The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #42332

Productivity Improvement Through Assembly Line Balancing

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A Case Study of Productivity Improvement Through Assembly Line Balancing:

ABSTRACT

Balancing assembly lines becomes one of the most important activities for an industrial manufacturing system that should be supervised carefully. The success of achieving the goal of production is influenced significantly by balancing assembly lines. An assembly line consists of workstations that produce a product as it moves successively from one workstation to the next. The work content on a typical assembly line is composed of many separate and distinct work elements. The line balancing problem is concerned with assigning individual work elements to workstations so that all workers have an equal amount of work. Two important concepts in line balancing are the separation of the total work content into minimum rational work elements and the precedence constraints that must be satisfied by these elements. A minimum rational work element is a small amount of work that has a specified objective. A minimum rational work element cannot be subdivided any further without loss of practicality. In addition, there are restrictions on the order in which the work elements can be performed. These technological requirements on the work sequence are called precedence constraints. The precedence constraints can be presented graphically in the form of a precedence diagram, a network diagram that indicates the sequence in which work elements must be performed. This study involved applying the three heuristic algorithms to study process planning for a manual assembly of a commercial appliance. A total of 101 work elements have been considered. The work breakdown structure lists the work elements with their corresponding service times and precedence. Three assembly line balancing methods have been explored, namely, the largest Candidate Rule (LCR), Kilbridge and Wester (KWC), and Ranked Positional Weight (RPW) to select best option for the Manual Assembly Line.

INTRODUCTION

Assembly is the final production stage of manufactured products, where interchangeable parts are linked together to form final products or sub-assemblies. The assembly line is a system consisting of sequential workstations where materials and operations on the part are transferred along the line with the labor or material handling system Assembly lines are widely used in many manufacturing sectors, such as automotive, food, electronics, etc.

Producing a perfectly balanced assembly line requires that the work advance from station to station in the same amount of time. Since a perfect balance is not possible, we attempt to advance the work in approximately the same amount of time. The process that helps us achieve that is called assembly line balancing. Thus, we can say that line balancing is the assignment of work to stations in the line to achieve the desired rate of output with the smallest number of workstations. The fundamental of line balancing problems is to assign the tasks to an ordered sequence of stations, such that the precedence relations are satisfied, and some measurements of effectiveness are optimized. (e.g., minimize the balance delay or minimize the number of workstations; etc.) Most assembly lines must satisfy some technological precedence requirements – that is, certain work elements must be done before the next one can begin. The jobs are consecutively launched down the line and are moved from station to station. At each station, certain operations are repeatedly performed regarding the cycle time. In general, the line balancing problem consists of optimally balancing the assembly work among all stations with respect to some objective. For this purpose, the total amount of work necessary to assemble a work piece (job) is split up into a set of elementary operations named tasks or work elements. The problem is further complicated by the relationships among tasks imposed by product design and process technologies. This is called the precedence relationship which specifies the order in which the work elements must be performed in the assembly process. These elements can be summarized by a precedence diagram. It contains a node for each task, node weights for the task times, arcs the direct and paths for the indirect precedence constraints. A Precedence Diagram is like a flow process diagram with shapes and arrows describing significant and critical steps within assembly of the product.

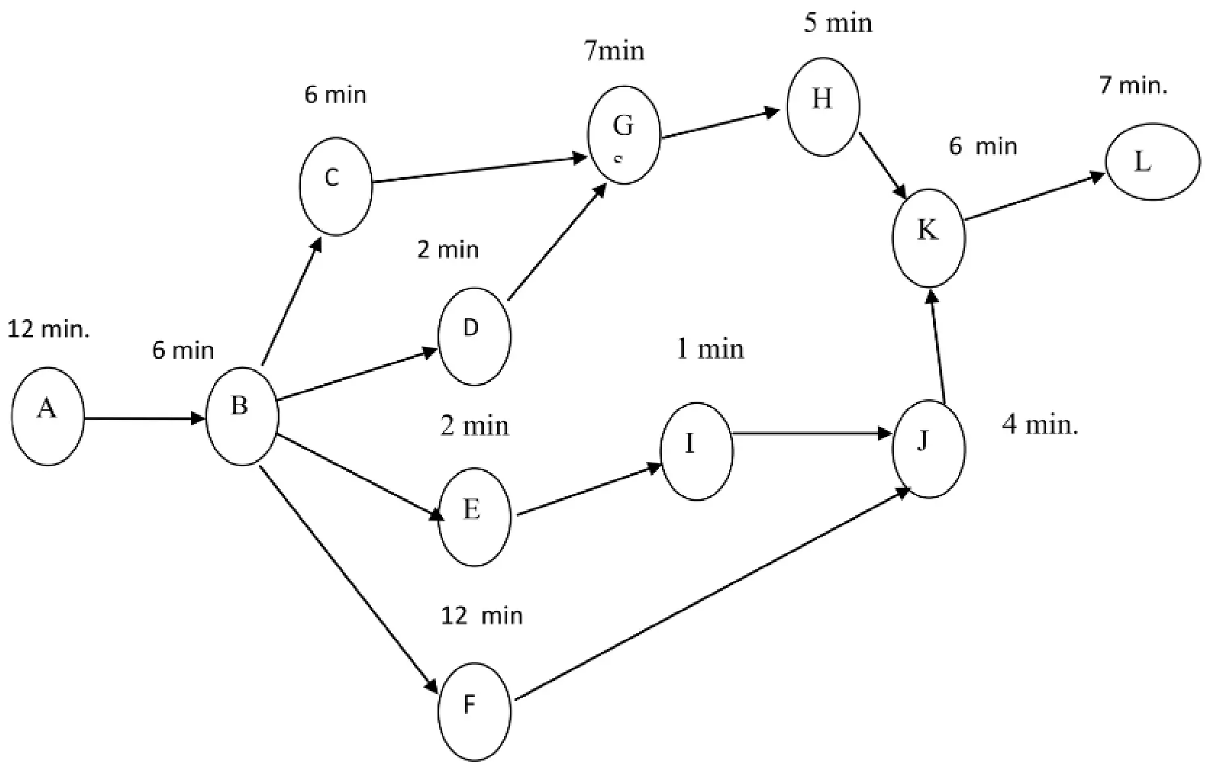

Figure 1 A Typical Precedence Diagram

Figure 1 shows a precedence diagram with n = 12 tasks having task times between 1-12 minutes. It shows that the task A must be completed before task B can be started. It also shows that the tasks C, D, E, and F can be started simultaneously after the task B has been completed. Moreover, both tasks C and D must be completed before task G can start. The assembly line balancing problem is one of assigning all the tasks required to a series of workstations so that the time required to do the work at each station does not exceed the takt time, and at the same time. the unassigned (i.e., idle) time across all workstations is minimized. An additional consideration in designing the line is to assign the tasks as equitably as possible to the stations.

