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AN AHP APPROACH FOR COMPARAING MULTI CRITERIA ASSEMBLY LINE BALANCING HEURISTICS

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ABSTRACT

Assembly line balancing often has significant impact on performance of manufacturing systems, and is usually a multiple-objective problem. The focus of this paper has been on Simple Assembly Line Balancing Problem (SALBP). In this paper, Assembly Line Balancing (ALB) is formulated as a multiple criteria problem where several easily quantifiable criteria (objectives) and constraints are defined. Objective criteria include Number of stations; Line Efficiency, Smoothness Index, and Line Time are calculated by using five Immediate Update First Fit (IUFF) heuristics.. Basic definitions and properties of Multi Criteria Decision Making (MCDM) for ALB are outlined and then an interactive MCDM approach Analytical Hierarchy Process (AHP) is developed for solving the Multi Criteria-ALB problem. An example is solved and computational experiments are reported. The motivation for development of the method, based on a case study of Assembly Process of ABS Motor is discussed.

KEYWORDS: Simple Assembly Line Balancing (SALB), Analytical Hierarchy Process (AHP), Pair wise Comparison Scale, Smoothness Index

INTRODUCTION

Definition of Assembly Line Balancing (ALB)

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. The fundamental of line balancing problems is to assign the tasks to an ordered sequence of stations, such that the precedence relations are satisfied and some measurements of effectiveness are optimized. Figure 1 shows the schematic arrangements of a simple assembly line with workstations.

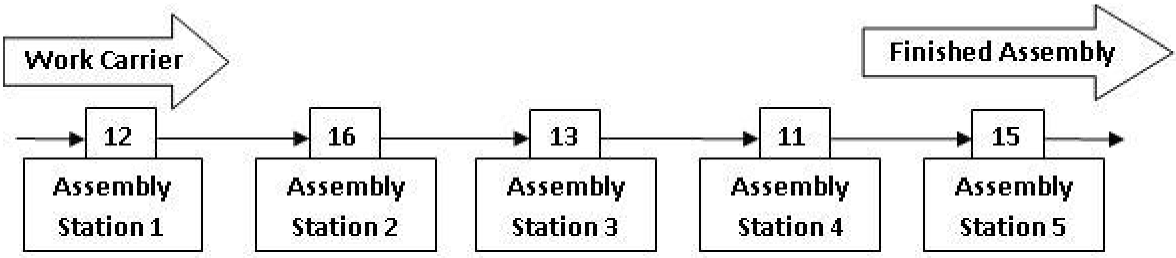


Figure1: A Typical Assembly Line with Few Work Stations (Becker, C. & Scholl, A. 2006)

An assembly line consists of work stations $k = 1\ldots m$ usually arranged along a conveyor belt or a similar material handling equipment. The jobs are consecutively launched down the line and are moved from station to station. At each station, certain operations are repeatedly performed regarding the cycle time. In general, the line balancing problem consists of optimally balancing the assembly work among all stations with respect to some objective. For this purpose, the total amount of work necessary to assemble a work piece (job) is split up into a set V = {1… n} of elementary operations named tasks. Performing a task j takes a task time t_j and requires certain equipment of machines and/or skills of workers. The total workload necessary for assembling.

A work piece is measured by the sum of task time's Σt. These elements can be summarized by a precedence diagram. It contains a node for each task, node weights for the task times, arcs the direct and paths for the indirect precedence constraints. Figure 2 shows a precedence diagram with n = 9 tasks having task times between 2-9 in time unit.

A feasible line balance, i.e. an assignment of tasks to stations has to ensure that no precedence relation

ship is violated. The set S_k of tasks assigned to a station k constitutes its station load or work content, the cumulated task time $t\ (S_k) = \Sigma j \in S_k\ j\ t$ is called station time. When a fixed cycle time **c** is given (paced line), a line balance is feasible only if the station time of neither station exceeds c. In case of $\mathbf{t\ (S_k) < c}$, the station k has an idle time of $\mathbf{c - t(S_k)}$ time unit in each cycle.

