

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

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Received: 14 December 2011 Accepted: 1 January 2012 Published: 15 January 2012

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.

Index terms— Line Balancing, Kilbridge-Wester Heuristic Approach, Helgeson-Birnie Approach, Optimization.

1 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.

2 II.

3 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

41 as minimizing balance delay. Balance delay is defined as the amount of idle time for the entire assembly line as a
 42 fraction of total working time resulting from unequal task time assigned to the various stations. Mathematically,
 43 this objective can be stated as follows: $\min Z = \sum_{j=1}^R W_j$

44 Subject to $t_j \leq C$ for $j = 1..R$ (1) Where,

45 R is the number of work centers,

46 W_j is the (integer-adjusted) number of required workers in work centre j ,

47 t_j is the estimated time required to complete the tasks in work centre j , and

48 C is the pre specified cycle time.

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

52 4 III.

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

64 5 IV. Aims and Objectives of the Present Study

65 The aims and objectives of the present study are as follows ? To minimize the total amount of idle time and
 66 equivalently minimizing the number of operators to do a given amount of work at a given assembly line speed

67 ? To optimize the production functions through construction of mix form of automation assembly and manual
 68 assembly.

69 ? To classify the whole assembly process into each unit and decide the automation possibility of each process,
 70 and if, automation assembly is not possible, decide criteria for manual assembly. ? To determine machinery and
 71 equipment according to assembly mechanism.

72 V.

73 6 Literature Review

74 According to Becker and Scholl [1,2] and Scholl and Becker [3] the earliest forms of the presented problem, along
 75 with the more modern research efforts, have typically concentrated on the minimization of workers needed to
 76 staff a line while adhering to task precedence and cycle time restrictions. In short, with the traditional assembly
 77 line-balancing problem, it is desirable to place workers in work centres in such a way that as few workers as
 78 possible as used, while simultaneously adhering to the policy that no single worker can be 'overloaded'. Askin
 79 and Zhou [4] have explained that with line balancing the objectives of system utilization could be met. Gocken
 80 and Erel [5,6] expressed the similar views.

81 7 Vilarinho and

82 Simaria [7]gave the mathematical solution about the probability of jobs being completed within a desired time
 83 frame. Merengo et al [8], have addressed the issue of system design cost. Askin and Zhou [4], Rekiek et al.
 84 [9], Bukchin and Rubinovitz [10] and Ponnambalam et al. [11], have proposed and concluded that evenness of
 85 workload assignments is pre requisite for line balancing. Either a cycle time is given that cannot be exceeded by
 86 the sum of durations of all tasks assigned to any workstation and the number of workstations is to be minimized or
 87 the number of workstations is fixed. The line cycle time, equal to the largest sum of durations of task assigned to
 88 a workstation, is to be minimized. Falkenauer and Delchambre [12], Salvesson [13] provided the first mathematical
 89 attempt by solving the problem as a linear program.

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

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

108 Similarly, Gen et al [22] have presented their work in assembly line balancing using genetic algorithm.
109 The important conclusions witnessed from the literature reviews [21-22] on Line balancing are to minimize
110 time of worker's movement and assembly. It has been recommended that it ensure balanced allocation of assembly
111 work to each worker by realizing assembly line balancing after deciding the number of workers who can produce
112 the target yield.

113 8 VI.

114 9 Optimization Criteria in Line Balancing

115 The following terms are very much associated with Kilbridge-Wester Heuristic approach and the Helgeson-Birnie
116 Approach. a) Line efficiency (LE) This is the ratio of total station time to the product of the cycle time and
117 the no of workstations. We can express this as It may be noted that in designing an assembly line the no of
118 work stations, K cannot exceed the total no of work elements, N (in fact K is an integer such that $1 \leq K \leq N$). Also the cycle time is greater than or equal to the maximum time of any work element and less than the
119 total of all work element times, that is Many of the OR approaches implicitly assume that the problem to be
120 solved involves a new, yet-to-bebuilt assembly line, possibly housed in a new, yet-to-bebuilt factory. The vast
121 majority of real-world line balancing tasks involve existing lines, housed in existing factories -in fact, the target
122 line typically needs to be rebalanced rather than balanced, the need arising from changes in the product or the
123 mix of models being assembled in the line, the assembly technology, the available workforce, or the production
124 targets. $LE = \left[\frac{\sum T_i}{K \times CT} \right] \times 100\%$ $T_{max} \leq CT \leq \sum T_i$ (5)

126 10 b) Workstations identities

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

130 11 c) Unmovable operations and zoning constraints

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

134 12 d) Elimination of workstations

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

139 13 e) Need to match loads and time

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

147 14 f) Many operators

148 In many industries, in particular automotive, the product being assembled is sufficiently voluminous to allow
149 several operators to work on the product at the same time. Since that possibility does exist, not exploiting
150 it would lead to unnecessarily long assembly lead times, implying a reduced productivity. Once a workstation
151 features more than one operator, the workstation's lead time ceases to be a simple sum of durations of all

152 operations assigned to it. First of all, the workstation as a whole will need the time equal to the lead-time of its
153 "slowest" operator.