This arrangement may be somewhat subjective but must be dictated by implied rules set forth by the production sequence. For the manufacturing of any item, there are some sequences of tasks that must be followed. The assembly line balancing problem originated with the invention of the assembly line. However, during the initial years of the assembly line's existence, only trial-and-error methods were used to balance the lines. Since then, there have been numerous methods developed to solve the different forms of the assembly line balancing. Development of assembly line and then balancing of the assembly line is having importance from the productivity point of view. As most of the small scale and medium scale industries are not following the various techniques available for line balancing or even line developing which may cause the loss of the productivity. These tasks can be performed by machinery, and or human operators. Once the part enters a station, a task is then performed on the part, and the part is fed to the next operation.

The most crucial problem in assembly lines is distributing the operations that need to be done in a balanced way between workstations, considering one or more purposes, under some constraints. This problem is considered the assembly line balancing problem. Its emphasis on reducing the waste related to waiting, motion, transportation time, and WIP inventory. It ensures a smooth and an undisrupted flow of materials across the line by assigning equal workloads to the workstations.

LINE BALANCING METHODS

In the literature of productivity improvement various methods have been introduced and discussed for balancing production and assembly lines. While there are various methods available for solving the line balancing problem, we can generally categorize those methods into two groups: heuristic and computerized. The term heuristic is meant for methods that are based on logic or common sense rather than on mathematical proof. There are three primary heuristic line balancing methods: (a) Largest Candidate Rule (LCR), (b) Ranked Position Weight (RPW) method, and (c) Kilbridge and Wester (K&W) method [1]

The Largest Candidate Rule (LCR) has been termed by Krajewski and Ritzman [2] as the rule of picking the candidate with the largest work element time. They also mention a second rule of picking the candidate having the largest number of followers. Helgeson and Birnie [3] found a solution to the assembly line balancing problem using the ranked position weight method. Kilbridge and Wester [4) developed, created an assignment table by paying attention to the cycle time and the antecedents of the work items and assigned work items to the stations

These are heuristic methods based on logic and understandings rather than mathematical proofs and formulas. These methods are used to develop solutions, which are not optimal but good solutions which approach the true optimum. These heuristic methods commonly used to arrange and distribute the tasks and workload amongst workstations.

In LCR method, work elements are arranged in descending order and assigned to workstations based on the duration of standard time (T_e), and the sequence of elements. In RPW method, the elements are assigned to the workstations based on the size of RPW and their position in precedence diagram. In Kilbridge and Wester Method (K&M) method elements are assigned to the workstations according to their position in the precedence diagram.

The cycle time, minimum no of workstations, balance delays, line efficiency, and line smoothness index of assembly line are calculated using the following formulas

Cycle Time = (Total available production time)/ Total No. of Units to be produced.... (1)

Min no. of workstations required (theoretical) = Total Work Content/Cycle time ...... (2)

Balance delays = [(No of workstations × Cycle Time – Total Work Content)/ (No of workstations× Cycle Time)] x 100% .... (3)

Line Efficiency = (100 – Balance Delay) % .... (4)

1, Largest-Candidate Rule (LCR)

Largest Candidate Rule is commonly used method for line balancing to evenly distribute workload amongst workstations. It ensures smooth flow of work in progress (WIP) through the line with minimal or no buffer among the workstations. However, bottlenecks are often occurred because the assembly are difficult to balanced perfectly LCR considers the cycle time and precedence relationship in line designing. In this method, the work elements are assigned to workstations based on size of elements time, Te (work elements time) values.

Procedure
Step 1. List all elements in descending order of Te value, largest Te at the top of the list.
Step 2. To assign elements to the first workstation, start at the top of the list and work done, selecting the first feasible element for placement at the station. A feasible element is one that satisfies the precedence requirements and does not cause the sum of the Tej value at station to exceed the cycle time Tc.
Step 3. Repeat step 2.

Rank Positional Weight method (RPW)

Developed by Helgeson and Birnie in 1961, it is a frequently used method among the heuristic methods in the literature in solving assembly line balancing problems. The position weight of each task is obtained by adding up all subsequent task times, including itself. The point to be considered here is that the task with a high position weight is selected in the first assignment process. The steps applied in the rank positional weight method technique are as follows:
Step 1: A precedence diagram is drawn.
Step 2: Position weight (position weight) is calculated for each task. The position weight of a

task is the sum of the time required to perform that task and the duration of the tasks that follow that task.
Step 3: Tasks are sorted by position weight from largest to smallest.
Step 4: The task with the highest position weight is selected and assigned to the workstation.
Step 5: After the task with the highest position weight is assigned to the workstation, the task with the highest position weight is selected among the remaining tasks and assigned to the station considering the following constraints.
a) The reserved jobs list is checked. If tasks with no predecessor are assigned, go to b; if not, go to step 6.
b) The durations of the tasks are compared to the unused time of the station. If the duration of the task to be assigned is less than the unused time, the assignment is made and the unused time of the station is recalculated and step 5 is repeated, if it is greater than the unused time, step 6 is passed.
Step 6: The process continues until the assignment to the station is selected, checked, and, if possible, until two conditions are met:
a) All work items are assigned.
b) There are no tasks that meet the priority requirement and the unassigned time requirement.
Step 7: The task with the highest position weight that is not assigned is assigned to the next station, and the first six steps are repeated.
Step 8: Assignment continues until all tasks are assigned to the workstations. After the implementation of all these steps, the assembly line balancing problem is solved.

Kilbridge and Wester's Method (K&W)

It is a heuristic procedure which selects work elements for assignment to stations according to their position in the precedence diagram. This overcomes one of the difficulties with the largest candidate rule (LCR), with which elements at the end of the precedence diagram might be the first candidates to be considered, simply because their values are large.

Procedure:
Step 1. Construct the precedence diagram so those nodes representing work elements of identical precedence are arranged vertically in columns.
Step 2. After drawing the precedence diagram, columns (layers) are created with the tasks without antecedents in the first column. List the elements in order of their columns, column I at the top of the list. If an element can be in more than one column, list all columns by the element to show the transferability of the element.
Step 3. To assign elements to workstations, start with the column I elements. Continue the assignment procedure in order of column number until the cycle time is reached (Tc).: The tasks are assigned to the workstations in a way that is within the cycle time and by paying attention to the antecedents

In addition, assigning a layer to the workstation is necessary for the other layer to pass.

INSTRUCTIONAL DETAILS

The topic of assembly line balancing was covered in four class sessions each of 105 minutes duration in the course entitled "Manufacturing Systems Engineering," The class consisted of typically 10 advanced undergraduate students and about 40 graduate students. Some of the details of the instruction are discussed in the following.

