RECENT J. (2023), 71:243-248
https://doi.org/10.31926/RECENT.2023.71.243

Assembly Line Balancing

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Abstract
The main objective of balancing an assembly line is to allocate elementary assembly tasks to workstations in order to obtain a uniform load within the line. An assembly line is optimally balanced, when the cycle time is approximately equal to the tact time and the waiting times are minimal. For the optimal balancing of an assembly line, heuristic engineering methods will be used, as well as simulation with the Tecnomatix Plant Simulation software. The method of allocating elementary tasks to workstations is also called the line balancing method. The method uses engineering heuristics and consists of logical solving, through several attempts, and does not guarantee ideal optimization, but finding good, practically acceptable solutions.

Keywords
simulation, assembly line, line balancing, production productivity, workstation

1. Definition of the Assembly Line Balancing Concept

In mass production, assembly processes play an important role. In order to meet requirements related to high labour productivity, assembly lines must have an optimal number of successive workstations in their structure. A group of elementary assembly tasks is performed on the workstations, with the cycle time as close as possible to the tact time. Balancing assembly lines requires establishing a minimum number of workstations, with maximum productivity. The main criteria that apply to the balancing of assembly lines are the constraints related to the previous assembly tasks, the technological constraints and the constraints related to the cycle time [5].

The method of line balancing leads to the elimination of bottlenecks, avoiding delays and/or overloading of each workstation [1].

The problem of balancing an assembly line consists in reallocating the partial processes on the line and the assembly tasks on stations so that the work cycle period on any station is approximately the same.

The procedure for defining assembly operations is also called the procedure for assigning tasks to workstations. Any assembly process can be decomposed into a finite number of elementary tasks. For example, drilling a hole, reaming a hole with a reamer, assembling two components with a screw-nut, etc. The assembly rate is expressed as the hourly frequency of the process [4]. If the tact is theoretical then the rate will be theoretical and if the tact is real, then the rate will be real.

The theoretical rate of assembly for an operation will be

$$R_{Ai} = \frac{60}{T_{Ai}} \tag{1}$$

1.2. Precedence constraints

Precedence expresses the dependence of an activity on the prior execution of another successor. Precedence results from the divided technological sheet, from the natural sequence of execution of the respective task. Precedence constraints are expressed by the set of rules for ordering elementary tasks in the unitary assembly process. Constraints express the rules that the paired (adjacent) elements of an ordered string must respect in the formation of partitions. Constraints can be combinational and interference. Combinational constraints are those that allow or not to combine elementary tasks with each other. They can be strictly ordered or simply ordered. A constraint is of strict ordering if the task must be placed in an invariable position in the ordered string of elementary tasks of an operation that is performed on a single workstation. If the position of the elementary task can be changed in their ordered series, being able to be executed on another workstation, in another combination, then the respective task is subject to a simple ordering constraint. The interference constraints are those that require the elimination of collisions, intersections of components, which may occur in the assembly process.

The combination of elementary tasks is done by observing the following rules:

- only tasks of the same type are combined, that is, either all mechanical, or all hydro-pneumatic, or all electrical;
- the assembly of the elastic components is separated into a separate station, the processing operations of the same type are separated into separate stations, such as for example the turning ones from the milling ones, the grinding ones, etc., the pressing ones from the welding ones, the welding of mechanical assembly and soldering, etc.;
- auxiliary (indirectly productive) activities are separated from directly productive ones, except for assembly activities;
- separate the final control and testing with adjustments from the rest of the activities of any other kind;
- assembly activities are separated from processing activities; manual and automatic activities are separated.

2. Assembly Line Balancing Methodology

The method of allocating elementary tasks to workstations is also called the line balancing method. The method uses engineering heuristics and consists of logical solving, through several attempts, and does not guarantee ideal optimization, but finding good, practically acceptable solutions. Among these, the most common ones will be treated, namely: the method of the largest load, the Killbridge-Wester method, the method of the series of weights and the method of parallel stations. The allocation is made starting with the inputs, upstream, and ending with the outputs, downstream, step by step, adjacency to adjacency [2].