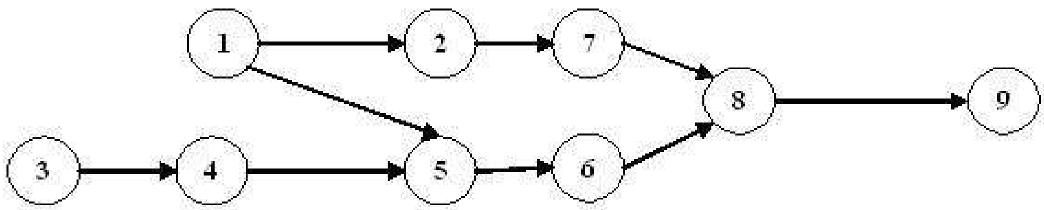
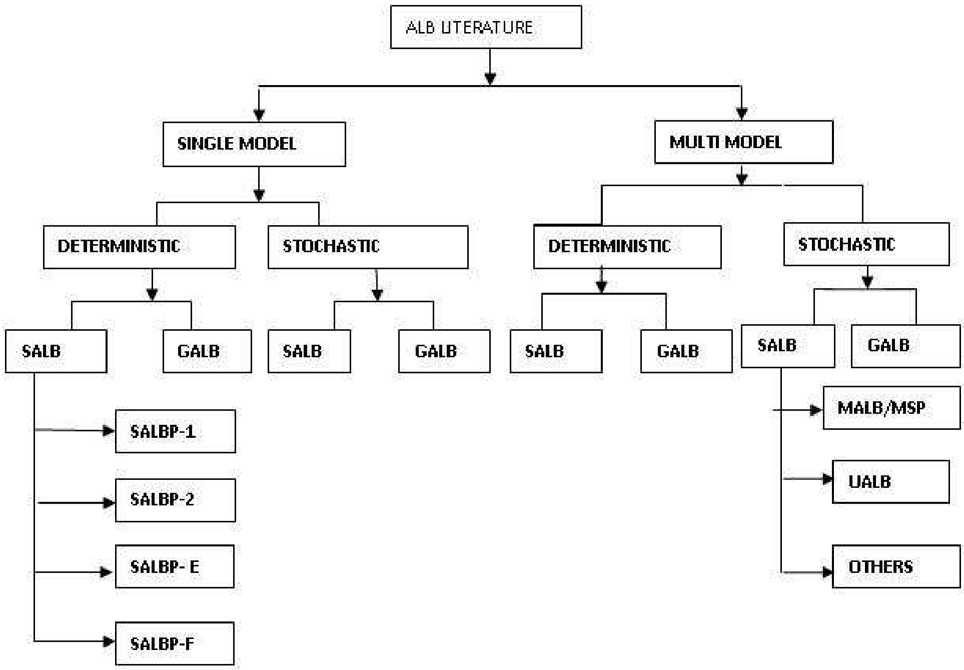


Figure 2: Precedence Graph (Becker,C. & Scholl, A. 2006)



Classification of Assembly Line Balancing Problem

Figure 3: Classification of Assembly Line Balancing Problem (Becker, C. & Scholl, A. 2006) (ALBP)

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

(1) Single Model Deterministic (SMD) (2) Single Model stochastic (SMS)

(3) Multi/Mixed Model Deterministic (MMD) (4) Multi/Mixed Model stochastic (MMS)

Ghosh and Gagnon (1989) classified the ALBP into four categories; as shown in figure 3:

The **SMD** version of the ALB problem assumes dedicated, single model assembly lines where the task times are known deterministically and an efficiency criterion is to be optimized. This is the original and simplest form of the assembly line balancing problem (SALB). Introduce other restrictions or factors (e.g. parallel stations, zoning restrictions) into the model and the problem becomes the General Assembly Line Balancing Problem (GALB)The **SMS** problem category introduces the concept of task-time variability. This is more realistic for manual assembly lines, where workers' operation times are seldom constant. With the introduction of stochastic task times many other issues become relevant, such as station times exceeding the cycle time (and perhaps the production of defective or unfinished parts), pacing effects on workers' operation times, station lengths, the size and location of inventory buffers, launch rates and allocation of line imbalances.

