Re-balancing of Generalized Assembly Lines – Searching Optimal Solutions for SALBP

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Abstract

Assembly line balancing is an attractive means of mass manufacturing and large-scale serial production systems. Traditionally, assembly lines are arranged in straight single-model lines and the problem is known as 'Simple Assembly Line Balancing problem' (SALBP). The objectives of this case study research are to investigate the performance of generalized assembly line – currently which is dedicated to effectively manufacturing the end product (a tricycle), to identify the opportunity of re-balancing the existing assembly line, and to consider alternative optimal solutions to this traditional flow line balancing. With regard to the traditional assembly-line layout, perhaps the greatest problems the operations department is facing today are the high levels of boredom, absenteeism, personnel turnover, and dissatisfaction among assembly-line workers. In order to overcome the negative consequences experienced from traditional assembly line, re-balancing of generalized assembly lines is particularly essential. Through the analysis of re-balancing the existing assembly line, it has been identified that an existing balance might have been changed to accommodate changes in the work force and the desired output rate in order to cope up with the demand variation of the product.

Keywords
Line balancing, mass manufacturing, generalized assembly line, re-balancing

1. Introduction
Assembly line balancing problem (ALBP) is a well known mathematical model for optimal balancing of the assembly lines or flow lines in mass/repetitive manufacturing systems. Traditionally, assembly lines are arranged in straight single-model lines and the problem is known as 'Simple Assembly Line Balancing problem' (SALBP), the layout of which requires tasks to be grouped into workstations in a feasible sequence such that the 'Line efficiency' (e) is maximized. Many developments have been taking place in SALB models towards formulating generalized assembly line balancing problems (GALBP) with different additional characteristics including, among others, paralleling workstations, U-shaped lines and mixed-model lines or multi-model lines as well as un-paced lines.

2. Objectives of Study
The objectives of this case study research are:

- To investigate the performance of generalized assembly line – currently which is dedicated to effectively manufacturing the end product (a tricycle which is an assembled product manufactured by the *XYZ Co*.)
- To identify the opportunity of re-balancing the existing assembly line
- To search for alternative optimal solutions to this traditional flow line balancing.

3. Background of the Case-Study

3.1 Manufacturing system Scenario
The *XYZ Co.* is a leading manufacturer of 'Tricycle' exclusively for kids use. The company manufactures tricycle parts of different varieties and then assemble it. The end product (tricycle) is an assembled one made up of a frame, two rear wheels, a front wheel, a fork and fender, a handlebar, two handle grips, and a seat. Certain technological constraints must be observed in assembling the tricycle. Currently, an assembly line is dedicated to effectively manufacturing the end products in large volumes as per the demand forecast. The assembly line is a *single-line straight* flow-line operation system. The sequence of assembly operations in the flow-line processes depends upon the design of the product.

Certainly, there is a significant impact of assembly lines on the work force. With regard to the traditional assembly-line layout, perhaps the greatest problems the operations department is facing today are the high levels of boredom, absenteeism, turnover, and dissatisfaction among assembly-line workers. Undoubtedly, personnel turnover is the most adverse side-effect of this straight flow-line operation system. It entails the management, therefore, to consider alternatives to this traditional flow-line. Moreover, flexibility in production volumes and flexibility in workstations configuration are strongly required in this kind of manufacturing systems design. As a result, a manufacturing system designer urges that the re-balancing of the existing assembly line is necessary in order to match the demand (output rate) of the flow line with the changing demand rate and to change the work force as and when the demand varies. A number of possible alternatives are available to consider for the purpose of fulfilling the above requirements as well as to overcome the negative consequences experienced from traditional assembly line.

3.2 Facts and Information on the Assembly Line

The various steps in the assembly process and the parts which go into the end product, the exact sequence of operations, the task times, and their precedence requirements are shown in the following table and figure through precedence graph.

