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An Empirical Investigation of Assembly Line Balancing Techniques and Optimized Implementation Approach for Efficiency Improvements

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Dalgobind Mahto [α], Anjani Kumar [σ]

Abstract - The concept of mass production essentially involves the assembly of identical or interchangeable parts of components into the final product at different stages and workstations. The relative advantages and disadvantages of mass or flow production are a matter of concern for any mass production industry. How to design an assembly line starting from the work breakdown structure to the final grouping of tasks at work stations has been discussed in this paper using two commonly used procedures namely the Kilbridge-Wester Heuristic approach and the Helgeson-Birnie Approach. Line Balancing (LB) is a classic, well-researched Operations Research (OR) optimization problem of significant industrial importance. The specific objectives of this paper is to optimize 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 results obtained are compared with those of single-objective approaches.

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I. Introduction

Recently some of the most successful business corporations seem to have hit upon an incredible solution: Line Balancing. Line Balancing is a classic Operations Research optimization technique which has significant industrial importance in lean system. The concept of mass production essentially involves the Line Balancing in assembly of identical or interchangeable parts or components into the final product in various stages at different workstations. With the improvement in knowledge, the refinement in the application of line balancing procedure is also a must.

This reproof gives the methodology of application of line balancing in an ABC company, where four areas were selected as a sampling to study and implement line balancing. The four areas are Feeder frame assembly, Base frame assembly, Revolving vibratory feeder, and Gear housing. The characteristics of the relevant departments of ABC Company are studied and with the purpose of reducing assembly time and hence cost, this assignment has been undertaken. The assembly machines are selected and then the layout of the selected facilities has been performed. Task allocation of each worker was achieved by assembly line balancing to increase an assembly efficiency and productivity.

II. Formulation of Assembly Line-Balancing Problem

The Assembly line balancing is generally a problem of minimizing the total amount of idle time or equivalently minimizing the no of operators to do given amount of work at a given assembly line speed. This is also known as minimizing balance delay. Balance delay is defined as the amount of idle time for the entire assembly line as a fraction of total working time resulting from unequal task time assigned to the various stations. Mathematically, this objective can be stated as follows:

$$\min \sum_{J=1}^{R} w_j \text{ Subject to } t_j \leq C \; wj \text{ for } j = 1\ldots..R \quad (1)$$

Where,

- R is the number of work centers,
- W is the (integer-adjusted) number of required workers in work centre j,
- t_j is the estimated time required to complete the tasks in work centre j, and
- C is the pre specified cycle time.

In short, with the traditional assembly line-balancing problem, it is desirable to place minimum number of workers, as far as possible, to each work centers, at the same time one should also adhere to the policy that no worker is 'overloaded'.

III. Or Characterization of Line Balancing

The OR definition of the line balancing problem was christened by Becker and Scholl [2,3] as SALBP, which stands for Simple Assembly Line Balancing

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Problem. SALBP is defined as follows, “Given a set of tasks of various durations, a set of precedence constraints among the tasks, and a set of workstations, assigns each task to exactly one workstation in such a way that no precedence constraint is violated and the assignment is optimal”. The optimality criterion gives rise to two variants of the problem: either a cycle time is given that cannot be exceeded by the sum of durations of all tasks assigned to any workstation and the number of workstations is to be minimized, or the number of workstations is fixed and the line cycle time, equal to the largest sum of durations of task assigned to a workstation, is to be minimized. Becker and Scholl [2, 3] define many extensions to SALBP. One of the extensions is GALBP, which stands for Generalized Assembly Line Balancing Problem. Each of the extensions reported in their authoritative survey aims to handle an additional difficulty present in real-world line balancing. The real-world line balancing, as faced in particular by the automotive industry, requires tackling many of those generalizations, simultaneously.

IV. Aims and Objectives of the Present Study

The aims and objectives of the present study are as follows

- To minimize the total amount of idle time and equivalently minimizing the number of operators to do a given amount of work at a given assembly line speed
- To optimize the production functions through construction of mix form of automation assembly and manual assembly.
- To classify the whole assembly process into each unit and decide the automation possibility of each process, and if, automation assembly is not possible, decide criteria for manual assembly.
- To determine machinery and equipment according to assembly mechanism.

V. Literature Review

According to Becker and Scholl [1,2] and Scholl and Becker [3] the earliest forms of the presented problem, along with the more modern research efforts, have typically concentrated on the minimization of workers needed to staff a line while adhering to task precedence and cycle time restrictions. In short, with the traditional assembly line-balancing problem, it is desirable to place workers in work centres in such a way that as few workers as possible as used, while simultaneously adhering to the policy that no single worker can be ‘overloaded’. Askin and Zhou [4] have explained that with line balancing the objectives of system utilization could be met. Gocken and Erel [5,6] expressed the similar views. Vilarinho and Simaria[7]gave the mathematical solution about the probability of jobs being completed within a desired time frame. Merengo et al [8], have addressed the issue of system design cost. Askin and Zhou [4], Rekiek et al. [9], Bukchin and Rubinovitz [10] and Ponnambalam et al. [11], have proposed and concluded that evenness of workload assignments is pre requisite for line balancing. Either a cycle time is given that cannot be exceeded by the sum of durations of all tasks assigned to any workstation and the number of workstations is to be minimized or the number of workstations is fixed. The line cycle time, equal to the largest sum of durations of task assigned to a workstation, is to be minimized. Falkenauer and Delchambre [12], Salveson [13] provided the first mathematical attempt by solving the problem as a linear program.