The **MMD** problem formulation assumes deterministic task times, but introduces the concept of an assembly line producing multiple products. Multi-model lines assemble two or more products separately in batches. In mixed-model lines single units of different models can be introduced in any order or mix to the line. Multi-mixed model lines introduce various issues that are not present in the single-model case. Model selection, model sequencing and launching rate(s) and model lot sizes become more critical issues here than in the single model case. The **MMS** problem perspective differs from its MMD counterpart in that stochastic times are allowed. However, these issues become more complex for the MMS problem because factors such as learning effects, worker skill level, and job design and worker task time variability become more difficult to analyze because the line is frequently rebalanced for each model assembled. **Becker and Scholl (2006):** They have classified the main characteristics of assembly line balancing problems considered in their several constraints and different objectives as shown in Figure 4. **SALB:** The simple assembly line balancing problem is relevant for straight single product Assembly lines where only precedence constraints between tasks are considered (for a survey see Scholl and Becker, 2006)**Type 1** (SALB-1) of this problem consists of assigning tasks to work stations such that the number of stations *(m)* is minimized for a given production rate (fixed cycle time, *c*).

Type 2 (SALBP-2) is to minimize cycle time (maximize the production rate) for a given number of stations *(m).***Type E** (SALBP-E) is the most general problem version maximizing the line efficiency *(E)* thereby simultaneously minimizing *c* and *m* considering their interrelationship. **Type F** (SALBP-F) is a feasibility problem which is to establish whether or not a feasible line balance exists for a given combination of *m* and *c*. **GALBP:** In the literature, all problem types which generalize or remove some assumptions of SALBP are called generalized assembly line balancing problems (GALBP). This class of problems (including UALBP and MALBP) is very large and contains all problem extensions that might be relevant in practice including equipment selection, processing alternatives, assignment restrictions etc. (for a survey see Becker and Scholl, 2006).- MALBP and MSP : Mixed model assembly lines produce several models of a basic product in an intermixed sequence. Besides the mixed model assembly line balancing problem (MALBP), which has to assign tasks to stations considering the different task times for the different models and find a number of stations and a

SALBP are called generalized assembly line balancing problems (GALBP). This class of problems (including UALBP and MALBP) is very large and contains all problem extensions that might be relevant in practice including equipment selection, processing alternatives, assignment restrictions etc. (for a survey see Becker and Scholl, 2006).

MALBP & MS

Mixed model assembly lines produce several models of a basic product in an Inter mixed sequence. Besides the mixed model assembly line balancing problem (MALBP), which has to assign tasks to stations considering the different task times for the different models and find a number of stations and a1999, Chapter 3.2.2). However, the problem is more difficult than in the single-model case, because the station times of the different models have to be smoothed for each station (horizontal balancing; cf. Merengo et al., 1999).

The better this horizontal balancing works, the better solutions are possible in the connected short-term mixed model sequencing problem (MSP). MSP has to find a sequence of all model units to be produced such that inefficiencies (work overload, line stoppage, off-line repair etc.) are minimized.(e.g. Bard et al., 1992 and Scholl et al., 1998)

UALBP: The U-line balancing problem (UALBP) considers the case of U-shaped (single product) assembly lines, where stations are arranged within a narrow U. As a consequence, worker 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. By analogy with SALBP, different problem types can be distinguished. (cf. Miltenburg and Wijngaard, 1994; Urban, 1998; Scholl and Klein, 1999; Erel et al., 2001)

