bowman, 1960; Hoffmann, 1963; Lu and Zhao, 2008; McMullen and Tarasewichz, 2006; Baybars, 1986; Henig, 1986; Wee and Magazine, 1981) 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; Kumar, 2006;

Meloy and Soyster, 1990; Arcus, 1966; Lu and Zhao, 2008; Smith and Daskalki, 1988) and also some recent works by (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.Patterson and Albracht (1975) 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. Malakooti, (1990), 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 (Moodie and Young, 1965), 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.Moodie and Young (1965) 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. Malakooti (1990) 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. Kriengkorakot and Pianthong (2007) 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. 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 knownKottas 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.

3. Heuristics for the solution of assembly line balancing problems

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. The Heuristic approach bases on logic and common sense rather than on mathematical proof. Heuristics do not guarantee an optimal solution, but results in good feasible solutions which approach the true optimum. Most of the described Heuristic Solutions in literature are the ones designed for solving single assembly line balancing problems (SALBP). Moreover, most of them are based on simple priority rules (Constructive Methods) and generate one or a few feasible solutions. In the following section five different heuristics found in the literature are presented along with the required steps to obtain the solution are as follows:

Method 1: Ranked Positional Weight Method

The steps involved in the (Helgeson and Birnie, 1961) positional weight method are as follows:

1) Determine the positional weight (PW) for each task. (Time of the longest path from the beginning of the operation through the remainder of the network.)
2) Rank the work elements based on the PW. The work element with the highest PW is ranked first.
3) Proceed to assign work elements (tasks) to the workstations, where elements of the highest positional weight and rank are assigned first
4) If at any workstation additional time remains after assignment of an operation, assign the next succeeding ranked operation to the workstation, as long as the operation does not violate the precedence relationships, and the station times do not exceed the cycle time.
5) Repeat steps 3 and 4 until all elements are assigned to the workstations.

Method 2: Hoffmann (Precedence Matrix)

Hoffmann (1963) proposed an ALB algorithm using a precedence matrix. The procedure is described below:

1) Starting with station 1, a precedence feasible list of tasks is maintained from which the combination of tasks which will minimize station idle time is found via complete enumeration.
2) These tasks are assigned to station 1; the process continues with station 2 using an updated precedence feasible list. This procedure is repeated for each station in numerical order, until all tasks have been assigned.Hoffmann uses a special zero-one precedence matrix and Vector to implement the enumeration procedure. This is a square matrix, consisting of zeros and ones, in which the rows are labeled with consecutive element numbers and the columns are labeled in the same order. Entries in the matrix are as follow.

A. If the element of row i immediately precedes the element of column j, a 1 is placed in row i, column j. All other entries are zero. (Note that only immediate, 1>>3 relationships are stated explicitly. If 1>>3>>4 a one (1) is not entered in row 1, column 4.)

B. To use this matrix in generating all the feasible permutations, each column of the matrix is summed and these sums from another row adjoined to the bottom row of the matrix. The new row in the augmented matrix is termed a "code number". Next, the diagonal of the matrix is labeled with any arbitrary value (D).

C. This first code number, K_1, consists of α integers (α being the number of elements to be balanced), at least one of which is zero. The elements heading the columns, in which there are zeros in K_1, are candidates for the first position in the list of feasible permutations and only those elements can be candidates.

The scheme for generating the feasible combinations and balancing the line, station by station, is as follows:

1) Search left to right in the code number for a zero.
2) Select the element which heads the column in which zero is located.
3) Subtract the element's time from the cycle time remaining.
4) If the result is positive go to step 5.
5) 4a. If the result is negative go to step 6.
6) Subtract from the code number the row corresponding to the element selected and use this result as a new code number. Go to step 6.
7) Go to step 1 and start search one element to the right of the one just selected and repeat step 1- 6 until all the columns have been examined, then go to step 7.
8) Subtract the remaining cycle time (the slack time) from the slack time of the previous combination generated (If this is the first, then subtract from the cycle time).

9) If zero or negative go to step 4a. If positive, then this set of elements just generated becomes the new combination for this station. Go to step 10.
10) Go back one code number and go back to step 1 starting one element to the right of the element which had been selected from the code number. Repeat this procedure until the last column of the first code number has been tested; the result is that the last combination generated by step 8 is the one having the maximum elemental time for this station.
11) Replace the first code number with the last code number corresponding to the previous result. (This eliminates from further consideration the elements already selected.)
12) Repeat the previous steps until all the elements have been assigned. (Code number is entirely negative.)