It has been seen from the literatures [14] that assembly line balancing problem is generally minimizing the total amount of idle time or equivalently minimizing the number of operators to do a given amount of work at a given assembly line speed. This is known as minimizing the balance delay. One very compelling reason why few researchers have addressed the multiple objectives of the assembly line-balancing problem simultaneously is because the job is very difficult. Past research by McMullen and Frazier[14] has indicated that many of these important objectives are in conflict with each other. According to them, these objectives are directly opposed to each other. They further emphasized that when a solution is obtained requiring a relatively large number of workers, there is a high probability that these jobs will be assembled within a certain period. The Line balancing problem can be gauged with the help of data like line efficiency, Balance delay and smoothness index.

Kirkpatrick et al.[15], Glover[16], Goldberg [17], Dorigo and Gambardella [18] have mentioned that construction of the efficient frontier for a problem cannot be obtained by direct application of a simple rule . Even though the assembly line balancing problem has received significant attention over its lifetime, many companies still do not utilize the methods proposed in the literature. This fact can be seen in a survey conducted by Chase [19]. His survey showed that roughly only 5% of companies with production lines utilize traditional line balancing techniques to balance their assembly lines. A more recent article by Milas[20] showed that this trend is still valid in today’s manufacturing environment. Milas further stated that most companies perform their line balancing based on historical precedent or the ‘gut feel’ of their engineers. Tsujimura, et al [21] presented solutions for assembly-line balancing problem with genetic algorithms. Similarly, Gen et al 22have presented their work in assembly line balancing using genetic algorithm.

The important conclusions witnessed from the literature reviews [1 – 22] on Line balancing are to minimize time of worker's movement and assembly. It has been recommended that it ensure balanced allocation of assembly work to each worker by realizing assembly line balancing after deciding the number of workers who can produce the target yield.

VI. Optimization Criteria in Line Balancing

The following terms are very much associated with Kilbridge-Wester Heuristic approach and the Helgeson-Birnie Approach.

a) Line efficiency (LE)

This is the ratio of total station time to the product of the cycle time and the no of workstations. We can express this as

$$LE = [\{ \sum_{I=1}^{K} STi \ / (K) \times (CT)\} \times 100\ \%] \quad (2)$$

Where,

ST_i= Station time of station I, K= Total No of work stations and CT = Cycle time

b) Balance delay (BD)

This is the measure of line inefficiency and the total idle time of all stations as a percentage of total available working time of all stations

Thus,

$$BD= [\{(K) \times (CT) - (\sum_{I=1}^{K} STi)\} / \{(K) \times (CT)\} \times 100\ \%] \quad (3)$$

Where,

ST_i = Station time of station i , K = Total No of work stations and CT = Cycle time

c) Smoothness index (SI)

This is an index to indicate the relative smoothness of a given assembly line balance. A smoothness index of 0 indicates a perfect balance. This can be expressed as:

$$SI = \sqrt{\sum_{i=1}^{K} (ST\max - STi)^2} \quad (4)$$

Where,

ST_{max} =Maximum Station time, ST_i = Station time of station I, K = Total No of work stations

d) Limitations

It may be noted that in designing an assembly line the no of work stations, K cannot exceed the total no of work elements, N (in fact K is an integer such that $1 \le K \le N$. Also the cycle time is greater than or equal to the maximum time of any work element and less than the total of all work element times, that is

$$T_{max} \le CT \le \sum_{I=1}^{N} Ti \quad (5)$$

Where,

T max = Maximum work element time

Ti = the time for work element i

N = Total No of work elements

CT = Cycle time

e) Line Balancing Methodologies

Many scholars argue that while doing line balancing one must consider the complex social problems with the fear that this will create social problem. This is being discussed with this tool because it aims to minimize manpower. The frequently used line balancing problems are two types namely, Assembly line balancing and Fabrication line balancing: The Assembly line balancing refers to the type of operation taking place on the line to be balanced on the other hand Fabrication line balancing refers a production line made up of operations that form or change the physical or sometimes, chemical characteristics of the product involved. The term assembly line indicates a production line made of purely assembly operations. Machining or heat treatment would fall into operations of Fabrication line balancing. In this research the two line Balancing methods are studied

- Kilbridge-WesterHeuristic approach, and
- Helgeson-Birnie Approach

i. *Kilbridge-Wester heuristic approach*

The procedures proposed by Kilbridge and Wester numbers are assigned to each operation describing how many predecessors it has. Operations with the lowest predecessors are assigned first to the workstations. The procedure consists of the following steps