A complete class period was devoted to teaching students how to construct a precedence diagram. We began with a simple example of a pizza assembly line in which pizza packages were produced, with the work elements such as preparing dough, adding cheese and toppings if mushroom, pepperoni, and sausage, etc, and packing and shipping. The Largest Candidate Rule was used for balancing the assembly line. This activity was instrumental in providing understanding of how to construct the precedence diagrams and how to arrange the different work elements depending on the method chosen for assembly line balancing. A few other examples were also discussed. These examples involved relatively small number of work elements.

We next turned our attention to examples of assembly lines used in industry. The first example used the Largest Candidate Rule (LCR), and the second example used the Ranked Positional Weight (RPW) method as well as the Kilbridge and Wester (K&W) method. The number of workstations for these examples were relatively large. The details of the examples are provided below.

The first example [5] presents a case study of a multi-national manufacturing organization having traditional straight single model assembly line assembling "Pix Cassette Panels". The industry had huge bottlenecks and idle times along the assembly lines. This was attributed to unequal tasks distribution among the workstations. This study focused on reducing or optimizing the number of workstations and cycle time to improve the productivity. The existing assembly line was redesigned by using Largest Candidate Rule (LCR) to equalize the workload among workstations. This resulted in a reduction of cycle time, workstations, balance delays, and improvement of the efficiency.

The second example [6] reports a study aimed to solve the assembly line balancing problem in an automotive supplier industry company that produces cables. The processes on the line where balancing work are required are, respectively, airbag pre-assembly, electrical airbag test, pre-assembly, laying, taping, latch check, electrical test, final assembly, temporary taping, final observation, and shipment. The targeted cycle time is 143.33 s. However, the duration of the pre-assembly six stations is 170 s, which is longer than the other stations. The reason for this problem was investigated, and it was determined that the workload of the operator working at the six pre-assembly stations was higher. This problem at the pre-assembly 6 station causes operators working at other stations to wait. The Rank Positional Weight method and Kilbridge and Wester method were used in the assembly line balancing work to be carried out between 4 workstations in the factory. There are 39 work items in total at the stations on the pre-assembly line.

The details of the results obtained for Example 1 and Example 2 are presented in Tables 1 through 8. Tables 1 and 2 describe the problem and the results obtained for Example 1 using the LCR Method. Table 3 describes the problem for Example 2 along with the precedence diagram used for the evaluation based on RPW method. Tables 4 and 5 provide results for the Example 2 using the RPW Method. Tables 6 and 7 provide results for the Example 2 using the K&W Method. Table 8 provides a comparison summary of the RPW and K&W methods used for assembly line balancing for Example 2.

PROJECT PROBLEM

A project problem on Assembly Line Balancing was assigned to students taking the course entitled Manufacturing Systems Engineering. The object is to balance the assembly line to ensure smooth flow across the workstations with no or minimal idle time. The details of the project on assembly line balancing and a typical solution is provided in the Appendix. Other details:

1) % of project in total grade: 20&
2) assigned time: middle of the term and duration: 4 weeks
3) project format - individual,
4) preferred methods of approach: computer software like Excel
5) assessment rubric - (a) Establish workstations – 10%, (b) Precedence diagram – 15%, (c) LCR Method – 20%, (d) RPW Method - 20%, (e) K&W Method – 20%, (f) Conclusions – 15%
6) Year and term offered. Annually, spring semester

CONCLUSIONS

Through the student activity it can be demonstrated that significant improvements in productivity are possible through the implementation of various line balancing techniques. It was emphasized to the students that line balancing is an optimization problem with significant industrial importance. By improving the efficiency of their assembly lines, organizations can reduce idle time. Line balancing ensures that all operators and machines work together in a balanced fashion. No operator or machine is overburdened or idle. This message was communicated to the students and it seemed to have left a good impression on them. As far as choosing a particular heuristic method, the students were made aware of the fact that some of the methods work better on some problems while other methods work better on other problems. The students were also advised that heuristic methods do not guarantee the optimal solution, but they are likely to have good solutions that approach the optimal one.

Although no attempt was made in this course to highlight computerized balancing methods in which computer software is used to analyze and optimize the production processes, it was mentioned in the course that computerized method allows for more flexibility in testing various scenarios and evaluating the results,

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TABLE 1

EXAMPLE 1

S. No	Activities	Standard Time	Precedence
1.	Assembly of Front Unit	5339.2	
2.	Assembly of Rear Unit	5580.75	---
3.	Installation of Fiber in Front Unit Frame	173.25	1
4.	Assembly & Installation of insulator Plate	439.5	3
5.	Fixing of PT's Support Channels on both Side	202.65	2
6.	Fixing of PT's Mounting Channel & PT Link	493.5	5
7.	Fixing of PT's	543.9	6
8.	Installation of Earth Switch in Rear Unit Frame	430.5	2
9.	Coupling of Front & Rear Unit	1012.2	1,2
10.	Installation of Spout Plate	346.5	9
11.	Assembly & Fixing of Spout	556.5	10
12.	Installation of Angle Support on both side	604.8	10
13.	Installation of Fixing Angle	96.6	12
14.	Installation of Floor Shiftener	415.5	12
15.	Installation of Fixing Bracket	118.65	12
16.	Installation of CT mounting Channel & CT Link	498.75	2
17.	Installation of CT's	637.35	16
18.	Installation of Ground Earth at Bottom of Panel	254.1	8
19.	Fixing of Copper Contact with Copper Raise Connector	369.6	4,11
20.	Installation of Copper Riser	488.25	19
21.	Fixing of Copper Contact with Copper, CT & Earthing Switch	1383.9	11,17
22.	Installation of Gas Kit	309.75	9
23.	Installation of Instrument Box	1488.9	22
24.	Installation of Shutter	178.5	19,21
25.	Installation of Lifter	189	24
26.	Wiring of CTs	2782.5	17,23
27.	Installation & Wiring of Heater	693	26
28.	Earthing Switch Wiring	2510.55	8,23
29.	Wiring of PTs	2642.85	7,27
30.	Installation of Drive Shaft	1949.85	8,18
31.	Installation of Cross Bar	263.55	28,30
32.	Installation of Rail Base Plate	333.9	13,14,15,25,31
33.	Installation of HVX	643.65	29,32
34.	Installation & Adjusting of Door	861	31,33
35.	Installation of Access Cover on Bottom of Panel	129.15	34
36.	Installation of End Plate	63	35
	Total Standard Time (Seconds)	35025.1	

Table 1 shows the data of Medium Voltage (MV) assembly line which includes activities, standard time for activities and precedence relationships. The total standard time or total contents time of the product required for its assembling is 35025.1 seconds or 583.75 minutes.