Method 3: Immediate update first-fit (Maximum Task Time)

The immediate update first-fit (IUFF) heuristic was proposed by (Jackson, 1962). It depends on numerical score functions that have been proposed in the literature. The steps of the heuristic are as follows:

1) Assign a numerical score n(x) to each task x.
2) Update the set of available tasks (tasks whose immediate predecessors have been assigned).
3) Among the available tasks, assign the task with the highest numerical score to the first station in which the capacity and precedence constraints will not be violated. Go to step 2.

Method 4: Rank And Assign (Ra) Heuristic (Maximum Backward Recursive Positional Weight)

The rank-and-assign (RA) heuristic is similar to the IUFF heuristic, with the exception that the tasks are ranked from the highest to the lowest numerical score, and assignment of tasks to stations is based on this rank. We summaries the steps of the RA heuristic as follows:

1) Assign a numerical score to each task using the functions.
2) Rank tasks from the highest to the lowest numerical score.
3) Assign tasks successively to the first station in which both the precedence and capacity constraints are met.

Method 5: Incremental Utilization Technique

The Incremental Utilization Technique simply adds tasks to a workstation in order to task precedence one at a time until utilization is 100 percent or is observed to fall. Then this procedure is repeated at the next workstations for the remaining tasks. The incremental utilization heuristic is appropriate when one or more task times are equal to or greater than the cycle time.
An important advantage of this heuristic is that it is capable if solving line-balancing problems regardless of the length of task times relative of the cycle time. Under certain circumstances, this heuristic creates the need for extra tools and equipment. If the primary focus of the analysis is to minimize the number of workstations or if the tools and equipment used in the production line are either plentiful or inexpensive, this heuristic is appropriate (Chica*et al.*, 2011).

4. Performance measures

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.Four technical (objectives) criteria's have been used in the present article are developed on the basis of literature review and industrial survey. Table 1 is showing technical Objectives Criteria's, Optimization Type and Reference No. (Salveson, 1955).

Line Efficiency: Line Efficiency represents positive achievement in line utilization and is the key representation of economic performance.

$$LE = \frac{\sum t_i}{m \times CT} \times 100$$

Balance Delay: Balance Delay (Kumar, 2006) represents line inefficiency and has no mathematical connection to the 'balance' or evenness of work allocation. BD represents negative achievement in line utilization and is the key representation of uneconomic performance.

$$BD = \left(1 - \frac{\sum t_i}{m \times CT}\right) \times 100$$

Smoothness Index: Smoothness Index (Melloy and Soyster, 1990) is unfortunately dimensional and influenced by individual problem values, making inter problem comparison meaningless and raising a question on the interpretation of index values for individual results.

$$SI = \left[\left(\sum_{j=1}^{m} CT - S_j\right)^2\right]^{0.5}$$

Line Time: Time of the line (LT) describes the period of time which is need for the product to be completed on an assembly line.

CT (m-1) + Tm

where: Sj = Station j Task Time, CT= Cycle Time, m= No. of Workstations, Tm=Processing Time of Last Station

Table 1. Objectives (Criteria's) for the evaluation of assembly line balancing problems

S. No	Objectives (Criteria's)	Optimization	References/Sources
1.	Line Efficiency	Maximize Line Efficiency	(Gosh and Gargon, 1989; Malakooti and Kumar, 1996)
2.	Balance Delay	MinimizeBalance Delay	(Malakooti and Kumar, 1996; Malakooti, 1991; Kilbridge and Wester 1961)
3.	Smoothness Index	Maximize Smoothness Index	(Hamta *et al.*, 2011)
4.	Line Time	Minimize Line Time	(Hamta *et al.*, 2011)

5. MCDM approaches

5.1 Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a structured technique for helping people deal with complex decisions. It consists of an overall goal, a group of options or alternatives for reaching the goal, and a group of factors or criteria that relate the alternatives to the goal. In most cases the criteria are further broken down into sub criteria, sub-sub criteria, and so on, in as many levels as the problem requires (Figure 1). The hierarchy can be visualized as a diagram like the one below, with the goal at the top, the alternatives at the bottom, and the criteria filling up the middle.