154 15 g) Multi-operator operations

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

160 16 h) Ergonomic constraints (operator position)

161 A major difficulty in assembly of large products is that they are too bulky to be moved (elevated, rotated)
162 easily. In other situations, the working position is imposed from the outset. These considerations give rise to
163 Workstation-Level Ergonomic Constraints. housings, feeder frames, revolving frames, couplings, arms, booms
164 and gears. Feeder frame is an important prime complicated part and its subassembly is composed of base frame,
165 tension holder, magnetic load cell, drive pulley, tail pulley, struts, guide chutes, guide covers, idlers, bearings,
166 motors, gear drive, couplings, bolts and belt. Hence, the case study was selected to balance the assembly process
167 as the misbalancing of production of this item effects the other activities. Variables: L = List of tasks for
168 assignment into work centers n j = number of tasks in work center j R = total number of work canters from the
169 solution t j = expected duration of all tasks in work center j ? j = estimated standard deviation of work center j j
170 ? = workers required in work center j W j = integer-adjusted workers required in work center j p j = probability
171 of on-time completion in work center j u j = utilization of work center j metric i =evaluation metric associated
172 with task i ph i = pheromone associated with task i M (i, g i) = n by n linkage matrix to used to detail the
173 number of times task i is preceded by task g i .

174 17 b) Selection of Tasks for Work Centers

175 All relevant entities in the above list are initialized to their appropriate values. Before actually selecting a task
176 for membership in the current (nonempty) work center, a decision must be made whether or not to create a new
177 work center. This is done via the following relationship: $P(\text{New work center}) = j n ?$ (6)

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

182 18 c) Task selection

183 In the event of an empty work center, all relevant statistics are initialized to zero. For each task eligible for
184 membership in L, the utilization and probability of ontime completion are calculated to reflect work center
185 utilization (u_j) and probability (p_j) if task i were to be added to the current work center j: $u_j = j j W ?$ (7)

186 Where, $j ? = C t i t^* (+ , \text{ for } i? L \text{ and } W j = 1 + \text{int} (j ?) p i = 1 d z z y) 5 . 0 \exp(2 2 ? ? ? ?)$ (8)

187 Where, $Y = \{C (W j - j ?)\} / ? j$, (9)

188 and $? j = (2 * 2 i i ? ? +)$ (10)

189 Utilization (u_j) is a representation of how 'busy' is work centre j, while probability (p_j) is the work centre's
190 ability to finish its tasks within the cycle time. A busy system typically reflects a low probability of on-time
191 completion, and vice versa. After determination of u_j and p_j , the following multiple-objective function value is
192 determined: $\text{metric } i = a 1 u j + a 2 p j + a 3 (u j p j) + a 4 u j (1 - p j)$ (11) This value, $\text{metric } i$, is intended to
193 show the relative desirability of adding task I to work centre j. It is desired to maximize this value. The first
194 component of this measure provides the utilization contribution. The second component shows the probability of
195 on-time completion contribution. The third component shows the contribution of a composite measure of u_j and
196 p_j . The fourth component is included as a surrogate for system The number of workers required for the recently
197 completed assembly line-balancing solution is as follows: $W = ? = R J W j 1$ (12)

198 The utilization associated with this solution is as follows: $U = c w t n i i) (1 * ? =$ (13)

199 The probability of completing all tasks within cycle time is as follows: $P = ? R j P j 1 =$ (14)

200 The design cost associated with the assembly linebalancing solution is as follows: $\text{Cost} = 60000 + 2510 ? = R i$
201 $w n i j 1$ (15)

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

208 With the individual assembly line-balancing statistics calculated, the objective measure of performance
209 associated with W workers is as follows: $S [W] = a 1 U + a 2 P + a 3 U P + a 4 \{ \text{Cost} - \text{Cost} \} / (\text{Cost})$ (16)

210 The above function contains the 'ah' values as shown in equation (11), and these ah values are contained in the
211 [0, 1] interval. Cost is the highest possible system design cost for the problem at hand. The above calculations
212 represented by equations (??2) -(??5) are performed each time an assembly line-balancing solution is completed.
213 For each solution, the largest value of S [W] is noted for each value of W. The steps above are repeated number of
214 times -a user-specified number of solutions. The S [W] values and the corresponding values of W then comprise
215 the multipleobjective efficient frontier.

216 19 IX.