As the daily average demand of the product is 4.5 panels. The MV assembly line needs to assemble 4.5 panels per day to fulfil the demand. The total available time per shift is 7.5 hours or 450 minutes. Therefore, the cycle time and the number of workstations will be,

- Cycle time/ Takt time = 450/4.5 = **100 Minutes**
- Min No. of workstations required (Theoretical) = 583.75 / 100 = 5.83 ≈ **6** WS

Cycle time for MV assembly line should be 100 minutes where the number of workstations should be 06 as shown in the above calculations to fulfil the require demand. Earlier the cycle time was considered 120 minutes and number of workstations in the assembly line were 07.

TABLE 2

EXAMPLE 1 (CONTD)

Descending Order

Standard Time	Precedence	Elements
5580.75	___	2
5339.2	___	1
2782.5	17,23	26
2642.85	7,27	29
2510.55	8,23	28
1949.85	8,18	30
1488.9	22	23
1383.9	11,17	21
1012.2	1,2	9
861	31,33	34
693	26	27
643.65	29,32	33
637.35	16	17
604.8	10	12
556.5	10	11
543.9	6	7
498.75	2	16
493.5	5	6
488.25	19	20
439.5	3	4
430.5	2	8
415.5	12	14
369.6	4,11	19
346.5	9	10
333.9	13,14,15,25,31	32
309.75	9	22
263.55	28,30	31
254.1	8	18
202.65	2	5
189	24	25
178.5	19,21	24
173.25	1	3
129.15	34	35
118.65	12	15
96.6	12	13
63	20,35	36

Assign Elements to Working Stations

Standard Time	Elements	Working Stations	Work Content	Idle Time
5339.2	1	A	5951.95	48.05
173.25	3			
439.5	4			
5580.75	2	B	5783.4	216.6
202.65	5			
1012.2	9	C	5932.5	160.95
498.75	16			
493.5	6			
430.5	8			
346.5	10			
309.75	22			
254.1	18			
1949.85	30			
637.35	17			
1488.9	23	D	5756.85	149.7
604.8	12			
556.5	11			
543.9	7			
415.5	14			
369.6	19			
118.65	15			
96.6	13			
1383.9	21			
178.5	24			
2782.5	26	E	5986.05	13.95
2510.55	28			
693	27			
2642.85	29	F	5614.35	385.7
488.25	20			
263.55	31			
333.9	32			
189	25			
643.65	33			
861	34			
129.15	35			
63	36			

Descriptions	Before	After
Work Stations	7	6
Cycle Time	120 mins	100 mins
Efficiency	48.96 %	97.3 %
Balance Delay	51.04 %	2.70%

TABLE 3

EXAMPLE 2

Work items, durations, and predecessor work items.

Work items	Predecessor work item or items	Duration	Work items	Predecessor work item or items	Duration
1	-	8,17	21	20	15,95
2	1	38,77	22	21	5,62
3	2	35,92	23	22	5,36
4	3	23,62	24	23	8,82
5	4	6,53	25	24	2,43
6	5	3,59	26	25	7,39
7	6	9,12	27	26	6,79
8	7	10,62	28	-	8,96
9	8	4,32	29	-	6,32
10	-	21,49	30	28	7,45
11	10	39,7	31	29	9,78
12	10	10,63	32	30,31	5,33
13	10	56,59	33	32	3,63
14	11,12,13	27,93	34	33	6,53
15	14	1,38	35	34	30,67
16	15	12,28	36	35	8,1
17	-	9,95	37	36	7,26
18	17	27,28	38	37	9,66
19	18	27,49	39	1,10,17,28,29	15,68
20	19	12,92			

PRECEDENCE DIAGRAM

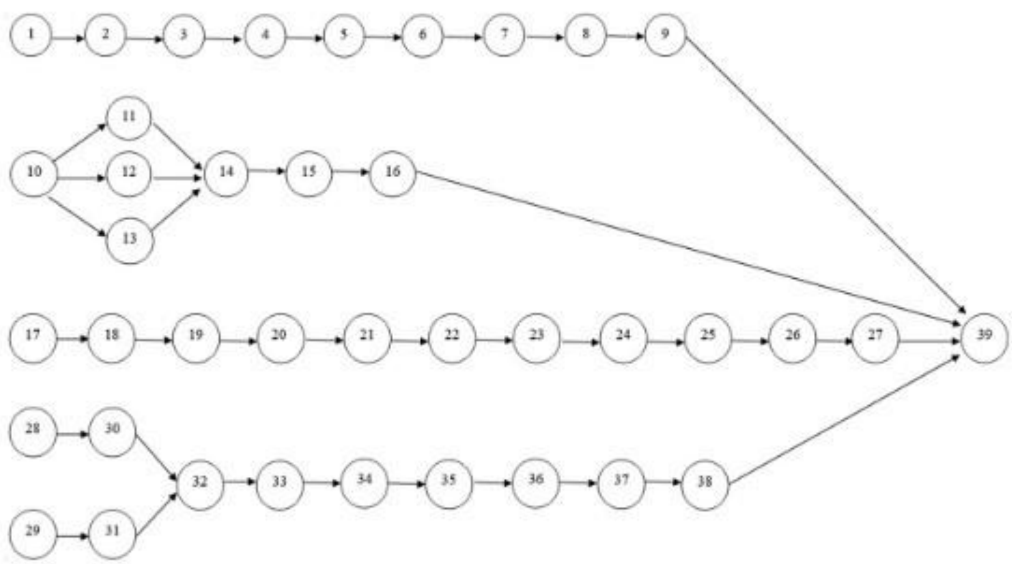


TABLE 4

EXAMPLE 2 RPW METHOD

Position Weights of Tasks.

Item	Position Weights	Item	Position Weights
1	156,34	21	68,04
2	148,17	22	52,09
3	109,4	23	46,47
4	73,48	24	41,11
5	49,86	25	32,29
6	43,33	26	29,86
7	39,74	27	22,47
8	30,62	28	103,27
9	20	29	102,96
10	185,68	30	94,31
11	96,97	31	96,64
12	67,9	32	86,86
13	113,86	33	81,53
14	57,27	34	77,9
15	29,34	35	71,37
16	27,96	36	40,7
17	145,68	37	32,6
18	135,73	38	25,34
19	108,45	39	15,68
20	80,96		

Sorting position weights from smallest to largest.

Row	Item	Duration	Position Weights	Row	Item	Duration	Position Weights
1	10	21,49	185,68	21	12	10,63	67,9
2	1	8,17	156,34	22	14	27,93	57,27
3	2	38,77	148,17	23	22	5,62	52,09
4	17	9,95	145,68	24	5	6,53	49,86
5	18	27,28	135,73	25	23	5,36	46,47
6	13	56,59	113,86	26	6	3,59	43,33
7	3	35,92	109,4	27	24	8,82	41,11
8	19	27,49	108,45	28	36	9,12	40,7
9	28	8,96	103,27	29	7	8,1	39,74
10	29	6,32	102,96	30	37	2,43	32,6
11	11	39,7	96,97	31	25	7,26	32,29
12	31	9,78	96,64	32	8	10,62	30,62
13	30	7,45	94,31	33	26	7,39	29,86
14	32	5,33	86,86	34	15	1,38	29,34
15	33	12,92	81,53	35	16	12,28	27,96
16	20	3,63	80,96	36	38	9,66	25,34
17	34	6,53	77,9	37	27	6,79	22,47
18	4	23,62	73,48	38	9	4,32	20
19	35	30,67	71,37	39	39	15,68	15,68
20	21	15,95	68,04				

TABLE 5

EXAMPLE 2 RPW METHOD (CONTD)

Assigning tasks to stations.