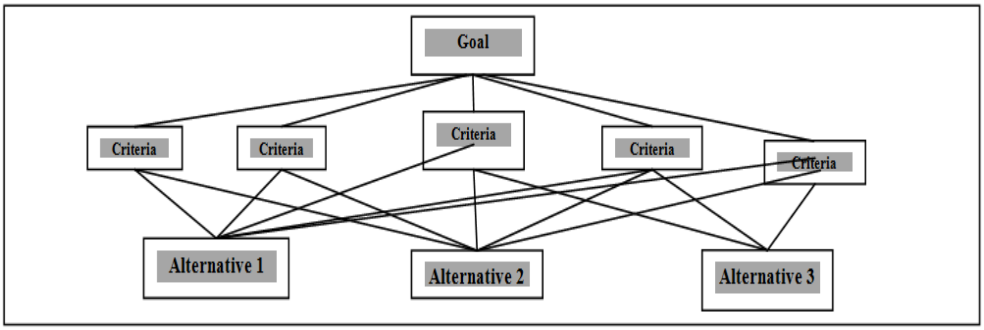

Figure 1. Hierarchical Structure for AHP (Hackman *et al.*, 1989; Saaty, 1990)

Once the hierarchy is built, the decision makers systematically evaluate its various elements, comparing them to one another in pairs. In making the comparisons, the decision makers can use concrete data about the elements, or they can use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations. For this purpose a pair wise comparison scale is used, which is shown in the Table.2 given below. After that AHP converts the evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. The priority of an attribute with respect to the ultimate goal is called Global Priority. The priorities indicate the relative weights given to the items in a given group of nodes. Depending on the problem at hand, *weight* can refer to importance, or preference, or likelihood, or whatever factor is being considered by the participants. This capability distinguishes the AHP from other decision making techniques. In the final step of the process, numerical priorities are derived for each of the decision alternatives. Since these numbers represent the alternatives' relative ability to achieve the decision goal, they allow a straightforward consideration of the various courses of action.

Table2. Pair Wise Comparison Scale (Saaty, 1990; Saaty, 1977; Kottas and Lua, 1973)

The Fundamental Scale for Pair wise Comparisons		
Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6 and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc., can be used for elements that are very close in importance.		

Saaty (1980, 1990) has defined the following steps for applying AHP.

1. Define the problem and determine its goal.
2. Structure the hierarchy with the decision maker's objective at the top with the intermediate levels capturing criteria on which subsequent levels depend and the bottom level containing the alternatives, and
3. Construct the set of n× n pair wise comparison matrices for each to the lower levels with one matrix for each element in the level immediately above. The pair wise comparisons are made suing the relative measurement scale (as discussed above). The pair wise comparisons capture a decision maker's perception of which element dominates the other.
4. There are n(n-1)/2 judgments required to develop the set of matrices in step 3. Reciprocals are automatically assigned in each pair wise comparison.
5. The hierarchy synthesis function is used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.
6. After all the pair wise comparisons are completed, the consistency of the comparisons is assessed by using the Eigen value, **λ**, to calculate a consistency index, CI:CI = (λ-n)/ (n-1)

where n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR).
CR = CI/RI; where RI = Random Consistency Index.

Random Consistency Index (RI) with the appropriate value in Table 3 is given below. Saaty (1980) suggests that the CR is acceptable if it does not exceed 0.10. If the CR is greater than 0.10, the judgment matrix should be considered inconsistent. To obtain a consistent matrix, the judgments should be reviewed and repeated.

Table.3 Average Random Consistency (Saaty, 1977; Saaty, 1990)

Matrix Size	1	2	3	4	5	6	7	8	9	10
Random Consistency Index	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Let n be the number of criterion and z_1, $z_2,\ldots,z_n$ be their corresponding relative priority given by a decision maker. Then the judgment matrix A which contains pair wise comparison value a_{ij} for all i, j ϵ {1, 2,…, n} is given by (1).

$$A=\begin{bmatrix} a11 & a12 \ldots & a1n \\ a21 & a22 \ldots & a2n \\ an1 & an2 \vdots & ann \vdots \end{bmatrix} = \begin{bmatrix} 1 & \frac{z1}{z2} \ldots & z1/zn \\ z2/z1 & 1 \ldots & z2/zn \\ zn/z1 & \frac{zn}{z2} \ldots & 1 \end{bmatrix} \quad (1)$$

For multiple decision makers, let h be the number of decision maker and a_{ijk} be the pair wise comparison Value of criteria I and j given by decision maker k, where k = 1,2,…,h. then by using geometric mean of the a_{ijk}conducted by each decision maker, we have a new judgment matrix with element given by (2).