- Construct the precedence diagram for the work elements
- Select a feasible cycle time
- Assign work elements to the station so that the sum of elemental time does no exceed the cycle time (Step 3)
- Delete the assigned elements from the total no of work elements and repeat the step 3
- If the station time exceeds the cycle time due to the inclusion of a certain work elements this work element should be assigned to the next station
- Repeat step 3 to 5 untill all elements are assigned to workstations

ii. *Helgeson-Birnie approach*

The procedure proposed by Helgeson and Birnie is based on the ranked positional weight technique having the following steps

- Construct the precedence diagram for the work elements
- Determine the positional weight for each work elements
- Rank the work elements based on the positional weight in step 2. The work element with highest positional weight is ranked first
- Proceed to assign work elements to the workstations where elements of the highest positional weight and rank are assigned first.
- If at any work station additional time remains after assignment of an operation, assign the succeeding ranked operation to the work station, as long as the operation does not violate the precedence relationship diagram and the station time does not exceeds the cycle time
- Repeat step 4 and 5 untill all elements are assigned to workstations

VII. Combination of Process for Line Optimization and its Constraints

a) Re-balancing constraints

Many of the OR approaches implicitly assume that the problem to be solved involves a new, yet-to-be-built assembly line, possibly housed in a new, yet-to-be-built factory. The vast majority of real-world line balancing tasks involve existing lines, housed in existing factories – in fact, the target line typically needs to be rebalanced rather than balanced, the need arising from changes in the product or the mix of models being assembled in the line, the assembly technology, the available workforce, or the production targets.

b) Workstations identities

As pointed out above, the vast majority of real-world lines balancing tasks involve existing lines housed in existing factories. In practice, this seemingly “uninteresting” observation has one far-reaching consequence, namely that each workstation in the line does have its own identity.

c) Unmovable operations and zoning constraints

The need to identify workstations by their position along the line (rather than solely by the set of operations that would be carried out there) is illustrated by the typical need of line managers to define unmovable operations and zoning constraints.

d) Elimination of workstations

Since workstations do have their identity (as observed above), it becomes obvious that a real-world LB tool cannot aim at eliminating workstations. Indeed, unless the eliminated workstations were all in the front of the line or its tail, their elimination would create gaping holes in the line, by virtue of the other workstations' retaining of their identities, including their geographical positions in the workshop.

e) Need to match loads and time

Since eliminating workstations cannot be the aim of the optimization of the line, as pointed out above, it is the equalization or smoothing (indeed “balancing”) of the workload and time among workstations that should be the practical aim of LB. It is worth noting that the classic objective of minimization of the cycle time, i.e. minimization of the maximum lead-time over all workstations, is not necessarily the same objective as load equalization. The important practical point to be made here is that the line's cycle time is almost always given by the company's marketing that sets production targets. The maximum cycle time set by marketing cannot of course be exceeded by the line, but it is typically useless to reduce the line's cycle time below that value.

f) Many operators

In many industries, in particular automotive, the product being assembled is sufficiently voluminous to allow several operators to work on the product at the same time. Since that possibility does exist, not exploiting it would lead to unnecessarily long assembly lead times, implying a reduced productivity. Once a workstation features more than one operator, the workstation's lead time ceases to be a simple sum of durations of all operations assigned to it. First of all, the workstation as a whole will need the time equal to the lead-time of its “slowest” operator.

g) Multi-operator operations

Assembly of large products such as cars sometimes requires the collaboration of several operators to carry out an operation. It is therefore desirable to make that operator carry out other operations as well. That, however, significantly complicates the scheduling of operations within the workstation: all the operators in the workstation must be kept as busy as possible, must execute the operations in compliance with the precedence constraints, and must be made available at the same time to carry out multi-operator operations.

h) Ergonomic constraints (operator position)

A major difficulty in assembly of large products is that they are too bulky to be moved (elevated, rotated) easily. In other situations, the working position is imposed from the outset. These considerations give rise to Workstation-Level Ergonomic Constraints.

VIII. Case Studies: Analysis of Assembly Object and Processes

There are 9 subassemblies in ABC Industry according to category of main parts. They are buckets,

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housings, feeder frames, revolving frames, couplings, arms, booms and gears. Feeder frame is an important prime complicated part and its subassembly is composed of base frame, tension holder, magnetic load cell, drive pulley, tail pulley, struts, guide chutes, guide covers, idlers, bearings, motors, gear drive, couplings, bolts and belt. Hence, the case study was selected to balance the assembly process as the misbalancing of production of this item effects the other activities.

a) Optimization methodology

To justify the improvement of productivity the ant optimization methodology has been created. The following parameters and variables have been considered, which are presented with their notations as under.