Workstation	Item numbers	Position Weights	Previous transactions	Processing time	Cumulative processing time
1	10	185,68	_	21,49	21,49
	1	156,34	_	8,17	29,66
	2	148,17	1	38,77	68,43
	17	145,68	_	9,95	78,38
	18	135,73	17	27,28	105,66
	3	109,4	2	35,92	141,58
2	13	113,86	10	56,59	56,59
	19	108,45	18	27,49	84,08
	28	103,27	_	8,96	93,04
	29	102,96	_	6,32	99,36
	11	96,97	10	39,7	139,06
3	31	96,64	29	9,78	9,78
	30	94,31	28	7,45	17,23
	32	86,86	30,31	5,33	22,56
	20	80,96	19	12,92	35,48
	33	81,53	32	3,63	39,11
	34	77,9	33	6,53	45,64
	4	73,48	3	23,62	69,26
	35	71,37	34	30,67	99,93
	21	68,04	20	15,95	115,88
	12	67,9	10	10,63	126,51
	22	52,09	21	5,62	132,13
	5	49,86	4	6,53	138,66
	6	43,33	5	3,59	142,25
4	14	57,27	11,12,13	27,93	27,93
	23	46,47	22	5,36	33,29
	24	41,11	23	8,82	42,11
	7	39,74	6	9,12	51,23
	36	40,7	35	8,1	59,33
	25	32,29	24	2,43	61,76
	37	32,6	36	7,26	69,02
	8	30,62	4,6,7	10,62	79,64
	26	29,86	25	7,39	87,03
	15	29,34	14	1,38	88,41
	16	27,96	15	12,28	100,69
	38	25,34	37	9,66	110,35
	27	22,47	26	6,79	117,14
	9	20	8	4,32	121,46
	39	15,68	1,10,17,28,29	15,68	137,14

The tasks assigned to the station with the Rank positional weight method and the total duration of each station.

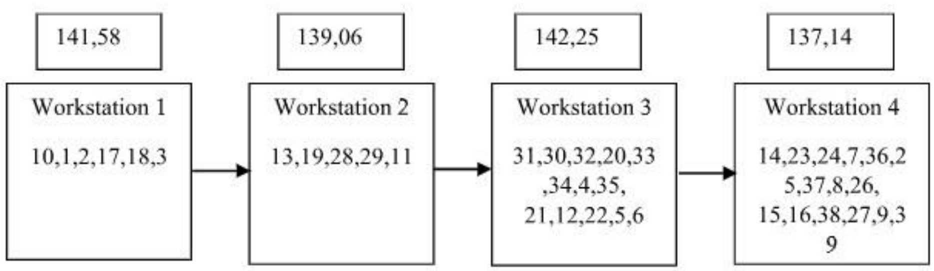
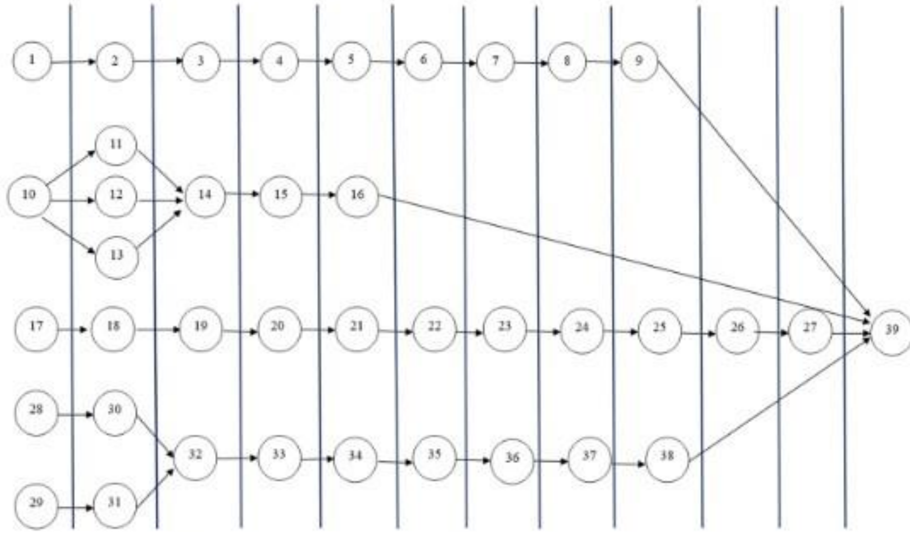


TABLE 6

EXAMPLE 2 K&W METHOD

Layers created for Kilbridge and Wester Heuristics



Cumulative performance time.

Layers	Each layer time	Cumulative time
1	54,89	54,89
2	190,2	245,09
3	96,67	341,76
4	41,55	383,31
5	41,29	424,6
6	39,88	464,48
7	22,58	487,06
8	26,7	513,76
9	16,41	530,17
10	7,39	537,56
11	6,79	544,35
12	15,68	560,03

TABLE 7

EXAMPLE 2 K&W METHOD (CONTD)

Tasks assigned to workstations.

Workstation	Item number	Previous transactions	Processing time	Cumulative processing time
1	1	-	8,17	8,17
	10	-	21,49	29,66
	17	-	9,95	39,61
	28	-	8,96	48,57
	29	-	6,32	54,89
	13	10	56,59	111,48
	18	17	27,28	138,76
2	2	1	38,77	38,77
	11	10	39,7	78,47
	12	10	10,63	89,1
	30	28	7,45	96,55
	31	29	9,78	106,33
	3	2	35,92	142,25
3	14	11,12,13	27,93	27,93
	19	18	27,49	55,42
	32	30,31	5,33	60,75
	4	3	23,62	84,37
	20	19	12,92	97,29
	33	32	3,63	100,92
	15	14	1,38	102,3
	21	20	15,95	118,25
	16	15	12,28	130,53
	5	4	6,53	137,06
4	34	33	6,53	6,53
	6	5	3,59	10,12
	22	21	5,62	15,74
	35	34	30,67	46,41
	7	6	9,12	55,53
	23	22	5,36	60,89
	36	35	8,1	68,99
	8	4,6,7	10,62	79,61
	24	23	8,82	88,43
	37	36	7,26	95,69
	9	8	4,32	100,01
	25	24	2,43	102,44
	38	37	9,66	112,1
	26	25	7,39	119,49
	27	26	6,79	126,28
	39	1,10,17,28,29	15,68	141,96

Tasks assigned to the station and total time of each station with Kilbridge and Wester Heuristics.