$$A_{ij}=(a_{ij1}*a_{ij2}* \ldots a_{ijk}* \ldots a_{ijh})\ 1/h = (\prod h\ k\text{-}1 a_{ijk})\ 1/h \quad (2)$$

The basic procedure for AHP approach by the mean of normalized values method is given as follows:

1) Normalize each column to get a new judgment matrix A'

$$A' = \begin{bmatrix} a11' & a12' \dots & a1n' \\ a21' & a22' \dots & a2n' \\ an1' & an2' \dots & ann' \end{bmatrix} = \begin{bmatrix} \frac{a11}{\sum_{i=1}^{n} ai1} & \frac{a12}{\sum_{i=1}^{n} ai2 \dots} & a1n/\sum_{i=1}^{n} ain \\ \frac{a21}{\sum_{i=1}^{n} ai1} & \frac{a22}{\sum_{i=1}^{n} ai2 \dots} & a2n/\sum_{i=1}^{n} ain \\ \vdots & \vdots & \vdots \\ an1/\sum_{i=1}^{n} ai1 & \frac{an2}{\sum_{i=1}^{n} ai2} \dots & ann/\sum_{i=1}^{n} ain \end{bmatrix} \quad (3)$$

where $\sum_{i=1}^{n} aij$ is the sum of column j of judgment matrix A.

2) Sum up each row of normalized judgment matrix A' to get weight vector V.

$$V = \begin{bmatrix} v1 \\ v2 \\ vn \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{n} a1j' \\ \sum_{j=1}^{n} a2j' \\ \sum_{j=1}^{n} anj' \end{bmatrix} \quad (4)$$

3) Define the final normalization weight vector W.

$$W = \begin{bmatrix} w1 \\ w2 \\ wn \end{bmatrix} = \begin{bmatrix} v1/\sum_{i=1}^{n} vi \\ v2/\sum_{i=1}^{n} vi \\ vn/\sum_{i=1}^{n} vi \end{bmatrix} \quad (5)$$

5.2The TOPSIS Method

The technique for order preference by similarity to ideal solution (TOPSIS) (Jackson, 1962) is one of the well known classic MCDM methods. TOPSIS is a widely accepted multi- attribute decision- making technique due to its sound logic, simultaneously consideration of the ideal and the anti- ideal solutions, and easily programmable computation procedure. This technique is based on t he concept that the ideal alternative has the best level for all attributes, where as the negative ideal is the one with all of the worst attribute values.

The basic principle of TOPSIS is that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative ideal solution. The various J alternatives are denoted as A_1, A_2 ….A_J. For alternative A_J the rating of the i^{th} aspect is denoted by f_{ij}, f_{ij} is the value of i^{th} criterion function for alternative A_J; n is the no. of criterion. The TOPSIS procedure consists of the following steps:

Step 1: Calculate the normalized decision matrix.

$$r_{ij} = \frac{f_{ij}}{\sum_{j=1}^{J} f_{ij}^2} \text{ where } j = 1,2,3,\dots\dots\dots\dots J,\ i = 1, 2, 3 \dots n \quad (6)$$

Step 2: Calculate the weighted normalized decision matrix.

The weighted normalized value is calculated as:

$V_{ij} = w_{ij} \times r_{ij}$ (7)

where w_i is the weight of the i_{th} attribute or criterion, and it is calculated by AHP method.

$w_i = 1$ (8)

Step 3: Determine the ideal and negative-ideal solution.

$A^* = \{v_1^*, v_2^*, \ldots\ldots v_i^*\} = \{(\max v_{ij}/i \in I')_i.(\min v_{ij}/j \in I'')_j\}$ (9)

$A^- = \{v_1^-, v_2^-, \ldots\ldots v_i^-\} = \{(\min v_{ij}/i \in I')_i.(\max v_{ij}/j \in I'')_j\}$ (10)

Step 4: Calculate the separation measures, using the n dimensional Euclidean Distance.

The separation of each alternative from the ideal solution is given as:

$$D_j^* = \sqrt{\sum_{i=1}^{n} (vij - vi*)^2} \; ; \text{ where } j = 1, 2, 3\ldots\ldots J \quad (11)$$

Similarly, the separation from the negative ideal solution is given as:

$$D_j^- = \sqrt{\sum_{i=1}^{n} (vij - vi-)^2} \; ; \text{ where } j = 1, 2, 3..J \quad (12)$$

Step 5: Calculate the relative closeness to the ideal solution.