Parameters:

n = Total number of tasks

t_i^* = Expected duration of tasks i

σ_i^* = Estimated standard deviation of tasks i

C = Pre-specified cycle time

αh = Multipliers of objective function (h = 1, …, 4)

α = Work center creation factor $(0 < \alpha < 1)$

Variables:

L = List of tasks for assignment into work centers

n_j = number of tasks in work center j

R = total number of work canters from the solution

t_j = expected duration of all tasks in work center j

σ_j = estimated standard deviation of work center j

ω_j = workers required in work center j

W_j = integer-adjusted workers required in work center j

p_j = probability of on-time completion in work center j

u_j = utilization of work center j

$metric_i$ =evaluation metric associated with task i

ph_i = pheromone associated with task i

M (i, g_i) = n by n linkage matrix to used to detail the number of times task i is preceded by task g_i.

b) Selection of Tasks for Work Centers

All relevant entities in the above list are initialized to their appropriate values. Before actually selecting a task for membership in the current (non-empty) work center, a decision must be made whether or not to create a new work center. This is done via the following relationship:

$$P\text{ (New work center)} = \frac{\alpha}{n_j} \qquad (6)$$

Where, j is the current work center. The above relationship guards against a very large number or a very small number of work centers, thereby guarding against high fixed costs (several machines) and high variable costs (several workers). When a new work center is opened, tj and σ_j for new work center j are initialized to zero.

c) Task selection

In the event of an empty work center, all relevant statistics are initialized to zero. For each task eligible for membership in L, the utilization and probability of on-time completion are calculated to reflect work center utilization (u_j) and probability (p_j) if task i were to be added to the current work center j:

$$u_j = \frac{\omega_j}{W_j} \qquad (7)$$

Where, $\omega_j = \frac{(t + ti^*)}{C}$,

for $i \in L$ and $W_j = 1 + \text{int}(\omega_j)$

$$p_i = 1\sqrt{2\pi \int_{\propto}^{y} \exp(-0.5z^2)dz} \qquad (8)$$

Where, $$Y = \{C(W_j - \omega_j)\} / \sigma_j, \qquad (9)$$

and $$\sigma_j = \sqrt{(\sigma_i^2 + \sigma_i^{*2})} \qquad (10)$$

Utilization (uj) is a representation of how 'busy' is work centre j, while probability (pj) is the work centre's ability to finish its tasks within the cycle time. A busy system typically reflects a low probability of on-time completion, and vice versa. After determination of uj and pj, the following multiple-objective function value is determined:

$$metric_i = a_1 u_j + a_2 p_j + a_3(u_j p_j) + a_4 u_j (1 - p_j) \qquad (11)$$

This value, metrici, is intended to show the relative desirability of adding task I to work centre j. It is desired to maximize this value. The first component of this measure provides the utilization contribution. The second component shows the probability of on-time completion contribution. The third component shows the contribution of a composite measure of uj and pj. The fourth component is included as a surrogate for system design cost — a combination of personnel requirements and equipment requirements. McMullen and Frazier (1998) showed that high probabilities of on-time completion are directly related to large equipment needs, which is the reason for the $(1-p_j)$ term.

d) Determining line balance statistics and construct efficient frontier

The following is a list of definitions for entities associated with final assembly line-balancing solution:

W = number of workers required for the solution,

U = utilization of assembly line layout,

P = probability of all work centres completing work on time,

Cost design cost of assembly line layout,

S [W] composite objective function value associated with W workers.

The number of workers required for the recently completed assembly line-balancing solution is as follows:

$$W=\sum_{J=1}^{R} wj \qquad (12)$$

The utilization associated with this solution is as follows:

$$U = \left(\sum_{i=1}^{n} t_i^*\right) / cw \qquad (13)$$

The probability of completing all tasks within cycle time is as follows:

$$P = \prod_{j=1}^{R} Pj \qquad (14)$$

The design cost associated with the assembly line-balancing solution is as follows:

$$Cost = 60000+2510 \sum_{i=1}^{R} n_j w_i \qquad (15)$$

The design cost expressed above considers the total cost associated with both personnel and equipment needed to process jobs passing through the assembly line. The major assumptions of this model are that the annual labour cost for an employee is Rs 60000 /year, and the annual cost for a piece of equipment is Rs2510/year. The labour cost can be modified to reflect the actual average cost of employees on the assembly line. In addition, equipment costs might vary according to the tasks performed, the age of the equipment, and which tasks are assigned to a particular workstation.

With the individual assembly line-balancing statistics calculated, the objective measure of performance associated with W workers is as follows:

$$S\,[W]=a_1U + a_2P + a_3UP + a_4\{Cost - Cost\} / (Cost) \qquad (16)$$

The above function contains the 'ah' values as shown in equation (11), and these ah values are contained in the [0, 1] interval. Cost is the highest possible system design cost for the problem at hand. The above calculations represented by equations (12) - (15) are performed each time an assembly line-balancing solution is completed. For each solution, the largest value of S [W] is noted for each value of W. The steps above are repeated number of times — a user-specified number of solutions. The S [W] values and the corresponding values of W then comprise the multiple-objective efficient frontier.