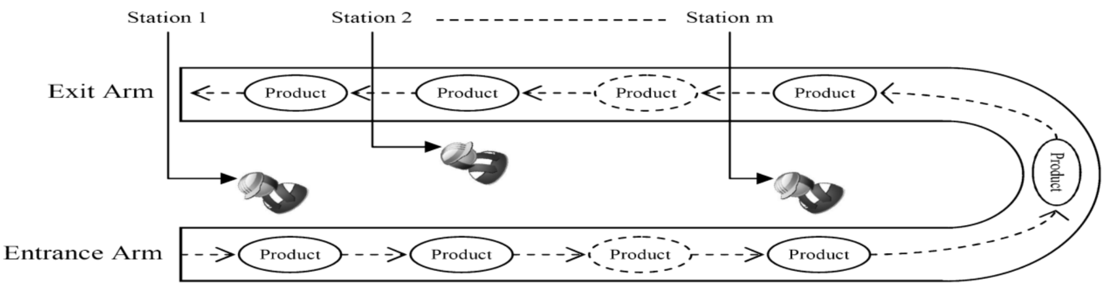


Figure 4: U-Assembly Line Balancing (Boysen, N., Fliendner, M. & Scholl , A. (2006))

ASSEMBLY LINE BALANCING HEURISTICS

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.

Simple Assembly Line Balancing Methods

Most of the described Heuristic Solutions in literature are the ones designed for solving Single Assembly Line Balancing Problems. Moreover, most of them are based on simple priority rules (Constructive Methods) and generate one or a few feasible solutions. Task oriented procedures choose the highest priority tasks from the list of available tasks and assign it to the earliest station which is assignable. Among the task oriented procedures we can distinguish Immediate – Update- First - Fit (IUFF) and General- First –Fit Methods depending upon whether the set of available task is updated immediately after assigning a task or after the assigning of all currently available tasks.

Due to its greater flexibility immediate update first fit method is used more frequently. The main idea behind this heuristic is assigning tasks to stations basing on the numerical score. There are several ways to determine (calculate) the score for each tasks. One could easily create his own way of determining his score, but it is not obvious if it yields good result. In the following section five different methods found in the literature are presented along with the solution they five for our simple example. The methods are implemented in the line balancing problem as well. There is no difference in the execution of methods and the required steps to obtain the solution are as follows:

STEP 1: Assign a numerical score n (x) to each task.

STEP 2: Update the set of available tasks (those whose immediate predecessors have been already assigned).

STEP 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 the STEP 2.The most popular Heuristic which belongs to IUFF group are:

IUFF- RPW: Immediate Update First Fit – Ranked Position Weight,

IUFF- NOF: Immediate Update First Fit – Number of Followers,

IUFF- NOIF: Immediate Update First Fit –Number of Immediate Followers,

IUFF- NOP: Immediate Update First Fit – Number of Predecessors,

IUFF- WET: Immediate Update First Fit – Work Element Time.

Objective Criteria for the Comparative Analysis of ALB Heuristics

Finally, the optimization of ALB will be guided by some objective which evaluates solutions. In the case of multi-objective optimization more than a single objective can be selected various technical and economic objective criteria have been used in the ALB literature, as can be seen in Table 1. In this research, the objective criterion has been developed on the basis of literature review.

Table 1: Objective Criteria for the Comparative Analysis of ALB Heuristics

S. No	Objective Criteria	References
1	Number of work stations	Ghosh and Gagnon,1989; Malakooti B, 1991
2	Line Efficiency	Malakooti,1991,1994;Malakooti and Kumar, 1996; Gok-cen and Agpak,2006
3	Smoothness Index	Kriengkorakot Nuchsara and Piathong Nalin,2007
4	Line Time	Kriengkorakot Nuchsara and Piathong Nalin,2007

ANALYTICAL HIERARCHY PROCESS (AHP)

The Analytic Hierarchy Process (AHP) is a structured technique for helping people deal with complex decisions. Rather than prescribing a "correct" decision, the AHP helps people to determine one. An AHP hierarchy is a structured means of describing the problem at hand. 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 6).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. In such diagrams, each box is called a node. The boxes descending from any node are called its children. The node from which a child node descends is called its parent. Applying these definitions to the diagram below, the five Criteria are children of the Goal, and the Goal is the parent of each of the five Criteria. Each Alternative is the child of each of the Criteria, and each Criterion is the parent of three Alternatives (T. L Saaty, 1990, 1994).