Table 3.2.1: Tricycle assembly operations and their times

Operations Number	Description of Operations	Time (Seconds)
1	Starting Assembly	0
	Left Wheel Assembly to Frame	
2	Fit washer on left axle	10
3	Fit left wheel on axle	18
4	Fit washer on left axle	10
5	Insert and fasten cotter/bolt key	15
6	Insert and fasten hub cap	17
	Right Wheel Assembly to Frame	
7	Fit washer on right axle	10
8	Fit right wheel on axle	18
9	Fit washer on right axle	10
10	Insert and fasten cotter/bolt key	15
11	Insert and fasten hub cap	17
12	Inspect the rear wheels assembly to frame	4
	Front-Wheel and Handlebar Assembly to Frame	
13	Insert front-wheel fork in frame	18
14	Fit collar on front-wheel fork	11
15	Insert handle bars into fork	15
16	Tighten front-wheel collar	18
17	Attach left handle grips	12
18	Attach left right grips	12
	Seat Assembly to Frame	
19	Insert seat into frame	9
20	Tighten seat set screw	18
21	Inspect final assembly	4
	Total Assembly Time	**261**

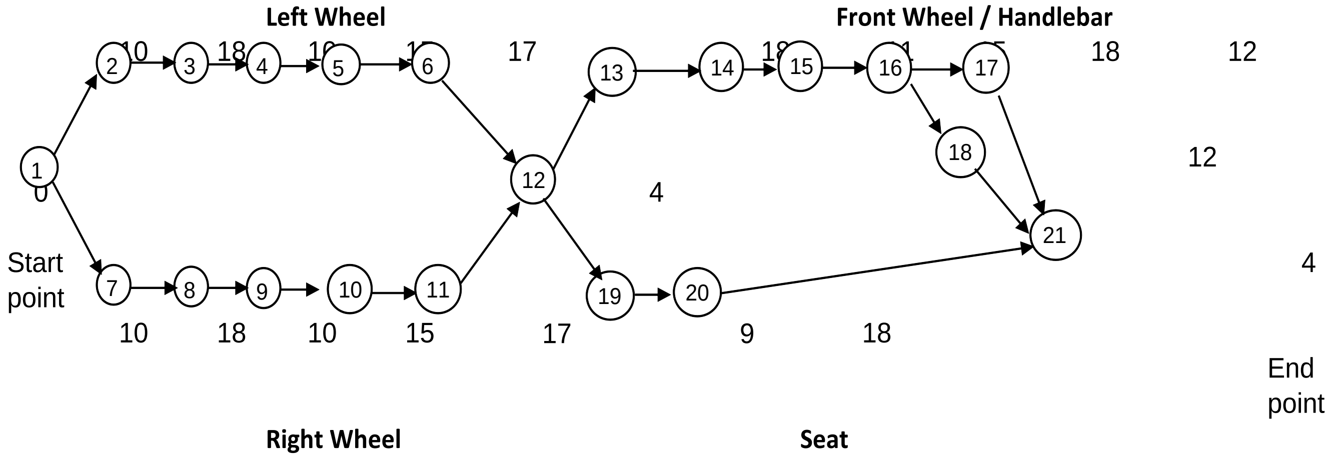

Figure 3.2.1: Tricycle Precedence Diagram

Capacity available in 'Tricycle' Assembly Line:
Actual work hours = 10 hours per day, and 5 days per week;
Given, 80% effective production time
= (10*5*0.8) hours = 40 hours per week capacity = 2400 minutes per week capacity
Weekly units demand = 2875 units, this gives:
2875 production cycles × 261 seconds (total assembly time) per cycle = 750375 production seconds required.
Hence, the *cycle time* or the maximum time allowable at any workstation is:
= weekly capacity/ weekly production units demanded = (2400*60)/2875 = 50 seconds.

4. Evaluation of the Assembly Line

The efficiency rating or performance of the assembly line designed to assemble the tricycle has been evaluated through 'line balancing' model. The objective here is to minimize the number of workers required to achieve the given production capacity.

Initially, the 'Heuristic method' - "Select the operation with the least number of predecessors (as long as it will fit within the workstation's available time) and then move on to those with more predecessors" has been used in this line balancing problem.