IX. Numerical Examples: Analysis of Assembly Processes

Assembly processes of ABC Industry are made up of a number of 27-unit processes like buckets, housings, feeder frames, revolving frames, couplings, arms, booms and gears etc. They can be combined into of 15 processes like frame assembly, magnetic load cell assembly, pulley assembly, grease application, bolting of frames, magnetization of magnet and airtight test, etc. An assembly process of ABC Industry is given in Table 1.

Table 1 : Assembly process of ABC industry

Sl No	Assembly Process	Time (Min)	No of Manpower / Shift
1	Base Frame and Strut	20	2
2	Load Cell and Feeder Frame	12	3
3	Tension Holder and Feeder Frame	27	2
4	Plummer Block, Pulley and Bearing with O ring	35	2
5	Idlers and Bearings	25	1
6	Motor, Gear Box and Pulley coupling	55	3
7	Belt Vulcanizing with Feeder Frame	30	2
8	Fixing of Guide Chutes and Covers	20	2

9	Checking Alignment	15	1
10	Magnetization of Load cell	8	1
11	Aging (Load test)	12	2
12	Air tight test	8	1
13	Painting	15	1
14	Sticker sticking	5	1
15	Packing	20	2
	∑	307	26

a) Layout of assembly machinery equipment

The basic objective of machinery equipment and facility layout in assembly system is to improve assembly productivity. Its detail objectives shall be smooth inner transporting, efficient place utilization, safe location for the machinery and equipment, and creation of safe and ease inner circumstances for workers, etc.The information and data that are needed to plan and determine the placement of equipment are production capacity, forms of production and processes, inner systems, amount of transporting, amount of work at each positions; and size and form of plants. There are several equipment layouts namely product layout (line layout), process layout, fixed position layout. In this research, the existing old product layout has been studied for the selected item of ABC Industry. The existing process layout is presented in Fig 1.

Work allocation to each worker in a shift has been studied, which was done on the basis of above existing product layout and data has been collected.Then worker allocation has been changed from a shift into groups. The group-work allocation analysis has been tabulated in Table 2.

b) Determination of Automation possibility of assembly process automation

According to geometrical characteristics of products and degree of complexity of assembly process, it can be determined whether the assembly processes has to be automated or not. Sometimes, manual assembly may be performed easily. There are some more factors or parameters, i.e. production volume, cycle time, investment cost, etc., may also influence upon the decision of automatic or manual assembly as to its economic consideration. Secondly, Manual assembly is performed, if part characteristics are weak in transporting, arrangement, feeding, joining areas. In the present work, it was analyzed that whether assembly process can be automated or not. The processes that are determined by manual assembly are decided upon the method of transporting, arrangement, feeding and joining.

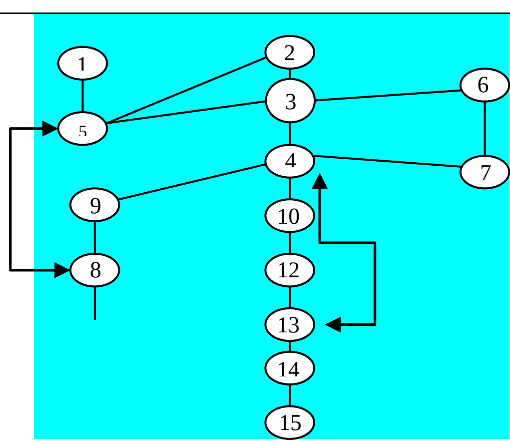

Fig. 1 : Product layout of processes before line balancing

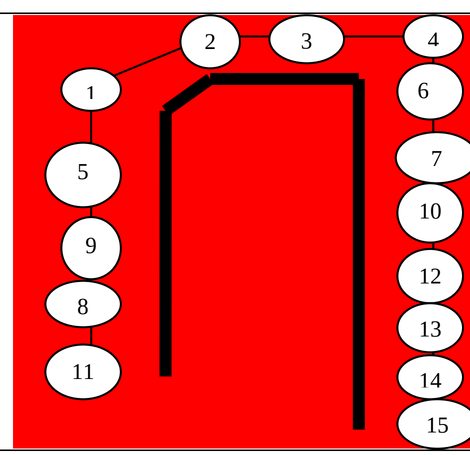

Fig. 2 : Product layout of processes after line balancing

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Table 2 : Work allocation of each group

Production Volume: 100 / Month, Item: Feeder Frame									
Worker	Sequence	Process	Time	Distance	Worker	Sequence	Process	Time	Distance
Group A = 7	1	2	12	2.3	Group C = 5	1	6	55	0.9
	2	3	27	1.5		2	7	20	1.2
	3	4	35	1.2		3			
	Sum		74	5.0		Sum		75	2.1
Group B = 5	1	1	20	1.0	Group D = 9	1	8	20	3.7
	2	5	25	0.7		2	11	12	0.7
	3	9	16	0.7		3	12	8	0.6
	4	10	10	1.0		4	13	15	1.2
	Sum		71	0.8		5	14	5	0.5
				4.2		1	15	20	2.5
						Sum		80	9.5
Unit	Time (Minutes) = 307		Distance (Meter) = 20.8		∑ **Worker = 26**				