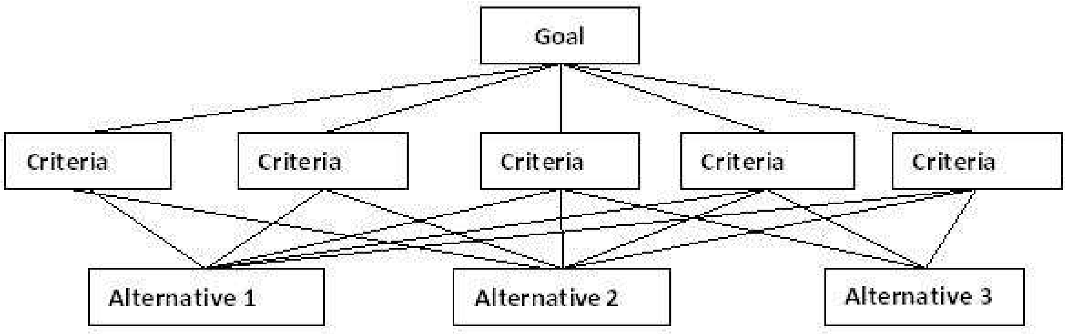


Figure 5: Hierarchical Structure for AHP (T. L Saaty, 1977 & 1994)

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. Priorities are numbers associated with the nodes of the hierarchy.

The priority of the Goal is taken as 1.000. The priorities of the children of any Criterion can also vary but will always add up to 1.000, as will those of their own children, and so on down the hierarchy. If the priorities within every group of child nodes are equal then the priorities are called Default Priorities. 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 (T. L Saaty, 1977, 1980 & P. Kumar, 2006)

The Fundamental Scale for Pair wise Comparisons		
Intensity of Importance	**Definition**	**Explanation**

Table 2: Contd.,

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 (1990 & 1994) has defined the following steps for applying AHP

- Define the problem and determine its goal,
- 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
- 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.
- 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.
- 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.
- 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 = $(\lambda\text{-n})/(\text{n-1})$.

Where n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value in table 3, 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 Index

Size of Matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

CASE STUDY

Analysis of Assembly Process of ABS Motor (Ponnambalam, S.G., Aravindan, P. & Naidu, G.M. ,1999**)**

Assembly process of ABS Motors Ltd is made up of a number of 34 units process; they can be combined into 12 processes like Table3.The number of tasks, precedence graphs (figure 5.), and task times are known and are given in the

Table. The cycle time is 10.

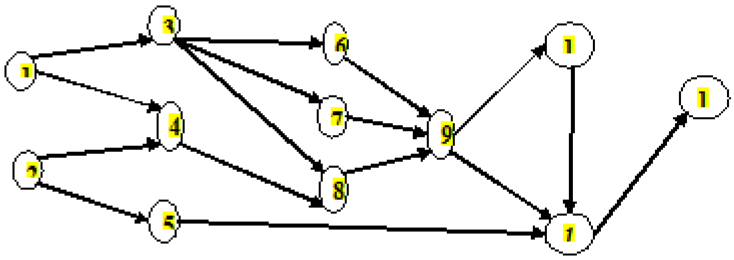


Figure 6: Precedence Diagram(Ponnambalam, S.G., Aravindan, P.& Naidu,G.M.,1999)