The relative closeness of the alternative a_j is defined as:

$$CC^*_j = \frac{Dj*}{Dj*+D_j-} \quad (13)$$

Step 6: Rank the preference order.

6. Methodology Adapted

6.1 Assembly Line Balancingproblem formulation

A benchmark single-model Assembly Line Balancing problem is considered named (Elsyaed, 1994). It consists of 11tasks and precedence diagram is drawn for the problem shown in figure2. Cycle time is as 1 min. and a precedence relationship is shown in table 3.

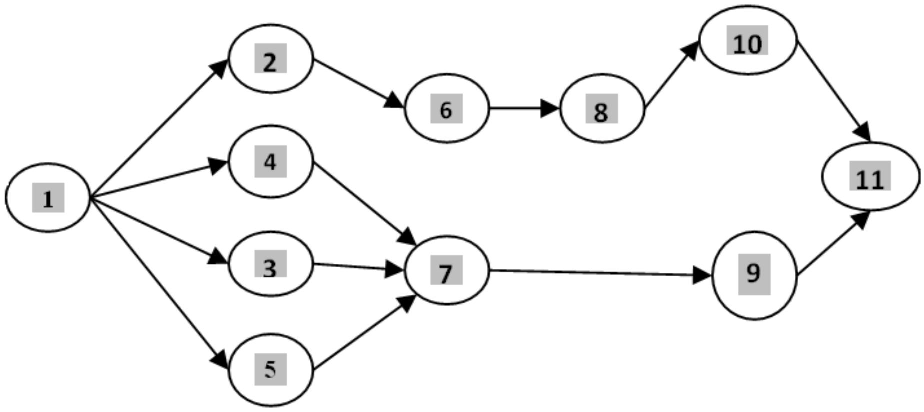

Figure 2. Precedence Diagram (Dar-El, 1964; Dar-El, 1973)

Table 3. Precedence relationship

Task No.	Task Time (sec.)	Precedence Relationship
1	6	-
2	2	1
3	5	1
4	7	1
5	1	1
6	2	2
7	3	3, 4, 5
8	6	6
9	5	7
10	5	8
11	4	9, 10

6.2 Computational results using the heuristic rules

Values of objectives (criteria's) for the evaluation of simple assembly line balancing problem is determined using heuristics as shown in table 4.

Table 4. Values of objectives (criteria's) for the heuristics

S. No	Heuristic Methods	Balance Delay (C_2)	Line Efficiency (C_1)	Line Time (C_4)	Smoothness Index (C_3)
1.	Ranked Positional Weight Method (RPWT)	0.3	80%	4	0.404
2.	Hoffmann's Precedence Matrix	0.3	80%	5	0.556
3.	Immediate Update First-Fit (IUFF)-Maximum Task Time	0.3	80%	3	0.591
4.	Rank And Assign (Ra) Heuristics- Maximum Backward Recursive Positional Weight	0.3	80%	2	0.404
5.	Incremental Utilization Technique	0.3	80%	3	0.544

6.3 Prioritization of assembly line balancing heuristics using MCDM approaches

We have considered the above mentioned performance measures shown in the Table.4 as criteria and assembly line balancing heuristics as alternatives for prioritization and for this purpose, a hierarchal model is constructed as shown in Figure 3 For the solution of above mentioned model a hybrid AHP-TOPSIS approach was proposed. The action plan is described below:

A. Analytical Hierarchy Process (AHP) calculations

In this approach, weights for different criteria were calculated using AHP software (super decision) and for evaluation of alternatives TOPSIS was used.