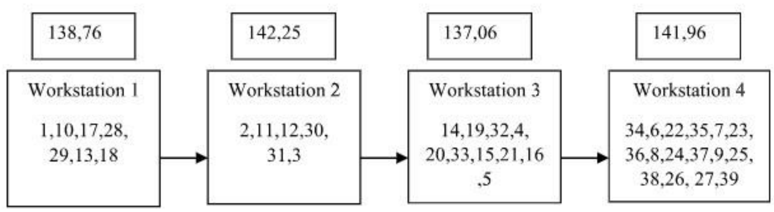


TABLE 8

EXAMPLE 2 COMPARISON OF RPW AND K&W METHODS

Comparison of the methods used in the study.

	Rank positional weight method	Kilbridge and wester heuristics
Line efficiency	0,9842	0,9842
Loss of balance	0,0158	0,0158
Number of workstation	4	4
Idle time	13,29	13,29

Station times obtained with the Rank positional weight method and Kilbridge and Wester heuristics.

	Station times obtained by the Rank positional weight method	Station times obtained with Kilbridge and Wester Heuristics
Workstation 1	141,58	138,76
Workstation 2	139,06	142,25
Workstation 3	142,25	137,06
Workstation 4	137,14	141,96

APPENDIX A

PROJECT PROBLEM

Question

Attached is the work breakdown structure for the manual assembly of a commercial appliance. It is expected that this current model will be produced over the next the 5 years. The uptime efficiency at 90%. The repositioning efficiency is 90% and M= 1.

1. What is the maximum theoretical production rate of this line?

2. What is the balance efficiency for the theoretical case?

3. Suppose that the demand for the product was only 40 units per hour. What is the actual balance delay?

4. Using the (i) Largest Candidate Rule, (ii) Ranked Position Weight Method, and (iii) Kilbridge and Wester Method balance the line.

Draw the Precedence diagram. Show the columns (layers) for the Kilbridge and Wester Method

Answer the following for each of the three methods:

a) What is the number of stations required?

b) How many workers will be needed?

c) Determine the balance efficiency.

d) Determine the balance efficiency.

5. Is it possible for this line to produce at a rate of 75 units per hour?

1.1 WORK BREAKDOWN STRUCTURE

Element #	Te	Precedence
1	0.2	0
2	0.5	1
3	0.7	2
4	0.7	3
5	0.6	4
6	0.5	5
7	0.2	6
8	0.1	7
9	0.3	2
10	0.8	9
11	0.5	10
12	0.5	11
13	0.2	12
14	0.7	13
15	0.6	9
16	0.3	15
17	0.1	16
18	0.2	17
19	0.7	18
20	0.8	19
21	0.1	20
22	0.7	8,14,21
23	0.8	22
24	0.6	23
25	0.6	24
26	0.4	0
27	0.8	26
28	0.3	27
29	0.9	28
30	0.2	29
31	0.3	30
32	0.6	31
33	0.5	32
34	0.1	33
35	0.9	34

Element #	Te	Precedence
36	0.3	35
37	0.9	36
38	0.2	0
39	0.8	38,50
40	0.9	39,51
41	0.2	40
42	0.3	41
43	0.1	42
44	0.5	43,56
45	0.9	44
46	0.3	45
47	0.9	46
48	0.1	47
49	0.5	48
50	0.7	0
51	0.2	0
52	0.3	0
53	0.9	52
54	0.8	53
55	0.3	54
56	0.6	55
57	0.1	0
58	0.2	57
59	0.7	58
60	0.6	59,70
61	0.6	60
62	0.5	61
63	0.8	62
64	0.8	63
65	0.1	64
66	0.3	65
67	0.2	66
68	0.9	0
69	0.8	68
70	0.7	69

Element #	Te	Precedence
71	0.2	25,37
72	0.8	71
73	0.5	72
74	0.8	73
75	0.7	74
76	0.8	75
77	0.6	76
78	0.3	77
79	0.9	49,67
80	0.6	79
81	0.8	80
82	0.1	81
83	0.8	82
84	0.9	83
85	0.6	84
86	0.3	85
87	0.1	86
88	0.2	87
89	0.9	78,88
90	0.2	89
91	0.4	90
92	0.7	91
93	0.3	92
94	0.1	93
95	0.2	94
96	0.8	95
97	0.7	96
98	0.2	97
99	0.1	98
100	0.2	99
101	0.3	100

SOLUTION

Note: Only the Largest Candidate Rule is shown here.
Also, the Precedence Diagram is not drawn,

Q1 What is the maximum theoretical production rate of the line?
Answer:

The theoretical or ideal production rate also known as the cycle rate R_c can be calculated by taking the reciprocal of the cycle time T_c .

From the given table of contents Te is the service time for each element of the corresponding component.

Assuming that highest among the work element as the total service time for a single station, which is equal to 0.9 min.

The total work content time is the sum of all the work element times from the table 1.

TWC = $\sum$ (T_e) = 50.1 min.

T_s = 0.9 min.

We know that Ts /T_c = 0.9 (the repositioning efficiency – given date)

So T_c = (Ts / 0.9) = 0.9/0.9 = **1** min

And thereby R_c = (60 /T_c) units/hr = 60 /1 = 60 units/hr.

Therefore the maximum theoretical production rate for this line is 60 units/hr.

Q2. What is the balance efficiency for the theoretical case?
Answer

We know the equation **E_b** = $\frac{TWC}{W*Ts}$. Now we find out the theoretical number of work stations/ workers to calculate the balance efficiency. Here the number of workers and the number of work stations are taken as same because the manning level for this production line M= 1.

The theoretical minimum number of workers = (TWC/ T_c) = (50.1/ 1) = 50.1 ~ 51workers.

TWC = 50.1 min.

Ts = 0.9 min.

So E_b $= \frac{50.1}{51*0.9} = 1.09$

The balance efficiency for the theoretical case is 109%. This means that the production line is unbalanced (balanced efficiency cannot be more than 100%). In this unbalanced production line set-up, the theoretical number of workers is calculated by nominally distributing the work time without considering the precedence of each element.

Here, the total work content TWC > the work accomplished by or that can be done by the workers.

Q3 Suppose that the demand for the product was only 40 units.hr. What is the balance delay?

Answer

Here the demand or the production rate Rp is given. Rp = 40 u/hr. From the uptime efficiency given E= 0.9, we find the available time AT.

AT = 60* E = 60* 0.9 = 54 min.

We know the equation to find out the cycle time, $Tc = \frac{AT}{Rp}$ = 54 /40 = 1.35 min.

We know TWC = 50.1 min. Therefore from the equation w = (TWC /Tc), we find out the theoretical minimum number of workers.