Table 3 : Automation possibility of grease application

Determination of automation possibility of each area functional factor					
Transporting	Criteria	Degree	Arrangement	Criteria	Degree
	T1	-2		A1	0
	T2	-1		A2	-1
	T3	-2		A3	-2
	T4	-1		A4	-1
	Sum	-6		Sum	-4
Feeding	Criteria	Degree	Joining	Criteria	Degree
	F1	0		J1	+1
	F2	-1		J2	-1
	F3	-2		J3	+1
	F4	-1		J4	-1
	Sum	-4		Sum	0
Total Point = -14					
Legend: -2 = Very difficult, -1 = Difficult, 0 = Same, +1 = Easy, +2 = Very easy					

c) Determination of assembly equipment

After determination of automation possibility of each assembly process; the method and machine of transporting, arrangement and feeding were determined. Assembly machines and equipments are determined on only process that is performed by automation assembly. Assembly machines equipment is determined by characteristics of process. Therefore, this research is consisted of two numbers assembly; Bearing Placing Machine, Motor Pulley Coupling Tester Machine.

X. Work Allocation According to New Process Layout and Selection of Equipment

Actually, as observed there are coexistence forms of different layout in ABC industry. The required space to assembly lines of ABC Industry is 5700mm x 40000mm. In this space, it is impossible and inefficient that equipment like a straight line is determined. So, it has been chosen U-line like Fig.2 in order to efficient rationing and flexible production. The advantages of U-line are to improve line balancing and work efficiency with minimum space size with a free movement of worker in a coexistence of manual and automation line. A U- like shape platform was created for assembly, and an automatic hanging type Monorail system was erected for smooth advancing of the job with a provision of rotation of 3600. The monorail enabled the workers of Group B and C to assemble the components simultaneously after completion of the work of Group A. This reduces the idle time between B and C and ultimately the cost of adjoining group activities. The new process layout and selection of equipment were done in order to improve and optimize the line efficiency. The Table 4 represents the situations after line balancing study.

Table 4 : Work allocation of each worker after re-layout of process

Production Volume: 150 / Month, Item: feeder Frame									
Worker	Sequence	Process	Time	Distance	Worker	Sequence	Process	Time	Distance
Group A = 6	1	2	10	1.5	Group C = 5	1	6	30	
	2	3	21	1.0		2	7	12	
	3	4	30	1.2		3	10	20	2
	Sum		61	3.7		Sum		62	
Group B = 5	1	1	17		Group D = 5	1	7	15	
	2	5	17			2	11	12	
	3	9	12			3	12	8	
	4	8	10			4	13	10	
	5	11	8			5	14	5	
	Sum		64	2		1	15	15	2
						Sum		65	
Summary	Time (Minutes) = 252		Distance (Meter) = 9.7		∑ **Worker = 21**				

a) *Comparison of status before and after Line Balancing*

From the Table 2 and 4 it is evident that there are improvements in the assembly process. The cost is considered for 600 assemblies per annum. The cost has been calculated using Eqn. (15) and it has been tabulated in Table 5.

Table 5 : Comparison of before and after line balancing results

Sl No	Influencing factors	Before Line Balancing	After Line Balancing	Saving in Cost	% Saving
1	Time (min)	307	252	55	17.92
2	Distance (meter)	20.8	9.7	11.1	53.36
3	Worker	26	21	5	

b) Case study 2: Improvement in line efficiency

To study the line efficiency of link aggregate, the following points were taken into consideration.

- First, the item is regular and used in various models of Apron
- The quantities required are huge and
- The Contribution to the revenue generation of this product is 21.2% of the monthly sales.

The product has to go through the primary operations in the sequence as Cutting, Grinding, Rolling, Bending, Drilling, Sub Assembly and Welding and Boring. The sequence of final operation is Assembly, Welding, Cleaning, and Painting. Based on the available data (Table 6) the numbers of predecessors for each work element has been determined. Assignment of work elements to different stations is given in Table 7 following the Kilbridge – Wester Method.

Table 6 : Determination of number of predecessors for each work element in a feeder

Work element I	Number of predecessors	Time duration of the element Ti (Hrs)	Remark
1	0	5	
2	1	3	
3	2	4	
4	1	3	
5	2	6	
6	5	5	
7	6	2	
8	7	6	
9	6	1	
10	6	4	
11	7	4	
12	11	7	

Table 7 : Assignment of work elements to stations (Kilbridge – Wester Method), Cycle Time = 10 hrs

Station	Element I	Ti (Hrs)	Station sum (Hrs)	Idle time (Hrs)
I	1 2	5 3	8	2
II	4 5	3 6	9	1
III	3 6	4 5	9	1
IV	7 9 10	2 1 4	7	3
V	8 11	6 4	10	0
VI	12	7	7	3
Σ	**12**	**50**	**50**	**10**

Calculations:

The Line Efficiency (LE) = [{50 / (6 x 10)} x 100 %] = 83.3 %
Balance Delay = (100% - 83.3%) = 16.7 %
Smoothness Index = $\sqrt{4+1+1+9+9}$ = 4.89