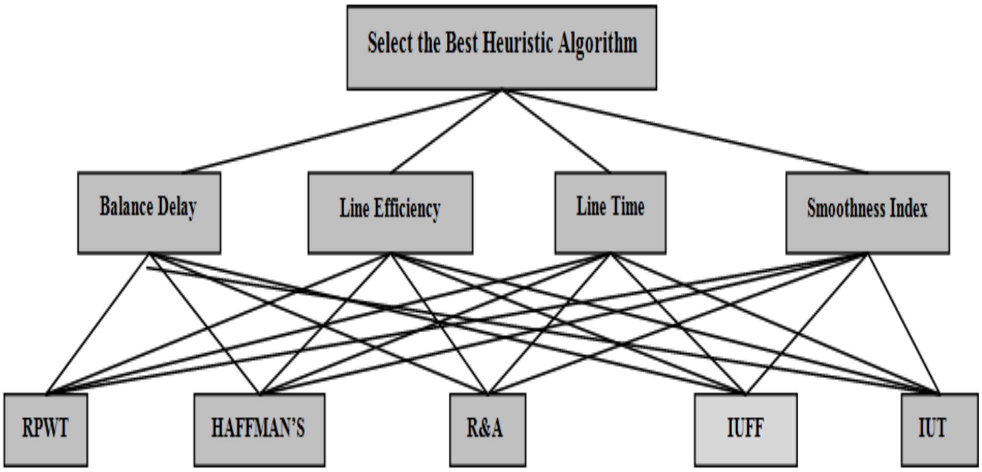

Figure 3. Hierarchical Structure for AHP (Saaty, 1977; Saaty, 1994)

Weights for different performance measures (criteria's) were calculated using AHP software (super decision) as shown in Figure 4.

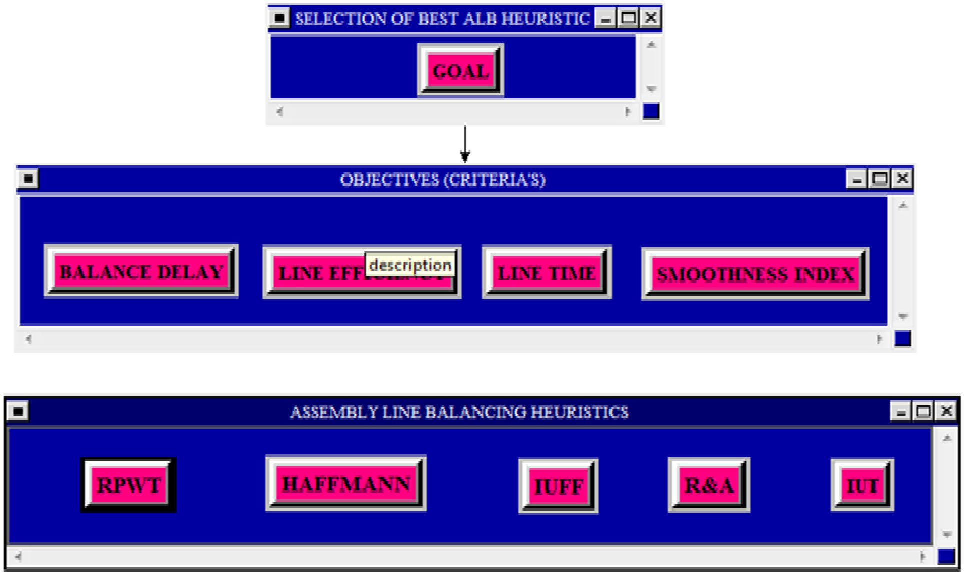

Figure 4. Hierarchical Structure for Super Decision Software

After creating hierarchical structure of the model, next step is to put the values of pair wise comparisons in the software which can be done as follows (please refer Figure 5).

Another common way is to directly put the values from questionnaire as follows (figure 6).

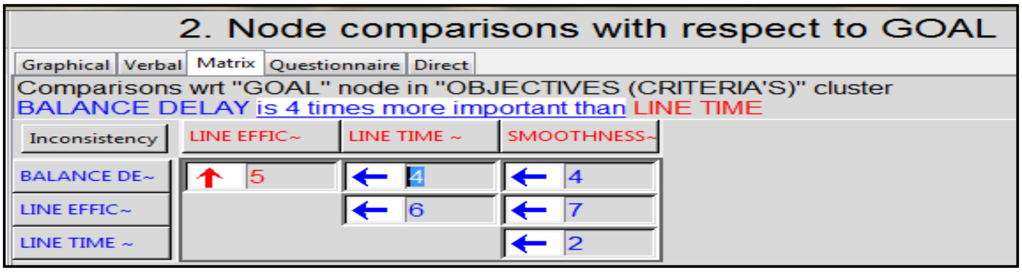

Figure 5. Matrix Form of Pair Wise Comparison

Figure 6. Priority values/Weights of criterion

B. Technique for order preference by similarity to ideal solutions (TOPSIS) method calculations:

The calculations of TOPSIS method is as follows:

Step1. Decision matrix for Alternatives

Construct normalized decision matrix. For this, determine the priority weights of objectives (criteria's) using AHP method as shown in the Table 11.

Now, Normalized score or data as follows: $r_{ij} = x_{ij} / (\Sigma x^2_{ij})^{1/2}$ for i= 1….m; j=1…….n.