Balancing the load of an assembly line consists in combining the elementary tasks so that any difference between the cumulative time of the tasks and the required is max ±10% of the tact time. If the difference is positive, a "bottleneck" results and the load is redistributed to the right of the graph. If the difference is negative, then the assembly station will be an underloaded station. In order to fully load it, to the existing operation, already formed, additional elementary loads are added, adjacent to the right, until the minimum difference is obtained.

The evaluation of the balancing of the assembly line is done by means of the indicator called the losses of the assembly line. Asynchronies of any kind produce waiting times, positive or negative, which negatively affect performance functions, especially efficiency. If we denote by P_{LA}-the total losses in all q stations of the assembly line, it follows that for the entire line, the losses will be:

$$P_{LA}=\frac{q_A*\bar{T}_A-\sum_{j=1}^{n_{tSAe}} t_{Aej}}{q_A*\bar{T}_A}\ [\%], \qquad (2)$$

where: q – the number of assemblies stations; $\bar{T}_A$ – the average assembly time imposed (tact time), and t_{Aej} – time for basic assembly task.

The previous expression expresses the total losses of the assembly line, caused by the delays, the waits, produced by the imbalances in all the stations of the line. The above losses caused by waiting times should not be confused with line component failure, which is caused by the functional blockages of line components. The main balancing methods of the assembly line provide the variation of the q_A and $\bar{T}_A$ parameters that will allow R_A adjustment. A perfect balancing of the line is obtained when the losses are zero.

3. Case study

Next, the assembly process will be analysed for a household electrical product, for which 12 elementary assembly tasks (A-L) are required. The times for each elementary assembly task and the precedences are in Table 1.

Table 1. Task Time

Task	Task Time (seconds)	Precedence
1	12	-
2	24	-
3	42	1
4	6	1, 2
5	18	2
6	6.6	3
7	19.2	3
8	36	3, 4
9	16.2	6, 7, 8
10	22.8	5, 8
11	30	9, 10
12	7.2	11
Total Time	**240**	

The objective of the assembly line is to produce 480 units per day in an 8-hour shift. Therefore, the tact time would be as follows:

$$Tact\ Time = \frac{Available\ working\ Time}{Customer\ Demand} = \frac{480\ minutes}{480\ units} = 1\ minute/unit = 60\ seconds/unit \quad (3)$$

The ideal number of stations is calculated with the relation:

$$Number\ of\ Stations = \frac{Total\ task\ Cycle\ Time}{Takt\ time} = \frac{240}{60} = 4\ stations \quad (4)$$

The first step in balancing the assembly lines is to draw up the “Precedence Diagram”, which includes the order of tasks. The "Precedence Diagram" is a graphical representation, in which the nodes are represented by the assembly activities, and the arcs represent the dependence of the activities on the previous ones. For our example, the Precedence Diagram is shown in Figure 1.

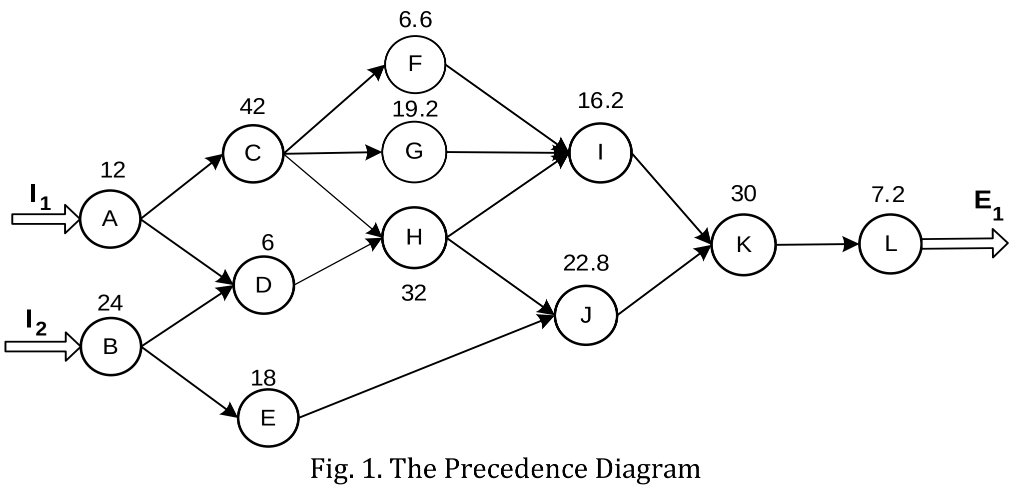


Fig. 1. The Precedence Diagram

If it is considered that each task (A-L) is performed at one workstation, the losses of the assembly line will be:

$$P_{LA} = \frac{12*60-240}{12*60} = 0.66 \quad (5)$$

Since the losses resulted above the permissible limit (≅20%-30%), it is necessary to combine several tasks on a single workstation.

Starting with Station 1; the only eligible tasks are Tasks A, B, no priorities. Assigning activities A and B to station 1 results in a cycle time of 36 seconds.

The remaining time left is equal to 60 seconds – 36 seconds = 24 seconds. The next eligible tasks that may be added to station 1 are C, D, and E; but C does not qualify because its cycle time is greater than the remaining cycle time. Therefore, D and E become the next eligible tasks. This now completes station 1 with a remaining time of 0 seconds. Applying the same principle, remaining tasks are assigned to stations 2, 3, 4 and 5. The result is presented in Table 2.

Table 2. Task Assignment Table

Station	Assigned Task	Task Time	Cumulative Time	Remaining Time
1	A	12	12	48
	B	24	36	24
	D	6	42	18
	E	18	60	0
2	C	42	42	18
	F	6.6	48.6	11.4
3	G	19.2	19.2	40.8
	H	36	55.2	4.8
4	I	16.2	16.2	43.8
	J	22.8	39	21
5	K	30	30	30
	L	7.2	37.2	22.8

The assembly line will be composed of 5 serial workstations (Figure 2), and the resulting losses will be 20%.

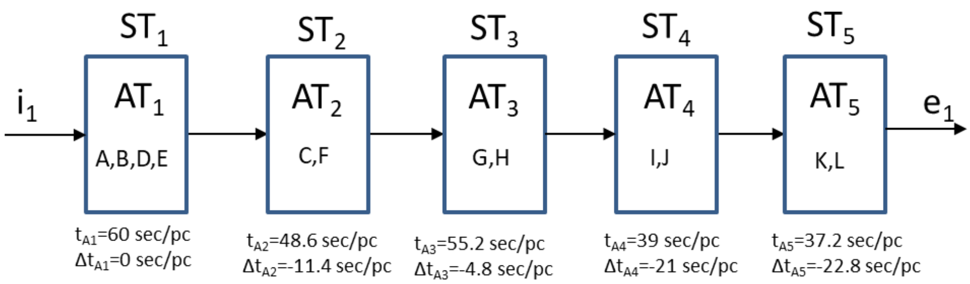


Fig. 2. Assembly line structure

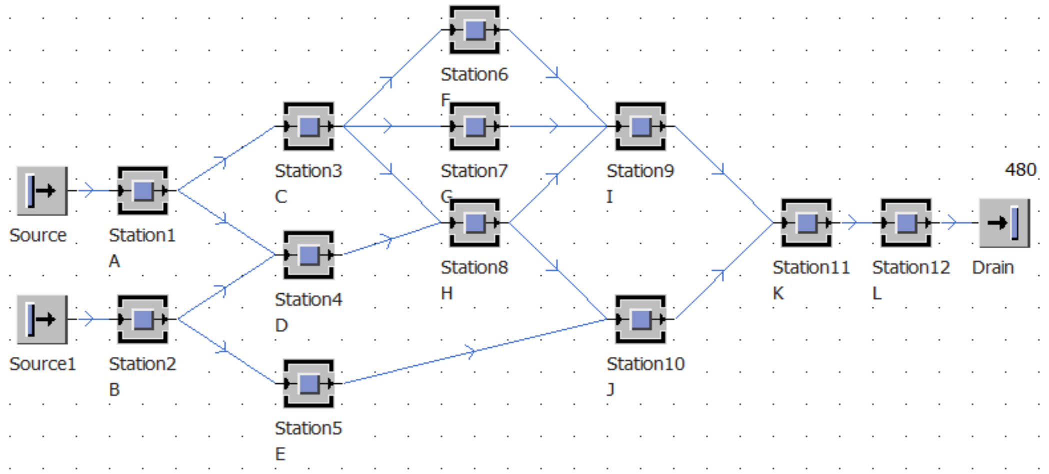
3.1. Assessment of assembly line balancing with simulation