Improvement in Line Balancing

In the light of study the Table 7 shows the methodology of reassignments of work elements in order to reduce idle time and balance the production line

Table 8 : Reassignment of work elements to stations (Kilbridge – Wester Method) for the improvement, cycle time = 9 Hrs

Station	Element I	Ti (Hrs)	Station sum (Hrs)	Idle time (Hrs)
I	1 2	5 3	8	1
II	4 5	3 6	9	0
III	3 6	4 5	9	0
IV	7 8	2 6	8	1
V	8 11	4 4	8	1
VI	9 12	1 7	8	1
Σ	**12**	**50**	**50**	**4**

Using Eqn. 2 to 4, The Line Efficiency (LE) = [{50 / (6 x 9)} x 100 %] = 92.6 %
Balance Delay = (100% - 92.6%) = 7.4 %
Smoothness Index = $\sqrt{1+1+1+1}$ = 2

XI. Results and Discussion

The results on empirical investigation of assembly line balancing are presented in Table 9. It shows that there is considerable improvement in LB. All the assembly items were regrouped into different stations and the above analysis were repeated. Then on the basis of the analysis it was decided as to how to put these items into different stations to have minimum optimal idle time, better line efficiency and minimum delay. The summary of improvements have been presented in Table 10.

Table 9 : Results on empirical investigation of assembly line balancing

Table Nos.	Line Efficiency %	Balance Delay %	Smoothness Index	Average Cycle time Reduction (Min)
Table 7	83.3	16.7	4.89	
Table 8	92.6	7.4	2	4.8
Difference %	9.3	9.3	2.89	

Table 10 : Summary of improvements in line balancing, average smoothness and average

Sl No	Category of Assembly Items	Average Line Efficiency %		Average Smoothness Index		Average Cycle Time (Hrs)	
		Before LB	After LB	Before LB	After LB	Before LB	After LB
1	Buckets	81.2	89.6	4.77	3.11	8	6.25
2	Housings	78.5	91.8	5.95	2.23	4	3.15
3	Feeder frames	83.7	92.4	4.52	3.1	6.3	5.4
4	Revolving Frames	84.4	91.3	5.36	3.7	12	9.5
5	Couplings	87.7	95.5	3.8	2.9	9	6.25
6	Arm	78.5	89.6	4.88	3.25	18	16
7	Boom	80.65	89.95	5.01	3.55	23.5	21
8	Gears	82.5	92.7	4.87	2.10	4	3.1
9	Bodies	76.8	91.45	5.37	2.12	14	11

XII. Test of Statistical Significance

Let the data, presented in Table 10, before Line balancing be x and after line balancing be y. Now, the t-test has been conducted because related data, before and after lines balancing, are independent in nature.

Null Hypothesis H_0:

$\mu_x = \mu_y$ i.e. there is no significant difference between the mean increase in line efficiency.

Alternate Hypothesis H0:

$\mu_x \neq \mu_y$ (Two Tailed)

Table 11 : Generation of data to compare Line efficiency statistically

Sl No	x	$x - \bar{x}$	$(x - \bar{x})^2$	y	$y - \bar{y}$	$(y - \bar{y})^2$
1	81.2	-0.35	0.1225	89.6	-1.99	3.9601
2	78.5	-3.05	9.3025	91.8	0.21	0.0441
3	83.7	2.15	4.6225	92.4	0.81	0.6561
4	84.4	2.85	8.1225	91.3	-0.29	0.0841
5	87.7	6.15	37.8225	95.5	3.91	15.2881
6	78.5	-3.05	9.3025	89.6	-1.99	3.9601
7	80.65	-0.9	0.81	89.95	-1.64	2.6896
8	82.5	0.95	0.9025	92.7	1.11	1.2321
9	76.8	-4.75	22.5625	91.45	-0.14	0.0196
Mean	81.55	0.00	93.57	91.59	-0.01	27.9339

From the Table 11,

Mean value of x, $\bar{x} = 81.55$.

Mean value of y, $\bar{y} = 91.59$,

No. of data of mean values of x, $n_1 = 9$,

No. of data of mean values of y, $n_2 = 9$,

$$S^2 = \frac{1}{n_1 + n_2 - 2}[\sum (x-\bar{x})^2 + \sum (y-\bar{y})^2] = 7.594$$

Where, S = An unbiased estimate of the common population Variance σ^2

Under Null Hypothesis, H_0:

$$t = [(\bar{x} - \bar{y}) / \{\sqrt{S^2}(\frac{1}{n1} + \frac{1}{n2})\}] \sim t\, n_1 + n_2 - 2 = -10.04$$

Where, t denotes the value of t-test.

Tabulated t at 5% level of significance is 2.12. Since, calculated t is less than tabulated t at 5% level of significance. Hence it may be concluded that Line efficiency x and y differ significantly. Further, $\bar{y} > \bar{x}$. Hence, Line efficiency y is superior to x.