Table11. Decision matrix for Alternatives

Weights	0.220	0.633	0.086	0.058
Objectives(Criteria's) → / Alternatives ↓	Line Efficiency (C_1)	Balance Delay (C_2)	Smoothness Index (C_3)	Line Time (C_4)
Ranked Positional Weight Method (RPWT) (A1)	5	6	8	5
Hoffmann's Precedence Matrix (A2)	6	7	7	7
Immediate Update First-Fit (IUFF)-Maximum Task Time) (A3)	7	6	6	6
Rank And Assign (Ra) Heuristic- Maximum Backward Recursive Positional Weight (A4)	6	5	7	7
Incremental Utilization Technique (A5)	5	8	6	8

Step 2. Calculations of decision matrix (Table 12)

Table 12. Calculations of decision matrix

Alternatives ↓ / Objectives(Criteria's) →	Line Efficiency (C_1)	Balance Delay (C_2)	Smoothness Index (C_3)	Line Time (C_4)
Ranked Positional Weight Method (RPWT) (A1)	0.08	0.262	0.044	0.019
Hoffmann's Precedence Matrix (A2)	0.100	0.305	0.039	0.027
Immediate Update First-Fit (IUFF)-Maximum Task Time) (A3)	0.117	0.262	0.033	0.023
Rank And Assign (Ra) Heuristic- Maximum Backward Recursive Positional Weight (A4)	0.100	0.218	0.039	0.027
Incremental Utilization Technique (A5)	0.08	0.349	0.033	0.031

Step 3. Normalized matrix for alternatives (Table 13)

Table 13. Normalized matrix for alternatives

Weights	0.220	0.633	0.086	0.058
Alternatives ↓ / Objectives(Criteria's) →	Line Efficiency (C_1)	Balance Delay (C_2)	Smoothness Index (C_3)	Line Time (C_4)
Ranked Positional Weight Method (RPWT) (A1)	25	36	64	25
Hoffmann's Precedence Matrix (A2)	36	49	49	49
Immediate Update First-Fit (IUFF)-Maximum Task Time) (A3)	49	36	36	36
Rank And Assign (Ra) Heuristic- Maximum Backward Recursive Positional Weight (A4)	36	25	49	49
Incremental Utilization Technique (A5)	25	64	36	64
Σx^2_{ij}	171	210	234	223
$(\Sigma x^2_{ij})^{1/2}$	13.07	14.49	15.29	14.93

Step 4. Weighted normalized decision matrix (Table 14) Multiply each column of the normalized decision matrix by its associated weight. An element of the new matrix is : $V_{ij}=W_j*r_{ij}$

Table 14. Weighted normalized decision matrix

Objectives (Criteria's) → / Alternatives ↓	Line Efficiency (C_1)	Balance Delay (C_2)	Smoothness Index (C_3)	Line Time (C_4)	$[\Sigma (V_i^*-V_{ii})^2]$	$S_i^*=[\Sigma (V_i^*-V_{ii})^2]^{1/2}$
(A1)	$(0.08-0.117)^2$	$(0.262-0.349)^2$	$(0.044-0.044)^2$	$(0.019-0.031)^2$	**0.009082**	**0.0952**
(A2)	$(0.100-0.117)^2$	$(0.305-0.349)^2$	$(0.039-0.044)^2$	$(0.027-0.031)^2$	**0.002266**	**0.0476**
(A3)	$(0.117-0.117)^2$	$(0.262-0.349)^2$	$(0.033-0.044)^2$	$(0.023-0.031)^2$	**0.007754**	**0.0880**
(A4)	$(0.100-0.117)^2$	$(0.218-0.349)^2$	$(0.039-0.044)^2$	$(0.027-0.031)^2$	**0.017491**	**0.1322**
(A5)	$(0.08-0.117)^2$	$(0.349-0.349)^2$	$(0.033-0.044)^2$	$(0.031-0.031)^2$	**0.00149**	**0.0386**

Step 5. Separation from the ideal alternatives

Now ideal solution **A^*= {0.117, 0.349, 0.044, 0.031}**

And Negative ideal solution **A'= {0.08, 0.218, 0.033, 0.019}** Now Calculate $S_i^* = [\Sigma (V_j^* - V_{ij})^2]^{1/2}$ for each row (Table 15).