Table 4.1: Tricycle assembly operations ranked by number of predecessors

Operations	No. of Predecessors	Task time	Operations	No. of Predecessors	Task time
1	0	0	12	11	4
2	1	10	13	12	18
7	1	10	19	12	9
3	2	18	14	13	11
8	2	18	20	13	18
4	3	10	15	14	15
9	3	10	16	15	18
5	4	15	17	16	12
10	4	15	18	16	12
6	5	17	21	20	4
11	5	17			

Calculation of Line Efficiency (e):

Since, cycle time, c = 50 seconds and total task time, T = $\sum_{j=1}^{21} t_j$ = 261 seconds;

Therefore the lower bound on the minimal number of work stations is, $K^o = [T_{sum} / c]$ = 261/50 = 5.22 ≈ 6, which are required at least to satisfy given the output rate.

Table 4.2: Least Predecessor Rule Line Balance

Work Stations	Assigned Operations	Idle Time
1	1, 2, 7, 3	12
2	8, 4, 9	12
3	5, 10, 6	3
4	11, 12, 13, 19	2
5	14, 20, 15	6
6	16, 17, 18, 21	4

The line efficiency in this case is, e = T/(m×c) = $\sum_{j=1}^{21} t_j/(m \times c)$ = 261/300 =0.87 = 87%. Moreover, if the line is run at its minimum cycle time of 48 seconds, as the work cannot flow through the line any faster than it could pass through the slowest stage (e.g. workstation-4 having cycle time of 48 seconds); then the efficiency of the line would be improved to, e = 261/ (6*48) = 0.9063 = 90.63%.

5. Re-balancing the Line – An Issue to Analyze

An existing balance may be changed to accommodate changes in desired cycle time, task completion times, precedence constraints, line improvements etc. The *XYZ Co.* management is thinking to modify the stations configuration as far as possible and to change the output rate in order to cope up with the demand variation of the product. Essentially, their target is 'to maximize the line efficiency' (e) of generalized assembly line of the manufacturing system of interest that is flexible enough to change the number of work stations (workers) required and the cycle time as well. Rebalancing of the existing line can be analyzed to seeking the answers of management question as well as to identify whether there is an opportunity for balanced-line improvements.
An example of Re-balancing:

Table 5.1: Operations Re-assigning Sequence without violating precedence graph

Work Stations	Assigned Operations	Time remaining	Idle Time
1	1, 2, 7, 3, 4	50, 50, 40, 30, 12, ***2***	2
2	8, 9, 5	50, 32, 22, ***7***	7
3	10, 6, 11	50, 35, 18, ***1***	1
4	12, 13, 19, 14	50, 46, 28, 19, ***8***	8
5	15, 16, 17	50, 35, 17, ***5***	5
6	20, 18, 21	50, 32, 20, ***16***	16

The rebalancing of line has been performed by slightly modifying the assignment of operations as long as it satisfies the 'Least Predecessor Rule'. Compared to the Table 4.2, here the workstations are more evenly loaded except the last station so that the line is as balanced as possible. The goal is to pack workstations as tightly as possible in the beginning of allocation of operations and the significant advantage resulting from line rebalancing is that the idle time is concentrated in a single station so that necessary improvement efforts can particularly be focused there.

6. Other Issues to Consider

The management of operations department could go on with other possible options; however there are many important facts which need to be considered carefully. It should be thoroughly judged whether the manufacturing system is 'capital-intensive' or 'labor-intensive' system while redesigning an existing work and machinery layout. The alternatives which the management can think about in this case are as follows –

- Multiple assembly lines assembling the same product, each with a longer cycle time
- Assembly lines which permit team work, thus allowing each team to organize its own work in precisely the fashion it wishes.
- Assembly lines with parallel workstations duplicating the same operations
- U-shaped assembly lines where workers able to work at two segments of the U-line are arranged in such a sequence so that during the same cycle two work pieces at different positions on the flow line can be handled. The use of U-shaped production lines inherently takes the advantages of cross-training of operators and continual review and revision of work practices into account. This provides greater flexibility in station configuration than is available on a comparable straight assembly line. As a result, the number of operators (workforce size) required on a U-line will be less than or equal to the number desired on an equivalent straight line configuration.
- Mixed model assembly lines where workers are not always making the same product.

7. Possible Solutions to Alternatives

7.1 Team Assembly

The management may consider various forms of assembly team permitting group organization. For e.g. one option to organize assembly of 2875 tricycles per week is to set up two-person team.