W = 50.1/ 1.35 = 37.11 □ 38 workers.

The total service time Ts = Tc* 0.9 (since repositioning efficiency E_r = 0.9- given, Er =Ts / Tc)

Therefore Ts = 1.35* 0.9 = 1.215 min.

The actual balance delay of this production line is calculated based on the equation

$$d = \frac{(W*Ts)-TWC}{W*Ts}$$

$d = \frac{(38*1.215)-50.1}{38*1.215}$ = -0.085. Here the balance delay is in negative which means the work is left behind and that the line is unbalanced.

This is because the total work content TWC > the work accomplished by or that can be done by the workers (W*Ts).

Balancing the line with a production rate of 40 units/hr.

The method used here to balance the line is the largest candidate rule.

Step 1. Re-arranging the given list of elements in their descending order of service time for each element from the top.

Step 2. Starting from the top of this list assigning the work elements to the stations one- by- one thereby satisfying the precedence requirement and not exceeding the total service time allotted to each station.

Step 3. When no more work element could be assigned to the station proceed to assigning them to next station.

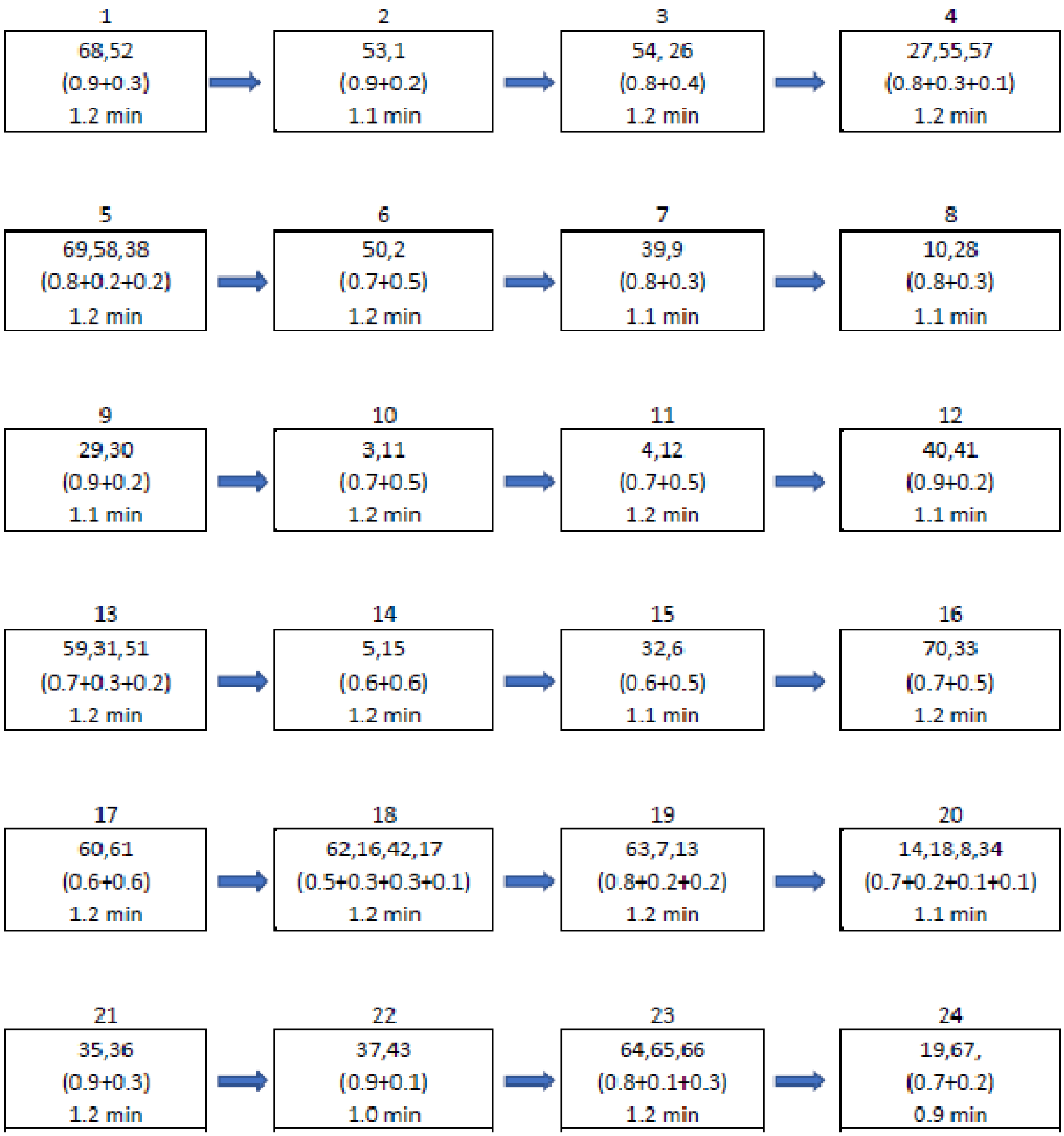
Step 4. Repeat steps 2, 3 until all the work elements have been assigned to as many workstations as required.