Table15. Separation from the ideal alternatives

Weights	0.220	0.633	0.086	0.058
Objectives (Criteria's) → / Alternatives ↓	Line Efficiency (C_1)	Balance Delay (C_2)	Smoothness Index (C_3)	Line Time (C_4)
Ranked Positional Weight Method (RPWT) (A1)	0.383	0.414	0.523	0.335
Hoffmann's Precedence Matrix(A2)	0.459	0.483	0.457	0.469
Immediate Update First-Fit (IUFF)-Maximum Task Time) (A3)	0.536	0.414	0.392	0.402
Rank And Assign (Ra) Heuristic- Maximum Backward Recursive Positional Weight (A4)	0.459	0.345	0.457	0.469
Incremental Utilization Technique (A5)	0.383	0.552	0.392	0.536

Step 6. Separation from the negative ideal alternatives

Now Calculate $S_i' = [\Sigma (V_j' - V_{ij})^2]^{1/2}$ for each row (Table 16).

Table 16. Separation from the negative ideal alternatives

Alternatives	S_i' / (S_i^*+S_i')	C_i^*	Remarks
Ranked Positional Weight Method (RPWT) (A1)	0.04535/(0.0952 +0.04535)	0.3226	
Hoffmann's Precedence Matrix (A2)	0.08982/(0.0476+0.08982)	0.6536	
Immediate Update First-Fit (IUFF)-Maximum Task Time) (A3)	0.05762/(0.0880+0.05762)	0.3956	
Rank And Assign (Ra) Heuristic- Maximum Backward Recursive Positional Weight (A4)	0.02236/(0.1322+0.02236)	0.1446	
Incremental Utilization Technique (A5)	0.13154/(0.0386+0.13154)	0.7731	←

Step 7. Relative closeness to the ideal solution (Table 17).

Now calculate the relative closeness to the ideal solution **$C_i = S_i / (S_i^* + S_i')$**

Table 17. Relative closeness to the ideal solution

Objectives (Criteria's) → / Alternatives ↓	Line Efficiency (C_1)	Balance Delay (C_2)	Smoothness Index (C_3)	Line Time (C_4)	$[\Sigma (V_j' - V_{ij})^2]$	$S_i' = [\Sigma (V_j' - V_{ij})^2]^{1/2}$
(A1)	$(0.08-0.08)^2$	$(0.262-0.218)^2$	$(0.044-0.033)^2$	$(0.019-0.019)^2$	0.002057	0.04535
(A2)	$(0.100-0.08)^2$	$(0.305-0.218)^2$	$(0.039-0.033)^2$	$(0.027-0.019)^2$	0.008069	0.08982
(A3)	$(0.117-0.08)^2$	$(0.262-0.218)^2$	$(0.033-0.033)^2$	$(0.023-0.019)^2$	0.003321	0.05762
(A4)	$(0.100-0.08)^2$	$(0.218-0.218)^2$	$(0.039-0.033)^2$	$(0.027-0.019)^2$	0.0005	0.02236
(A5)	$(0.08-0.08)^2$	$(0.349-0.218)^2$	$(0.033-0.033)^2$	$(0.031-0.019)^2$	0.017305	0.13154

7. Result

Thus, the best assembly line balancing heuristic among the five given heuristics is Incremental Utilization Technique for the solution of simple assembly line balancing problem. Result of above analysis suggests *Incremental Utilization Technique* as the best assembly line balancing heuristic. As its relative closeness to the ideal solution is 0.7731, after that *Hoffmann's Precedence Matrix*is suggested as second alternative with relative closeness to the ideal solution of 0.6536 respectively.

8. Conclusion and scope for the future research

In practice, measuring total profit for a given assembly line balancing (ALB) problem is an involved process that is sometimes impossible because of much uncertainty and unavailability of data. In this paper, a combined AHP-TOPSIS approach has been proposed to evaluate and prioritize assembly line problem. Considering heuristics as alternatives and the various performance measures as criteria. The AHP is a popular method for tackling MCDM problems involving quantitative and qualitative criteria, and has successfully been applied to many actual decision making situations so far. Therefore, to exploit the advantages of this method, we considered quantitative criteria Balance *Delay, Balance Efficiency, Line Efficiency and Smoothness Index.* To generate assembly line balancing solutions five heuristics are used. An illustrative example explains the effectiveness of the proposed methodology. In the future researches, this approach could be developed towards considering both of quantitative and qualitative criteria. This approach could be used for all type of assembly line problems and for various types of layouts, especially; a real case-study indicates the effectiveness of the existing framework raises the value of this research in the future.

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