Table 4: Assembly process of ABS Motor

c	Assembly Process	Duration (sec)
1.	Grease Application, Air supply ,O-ring insertion	15
2.	Magnet holder assembly	12
3.	Holder insertion to yoke	8
4.	Bearing insertion to yoke	8
5.	Armature & Bearing insertion	15
6.	Pig tail control, air supply	10
7.	Silicon application ,yoke insertion	14
8.	Grommet insertion	28
9.	Bolting of brush holder	10
10.	Bolting of yoke	10
11.	Spring insertion to brush holder	34
12.	Magnetization of magnet	15

Table 5: Results of IUFF Heuristic Methods

S. No	Heiuristic Methods	C_1	C_2	C_3	C_4	C_5
1.	Ranked Positional Weight Technique (RPWT)	5	S1-1,3,2	86	5,4	45
			S2-6,4,8			
			S3-7,9			
			S4-10,5			
			S5-11,12			
2.	Number of Followers (NOF)	5	S1-1,3,2	86	5,4	45
			S2-6,4,8			
			S3-7,9			
			S4-10,5			
			S5-11,12			
3.	Number of Immediate Followers (NOIF)	6	S1-1,2,3	71.7		52
			S2-5,4,7,8			
			S3-6			
			S4-9			
			S5-10,11			
			S6-12			
4.	Number of Predecessors (NOP)	6	S1-1,2,3	71.7	9,53	52
			S2-5,4,7,8			
			S3-6			
			S4-9			

			S5-10,11 S6-12			
5.	Work Element Time (WET)	6	S1-2,5,1 S2-3,6 S3-4,7,8 S4-9 S5-10,11 S6-12	71.7	9,33	52
Where, C1= Work Stations;C2 = Work Stations (Balance) C3= Line Efficiency (%); C4 = Smoothness Index, and C5= Line Time						

AHP-ALB MODEL FORMULATION

By using AHP software we will get the following priorities:

Table 6: Priority Values

CRITERIA	PRIORITY VALUES
Number of work stations/C1	**0.499667**
Line Efficiency/C2	**0.0670776**
Smoothness Index/C3	**0.298094**
Line Time/C4	**0.135161**

MaximumEigenValue=4.27249 C.I. =0.0908288

Table 7: Selection of Best Assembly Line Heuristic

SELECTION OF BEST ASSEMBLY LINE HEURISTIC – AN AHP APPROACH					
ALB TECHNIQUES	**NO. OF WORK STATIONS**	**LINE EFICIENCY**	**SMOOTHNESS INDEX**	**LINE TIME**	**TOTAL**
Ranked Positional Weight Technique/M1	0.25435	0.144	0.0785	0.028924	0.505862
Number of Followers /M2	0.075939	0.081	0.0472	0.011755	0.216149
Number of Immediate Followers/M3	0.049855	0.051	0.0472	0.008494	0.156876
Number of Precedessors/M4	0.032575	0.023	0.0139	0.003839	0.0738222
Work Element Time/M5	0.032807	0.018	0.0119	0.002851	0.0659401
Total	**0.445292**	**0.3186**	**0.18023**	**0.0558645**	**1**
	1				

RESULTS & DISCUSSIONS

On the basis of **Table 7,** we can find that the total sum of priorities is maximum for the Ranked Positional Weight Technique. Therefore, we can recommend the RPWT method for selection. The second best option may be Number of Followers Technique, which has scored the total sum of priorities is equal to 0.216, and other than these, the available alternatives are prioritize as NOIF, NOP and WET techniques respectively depending upon the priority values.

CONCLUSIONS

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, ALB is formulated as a multiple criteria problem where several easily quantifiable criteria (objectives) and constraints are defined. In this research paper, the example focuses on the Multi Criteria Decision Making approach for the Assembly Line Balancing problem. Example shows the suitability of the AHP technique for the ALB problem. Yet there the extensive research in the field of criteria selection and application of MCDM analysis is still awaited.

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