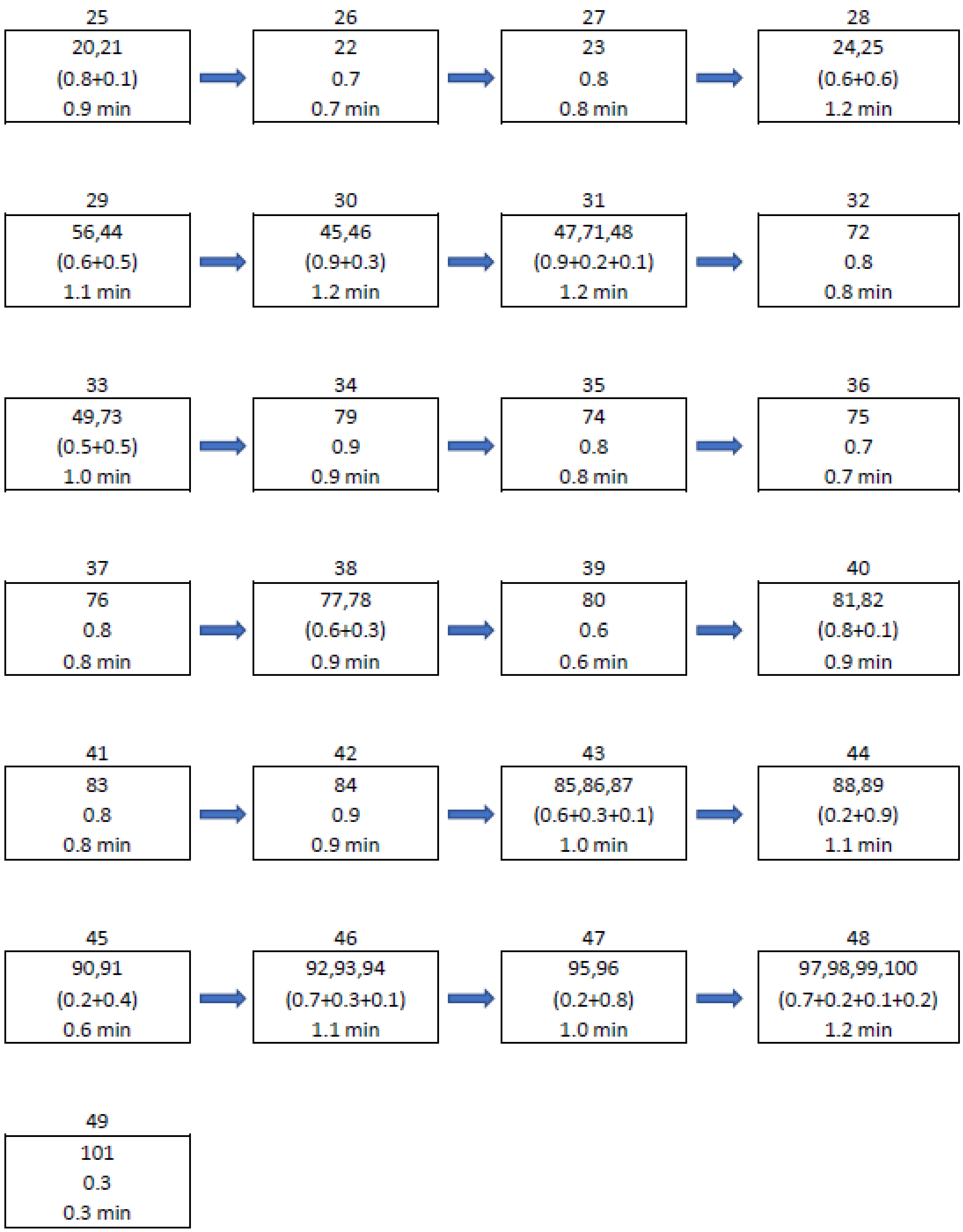
Thereby finding out the actual number of work stations /workers required for the smooth running of the production line, we can determine the line balance efficiency and the actual balance delay.

Element #	Te	Precedence
29	0.9	28
35	0.9	34
37	0.9	36
40	0.9	39,51
45	0.9	44
47	0.9	46
53	0.9	52
68	0.9	0
79	0.9	49,67
84	0.9	83
89	0.9	78,88
10	0.8	9
20	0.8	19
23	0.8	22
27	0.8	26
39	0.8	38,50
54	0.8	53
63	0.8	62
64	0.8	63
69	0.8	68
72	0.8	71
74	0.8	73
76	0.8	75
81	0.8	80
83	0.8	82
96	0.8	95
3	0.7	2
4	0.7	3
14	0.7	13
19	0.7	18
22	0.7	8,14,21
50	0.7	0
59	0.7	58
70	0.7	69
75	0.7	74
92	0.7	91
97	0.7	96
5	0.6	4
15	0.6	9
24	0.6	23
25	0.6	24
32	0.6	31
56	0.6	55
60	0.6	59,70
61	0.6	60
77	0.6	76
80	0.6	79
85	0.6	84
2	0.5	1
6	0.5	5
11	0.5	10
12	0.5	11
33	0.5	32
44	0.5	43,56
49	0.5	48
62	0.5	61
73	0.5	72
26	0.4	0
91	0.4	90
9	0.3	2
16	0.3	15
28	0.3	27
31	0.3	30
36	0.3	35
42	0.3	41
46	0.3	45
52	0.3	0
55	0.3	54
66	0.3	65
78	0.3	77
86	0.3	85
93	0.3	92
101	0.3	100
1	0.2	0
7	0.2	6
13	0.2	12
18	0.2	17
30	0.2	29
38	0.2	0
41	0.2	40
51	0.2	0
58	0.2	57
67	0.2	66
71	0.2	25,37
88	0.2	87
90	0.2	89
95	0.2	94
98	0.2	97
100	0.2	99
8	0.1	7
17	0.1	16
21	0.1	20
34	0.1	33
43	0.1	42
48	0.1	47
57	0.1	0
65	0.1	64
82	0.1	81
87	0.1	86
94	0.1	93
99	0.1	98

Table A2 Rearranged list in their descending order of service time for each element. (step 1)

2.4 Line Balancing Flowchart of the Workstations (Step 2)
Total service time available for each station = 1.215 min.





Flowchart 1 Schematic layout of Workstations with work distribution and acceptable Precedence

From the line balancing flowchart in the previous section we now know that the reasonable number of work station in order to maintain a good line balancing efficiency is 49.

Here the manning level for the production line is given as M = 1. So the number of workers is equal to the number of workstations.

W = 49.

We know that the TWC = 50.1 min, also Ts = 1.215 min.

$$Eb = \frac{TWC}{W*Ts} = \frac{50.1}{49*1.215} = 0.8415$$

Therefore the line balance efficiency for the given production line for the production rate is 84.15 %.

Q5 Is it possible to produce at the rate of 75 units per hour?
Answer

Case1. Theoretical calculation without balancing of line.

Given the demand/ production rate Rp is given. Rp = 75 u/hr. From the uptime efficiency given E= 0.9, we find the available time AT.

AT = 60* E = 60* 0.9 = 54 min.

We know the equation to find out the cycle time, $Tc = \frac{AT}{Rp}$ = 54 /75 = 0.72 min.

We know TWC = 50.1 min. Therefore from the equation w = (TWC /Tc), we find out the theoretical minimum number of workers.

W = 50.1/ 0.72 = 69.58 ~ 70 workers.

The total service time Ts = Tc* 0.9 (since repositioning efficiency E_r = 0.9- given, Er =Ts / Tc)

Therefore Ts = 0.72* 0.9 = 0.648 min

Here we see that the total service time Tc = 0.648 which is lower than some of the work element time (elements that are having Te >0.6)

In this case if we assume that **partial work** can be done on a work station and complete the work of the same element on the upcoming station, we can continue to find out the balance efficiency.

$$Eb = \frac{TWC}{W*Ts} = \frac{50.1}{70*0.648} = 1.1045 \text{ (the line here is unbalanced)}$$

Suppose by increasing the number of workers to 80.

$$Eb = \frac{TWC}{W*Ts} = \frac{50.1}{80*0.648} = 0.966 = 96.6\%$$

(Note: This doesn't mean that 96.6% is the best or proper line balance efficiency)

For this study, it is shown if partial work can be done by a station for an element, then we can have a production at a rate of 75 units per hour (up from 40 units per hour) with proper line balancing. Line balancing along with suitable changes (as per the product requirement) in layout shows drastic improvement in production output and helps a lot in assessing the manpower deployment