XIII. Conclusions

The field of assembly line balancing has been vigorously researched in recent decades. Some of these innovations include parallel treatment of workers, tasks with stochastic durations, multiple objectives (minimum crew, maximum probability of on-time completion and minimum design cost), and mixed-models for JIT systems. Complexity and suitability of automated assembly is also a deciding parameter in this regard. Plant layout is one of the vital aspects in improving the utility of plant spaces. It facilitates smooth functioning of various activities in a limited space. In Small Scale Industries, particularly when there is a constraint of space U-line layout should be preferred.

On the basis of the reported case studies, it can be concluded that Line balancing improves the product quality and productivity along with an improvement in line efficiency. Proper Line Balancing reduces worker's movement and thereby assembly time and minimizes the product cost.

References Références Referencias

1. Becker C. and Scholl, A.(2004), "A Survey on Problems and Methods in Generalized Assembly Line Balancing," European Journal of Operations Research,.
2. Becker, C. and Scholl, A.(2003), "A Survey on Problems and Methods in Generalized Assembly Line Balancing," European Journal of Operations Research,
3. Scholl, A. and Becker, C.(2003) "State-of-the-Art and Heuristic Solution Procedures for Simple Assembly Line Balancing," European Journal of Operation Research,
4. Askin, R.G. and Zhou, M.(1997), "A Parallel Station Heuristic for the Mixed-Model Production Line Balancing Problem," International Journal of Production Research, Vol.35, pp.3095–3106.
5. Gocken, H. and Erel, E. (1998) "Binary Integer Formulation for the Mixed-Model Assembly Line Balancing Problem," Computational. Industrial. Engineering. Vol.23, pp.451–461.
6. Gocken, H. and Erel, E. (1997), "A Goal Programming Approach to the Mixed-Model Assembly Line Balancing Problem,". International Journal of Production Economics, Vol.48, , pp.177–185
7. Vilarinho, P.M. and Simaria, A.S. (2002), "A Two-Stage Method for Balancing Mixed-Model Assembly Lines with Parallel Workstations," International Journal Production Research, Vol.40, Pp.1405–1420.
8. Merengo, C., Nava, F. and Pozzetti, A. (1999), "Balancing and Sequencing Manual Mixed Model Assembly Lines,"International Journal Production Research," Vol.37, pp.2835–2860.
9. Rekiek, B., Delit, P. and Delchambre, A. (2000), "Designing Mixed-Product Assembly Lines," IEEE Transactions. Robot. Automation, Vol.16, pp.268–280.
10. Bukchin, J. and Rubinovitz, J. (2002), "A Weighted Approach for Assembly Line Designs with Station Paralleling and Equipment Selection," IIE Transactions, Vol.35, pp.73–85.
11. Ponnambalam, S.G., Aravindan, P. and Mogileeswar Naidul, G. (2000), "A Multi-Objective Genetic Algorithm for Solving Assembly Line Balancing Problem," International Journal of Advanced. Manufacturing. Technology, Vol.16, pp.341–352
12. Falkenauer, E. and Delchambre, A.(1992), "A Genetic Algorithm for Bin Packing and Line Balancing," IEEE International Conference Proceedings 1992 on Robotics and Automation,May10-15,Nice, France. IEEE Computer Society Press, Los Alamitos, CA. pp. 1186-1192.
13. Salveson, M.E. (1955), "The Assembly Line Balancing Problem," Journal of Industrial Engineering, Vol.6, pp. 62-69.
14. McMullen, P.R. and Frazier, G.V.(1998), "Using Simulated Annealing to Solve A Multi Objective Assembly Line Balancing Problem with Parallel Workstations," International Journal Production Research, Vol.36, pp.2717–2741
15. Kirkpatrick, S., Gelatt, C.D. and Veechi, M.P. (1983), "Optimization by Simulated Annealing," Science, Vol. 220(4598), pp.671–679.
16. Glover, F. (1990), "Tabu Search: A Tutorial," Interfaces, Vol.20, pp.74–94.
17. Goldberg, D.E.(1989), "Genetic Algorithms in Search, Optimization and Machine Learning," Reading, MA, Addison-Wesley,
18. Dorigo, M. and Gambardella, L.M. (1997) "Ant Colonies for the Traveling Salesman Problem,". Biosystems, Vol.43, ,pp. 73–81
19. Chase, R.B. (1974), "Survey of Paced Assembly Systems," Industrial Engineering, Vol.6, pp. 82-90.
20. Milas, G., (1990), "Assembly Line Balancing: Let's Remove the Mystery," Industrial Engineering, Vol. 22, pp. 12-18
21. Tsujimura, Y., Gen, M., and Kubota, E. (1995), "Solving Fuzzy Assembly-line Balancing Problem

with Genetic Algorithms," Computers and Industrial Engineering, Vol.29, pp. 62-69.
22. Gen, M., Tsujimura, Y., and Li, Y. (1996), "Fuzzy Assembly Line Balancing Using Genetic Algorithms," Computers and Industrial Engineering, Vol.31, pp. 49 -52.