217 20 Numerical Examples: Analysis of Assembly Processes

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

222 21 An Empirical

223 22 a) Layout of assembly machinery equipment

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

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

235 23 b) Determination of Automation possibility of assembly 236 process automation

237 According to geometrical characteristics of products and degree of complexity of assembly process, it can whether
238 the assembly processes has to automated or not. Sometimes, manual assembly may be performed easily. There
239 are some more factors or parameters, i.e. production volume, cycle time, investment cost, etc., may also influence
240 upon the decision of automatic or manual assembly as to its economic consideration. Secondly, Manual assembly
241 is performed, if part characteristics are weak in transporting, arrangement, feeding, joining areas. In the present
242 work, it was analyzed that whether assembly process can be automated or not. The processes that are determined
243 by manual assembly are decided upon the method of transporting, arrangement, feeding and joining. A1 0 T2
244 -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
245 -1 J2 -1 F3 -2 J3 +1 F4 -1 J4 -1 Sum -4

246 Sum 0 Total Point = -14 Legend: -2 = Very difficult, -1 = Difficult, 0 = Same, +1 = Easy, +2 = Very easy

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

252 X.

253 24 Work Allocation According to New

254 Process Layout and Selection of Equipment Actually, as observed there are coexistence forms of different layout
255 in ABC industry. The required space to assembly lines of ABC Industry is 5700mm x 4000mm. In this space,
256 it is impossible and inefficient that equipment like a straight line is determined. So, it has been chosen U-line
257 like Fig. 2 in order to efficient rationing and flexible production. The advantages of Uline are to improve line
258 balancing and work efficiency with minimum space size with a free movement of worker in a coexistence of manual
259 and automation line. A U-like shape platform was created for assembly, and an automatic hanging type Monorail
260 system was erected for smooth advancing of the job with a provision of rotation of 3600. The monorail enabled
261 the workers of Group B and C to assemble the components simultaneously after completion of the work of Group
262 A. This reduces the idle time between B and C and ultimately the cost of adjoining group activities. The new
263 process layout and selection of equipment were done in order to improve and optimize the line efficiency. The
264 Table 4 represents the situations after line balancing study. From the Table 2 and 4 it is evident that there are

265 improvements in the assembly process. The cost is considered for 600 assemblies per annum. The cost has been
 266 calculated using Eqn. (15) and it has been tabulated in Table 5. To study the line efficiency of link aggregate,
 267 the following points were taken into consideration.

268 ? First, the item is regular and used in various models of Apron

269 ? The quantities required are huge and

270 ? The Contribution to the revenue generation of this product is 21.2% of the monthly sales.

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

276 25 Improvement in Line Balancing

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

279 26 Results and Discussion

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

285 27 Test of Statistical Significance

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

288 Null Hypothesis $H_0 : \mu_1 = \mu_2$ i.e. there is no significant difference between the mean increase in line
 289 efficiency. Alternate Hypothesis $H_1 : \mu_1 \neq \mu_2$

290 No. of data of mean values of y, 2 Where, t denotes the value of t-test. $n = 9$, $t_{0.05, 8} = 1.86$

291 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



Figure 1:



3

Figure 2: ? 3 ???

292

¹There are 9 subassemblies in ABC Industry according to category of main parts. They are buckets,

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Figure 3:



Figure 4:



12

Figure 5: Fig. 1 :Fig. 2 :

1

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Volume XII Issue v v v v III
Version I
(A)

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

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Figure 6: Table 1 :

2

Figure 7: Table 2 :

		Production Volume: 100 / Month, Item: Feeder Frame					
Work Sequence	Proces	Time	Distance	Worker	Sequence	Proces	
Group 1	2	12	2.3	Group 1	6	6	
A = 2	3	27	1.5	C = 2	7	7	
7				5			
	3				3		
	Sum	74	5.0		Sum		
Group 1	1	20	1.0	Group 1	8	8	
B = 2	5	25	0.7	D = 2	11	11	
5				9			
	3				3	12	
8	4	10	1.0		4	13	
Unit	Sum	Time (Minutes) = 307	Determination of automation possibility of each area function				

Volume XII
Issue v v v v
III Version I
Journal of
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Figure 8: Table 3 :

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

Primary
a) Comparison of status before and after Line Balancing

Figure 9: Table 4 :

5

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	

Figure 10: Table 5 :

6

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

Volume XII Issue v v v v III
Version I
(A)
Journal of Researches in Engineering
Global

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Figure 11: Table 6 :

7

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

Figure 12: Table 7 :

8

11
Volume XII Issue v v v III Version I
(A)
Journal of Researches in Engineering
Global

Figure 13: Table 8 :

9

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	

Figure 14: Table 9 :

10

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.

Figure 15: Table 10 :

11

Sl No	x	x -x	(x -x) ²	y	y -y	(y -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

Figure 16: Table 11 :

11

Figure 17: Table 11 ,

1 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.

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