In this case, one person can put on the right wheel while the other puts on the left wheel, one person can put on the seat while the other inserts the front fork, and they can both complete the front-wheel assembly and put on the handle grips, sharing each other work. Alternatively, there may be simply two-person workstations working independently. In this case, one person can complete the two rear wheels assembly to frame followed by inspecting the subassembly and the other person can put on the front-wheel and handlebars and grips to frame followed by inspecting the final assembly. A possible assembly sequence is shown in the figure 7.1.1 below.

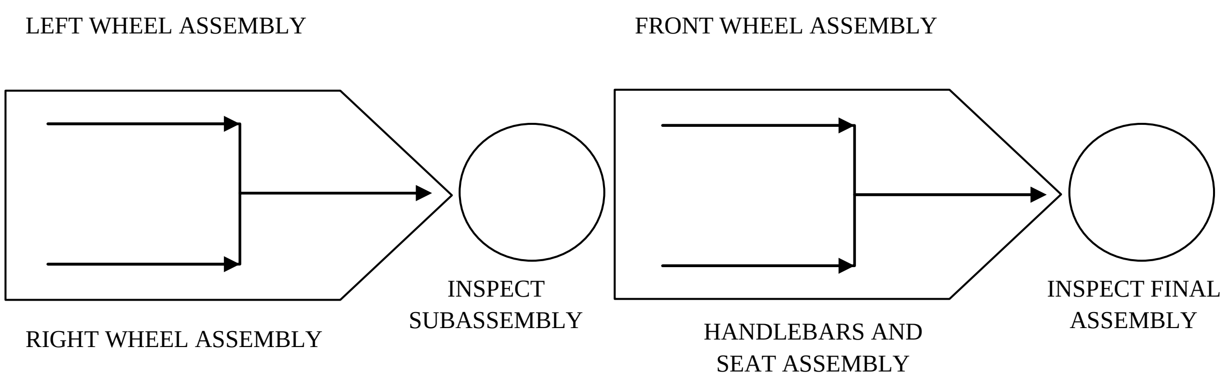

Figure 7.1.1: Tricycle Assembly Sequence with 2-person team

In this case, for the same productivity, a feasible solution may be three 2-person teams and each team produces 960 tricycles per week with a cycle time of three times the given cycle time (50 seconds). The team assembly allows more human interaction between workers while on the job. However, from the efficiency standpoint, it should be verified that whether the solution is optimal or not.

7.2 Multiple Assembly Lines

Another possible alternative the management may consider in this case is to redesign the assembly layout, i.e., to consider the possibility of multiple assembly lines. For e.g. cycle time can be increased using two short assembly lines each with three workstations instead of one long assembly line. In this case, these smaller assembly lines may have a cycle time of twice the initial cycle time and for the same efficiency a feasible solution may be each line assembling 287 tricycles a day. The multiple assembly lines allow more task variety for each worker than a single line. However, special attention should be paid to verify whether it is economically feasible for labor-intensive manufacturing system.

8. Conclusion

The decision of design and modification of line layout presents a substantial challenge for the management. This decision determines the efficiency of operations as well as the design of jobs. To provide flexibility in the assembly system illustrated in this case study, the existing assembly line is to be redesigned considering the possible alternatives and taking the facts noted above into account. With regard to the traditional assembly-line layout, perhaps the greatest problems the operations department is facing today are the high levels of boredom, absenteeism, personnel turnover, and dissatisfaction among assembly-line workers. In order to overcome the negative consequences experienced from traditional assembly line, re-balancing of generalized assembly lines is particularly essential. Through the analysis of re-balancing the existing assembly line, it has been identified that an existing balance might have been changed to accommodate changes in the work force and the desired output rate in order to cope up with the demand variation of the product. Moreover, the results from considering alternative optimal solutions to this traditional simple assembly line balancing indicate that team assembly and/or multiple assembly lines provide flexibility in production volumes and flexibility in workstations configuration which are strongly required in this kind of repetitive manufacturing system. Simultaneously, an attempt is to given to constantly search for optimal solutions of the balanced line with the cycle time and the number of workers being variables in assembly line balancing.

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