The evaluation of the balancing of the assembly line was also done with the simulation in Tecnomatix Plant Simulation software. It was first simulated in the initial version, with 12 workstations, and the results are in Figure 3.

The simulation results (Figure 3) show us the degree of load for each workstation (green colour), but also the fact that the workstations have a waiting time (grey colour), with the workstation empty or a time during which they are waiting to transfer the part of the next workstation (yellow colour). As you can see, there are long waiting times, and big differences between cycle times for workstations.

The simulation was also done for the line composed of 5 workstations as it resulted above (Figure 4).

The balancing of the assembly line led to a uniform loading of the workstations. Waiting times have decreased. For stations 1, 2 and 3 the load is 99.17%, 80.33% and 91.25% respectively, and for stations 4 and 5, the waiting times are longer, but this is accepted for the stations that are at the end of the assembly process.



Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Station1	19.88%	0.00%	2.54%	77.58%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station2	39.77%	0.00%	1.50%	58.73%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station3	69.01%	0.00%	2.20%	28.78%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station4	5.05%	0.00%	1.25%	93.70%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station5	14.91%	0.00%	1.14%	83.95%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station6	5.42%	0.00%	2.79%	91.79%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station7	15.77%	0.00%	2.30%	81.92%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station8	30.32%	0.00%	1.04%	68.63%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station9	26.84%	0.00%	1.10%	72.06%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station10	37.78%	0.00%	0.71%	61.51%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station11	99.42%	0.00%	0.58%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station12	23.86%	0.00%	76.14%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Portions of the States

Fig. 3. Assembly line simulation results- before balancing

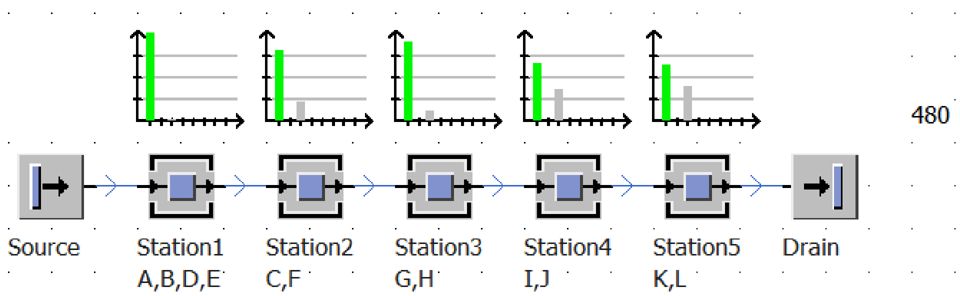


Fig. 4. Assembly line layout after balancing

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Station1	99.17%	0.00%	0.83%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station2	80.33%	0.00%	19.67%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station3	91.24%	0.00%	8.76%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station4	64.46%	0.00%	35.54%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station5	61.49%	0.00%	38.51%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

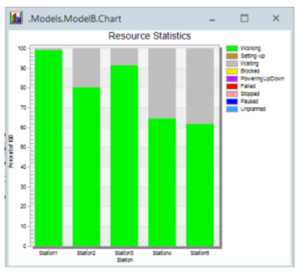


Fig. 5. Assembly line simulation results - after balancing

4. Conclusion

The results of this paper prove that the balancing of assembly lines, using heuristic-engineering methods in parallel with simulation software, is very effective, leading to the achievement of the main objective of increasing performance indicators.

The main advantages of assembly simulation are to shorten development times, to eliminate design errors in assemblies before putting them into operation, to test several versions of assembly systems or workstations. An example simulation of the assembly system was done in the Tecnomatix Plant Simulation software.

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